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Routing mechanism ensuring congestion free communication in wireless sensor networks enabled by internet of things for applications in smart healthcare

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ABSTRACT

Recently, the architecture of internet of things (IoT) has been applied towards gathering physical, biological, and dynamic signs of the patients within consumer-oriented electronic-health or health services. In these healthcare systems, various therapeutic sensors are placed on patients to monitor vital signs. However, the process of collecting data in IoT-enabled wireless sensor networks (WSNs) often faces congestion issues, resulting in packet loss, reduced reliability, and decreased throughput. To tackle this challenge, this proposed paper recommends a distributed congestion control algorithm tailored specifically representing IoT-enabled WSNs used in healthcare contexts. The suggested approach improves congestion by employing a priority-based data routing strategy and introduces the precedence queue-based scheduling method to improve reliability. Then the effectiveness of this congestion control process is analyzed statistically, and its performance is verified across extensive simulations and real-life experiments. This solution shows potential for applications like early warning systems for identifying peculiar heart rates, blood pressure, electromyography (EMG), and electrocardiogram (ECG) in hospital or home care settings, thus advancing the current diagnosis capabilities.

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1. INTRODUCTION

VLSI circuit technology and recent developments in microelectronics manufacturing have made it possible to create smart electronic devices that can sense, process, and send data [1]–[5]. The internet of things (IoT) is defined as a system of networked computing devices that communicate with one another and the physical environment via complex protocols and dispersed intel?ligence. These networks operate in concert to achieve shared objectives. To create the IoT, several network architectures, including radio frequency identification (RFID) systems, machine-to-machine (M2M) communication systems, and wireless sensor networks (WSNs), must be integrated. A vital aspect of the IoT infrastructure, WSNs are used for real-world item monitoring.

Self-organization, energy limitations, packet congestion, ad hoc deployment, and unattended operation are some of the particular issues that WSNs encounter. In the realm of customer-centric e-health and healthcare services, these unique features call for tailored procedures. Quality of service (QoS), simplicity, low power consumption, ease of integration, and cost-effectiveness are important factors to consider while deploying healthcare-aware wireless sensor networks (HWSNs) in consumer devices built on the IoT [6], [7].

Controlling congestion when physiological data is routed is a significant obstacle in HWSNs in maintaining excellent QoS. Because sensor nodes have limited resources (processing power, memory, bandwidth, and energy), congestion in HWSNs might occur at different sites compared to typical networks [8]–[10]. These networks are event-driven, making communication loads unpredictable; for example, medical situations might create burst traffic, causing congestion [11], [12]. Overworked nodes use more energy and could fail prematurely, leading to dynamic routing modifications that exacerbate congestion and delay medical staff's access to information [13], [14]. In healthcare applications, patient-attached sensors can send vital signs to gateway nodes at high rates, leading to congestion, packet loss, and delays in the network. Relaxation theory using max-min fairness and adaptive duty-cycle-based congestion control are two examples of existing congestion control schemes. However, these schemes do not always succeed in reducing transmission delays during vital sign transmissions and may even introduce significant message overhead, which shortens the network's lifespan [15], [16].

This article presents a distributed traffic-conscious congestion control technique designed specifically for WSNs empowered by the IoT to tackle these difficulties. The suggested technique improves QoS and optimizes network energy usage by arranging sensor nodes into hierarchical tiers and routing data through pathways free of congestion. The authors present a thorough multi-layer architecture for IoT networks that incorporates steady, congestion-free routing at the network layer, efficient admittance and broadcast power control at the media access control (MAC) layer, and lightweight control of the transmission by the transport layer to guarantee reliable and efficient communication. A middleware strategy is also proposed for bridging the gap between wireless LAN applications and the internet backbone. The rest of the article is organized as follows: section 2 delves into previous research in the field, section 3 introduces the problem design and network model, section 4 explains the proposed congestion control mechanism analytically, section 5 presents theoretical analysis, section 6 showcases experimental results, and section 7 concludes with the study's main findings.

2. RELATED WORKS

In healthcare environments, sensor nodes continuously collect patient information and transfer it to a base station (BS) to meet the needs of medical staff. In multi-hop WSNs, congestion control is a crucial goal. This section provides a survey of current literature on WSN congestion control. Yin *et al.* [7] presented the fairness-aware congestion control (FACC) approach, which utilizes rate-based fairness-aware congestion management. It detects congestion based on packet failure rates at the sink node by classifying intermediary nodes as either near the source or near the sink. Kang *et al.* [8] introduced topology aware resource adaptation (TARA) to decrease congestion in WSNs by dynamically activating sleeping nodes to create new network topologies and manage increasing traffic. However, in large-scale WSNs, this method causes significant overhead. Sergiou *et al.* [17] proposed the hierarchical tree alternative path (HTAP) algorithm to alleviate congestion by building a source-based tree that selects nodes with the lowest buffering to send extra packets to the sink. Zabin *et al.* [11] developed the reliable and energy efficient protocol (REEP) for on-demand routing in WSNs, but it led to high transmission costs and message overhead. Sharma *et al.* [18] proposed the bidirectional reliable and congestion control transport protocol (BRCCTP), which uses rate adjustment for congestion control and gives equal priority to data streams to reduce congestion, though it can increase data transmission delay when congestion is detected. Zhuang *et al.* [19] proposed congestion-adaptive data collection (CADC), which uses adaptive lossy compression and weighted data prioritization to handle cyber-physical applications in sensor networks. While useful, CADC does not optimize energy usage, shortening the network's lifespan.

Current congestion management approaches in healthcare applications built on the IoT often compromise QoS due to increased energy usage, data transmission delays, and unnecessary message exchanges. To efficiently categorize data packets and avoid congestion, this paper suggests a distributed level-based congestion control technique, using a level-based data routing strategy for optimal route selection. The proposed methodology aims to optimize energy consumption and latency in IoT sensor environments, unlike conventional congestion control routing algorithms that do not account for energy optimization in IoT scenarios. This method enhances QoS in healthcare applications that rely on IoT by effectively monitoring queues, reducing packet losses caused by congestion, and improving delivery rates.

3. METHOD

In this section explaination of proposed network model in section 3.1 as well as section 3.2 elaborates the problem innovation. Section 3.3 explains the proposed congestion control mechanism. Section 3.4 explains the theoretic analysis of suggested congestion control system and problem innovation techniques.

