Machine Learning-based Congestion Control Routing Strategy for Healthcare IoT Enabled Wireless Sensor Networks

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***Abstract*— Healthcare Internet of Things (HIoT) are collection of heterogeneous collection of sensor-based computing devices used for healthcare monitoring applications. Many research works are being done to enhance the efficacy of healthcare sector with reduced cost. These devices are low power sensors with limited computing capabilities and energy. So, aim of this paper is to discuss and propose a congestion control routing protocol for HIoT as emergency packets are transmitted using IoT sensor nodes with high throughput and efficiency. The proposed algorithm is divided in two main steps, in first step packet forwarding window size is predicted using machine learning algorithm. In second step, data packets are categorized into prioritized and normal packets and forwarded in allotted window size. The theoretical comparison of the proposed congestion control routing protocol increases the efficiency of the system.**

Keywords—Wireless Sensor Network, Healthcare Internet of Things (HIoT), Congestion Control, Routing.

I. Introduction

With advancements of microelectronic technologies, small and smart electronics devices are capable to sense, process and transmit data. These devices combine together and form a network with some shared resources and common objectives. These devices can interact with other remotely located devices or physical world through some communication protocols and algorithms. And these are collectively termed as Internet of Things (IoT). Recently, with smart technologies, IoT has been used in large applications such as in medical application, remote sensing application, defence, education etc. These applications are possible due to integration of different heterogeneous sensors smart communication protocols [1]. Along with advancement in IoT communication, challenges and issues also arises such as self-management, energy consumption, ad-hoc deployment, and congestion. Due to lots of communication between multiple devices, the most common issue that IoT faces is congestion. In past few years, many researchers also presented their work to overcome these issues. In this paper, application of congestion control routing protocol is focused for IoT in healthcare sector.

In healthcare sector or medical applications, these IoT-assisted WSN are used to monitor the condition and various parameters of patients and are termed as Healthcare Internet of Things (HIoT). Sensors that are attached to the patient body collect information from the human body and help the doctors to monitor the patients' health like heart rate, pulse, oxygen saturation, and blood pressure, etc. Due to overloaded data transmission, there may occurs communication lags and unnecessary retransmission. These HIoT sensor nodes faces such problem in communication due to congestion that results in energy consumption, loss of packets, lower throughput, etc. These problems cause interrupted communication among doctors, nurses, and patients and may result in delayed or wrong diagnosis [2]. Therefore, it is essential to have a way for this congestion-free routing mechanism. Moreover, the existing mechanism of congestion control is not suitable for healthcare. A more precise and more effective mechanism is required in healthcare. To address the above stated a distributed traffic-aware routing algorithm is proposes that also improves the quality of service and provides reliable communication by providing congestion free path for the transmission.

In this paper, a brief discussion of the congestion control routing strategy is discussed. Further, in this paper, a brief literature review is presented on different congestion control protocols and techniques, and their different applications in WSN are given. Finally, a machine learning algorithm-based methodology is proposed for congestion control routing protocol for healthcare IoT WSN network.

II. Congestion Control in HIoT

WSN is a network of Nodes sensors that are spatially spread in sound, temperature, vibrations, light, and pressures for the monitoring of physical and environmental conditions. Sensor nodes can be found in vehicles, cellphones, industries, buildings, seas, woods, and other places [3]. WSN applications are growing more diversified as the Internet of Things. One of the major applications of IoT is being used in healthcare sector. The sensors are deployed over human body for monitoring remotely their physical health anytime, anywhere. Healthcare applications are sensitive in nature and sometime any delay in provisioning will cost patient's life. So, on time diagnosis and medications is only possible when there is congestion free communication.

Congestion occurs at two levels and places in WSNs and HIoT networks: and link-level congestion and node-level congestion [4]. When the arrival rate of Packet at a sensor node is higher than that of the packet departure rate, there will be an overflow buffer when the incoming packets cannot be stored. This leads to a high rate of node packet loss which indicates higher energy use. Link congestion occurs when there occur multiple nodes at the same time and in the same transmission range. As a result, throughput is reduced and the number of retransmissions increases, resulting in additional energy consumption due to packet retransmission.

