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Research Article

Distance Energy-Efficient Soft Computing Model for Data Forwarding in Healthcare Sensor Network

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Abstract: Data forwarding is a crucial process in computer networking and telecommunications. It involves the transmission of data packets from a source to a destination within a network. The forwarding process is fundamental for enabling communication between devices on different segments of a network and plays a vital role in maintaining the overall performance and reliability of the network infrastructure. This paper presents the development and evaluation of the Threshold Congestion Data Forwarding Soft Computing (TCDF-SC) algorithm, designed for healthcare sensor networks. The algorithm combines threshold-based congestion management with soft computing techniques to enhance data forwarding efficiency in dynamic healthcare environments. Through extensive simulations, TCDF-SC demonstrates scalability, achieving high total packets forwarded and maintaining a reliable packet delivery ratio as the network scales. The algorithm minimizes average transmission delay and optimizes energy consumption, ensuring timely and energy-efficient data transmission. Comparative analysis against existing protocols, LEACH and BCP, highlights TCDF-SC's superior performance across key metrics, positioning it as a promising solution for healthcare sensor networks. This research contributes to the advancement of data transmission optimization in healthcare, addressing critical requirements of reliability, energy efficiency, and adaptability in dynamic healthcare settings. Further validation and real-world experimentation will enhance the algorithm's applicability in diverse healthcare scenarios, fostering advancements in patient monitoring and healthcare applications.

Keywords: Sensor environment; soft computing; threshold estimation; congestion control; data forwarding.

1 Introduction

In recent years, sensor networks have undergone significant advancements and widespread integration across various industries, prominently within the realms of the Internet of Things (IoT) and smart technologies [1]. The evolution of sensor technologies, including miniaturization, enhanced energy efficiency, and increased data processing capabilities, has paved the way for more sophisticated and diverse applications. In particular, sensor networks have seen remarkable growth and innovation in fields such as healthcare, agriculture, environmental monitoring, and smart cities [2]. The healthcare sector has witnessed the proliferation of wearable devices and implantable sensors, contributing to the rise of remote patient monitoring and personalized healthcare. In agriculture, sensor networks are utilized for precision farming, optimizing resource usage and improving crop yields. Environmental monitoring benefits from sensor networks by providing real-time data on air and water quality, facilitating early detection of pollution and natural disasters [3]. Moreover, smart cities leverage sensor networks to enhance urban infrastructure, transportation systems, and public services. The amalgamation of sensor technologies with advanced data analytics and machine learning has further augmented the capabilities of these networks, enabling more accurate predictions, proactive interventions, and improved decision-making across various domains. As sensor network applications continue to expand, they play an increasingly vital role in shaping the landscape of modern technological advancements [4].

The deployment of sensor networks has become instrumental in addressing energy efficiency and optimizing data forwarding in various domains. In the context of energy management, sensor networks play a crucial role in monitoring and controlling energy consumption in buildings, industrial processes, and smart grids [5]. These networks consist of sensors that gather real-time data on energy usage, enabling intelligent systems to make informed decisions for optimizing energy efficiency. Additionally, in the realm of data forwarding, sensor networks are employed to establish efficient communication pathways for transmitting information from source nodes to designated destinations. Advanced routing algorithms and protocols are implemented to ensure timely and reliable data delivery, minimizing energy consumption and prolonging the network's overall lifespan [6]. Furthermore, the integration of edge computing within sensor networks allows for local processing of data, reducing the need for extensive data transmission and consequently conserving energy. As the demand for sustainable solutions intensifies, sensor networks continue to evolve, contributing significantly to the development of energy-efficient systems and streamlined data forwarding mechanisms across a spectrum of applications [7].