3.1. Proposed network model

We are exploring the IoT-based healthcare arrangement that spans a hospital setting and comprises of N fixed sensor nodes. R_{max} is the maximum transmission range that each node has at the outset. An undirected weighted graph, $G = (V, E)$, depicts the topology of network. In this graph, $V=\{v_1, v_2, ..., v_N\}$ represents nodes, likewise $E = \{(v_i, v_j) \mid dist\ (v_i, v_j)$ less than $R_{max}\}$ represents edges. Here, $dist\ (v_i, v_j)$ is the gap between the nodes like v_i with v_j. Each edge that is $(v_i, v_j) \in E$ is given a specified size, $C(v_i, v_j)$, for transferring data packets from node v_i to node v_j, and the capacities of the communication lines between nodes might vary. On a periodic basis, the BS receives sensed data from every deployed node ($vi \in V$) during multi-hop transmission. The initial radio model is employed to evaluate energy consumption [20]–[22] since it determines how much energy is needed to send the β bit communication to the isolated receiver node.

$$\text{d}.E_t = \begin{cases} \beta T_{cl} + \beta\varepsilon_{fs} d^2 & \text{d} \le d_0 \\ \beta T_{cl} + \beta\varepsilon_{amp} d^2 & \text{d} > d_0 \end{cases} \tag{1}$$

T_{cl} stands for transmission circuit loss and do denotes the threshold distance in this context. The models employ ε_{fs} and εamp to represent the energy that is utilized for power amplification, respectively. How much energy is needed to receive a β-bit message is dependent on how efficient the circuit is. Hence, since (2)

$$E_r = \beta T_{cl} \tag{2}$$

An energy utilization measure of the sensor nodes during idle listening remains represented by E_{idle}.

3.2. Problem innovation

Give v_i's packet sending rate, x_i, and tell it to stop working when x_i is found to be zero. Thus, the graph $G_x = (V, E, X)$ represents a topology for an IoT network that relies on sensors, where $X = (x_1, x_2 ..., x_N)\ T$. X displays the time-varying transmitting rate of all deployed nodes. The data packets resolve to build up in the node caches, which leads to congestion, in the IoT network if the demand for traffic exceeds the capacity of the network. When data is sent starting node v_i to node v_j, if $x_i > x_j$, the cache queue length of node v_j will steadily expand, leading to network congestion. Various kinds of medical data are stored in Q_H, Q_L, and Q_C queues at relay nodes. As a measure of how congested the IoT network is, the congestion index may be calculated using (3):

$$C_i = \sum_{i,j \in n, v_{i,j} \in V} (x_j - x_i) + Q_i \tag{3}$$

where, $Q_i = \begin{cases} 1\ Length(Q) \ge threshold \\ 0\ Length(Q) \le threshold \end{cases}$

In order to offer a crucial roadmap intended for the network optimization-including routing strategy and lifetime of network-this article aims to estimating the network congestion during collecting the data, consumption of energy, and delay of routing for an IoT-based patient tracking network. The overall lifespan of the network is split into the distinct stages denoted by $[S_0, S_1, S_2 ..., S_{p-1}, S_p]$, with S_i standing for i^{th} stage of the network. For instance, in an IoT network, the initial sensor node fails at the death of stage S_0, and the system is completely decommissioned on stage S_p. The amount of data phases by each step S_i, measured in duration at separated stage represented by $[a_0, a_1, a_2 ..., a_{p-1}, a_p]$. So, $a^{(0)}$ stands the initiation time to first node death for an IoT network. In each data round of a stage, the mean traffic loads up of node v_i is represented by the variables $[t_i^{(0)}, t_i^{(1)}, t_i^{(2)}, ..., t_i^{(p-1)}, t_i^{(p)}]$. Here we lay out our goals in more detail.

- In an IoT healthcare network, every sensor node uses C_i to determine the highest energy-efficient query handling and gathering data channel while also accurately estimating congestion, routing delay, and energy consumption.
- At every step, for every $0 < i \le n, t_i^{(j)}, e_i^{(j)}$ should be at its lowest, as should the regular traffic load afterwards power utilization of the sensor nodes that have been installed. Then we can reduce issues with energy usage caused by heavy traffic. C_i should be used to determine the minimal average interval path of network stages represents $[a_0, a_1, a_2, ..., a_{p-1}, a_p]$. So, during periods of heavy traffic, we can lessen the likelihood of packet loss.

3.3. Proposed congestion control mechanism

In order to prolong the life of healthcare-aware WSNs that are founded on the IoT, the major purpose of the suggested method is towards control congestion within these networks. Equal distribution of sensing data to the gateway is another goal of the method. The suggested method centres on the two critical characteristics, energy, and delay, in order to accomplish these goals. Additionally, it separates traffic into two categories: sensitive, which deals with particularly important material, and non-sensitive, which deals with more mundane data. There are three stages to the suggested congestion management scheme: setup, request distribution, data routing, and event occurrence reporting. The suggested approach prioritises the forwarding of sensed information to the gateway node in healthcare situations where vital signs evolve through phases and different IoT-based medical devices have distinct priorities. The source node influences the importance of the data before sending packets and the intermediary nodes route them appropriately.

3.3.1. Setup phase

During the network's startup, the setup phase executes once. During this stage following deployment, not only are the nodes split into several tiers, but each node also finds its single-hop neighbour nodes. The first step in level detection is for the gateway to send a request note to all sensor nodes within the span of R_{max}, with the level value set to 1. Its location, *level (L)*, and ID are all included in the message. In response to the LEVEL message, then a level assessment of the receiving sensor node by v_i is increased by one, rendering it equal to $L(Gateway)$+1, and the parent node (P_N) of the receiving node by v_i is set to be a gateway. Like the gateway node, all sensor nodes within $2R_{max}$ of it raise their level to a level greater than the prescribed gateway node then designate it equally their parent node. Node v_i repeatedly notifies all deployed sensor nodes within the $2R_{max}$ range with a MOD_LEVEL message. Included in the transmission are its location details, current energy status ($E_{current}$), and *ID* ($L(v_1)$). In every other case, it becomes a parent node by updating the aforementioned level to one additional than v_i's level rate; in other words, $P_N(v_j) = v_i$. During setup, every node in the network checks its energy level and finds its parent node set, which is consisting of a single hop. Every single-hop child node and current energy state of every deployed sensor node is also identified recursively. Each sensor node updates the gateway node with its current level, ID, position, and energy status after level detection by way of its intermediate parent nodes. The present positions of sensor nodes are subject to change because they are mobile. As the sensor node ascends or descends a level, the mobile node, with the assistance of its neighbours, revises its current level value. As a whole, Algorithm 1 describes the procedure in large detail.