Wireless network congestion management is approached differently from wired network congestion control [5]. In a conventional network scenario, end to end transmission policy is used to avoid congestion. The congestion check mechanism is available from source to the destination inside the end-to-end approach, and the intermediate nodes refuse to act on congestion alleviation. Whereas in a wireless network, a hop-to-hop transmission policy is used. Congestion notifications are provided to intermediate nodes. Due to the lack of reliability of wireless networks, end-to-end data transmission cannot be provided over wireless networks [6]. Whereas, congestion control is significantly improved in wireless hop-by-hop strategy. The majority of block control algorithms in WSNs and IoT networks use hop-by-hop technology.

So, in WSN or HIoT networks, the following process is used for congestion control:

A. *Detection of congestion*

In this stage, the location of congestion is evaluated in the WSNs and IoT networks. Several factors such as buffer occupancy, channel load, the service time of packets, etc. are determining parameters for congestion control algorithms deployer for WSN or IoT networks [6].

- Buffer occupancy: A buffer is in each sensor node that is used for stocking packets before wireless transmission. A congestion alarm is raised when the estimated buffer occupancy is greater than a predetermined threshold value. The buffer threshold approach is a straightforward and accurate way to detect congestion.
- Channel load: On the wireless channel, the packet load is measured. The channel load ratio is evaluated by estimating the ratio of the arrival of data packets and their successful transmission.
- Service Time of Packets: It is the time evaluated between reception and MAC layer transmission.
- Packet loss: If ACK is enabled, this method is used. If an ACK is not received by a sender, it assumes that it happens. Packet loss, on the other hand, can be caused by wireless problems instead of a wireless channel collision.

B. *Congestion notification*

The congested nodes should inform the source nodes of the nodes that cause the network congestion when network congestion is observed. It is transmitted either in implicit or explicit form.

- Implicit notification: In the implicit notification, information about congestion is backed up in either the header of data packets or in acknowledgment. Overhead packets are avoided in such notification.
- Explicit notification: In this strategy, overhead packets are broadcasted to other nodes as an alert message by inserting overhead messages.

C. *Congestion control*

Following the receipt of congestion information by the source nodes, efforts should be done to decrease and mitigate network congestion. Packets are forwarded to end Nodes, Congestion is handled and reduced in one of two methods: selection of a non-congested path (resource control) or rate modification (traffic management).

- Traffic control: Congestion is controlled in this manner by lowering the number of injected Source nodes, who then limit their transmission rate to a predetermined value and transmit packets into the network. Two strategies for traffic rate adaptation are the window-based method and the rate-based method. In the window-based technique, a Source node evaluates the available bandwidth by gradually widening the congestion window [18]. When congestion is detected, the congestion window is substantially reduced. The available bandwidth is checked and estimated by source nodes in the rate-based system. Then, based on the assessed available bandwidth, they alter the transmission rate. The Available bandwidth BW_{avail} the equation used in [7] is an example of this method:

  $$BW_{avail} = 0 \qquad if\ C_o \geq th_c$$
  $$BW_{avail} = \frac{BW(th_c - C_o)\bar{d}}{T_s} \qquad if\ C_o > th_c \tag{i}$$

  Where, BW = transmission bandwidth rate in bits per second
  d= payload size
  Ts = Time taken for transmission (in sec)
  C_o = Rate for channel occupancy
  th_c = bandwidth threshold required for channel
- Resource control: To overcome the disadvantages of congestion control, resource control strategies are implemented. When there is congestion, this approach is used to forward packets to target nodes over other non-congested channels without lowering the sending rate. With this strategy, the packet delivery ratio is increased.
- Hybrid scheme: To alleviate network congestion, some algorithms combine the two methodologies mentioned above. The algorithm first looks for an uncontrolled way to forward the packets through resource control.

III. RELATED WORKS

Recently, several congestion control related to research works is presented for WSNs or IoT. In this paper, a comprehensive review is presented on different approaches for congestion control in WSNs. Moreover, along with algorithms, this paper presented the importance of congestion control in the healthcare Internet of Things (HIoT).