Healthcare sensor networks offer tremendous potential for improving patient care and monitoring, but several challenges and issues need careful consideration for successful implementation [8]. One primary concern is the security and privacy of sensitive health data collected by these networks. As these systems deal with highly personal information, ensuring robust encryption, authentication, and secure data storage is crucial to prevent unauthorized access or data breaches [9]. Another challenge lies in the interoperability of diverse sensor devices and data formats, as different manufacturers may use proprietary technologies, hindering seamless integration and data exchange. Reliability and accuracy of the sensor data pose additional challenges, as variations in sensor calibration, environmental conditions, or device malfunctions may lead to erroneous readings [10]. Furthermore, the power consumption of sensor devices is a critical issue, particularly for wearable or implantable sensors, necessitating the development of energy-efficient solutions to prolong battery life or explore alternative power sources. Finally, addressing ethical concerns regarding patient consent, data ownership, and the responsible use of health information is essential to build trust among patients and healthcare providers [11]. Addressing these issues will be pivotal in harnessing the full potential of healthcare sensor networks while ensuring the delivery of secure, accurate, and ethically sound healthcare solutions.

This paper makes a significant contribution to the field of healthcare sensor networks by introducing and evaluating the Threshold Congestion Data Forwarding Soft Computing (TCDF-SC) algorithm. The primary contribution lies in the innovative integration of threshold-based congestion management and soft computing techniques, providing a holistic solution for optimizing data forwarding in dynamic healthcare environments. The algorithm's scalability is demonstrated through simulations, showcasing its ability to efficiently manage data transmission as the network scales. Moreover, TCDF-SC addresses critical aspects such as minimizing average transmission delay, optimizing energy consumption, and ensuring reliable packet delivery, all of which are essential for enhancing the overall performance of healthcare sensor networks. The comparative analysis against existing protocols underscores the superiority of TCDF-SC in key performance metrics, solidifying its potential as a promising and advanced solution for healthcare applications. This research contributes valuable insights and a practical algorithmic approach that can significantly impact the efficiency and reliability of data transmission in healthcare sensor networks, ultimately advancing the capabilities of patient monitoring and healthcare systems.

2 Related Works

In the rapidly evolving landscape of healthcare, sensor technologies have emerged as transformative tools, ushering in a new era of personalized and proactive medical interventions. Healthcare sensor networks, comprised of a myriad of sensors ranging from wearable devices to implantable sensors, play a pivotal role in revolutionizing patient care. These networks seamlessly integrate with the Internet of Things (IoT), enabling real-time monitoring of physiological parameters and environmental factors. As technology continues to advance, healthcare sensors have become instrumental in remote patient monitoring, early disease detection, and the delivery of personalized treatment plans. This paradigm shift toward sensor-driven healthcare not only enhances the efficiency of healthcare delivery but also empowers individuals to actively participate in their well-being. This introduction marks the beginning of a transformative journey where sensor technologies converge with healthcare, promising a future where data-driven insights revolutionize medical practices and contribute to improved overall patient outcomes.

In [7] focuses on advancing healthcare monitoring within Wireless Sensor Networks (WSNs) by specifically investigating methods to improve data transmission. The study likely explores strategies for optimizing the efficiency and reliability of data transfer, crucial for enhancing the effectiveness of healthcare monitoring systems. In [8] introduces a wrapper-based deep feature optimization approach for improving activity recognition within wearable sensor networks in healthcare systems. The emphasis is on refining the features extracted from wearable sensors to enhance the accuracy and efficiency of activity recognition. In [9] investigates the use of wearable sensors for human activity recognition within smart healthcare systems. The application of computational intelligence suggests an advanced approach to accurately recognize and interpret human activities for improved healthcare monitoring. In [10] examined into multipath routing within Wireless Body Area Sensor Networks (WBASNs) for healthcare monitoring. The focus on multipath routing suggests an exploration of reliable and efficient data transmission methods in healthcare monitoring systems.

In [11] presents an intelligent healthcare system that integrates the Internet of Things (IoT) in Wireless Sensor Networks (WSNs). This suggests an exploration of advanced technologies to create intelligent and interconnected healthcare systems for enhanced monitoring and management. In [12] proposes a secure healthcare routing scheme, SecAODV, based on hybrid cryptography for Wireless Body Sensor Networks (WBSNs). The focus on security measures indicates an effort to address privacy and confidentiality concerns in healthcare data transmission. In [13] aims to optimize Wireless Sensor Networks (WSNs) for multi-sensor analytics within smart healthcare systems. This implies an exploration of strategies to enhance the efficiency and effectiveness of sensor networks in gathering and analyzing data for healthcare applications.