Algorithm 1. Detecting the level

```
Input: Implemented sensor nodes
Output: The Value of level gives assigned to every sensor node
1.Start.
2. L(Gateway) = 1;
3. The Gateway transmit a LEVEL message.
4.Range Limit in Rmax.
5. for (Every sensor node (vi))
6. if the D (Gateway, vi) equals to 2Rmax   then do
7.  Increment L(Gateway);
8.  Assign the L(Gateway) to L(s).
9.  Assign the Gateway to Pn(vi).
10. end of if condition
11. end of for loop
12. Likewise, node i.e. vi newscasts the MOD_LEVEL message.
13. if the node vj obtains a message. also, L(vj) greater than L(vi))
14. L(vj) = L(vi) + 1;
15. Pn (vj) = vi
16. Cn (vj) = vi.
17. else
18. Dispute the message
19. end of if condition
20. for every sensor node is vi
21. vi transmits its present level value, ID, state of energy.
22. end of for loop
23.Stop
```

3.3.2. Query distribution phase

At this point, the medical personnel (doctors and nurses) can submit queries to the gateway node, and the node will then allocate the received requirements to the deployed nodes to meet those needs. When collecting data for applications like healthcare, the kind of the data is very crucial. Health metrics may sometimes include very private information. The query packet's lifespan has the capacity to lessen message overhead in the network and improve data transmission dependability. The lifespan of a query packet is computed as develops.

$$L_{lp} = \sum_{1}^{d(level)} (T_R + T_T) * P_t \quad (4)$$

whereas *d(level)* represents a target node's level. The reception delay is represented by T_R, whereas transmission delay is denoted by T_T. The processing delay is denoted as P_t. The first step is for the gateway to send an R_{REQ}

message to all the sensor nodes on the first level. A request for the capacity of radio links, the destination node's ID, Every node, v_i, evaluates the radio connection associated with that parent represents v_p that denotes the ($v_p \in P_N(v_i)$), through transmitting a gushed of packets for a specific duration, T, in order to get an estimate of these capabilities. Upon receipt of the acceptance of earlier packet or upon a time out after the previous submission, each subsequent packet is transmitted. Next, we divide a total amount of acknowledged packets in the time T to get an approximation of the connection capacity, C_{v_i,v_p} Upon receiving an R_{REQ} message, a node v_i verifies the target node ID. While the request node ID matches v_i, v_i will use the greatest capacity link to deliver its update information to the gateway. In every other case, it verifies the request packet's lifespan, If the request packet's lifespan ends and the node's level, represented by v_i, is equal to or lower than the destination node's level, the received message is discarded. In all other cases, it relays the R_{REQ} signal to the child nodes. Multiple requests from the same or other IoT medical devices may arrive at the gateway simultaneously in healthcare applications. Gateway processing all of these requests at once can cause network congestion. Consequently, the suggested method determines the query's priority based on the patient's priority. The suggested method takes the time it takes to make a request into account when determining how a component node's query is executed. For instance, this sort of request is given top priority in healthcare purposes since vital signals pertaining to sensible statistics such as breathing state, the pulse rate of heart, with blood sugar are of great importance. The suggested approach can also take into account lower-priority forms of communication pertaining to non-sensitive data, including that from leg sensors. The suggested approach calls for the gateway node to set the query propagation time based on the existing time whenever it gets a query commencing the medical staff. Conversely, if any of the patient's sensor nodes detects a deviation from normal vital signs, it should notify the gateway. Under such circumstances, the vital sign transmission is given first priority by the source node. Algorithm 2 summarizes the detailed explanation of the query distribution procedure.

Algorithm 2. Requesting the distribution
Input: Doctor query
Output: Give response the Query
1.Start
2. Query receives by the Gateway
3. Give answering procedure corresponding to priority of the request
4. if not available necessary data, then
5. The Gateway discovers level likewise ID of v_j node
6. Determined L_1 employing EQ 1
7. Set lifetime of every packet of the query
8. Announce R_{REQ} message.
9. **for** every node v_i
10. **if** the node ID(v_i) equals ID(v_j) **then**
11. Transmit the important information to gateway
12. **end if**
13. **if** $L(v_i) = L(v_j)$ **then**
14 RREQ message is transmitted by V_i node surrounded by the sub nodes
15. **end of if condition**
16. **if** $L_{1p} = 0$ and $L(v_i) < L(v_j)$ then
17. Discard
18. end of **if condition**
19. end of **for loop**
20.Stop

Algorithm 3. Allocation of event
Input: Sensor node recognizes the Event
Output: Event information receives at the Gateway
1.Start
2. **for** every sensor node v_k
3. **for** every sensor v_i be the appropriate to P_N (v_k)
4. sum is add with the $E_{current}$ (v_i)
5. **end for**
6. $\delta(v_k)$ = sum is divided by $|P_N (v_k)|$
7. for every node v_i be appropriate to P_N (v_k)
8. **if** ($E_{current}$ (v_i) = $\delta(v_k)$)
9. S = combines (S and v_1)
10. **end if**
11. **end for**
12. **for** every node v_1 moves towards S
13. **if** (MAXIMUM > $E_{current}$ (v_k) && min $D(v_1,v_k)$ then
14. MAX = $E_{current}$(v**k**)
15. v_1 chooses data routing.
16. end of **if condition**
17. end of **for loop**
18.stop