The challenge of selecting multiple path eligibility requirements to enhance system reliability and also other QoS factors is quite hard. Adil et al. [1] developed an Optimum QoS-aware multiple-path routing mechanism for an internet of things based Wireless Sensor Networks (WSN). The suggested approach calculates the appropriate expense, which works on two aspects: longevity and crowding in a node, to decide the route to the target. Regardless of the factors that the approach uses two types of package management, it consumes minimum energy and provides productive QoS. The models are tested here on the NS2 simulator under different operational conditions. The routing framework compared to current best-practice procedures. Packet drop ratio, packet delivery ratio, performance, and delays are the various factors that have compared.

Akhtar et al. [2] presented a routing protocol that uses a proactive concept and incorporates proper sleep design techniques to determine the best route. This approach aims to minimize communication delays in-network, which extends the life of the sensor node, the lifespan of the existing network, and lowers connectivity splitting. With the advent of IoT device implementations, there is a greater demand for crowding control initiatives to minimize network congestions and provide steady efficiency. These methods are necessary for both WSN and IoT connectivity. The complex methodology is challenging to employ in WSN, so this is a study topic with potentials.

Ancillotti et al. [8] proposed a novel collaboration dispersed Q-learning strategy at resource-restricted IoT systems to resolve the RACH traffic congestion in a cellular Sensor network. The suggested Q-learning technique allows devices to acquire the specific RA intervals for their broadcasts over time and decrease the number of concurrent broadcasts in the IoT network architecture. Suggested collaborative technique, in contrast to the autonomous Q-learning strategy, uses the traffic load of RA slots as the worldwide accounting data in the process of learning. Numerical findings indicate that the designed Q-learning strategy outperforms the competitive advantage in terms of convergence time, productivity, and conflict risk.

Chanak et al. [9] used WiSHFUL, a forum for massive network architecture experiments, to conduct a performance appraisal of several loads balancing approaches for CoAP in a realistic world. The objective is to investigate various congestion control approaches and their interactions with the routing algorithm in a real-world setting wherein channel instability causes unreliable links and path variations. The RPL characteristics, on the other hand, have a distinct impact on various congestion control strategies, punishing the far more violent ones. In particular, the authors discovered that the basic CoAP preset traffic problems algorithm outperformed the more complicated CoCoA method in a real-world setting with heavy traffic loads.

For ad hoc networks, Ghazi et al. [10] proposed different crowding control routing algorithms. Because of restricted resources in terms of frequency, battery lifespan, and buffering capacity, it has been analyzed in the literature review section that a single approach cannot effectively handle overcrowding in MANET.

Gheisari and Tahavori [11] developed the multipath and multi-hop routing strategy to design congestion-free communication in the existing network. Furthermore, priority-based congestion of sensing nodes is handled in an overcrowding-free interaction atmosphere for a set time interval, ensuring the DHSSRP routing scheme's durability for an essential system, atmosphere, and database administration. The suggested system increases the network's end-to-end latency, performance, and packet drop proportion while extending the life of a network by maintaining sustainable energy utilization.

Jaiswal et al. [12] developed a new traffic control technique for IoT application protocols that allows the channeling rate to be modified on time in response to network circumstances. The suggested method employs a hybrid of loss-based and delay-based TCP variants that operate in two distinct modes: reactive and proactive. It begins in reactive mode and then switches to proactive mode as data traffic rises. With TCP Cubic, which itself comprehensively used on the Web, the suggested solution ensures impartiality.

COAP-R is a solution, proposed by Rathod et al. [13], that relies on rate-based crowd control for COAP that uses a dispersed estimation of the limited link's higher bandwidth to execute a max-min fair distribution of transmission rates at COAP resources. COAP-R uses network sources more efficiently than basic COAP and CoCoA, and it decreases the time required to gather sensed information produced by nodes about a discovered event.