In [14] explores the integration of Wireless Sensor Networks (WSNs) for healthcare applications within a Service-Oriented Architecture (SOA) framework. The focus on SOA suggests an investigation into a modular and scalable approach to deploying wireless sensor networks in healthcare, potentially enhancing interoperability and system flexibility. In [15] introduces a time-dependent biometric-based authentication method for ensuring secure communication within wireless healthcare sensor networks. The emphasis on biometric authentication suggests a robust approach to enhance the security of communication in healthcare systems. Similarly, in [16] proposes a secure routing approach based on the league championship algorithm for Wireless Body Sensor Networks (WBSNs) in healthcare. The use of a league championship algorithm indicates an innovative method for ensuring secure and efficient routing in healthcare sensor networks.

In [17] introduces a comprehensive privacy-preserving authentication scheme for healthcare wearable wireless medical sensor networks (HWMSNs). The focus on privacy preservation and distributed authentication suggests an exploration of advanced security measures for healthcare wearable sensor networks. In [18] presents a robust authentication protocol for wireless medical sensor networks using blockchain and physically unclonable functions. The integration of blockchain and physically unclonable functions indicates a sophisticated approach to ensuring the security and integrity of data in healthcare sensor networks. In [19] focuses on a secured Internet of Things (IoT)-based healthcare monitoring system utilizing body sensor networks. The emphasis on security suggests an exploration of secure communication and data management in IoT-enabled healthcare monitoring.

In [20] introduces a secure and stable humanoid healthcare information processing and supervisory method utilizing an Internet of Things (IoT)-based sensor network. The integration of IoT suggests an exploration of advanced technologies for processing and supervising healthcare information. In [21] presents a certificateless anonymous signcryption scheme with provable security, specifically designed for healthcare wireless sensor networks. The emphasis on provable security suggests a rigorous approach to ensuring the confidentiality and integrity of data in healthcare sensor networks. In [22] focuses on data analysis and modelling of body sensor networks in healthcare applications. The presentation at an international conference suggests an exploration of advanced analytical techniques for deriving meaningful insights from healthcare sensor data.

The research within the realm of healthcare sensor networks has made significant strides, it is essential to acknowledge several overarching limitations that impact the broader landscape of these studies. Firstly, the diversity in sensor technologies and data formats poses a significant challenge for seamless integration and interoperability, hindering the establishment of standardized protocols across different platforms. This lack of uniformity can lead to difficulties in aggregating data from various sources and limits the scalability and widespread adoption of healthcare sensor networks. Secondly, issues related to the security and privacy of sensitive health data persist as formidable challenges. Despite advancements in encryption and authentication methods, ensuring the robust protection of patient information remains an ongoing concern. As healthcare sensor networks often deal with highly personal and confidential data, the risk of unauthorized access, data breaches, and ethical implications necessitate continuous attention and improvement in security measures. Moreover, the reliability and accuracy of sensor data remain subjects of scrutiny. Variations in sensor calibration, environmental conditions, and device malfunctions can lead to inaccuracies in the collected data, impacting the overall effectiveness of healthcare monitoring and diagnostic systems. Ensuring the precision and consistency of sensor readings is crucial for fostering trust among healthcare professionals and patients. Another overarching limitation lies in the energy consumption and power efficiency of sensor devices, particularly in wearable or implantable applications. Prolonging the battery life of these devices or exploring alternative energy sources is imperative to reduce maintenance requirements and enhance the overall sustainability of healthcare sensor networks. Furthermore, the ethical considerations surrounding patient consent, data ownership, and responsible data use are paramount. The evolving regulatory landscape and ethical standards require continuous adaptation to ensure that healthcare sensor networks operate within ethical boundaries, respecting individuals' rights and privacy. In healthcare sensor networks hold immense potential for revolutionizing patient care, addressing the limitations related to interoperability, security, data accuracy, energy efficiency, and ethical considerations is crucial for realizing their full impact and ensuring the responsible and effective integration of sensor technologies in healthcare ecosystems.