3.3.3. Routing data and reporting events

Following the appeal propagation level, then the end node updates the gateway node using the most energy-effectual link by sending its update information via the highest capacity link. In a similar vein, a node will notify the gateway in accordance with the requirements if it detects a medical urgent situation while doing its role. The correct response and transmission of a medical urgent situation if any report to the doctor or a nurse can only occur if the reports contain the necessary parameter values. At this point, the gateway receives the details of the medical emergency that has just occurred. In order to do this, the node will craft a packet that includes all the relevant information about the detected event and transmit it to the parent node that is closest by using the link with the highest capacity. The configuration phase determines if a sensor node has one or more parent nodes and which routes lead to the gateway. With respect to set $P_N(v_k)$, let $\{v_1, v_2, v_3, \ldots, v_p\}$ denote the collection of nodes. The node v_k uses the formula to get the standard residual energy of a parent sensor nodes, which is necessary for transmitting both normal data packets and medical emergency packets.

$$\delta(v_k) = \sum_{i=1}^{p} E_{current}(v_i)/p \tag{5}$$

where $E_{current}$ denotes the present energy state and p denotes the total no. of nodes in the $P_N(v_k)$. The parent nodes whose residual energy is equal to or larger than $\delta(v_k)$ are denoted as $S=\{s_1, s_2, \ldots, s_p\}$. Then, based on the parent node's buffer condition and distance, v_k transmits all data packets to the parent node. While a parent node's buffer state is overflow, v_k chooses the next-to-nearest parent from the set S. What follows is an explanation of the routing algorithm's pseudo-code.

3.3.4. Congestion control

The fundamental goal of the propose stands towards develop a method for managing congestion and routing in healthcare networks that rely on the IoT. To lessen the likelihood of congestion occurrence, the data routing paths chosen by the deployed nodes are optimised in this study. The data routing algorithm is used to conduct the congestion management phase. The suggested congestion control method sorts of data into distinct queues based on its classification using a classifier at first, there are data packets with a more in priority, next packets with a lower priority, afterwards at last control data packets. The packet header of every data packet specifies its kind. The data packets that are received by the classifier are sorted into distinct queues based on their class. The suggested method for transmitting data makes use of a scheduler based on priority queues. When the scheduler detects class 1 data in the queue, it will begin transmitting class 1 data and halt transmission of second class and third-class data. The scheduler begins transmitting data packets for classes second and third once all first-class packets have been transmitted. The routing diagram and overall simulation diagram should be shown in Figure 1.

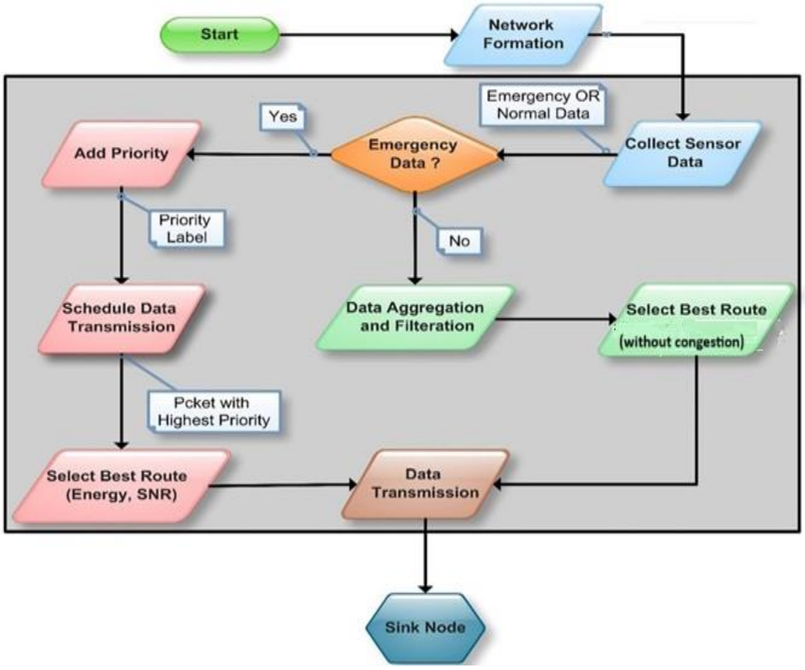


Figure 1. Simulation routing diagram of healthcare system

In the event that the maximum data transmission rate T_{xmax} is lower than maximum data reception rate $\sum_{i=1}^{c} Rx_i$, the node's buffer will eventually overflow after a certain amount of time has passed. As a result, the network experiences packet loss and the node stops receiving data from its child nodes. When the buffer level hits the threshold value, the suggested scheme chooses an alternate path (C_i identifies this value). Along with the acknowledgment message, a node may include buffer status when it receives a data packet from a child node. Node v_1 will notify all of its offspring via the *H_AlterPath* message if it determines that the first-class queue exhibits reached a certain threshold value, rerouting the data with the highest priority to a different, more energy-efficient channel. Node v_k chooses the next-to-adjacent node in the energy level after the parent node and transmits the entire more importance information when it gets an alternate path selection message from the parent node. Likewise, if node v_k notices that the second class and then the third-class queues have been overflows, it will notify all of its descendant nodes using the *L_AlterPath* and *C_AlterPath* messages. Data packets of classes 2 and 3 are also sent via an alternate way by child nodes. Based on the data rate of the node and the total of child nodes it holds the alternate path selection procedure uses a threshold value. According to this study, when a parent node notices that it has received 95% of the data packets in its queue, it will notify the child nodes to choose an alternate path. After a while, node v_k will send out REQ1, REQ2, in addition to the REQ3 messages to all of its child nodes in order to resend data packets for classes 1, 2, and 3, as well as to indicate that the value of buffer is below the threshold value.

3.4. Theoretic analysis of suggested congestion control system

In this part, we take a theoretical look at the suggested congestion control algorithm's complexity to see if it holds water in the actual world of healthcare. First Theorem: The suggested congestion management method has a message complexity is O(N), whereas the N is the amount of sensor nodes enabled by the IoT that have been installed.
Proof: Message complexity is total amount of network messages transmission between by the installed IoT-based sensor nodes in order to execute the suggested congestion control system. One message exchange throughout the network is required for the setup phase of the proposed congestion management strategy. This means that each node must broadcast a single message to its neighbours. The level value and parent node of each sensor node v_i are determined by the data that is received. Consequently, the suggested strategy for controlling congestion requires a maximum of O(N) messages sent over the network.
Theorem 1: The first theorem states that v_i must lie within the narrow area of A_d that has a width of σ. The distance among the base station and A_d is denoted by *d*. If every node gets one query packet for each stage, the typical amount of data transmitted per stage is denoted by (6)

$$t_{i_D}^{(0)} = \begin{cases} (Z_1 + 1) + \frac{Z_1(1+Z_1)r}{2d}, & if\ d \geq \sigma \\ \frac{1}{2}(z_2 + 2)\sigma^2\,\theta\rho + \frac{1}{2}Z_2(z_1 + 1)r\sigma\theta\rho\,, & otherwise \end{cases} \quad (6)$$

where $z_1 = (R - r)\,/r$ & $z_2 = (R - \sigma)/r$.