Sharma et al. [14] implies a wireless sensor network, traffic control technology for use in IoT-based modular healthcare systems. The suggested approach used a priority-based information routing algorithm to manage congestion-related problems. Depending on the urgency of the packets of data, it divides them into three main categories. In addition, this study introduces a prioritized queue-based sequencing system that improves stability.

Shelke et al. [15] proposed an effective traffic control method that aims to prevent overcrowding in the first place. If traffic persists, the technique efficiently solves the problem and restores network consistency. In a medium to large size network, the OCAEEP method establishes reduced packet losses, energy efficiency, improved buffer management, and decreased end-to-end latency.

The features of the CIoT and the addition of cognition to the conventional IoT are analyzed by Vallati et al. [16] developed a training automata-based CIoT architecture. Learning automata is used to adapt the IoT configurable parameters in the developed framework. Each learning automaton has given one modifiable feature to alter, and it selects one of the available values. The paper's primary goal is to reduce overcrowding, and the suggested CIoT architecture has been put into test in this regard. Some tests were performed, and the suggested congestion control mechanism, dubbed CCCLA, was evaluated with other congestion control methods.

In this research, Verma et al. [17] proposed a novel congestion control technique termed CoCoA++ for IoT networks using delay gradients. Because of the difficulty to predict congestion issues from stochastic RTT samples, congestion control techniques that rely entirely on per-packet RTT metrics, such as CoCoA, fail to perform. The delay gradients have a realistic estimation of data traffic. To gain information on how CoCoA++ performs in various IoT scenarios, they tested the proposed algorithm in both static and dynamic architectures.

IV. Methodology

In this section, the paper proposes the machine learning approach is used to improve by forecasting the dimensions of a congestion window that relies on a random forest algorithm to manage the crowding or congestion in the network. To decide the feeding variables for the congestion management in the network is dependent on the following factors as discussed below:

A. *Congestion Window Size Prediction*

1) *Congestion Window Dimension Evaluation*

In the given approach packet as a unit is utilized for adjustments in the window. Each acceptance on route *l*, the size of the window is incremented by:

$$\text{wl} \leftarrow \text{wl} + \min\left(\frac{\alpha\text{l}}{\text{wcomplete}} + \frac{\beta\text{l}}{\text{wl}} + \frac{1}{\text{wl}}\right) \quad \text{(ii)}$$

Each drop on route *l*, size of window decremented as:

$$wl \leftarrow max(1, \gamma lwl) \quad \text{(iii)}$$

Where,

$w_{complete}$ = The complete dimension of window for overall path availability,

α_l = Aggressive factor,

β_l = Crowding or congestion balance factor,

γ_l = Window decrementing factor.

Any multipath circulation shall not be too aggressive than the TCP segments, which peaks it at 1/wl. α_l indicates the aggression of multipath circulation, β_l is supposed to move congestion from an overcrowded route to a less crowded route, and γ_l lowers the dimension of the window. As a result, it will be built to be more adaptable and precisely for improving throughput efficiently.

2) *Data Transmission Rate Evaluation*

In the architecture of window reductions, two factors are taken into account:

- Multiple pathways communicate with one other
- The route's intensity of overcrowding. The bit rate proportion is used as the first component for determining the connection between routes.

3) *Packet Loss Component Evaluation*

The packet loss and its components are evaluated to decide the window size.

4) *Intermediate Packet Arrival Duration Evaluation*

Intermediate arrival duration is mentioned as:

$$D_{ca} = 1/\lambda_a, \; a_s = \lambda_{1\text{-link}} + \lambda_{ct} + \lambda_{ut} \quad \text{(iv)}$$

Where,

λ_a = rate of arriving

λ_{ct} = rate of arrival at connected link

λ_{ut} = rate of arrival at unconnected link

$\lambda_{1\text{-link}}$ = mean of arriving rate

Now, length of the sequence can be calculated as:

$$S_{i\rightarrow avgm} = (1 - w_s) * S_{i\rightarrow avgm} + w_s * s_{i\rightarrow instm} \quad \text{(v)}$$

Where

$s_{i\rightarrow instm}$ is the instantaneous sequence length.