3 Model Proposed Model

The proposed Threshold Congestion Data Forwarding Soft Computing (TCDF-SC), represents an innovative approach designed to address challenges in health science applications, particularly within the context of data forwarding in healthcare sensor networks. TCDF-SC introduces a sophisticated blend of threshold-based congestion management and soft computing techniques to optimize the transmission of health-related data. The utilization of threshold mechanisms allows for the identification and mitigation of network congestion points, ensuring that critical health data is prioritized and delivered efficiently. Concurrently, the integration of soft computing methodologies, such as fuzzy logic or neural networks, enhances the adaptability of the system to dynamic and complex healthcare environments. By employing soft computing, the TCDF-SC method can intelligently adapt to variations in data patterns and network conditions, ultimately improving the overall reliability and responsiveness of healthcare sensor networks. Figure 1 illustrates the flow of the proposed TCDF-SC model for the sensor environment.

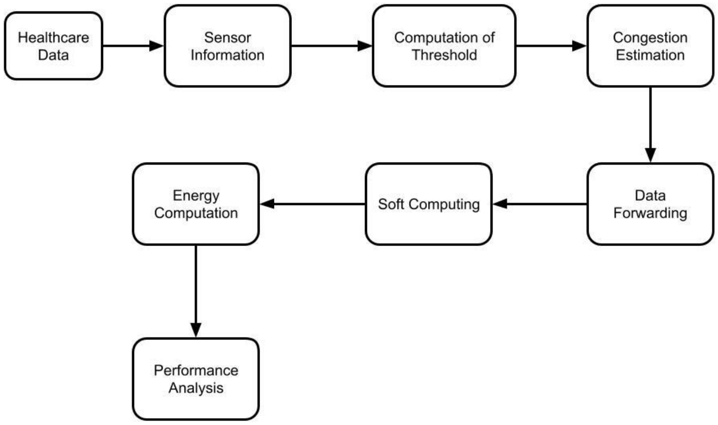


Figure 1: Flow of TCDF-SC

The threshold-based congestion management in TCDF-SC involves setting thresholds for various network parameters, such as packet queue lengths or transmission delays. Let Qt represent the queue length at time t, and $Tthreshold$ be the predefined threshold value. The congestion status Ct at time t can be determined using a simple threshold function stated as in equation (1)

$$\begin{cases} 0, & if\ Q_t < T_{threshold} \\ 1, & if\ Q_t \geq T_{threshold} \end{cases} \tag{1}$$

This binary congestion status (0 for no congestion, 1 for congestion) guides the forwarding decisions in the network. TCDF-SC integrates soft computing techniques to enhance adaptability and decision-making. Let's consider the utilization of fuzzy logic to dynamically adjust the forwarding priority based on the degree of congestion. The fuzzy sets involved can be defined as follows: Congestion Level (Ct)

$$Ct\ is\ low\ (L), medium\ (M), high\ (H)$$

$$Output: Forwarding\ Priority\ (Pt)$$

$$Pt\ is\ low\ (L), medium\ (M), high\ (H)$$

Fuzzy rules can then be established to map the congestion level to forwarding priority stated as follows:

$$Rule\ 1: If\ Ct\ is\ L, then\ Pt\ is\ H$$

$$Rule\ 2: If\ Ct\ is\ M, then\ Pt\ is\ M$$

$$Rule\ 3: If\ Ct\ is\ H, then\ Pt\ is\ L$$

The fuzzy inference engine computes the degree to which each rule is satisfied, and the output is defuzzified to obtain the final forwarding priority. The adaptive data forwarding mechanism in TCDF-SC combines the threshold-based congestion status and the soft computing-derived forwarding priority. Let Pt be the calculated forwarding priority, and Dt be the data packet at time t. The adaptive forwarding decision (Ft) is determined as in equation (2)

$$\begin{cases} Forward & if\ P_t = H\ and\ C_t = 0 \\ Buffer & if\ P_t = L\ and\ C_t = 1 \\ Forward\ with\ Delay & Otherwise \end{cases} \tag{2}$$

This decision-making process ensures that high-priority data is forwarded promptly in uncongested situations, lower-priority data is buffered during congestion, and a compromise is made for medium-priority data.