Our analytical model yields the following result: since node v_i represents a tiny portion of A_d, its traffic load is equal to the common traffic weight in A_d. For that reason, we begin by determining A_d's typical traffic load. We could be calculating the total amount of nodes in A_d. A_s for A_d, its node count is

$$N_{A_d} = \begin{cases} d\sigma\theta\rho\,, & if d > \sigma \\ \theta\sigma^2\rho\ \ , & otherwise \end{cases} \quad (7)$$

with the total quantity of nodes in the higher-level A_{d+ir} fluctuating due to data received and sent from lower-level areas,

$$N_{Ad+ir} = \begin{cases} (d + ir)\sigma\theta\rho|0 < i < z_1\,, if\ d > \sigma \\ \left(\frac{\sigma}{2} + ir\right)\sigma\rho\theta|0 < i < z_2\,, otherwise \end{cases} \quad (8)$$

where $z_1 = (R - r)/r$& $z_2 = (R - \sigma)/r$.

The amount of data packets is wholly proportional to the total number of nodes engaged, as each node only creates one packet every round in response to a single query. As a result, A_d's data packet count is

$$D_{A_d} = N_{A_d} + N_{A_{d+r}} + \cdots + N_{A_{d+zr}} \quad (9)$$

Proof: The average A_d traffic load is given by D_{Ad} / N_{Ad}, according to the previous equation. The load in traffic of each node v_i at S_0 must be the $t_i^{(0)} = \frac{D_{A_d}}{N_{A_d}}$ as It approximates the typical traffic flow of the sensor nodes in A_d used for transmitting data packets. After doing some basic maths, we get $t_i^{(0)}$as (6).
Theorem 2: It is assumed the v_i remains fashionable in the narrow area of A_d using a width denoted by σ. The space from A_d to the border node is denoted as b_0. Given that the sink node transmits only one query packet to every nodes in a round, that the average query transmitted by v_i by S_0 is (10).

$$t_{i_q}^{(0)} = \begin{cases} (z1+1) + \frac{z1(1+z1)r}{2b_0} & if\ b_0 \geq \sigma \\ \frac{1}{2(z_2+2)\sigma^2\theta\rho} + \frac{1}{2z_2(z_1+1)r\sigma\theta\rho} & otherwise \end{cases} \tag{10}$$

where $z_1 = (R-r)/r$ & $z_2 = (R-\sigma)/r$
Proof: Theorem 1 evidence. The node v_i average traffic load is influenced by the data gathering and query distribution during each stage's data round, is as follows: $t_i^{(0)} = (t_{id}^{(0)} + t_{iq}^{(0)}))$
Theorem 3: The time duration for a cycle of query processing, which includes both transmitting the query and gathering data, is denoted as μ_r. The area A_d contains node v_i, where d represents the distance from A_d to sink node. For a data round with a sensor node transmitting data at a rate of G bits/s, the average power consumption e_i^0 of v_i is $e_i^0 = e_{i,r}^{(0)} + e_{i,t}^{(0)} + e_{i,j}^{(0)} + e_{i,q}^{(0)}$, where

$$e_{i,q}^{(0)} = t_d^{(0)}\tau E_{ele} + (t_d^{(0)} - 1)(E_{ele} + \varepsilon_k K^\alpha)\tau \tag{11}$$

$$e_{i,r}^{(0)} = (t_d^{(0)} - 1)\tau E_{ele} \tag{12}$$

$$e_{i,t}^{(0)} = t_d^{(0)}\tau(E_{ele} + \varepsilon_k K^\alpha) \tag{13}$$

$$e_{i,j}^{(0)} = E_{idle} m_{d,j}^{(0)} = E_{idle}(m_\alpha - \frac{2t_d^{(0)}\tau}{B} + \frac{\tau}{B} \tag{14}$$

Proof: Node v_i's energy usage in a data round is comprised of the following 4 components.
Query distribution for Energy consumption: While the v_i node and as the A_d zone, the obtained queries $t_j^{(0)}$ in a single round and the send out queries $t_i^{(0)} - 1$. Then, the consumption of the energy for the question sharing is represented by $e_{i,q}^{(0)} = t_d^{(0)}\tau E_{ele} + (t_d^{(0)} - 1)(E_{ele} + \varepsilon_k K^\alpha)\tau$.

– Energy utilization for the data receiving: Then the v_i node is within the A_d region, then the obtained data volume in a cycle is $t_{i-1}^{(0)}$, corresponding in the direction of the Theorem 1. Hence, that the energy utilization for the receiving is $t_{i,r}^{(0)} = (t_j^{(0)} - 1)\tau E_{ele}$.
– Energy utilization for the data transmitting: While in the data quantity transmitted by v_i in a turn is $t_j^{(0)}$, the utilization of the energy for the transmission of the data represents are

$$\begin{cases} e_{i,t}^{(0)} = t_i^{(0)}\tau(E_{ele} + \varepsilon_{fs}k^2), & K \leq k_0 \\ t_{i,t}^{(0)} = t_i^{(0)}\tau(E_{ele} + \varepsilon_{amp}k^4), & otherwise \end{cases}$$

Energy utilization for the idle listening: Afterwards, a network model, assume that the duty cycle represents γ. Therefore, that active time for each round is $b_a = B_r\gamma$. The energy utilization used for the idle remains the proliferation of the E_{idle} likewise the time in idle eavesdropping. Because the time interval of the idle listening is expressed by $b_{i,j}^{(0)}$, we include time expecting for data communication of both ends $b_{i,j}^{(0)} = b_a - \frac{(t_i^{(0)}-1)\tau}{G}. - t_i^{(0)}\tau/G$ Consequently, we obtain the energy utilization for idle listening by way of $e_{i,j}^{(0)} = E_{idle}b_{i,j}^{(0)} = E_{idle}(b_a - \frac{2t_d^{(0)}\tau}{G} + \frac{\tau}{G})$. To synopsise, in a round, the energy utilization $e_j^{(0)}$ of the node v_i is $e_i^{(0)} = e_{i,r}^{(0)} + e_{i,t}^{(0)} + e_{i,q}^{(0)} + e_{i,j}^{(0)}$.