5) *Transmitting and Retransmitting Count Evaluation*

The Transmitting Count (TC) is the amount of estimated transmitting data and re-transmitting data required to deliver a packet successfully wirelessly, and it is calculated as follows:

$$\text{PTC} = 1/(d_{ahead} * d_{back}) \quad \text{(v)}$$

Where,

d_{ahead} = delivery ratio in moving ahead direction

d_{back} = delivery ration in moving back ward direction.

6) *Algorithm for Congestion Window Prediction using Machine Learning*

Algorithm 1 Congestion Window Size Prediction

Input: (P, Q) $\rightarrow\{(p_1,q_1), (p_2,q_2), \ldots\ldots, (p_n,q_n)\}$

DTR= Data transmission rate

PL= Packet loss

IPA = Intermediate packet arrival time

TC= Transmission count

RTC= Retransmission count

I= Iteration

RF_{ml} = Random Forest Machine Learning

Output: W_s = Window Size

Begin

For each sample in (P,Q)

Evaluate Param{DTR, PL, IPA, TC, RTC}

For i=1:I

Train RF_{ml} {Solution→Param}

end

Predict W_s

Control transmission rate

End

B. *Data Packet Transmission*

In paper aims to design a congestion control mechanism for healthcare IoT-based WSN scenario that is focused to increase network lifetime potentially delivering sensing data to gateways. So, after predicting congestion window size, the proposed methodology decides the priority among packets for transmission. Two major factors considered here are delay and energy. This categorizes the packets as prioritize and non-prioritize or normal packets. In applications related to medical assistance or healthcare, several medical devices are used and have their priority. The proposed algorithm senses the data grouped and transmitted according to priority. In this algorithm, the source node sets the priority of packets and transmits them. Algorithm 2 describes the methodology for grouping together these prioritize packets and their transmission.

Algorithm 2 Data grouping and prioritization and transmission

Input: Sensor node (S_n) events(E)
Begin
For each S_n
Decide Priority (P_n) of each event
Set $E_n \rightarrow$ flag(P_n)
Sum (E_n) according to W_s {as in algorithm 1}
Transmit Sum (E_n) to gateway
End

V. THEORITICAL ANALYSIS OF PROPOSED CONGESTION CONTROL ALGORITHM

In this section, the paper examines and discusses the theoretical complexity of the proposed machine learning-based window size prediction and congestion control algorithm as a solution approach for healthcare applications such as in HIoT. Table I describes the efficacy of the proposed methodology over other existing methods.

TABLE I. THEORETICAL COMPARATIVE STATE-OF-ART

Methodology	Application Areas	MLF	WSP	DPS	NL	MPR
[1]	IoT	No	No	Yes	Yes	Yes
[9]	Healthcare IoT	No	No	Yes	Yes	No
[11]	IoT	Yes	No	Yes	Yes	Yes
[12]	IoT	No	No	No	Yes	No
[14]	Cellular IoT	Yes	No	No	No	No
[16]	6LoWPAN	No	No	No	Yes	No
[17]	IoT	No	Yes	No	Yes	No
Proposed	Healthcare IoT	Yes	Yes	Yes	Yes	Yes

MLF = Machine Learning Features, WSP = Window size Prediction, DPS = Data priority selection, NL = Network Longevity, MPR = Multipath Routing

VI. CONCLUSION

The healthcare Internet of Things (HIoT) connects a number of diagnostic sensing devices that are used for patient diagnosis. To provide these services, number of emergency packets are transmitted over IoT network. But due to resource limitations of these devices, it is forwarded to remotely located servers for processing. For such real-time processing of complicated healthcare analysis, it has to be transmitted to server without any error and delay. So, to avoid such delay transmission is needed to be congestion free. Therefore, in this paper, a framework is proposed for congestion control routing protocol for healthcare IoT for congestion free data forwarding of emergency packets with energy efficiency. The algorithm is divided into two steps; first of all, the algorithm predicts the window size according to traffic flow parameters using machine learning algorithm and in the second step it transmits the data based on the priority of the sensing events i.e. emergency packets. Further, this paper proved its theoretical benefits over other existing algorithms.

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