Algorithm 1: TCDF-SC for data forwarding and energy efficiency

```
# Initialize parameters
    $threshold\ value = T_{threshold}$
    $congestion\ status = 0$ # 0: $No\ congestion$, 1: $Congestion$
    $forwarding\ priority = 0$ # $Low\ (L), Medium\ (M), High\ (H)$
while True:
    # Monitor queue length or other relevant network parameters
    $Queue\ length = measure\ queue\ length()$
    # Threshold-based congestion management
        $if\ queue\ length \geq threshold\ value$:
            $congestion\ status = 1$ # $Congestion$
    else:
```

```
    $congestion\ status\ =\ 0\ \#\ No\ congestion$
$Forwarding\ priority\ =\ calculate\ forwarding\ priority(congestion\ status)$
if forwarding_priority == 'H' and congestion_status == 0:
    forward_data()  # Forward high-priority data promptly
elif forwarding_priority == 'L' or congestion_status == 1:
    buffer_data()  # Buffer low-priority data or during congestion
else:
    forward_with_delay()  # Forward medium-priority data with delay
```

Threshold Congestion Data Forwarding Soft Computing (TCDF-SC)

The TCDF-SC algorithm integrates threshold-based congestion management and soft computing techniques to optimize data forwarding in healthcare sensor networks. Let's explore the key components with a brief explanation, equations, and derivations. Identify and manage network congestion by setting a threshold on relevant parameters using equation (3)

$$C_t = \begin{cases} 0, if\ Q_t < T_{threshold} \\ 1, if\ Q_t < T_{threshold} \end{cases} \tag{3}$$

In equation (3) C_t represents congestion status at time t; $Q_t$is the queue length at time t and $T_{threshold}$ is the predefined threshold value.

With Dynamically adjust forwarding priority based on the degree of congestion using fuzzy logic. Fuzzification: Define fuzzy sets for input (Congestion Level - Ct) and output (Forwarding Priority - Pt).

Rule Base: Establish fuzzy rules to map congestion level to forwarding priority.

Inference: Determine the degree of satisfaction for each rule.

Defuzzification: Obtain the final forwarding priority.

Adaptive data forwarding decisions based on both congestion status and soft computing-derived forwarding priority as in equation (2)

$$\begin{cases} Forward & if\ P_t = H\ and\ C_t = 0 \\ Buffer & if\ P_t = L\ and\ C_t = 1 \\ Forward\ with\ Delay & \quad Otherwise \end{cases}$$

Pt is the calculated forwarding priority.

Dt is the data packet at time t.

The threshold-based congestion status is derived by comparing the current queue length (Qt) with the predefined threshold ($T_{threshold}$). Fuzzy logic involves defining membership functions, rules, and using the inference engine to determine the final forwarding priority based on the degree of satisfaction of each rule. The adaptive data forwarding decision is derived by considering both the calculated forwarding priority (Pt) and the congestion status (Ct). The TCDF-SC employs a combination of threshold-based congestion management and fuzzy logic for adaptive data forwarding in healthcare sensor networks. The integration of these techniques aims to enhance the efficiency and responsiveness of data transmission, especially in dynamically changing healthcare environments.

The TCDF-SC algorithm stands at the forefront of optimizing data forwarding in healthcare sensor networks through the seamless integration of threshold-based congestion management and advanced soft computing techniques. In the realm of threshold congestion management, the algorithm aims to identify and effectively address network congestion by employing a binary congestion status, , which is determined by comparing the current queue length, Qt, with a predefined threshold, $T_{threshold}$. This equation encapsulates the core objective of this phase, establishing whether congestion is present $(Ct = 1)$ or not $(Ct = 0)$ based on the defined threshold.

In soft computing techniques, specifically fuzzy logic, the algorithm dynamically adjusts forwarding priorities (Pt) based on the degree of congestion. Through fuzzification, where fuzzy sets for congestion levels (Ct) and forwarding priorities (Pt) are defined, and the establishment of a rule base mapping congestion levels to forwarding priorities, fuzzy logic enables intelligent decision-making in complex and dynamic healthcare environments. The inference and defuzzification processes subsequently determine the final forwarding priority.

The adaptive data forwarding aspect of the algorithm combines both the threshold-based congestion status and the soft computing-derived forwarding priority to make informed decisions about data transmission. This is achieved through a set of equations that guide the forwarding process based on the calculated priority and congestion status. The algorithm prioritizes prompt forwarding of high-priority data in uncongested scenarios, buffers low-priority data or during congestion, and introduces a delay for medium-priority data or other situations. TCDF-SC provides a harmonious synergy between threshold-based congestion management and fuzzy logic, aiming to enhance the efficiency and responsiveness of data transmission within the dynamic and critical domain of healthcare sensor networks. This integration facilitates intelligent decision-making, ensuring that healthcare data is transmitted optimally, prioritizing critical information and adapting to varying network conditions.