4. RESULTS AND DISCUSSION

This section provides an in-depth explanation of the simulation results as presented in section 4.1. It offers a comprehensive analysis of the performance metrics, highlighting how the system behaves under different scenarios and configurations. Section 4.2 focuses on the implementation details and testing procedures carried out across various cases. These cases were developed and simulated using multiple models to evaluate the effectiveness and reliability of the system. The testing involved simulations with two different network sizes-one with 20 nodes and another with 100 nodes-to observe how the packet reception rate varies with the scale of the network. The results include detailed insights into the packet delivery percentages under each condition, showcasing the strengths and potential limitations of each model in handling different network loads and scenarios.

4.1. Simulation results

Using the network simulator 2 (NS-2) platform, we conducted a series of comprehensive experiments to evaluate the performance of the proposed approach as referenced in [23], [24]. The simulation environment was carefully designed to mimic a realistic deployment scenario. Specifically, a two-dimensional (2D) area was defined within which medical sensor nodes were randomly distributed. This random deployment reflects real-world applications where sensor placements may not follow a fixed pattern, such as in emergency response or mobile health monitoring environments.

When comparing the suggested congestion control system for IoT-constructed healthcare networks to existing schemes, such as BRCCTP [18], CADC [19], HTAP [17], REEP, TARA, we looked at metrics like average hop-by-hop delay, throughput in addition the percentage of efficaciously received packets. With each sensor node starting with an initial energy of E0 = 0.5 Joules, we also measured the network lifespan and the efficiency of the suggested algorithm in terms of energy savings. The results of the simulations, which used to the MAC protocol with collision-free, are listed in Table 1.

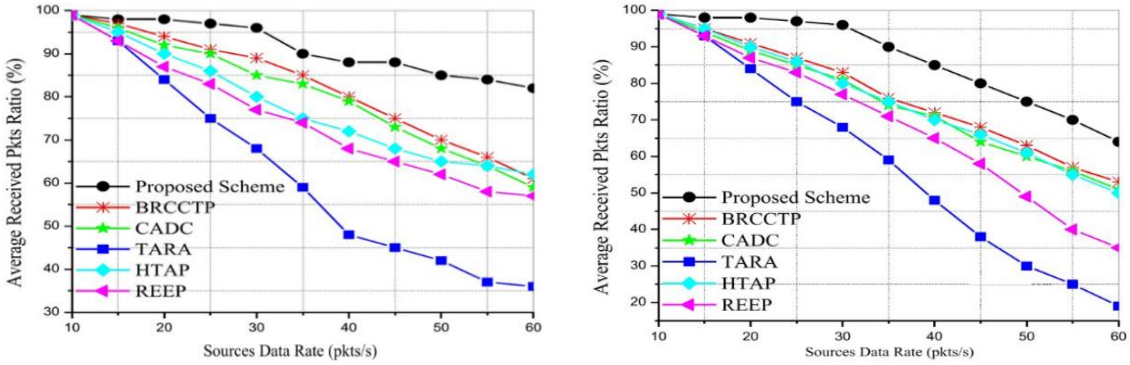
Table 1. The parameters used in a simulation

Parameter	Parameter value
No of nodes	30-100
Area for deployment	100X100 m^2
Size of data packet	500 bits
Each node primary energy	0.5 Joules
E_{elec}	50 nJ/bit
ε_{mp}	0.0012 pJ/bit/m^4
Size of the control message	100 bits
Function cycle	10%
Data period duration	10s
Rate of energy consumption (ideal)	0.87 mJ/s
Data transmission speed	512 kbps
Antenna type	Omni antenna
Queue size(packets)	50

Figure 2 shows the data packet reception rate at the gateway as a function of the suggested scheme's success rate. Figure 2(a) shows that the suggested scheme outperforms its competitors in terms of packet success rates. It outperforms BRCCTP by 37%, CADC by 39.4%, REEP by 41.3%, HTAP by 42.5%, and the TARA method by 57%. Moreover, as shown in Figure 2(b), the suggested scheme outperforms the alternatives by a significant margin: 38% vs BRCCTP, 42% versus CADC, 44% versus REEP, 45.7% versus HTAP, and 59% over TARA. Both the priority-based congestion management technique [25] and the level-by-level reduction of the data congestion throughout data routing are responsible for these gains [26]–[29].

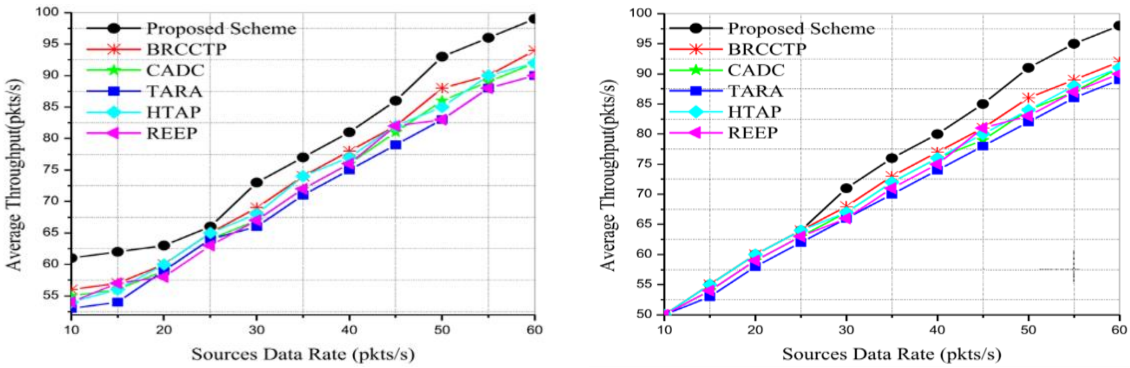
The suggested scheme's throughput, which represents the percentage of data reaching a gateway node, is shown in Figure 3 for different percentages of sensor nodes inside the network. The throughput gains shown in Figure 3(a) for our suggested system are as follows: up to 29% equated to BRCCTP, 31% equated to CADC, 33% equated to REEP, 34.33% equated to TARA, and 36% associated to HTAP. Similarly, Figure 3(b) shows that throughput may be improved by as much as 31.21% when compared to REEP, 32% when compared to TARA, 33.45% when compared to HTAP, 29% when compared to CADC, and 26.5% when compared to BRCCTP. All of these enhancements are the result of the suggested scheme's level-based congestion management mechanism, which chooses the best possible alternate data routing channels to handle data transmission congestion [30]–[32].

Figure 4 shows the mean delay by hop-by-hop findings from the algorithms that were tested in two different scenarios: one with 20 nodes and the other with 100 nodes. If we want to know how well the suggested system handles link-layer retransmissions, transparency from control packet exchanges and inter-path interferences, we need this performance metric. With reductions of 31% associated to BRCCTP, 38.5% associated to HTAP, 33.6% associated to CADC, 41% associated to the TARA algorithm and 35.4% associated to REEP. Our suggested approach clearly achieves a reduced average hop-by-hop latency Figure 4(a). In a similar vein, Figure 4(b) demonstrates that when compared to other algorithms, our suggested approach reduces average hop-by-hop latency by as much as 28% associated to BRCCTP, 31.3% associated to CADC, 32% associated to REEP, 35% associated to HTAP, and 37% associated to TARA. The less average data transmission time that results from the suggested scheme's efficient path selection for data routing with few control packet exchanges is the source of these enhancements.



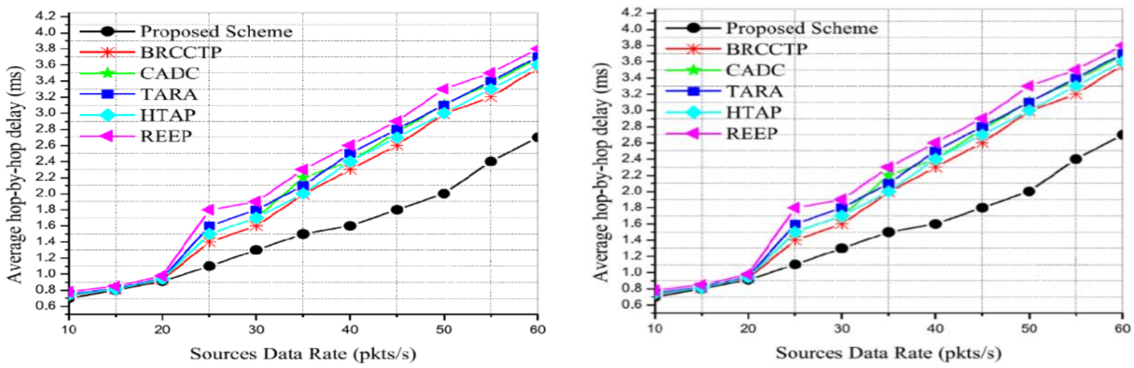
(a) (b)

Figure 2. Packets received percentage for (a) 20 nodes and (b) 100 nodes



(a) (b)

Figure 3. Average throughput plot for (a) 20 nodes and (b) 100 nodes



(a) (b)

Figure 4. Average hop-to-hop delay for (a) 20 nodes and (b) 100 nodes

Figure 5 shows the results of comparing our proposed scheme's energy efficiency to that of the BRCCTP, TARA, CADC, REEP and HTAP systems under different traffic loads. In comparison to BRCCTP, TARA, CADC, REEP and HTAP, our suggested method considerably extends network lives Figure 5(a). This is due to improvements of 37%, 40%, 43%, 42.3%, and 45%, respectively. Figure 5(b) further shows that our suggested strategy outperforms the competition by a wide margin: 38.5% vs BRCCTP, 42% versus CADC, 44.91% versus TARA, 43.78% versus HTAP, and 48% versus REEP. The first node failure is used to measure the lifespan of the network. Outperforming the BRCCTP, TARA, CADC, REEP and HTAP systems in terms of energy efficiency, our suggested strategy extends the lifetime of networks.

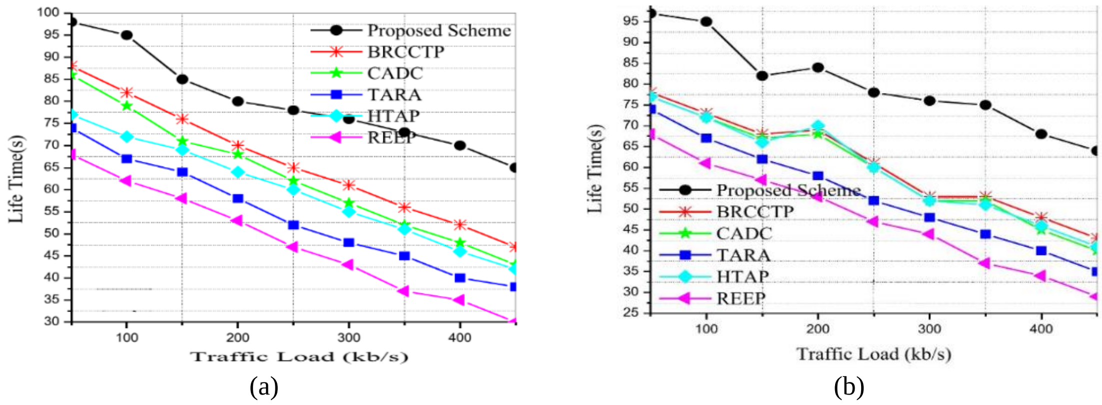


Figure 5. Relationship between the lifetime and traffic load for (a) 100 nodes and (b) 20 nodes

4.2. Implementation and testing

Twenty nodes equipped with medical sensors were used to provide a demonstration testbed for the congestion control strategy that was presented. Several sensors, including those for measuring blood pressure, pulse oximetry, electrocardiogram (ECG), and electromyography (EMG), are part of the experimental setup. A gateway, which is part of the testbed, processes queries and gathers data from the medical sensor nodes that have been placed. Each and every person is supervised by these four out of twenty sensors used in medical area, which are spread out over two separate lab rooms. Table 2 provides additional particular information about the parameters and their values that were utilised in the actual tests.