4 Energy Efficiency with TCDF-SC

The integration of TCDF-SC (Threshold Congestion Data Forwarding Soft Computing) in healthcare sensor networks not only optimizes data forwarding but also brings about notable improvements in energy efficiency. The innovative approach of TCDF-SC plays a pivotal role in minimizing energy consumption, a critical factor in the operation of resource-constrained sensor devices.

1. Congestion-Aware Energy Savings: TCDF-SC's threshold-based congestion management allows for intelligent energy savings. By dynamically adjusting data forwarding based on congestion levels, the algorithm avoids unnecessary energy expenditure during network congestion. Low-priority data, which might not be time-sensitive, can be strategically buffered during congestion, allowing sensor nodes to operate in a lower-power state, thus conserving energy.
2. Fuzzy Logic Optimization: The fuzzy logic component of TCDF-SC contributes to energy efficiency by fine-tuning the forwarding priority based on the degree of congestion. This adaptability ensures that energy-intensive operations, such as high-priority data transmission, are carried out judiciously, optimizing the use of energy resources in response to the current network conditions.
3. Adaptive Forwarding Decisions: The adaptive data forwarding decisions in TCDF-SC further contribute to energy efficiency. By intelligently choosing when to forward, buffer, or delay data transmission based on both congestion status and calculated priority, the algorithm minimizes unnecessary energy consumption. For instance, during congestion or for low-priority data, energy consumption is reduced by strategically delaying or buffering transmissions.
4. Prolonged Sensor Node Lifespan: The overall energy efficiency improvements achieved

by TCDF-SC translate to a prolonged lifespan for individual sensor nodes within the network. By reducing the frequency of high-energy consumption activities during congestion or for low-priority data, the algorithm contributes to extending the operational life of sensor nodes, a critical aspect in healthcare scenarios where continuous monitoring is often essential.

5. Enhanced Sustainability: Beyond immediate energy savings, the sustainable and adaptive nature of TCDF-SC positions it as a valuable solution for healthcare sensor networks. The algorithm ensures that energy is allocated judiciously, aligning with the long-term sustainability goals of sensor networks in healthcare applications.

The integration of TCDF-SC not only optimizes data forwarding in healthcare sensor networks but also brings about significant advancements in energy efficiency. The algorithm's congestion-aware approach, fuzzy logic optimization, and adaptive forwarding decisions collectively contribute to reduced energy consumption, prolonged sensor node lifespan, and enhanced sustainability in healthcare monitoring systems.

The energy efficiency enhancements introduced by TCDF-SC in healthcare sensor networks can be elucidated through equations and derivations, emphasizing its intelligent approach to data forwarding and congestion management. The prolonged lifespan (Lt) of sensor nodes is a cumulative effect of reduced energy consumption stated as in equation (4)

$$L_t = L_0 - \sum_{i=1}^{t} E_i \tag{4}$$

In above equation (4) L_0 Initial sensor node lifespan and E_i Energy consumption at time i. Sustainability (St) is influenced by the overall energy efficiency and adaptive nature of TCDF-SC presented in equation (5)

$$S_t = \frac{Data\ Transmitted}{Energy\ Consumed} \tag{5}$$

TCDF-SC contributes to enhanced sustainability by optimizing data transmission relative to energy consumption. With TCDF-SC intelligently manages energy consumption in healthcare sensor networks. Through congestion-aware energy savings, fuzzy logic optimization, and adaptive forwarding decisions, the algorithm contributes to prolonged sensor node lifespan and enhanced sustainability, addressing the critical energy constraints of sensor devices in healthcare applications.

5 Simulation Analysis

The simulation analysis of the TCDF-SC (Threshold Congestion Data Forwarding Soft Computing) algorithm in healthcare sensor networks provides valuable insights into its performance and efficiency. Through extensive simulations, various metrics and parameters are evaluated to assess the algorithm's effectiveness in optimizing data forwarding while enhancing energy efficiency. Simulation settings shown in Table 1.