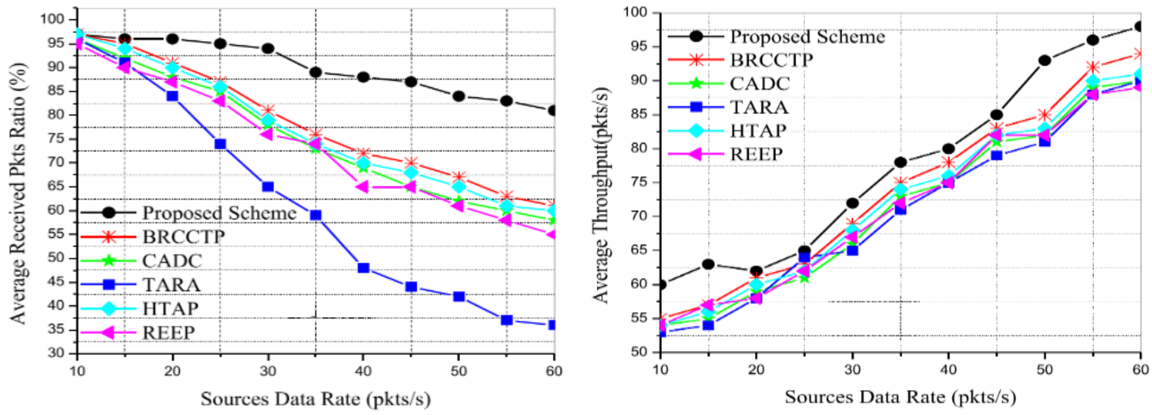
Figure 6(a) exhibits that the results of the realistic test are quite alike to the findings of the simulated instance in Figure 2. Our suggested scheme's proportion of correctly received packets declined as the source data rate rose, in line with the theoretical expectations shown in Figure 2. These results show that in real-world healthcare studies based on the IoT, our suggested methodology outperforms existing congestion control methods.

The results of our suggested scheme outperform TARA, REEP, HTAP, CADC and BRCCTP systems in terms of average throughput Figure 6(b), which is in line with the conclusions drawn from the theoretical study Figure 2. In an IoT healthcare system, these outcomes demonstrate how well our suggested congestion control technique works. The average delay of hop-by-hop that was found during practical testing is shown in Figure 7(a). As compared to other current systems as TARA, REEP, HTAP, CADC and BRCCTP, our suggested technique significantly reduces the latency of average hop-by-hop. As stated in the theoretical study, this enhancement is credited to the incorporation of a class-based congestion management technique.

The correlation between longevity and traffic load is seen in Figure 7(b). As the network's traffic load rose, the suggested scheme's lifespan grew longer, according to simulation studies. By outperforming high-tech congestion management methods that are TARA, REEP, HTAP, CADC and BRCCTP, in actual hardware trials, this result highlights the enhanced performance of our suggested scheme inside an IoT-based healthcare system.

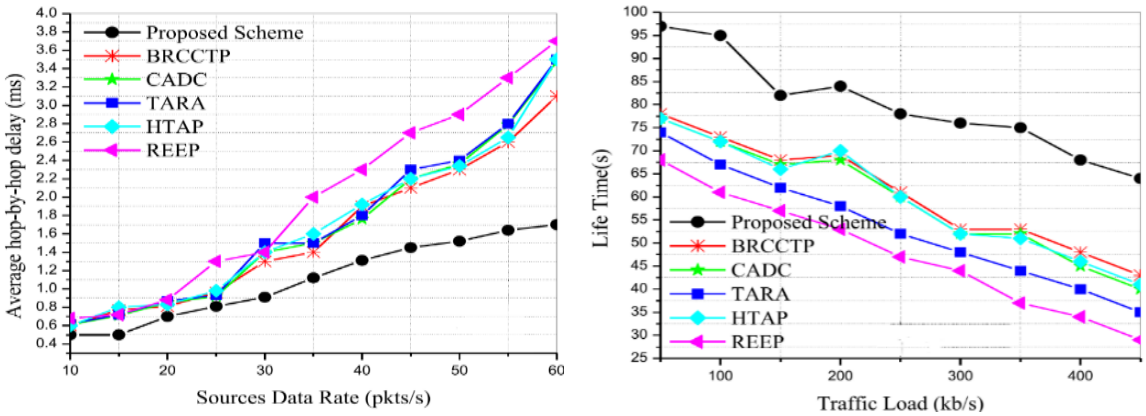
Table 2. Indoor tested experiment parameter values

Parameter	Parameter value
Sensor nodes	22
Base station	1
Deployment area	15×15 m^2
Data packet size	500 bits
Packet sending rate	1 packet/s
Initial battery voltage	1.6 V



(a) (b)

Figure 6. Average received (a) packets ratio and (b) throughput ratio



(a) (b)

Figure 7. Average ratio of (a) hop-to-hop delay and (b) packet traffic vs lifetime

5. CONCLUSION AND FUTUREWORK

This research presents a congestion control strategy that is designed specifically for healthcare IoT deployments including wireless sensor networks. To efficiently handle network congestion, the recommended technique employs a priority-based data routing approach. According to their significance, data packets exist to be categorized into three separate priority classifications. The scheduling of incoming data packets is also handled by a priority queue-based system. To evaluate how well the suggested technique works, we compare the results from real-world and simulation scenarios with those of modern algorithms. Network lifespan, packet delivery success rate, throughput, and average hop-by-hop latency are just a few of the performance parameters that the suggested technique surpasses current approaches in. For the majority of arrhythmia occurrences seen by the Holter monitor, the suggested mechanism shows potential. But there's still room for development, including making data more comprehensive, adding hardware problem detection, and making fault tolerance better. Adding more features and improving the suggested system will be the main goals of future studies.

Our future research will focus on evaluating the performance of the proposed scheme in both residential and office settings, where multiple individuals may be in close proximity for extended periods. Unlike traditional D2D communications, where the base station handles resource allocations, we aim to explore a hierarchical resource allocation framework. This approach is intended to alleviate the base station's workload, especially with the rapid increase in the number of WBANs

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C : **C**onceptualization
M : **M**ethodology
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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