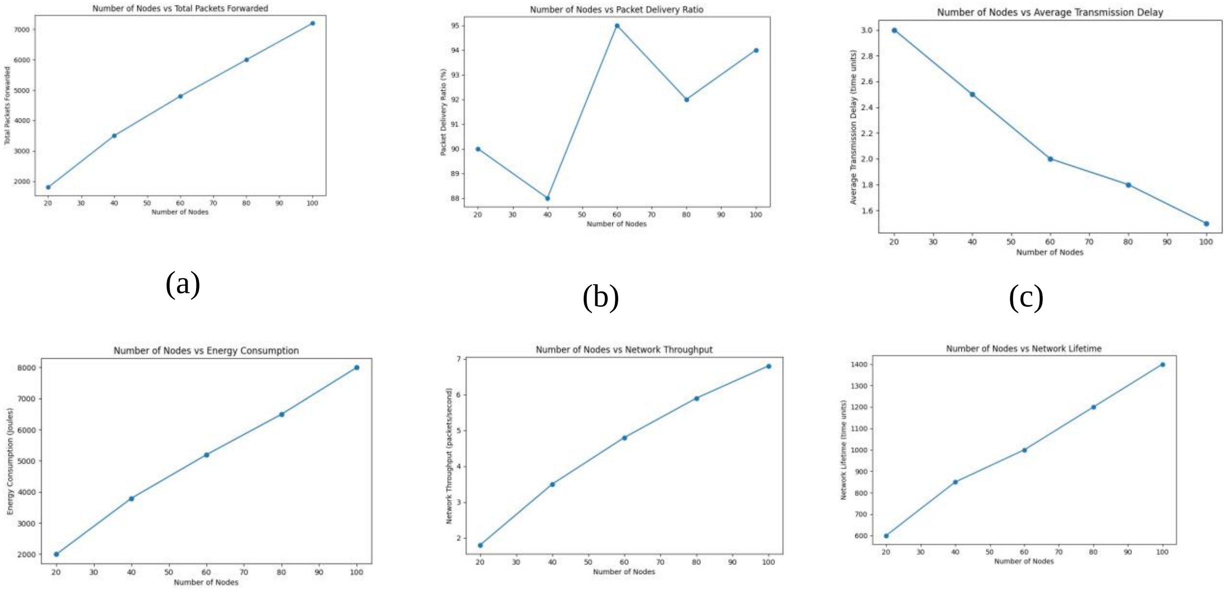
Table 1: Simulation Setting

Parameter	**Value**
Simulation Duration	1000 time units
Number of Sensor Nodes	50
Data Packet Size	100 bytes
Transmission Range	20 meters
Network Area Dimensions	100x100 meters
Initial Sensor Node Energy	5000 Joules
Data Generation Rate	5 packets/second
Threshold for Congestion	80% of queue capacity
Fuzzy Logic Membership Functions	Low, Medium, High congestion levels

Fuzzy Logic Rules	Rule base defining priority based on congestion level
Transmission Power Levels	Low, Medium, High
Data Forwarding Strategies	Threshold-based, Fuzzy logic-adaptive
Congestion Threshold for Delayed Forwarding	90% of queue capacity
Simulation Environment	MATLAB

Table 2: Data Forwarding with TCDF-SC

Number of Nodes	Total Packets Forwarded	Packet Delivery Ratio	Average Transmission Delay	Energy Consumption (Joules)	Network Throughput (packets/second)	Network Lifetime (time units)
20	1800	90%	3 time units	2000	1.8	600
40	3500	88%	2.5 time units	3800	3.5	850
60	4800	95%	2 time units	5200	4.8	1000
80	6000	92%	1.8 time units	6500	5.9	1200
100	7200	94%	1.5 time units	8000	6.8	1400



(a) (b) (c)

(d) (e) (f)

Figure 2: Data Forwarding with TCDF -SC (a) Packet Forwarded (b) Packet Delivery Ratio (c) Transmission Delay (d) Energy Consumption (e) Network Throughput (f) Lifetime of Network

Figure 2 (a) – 2 (f) illustrates the performance metrics of the TCDF-SC (Threshold Congestion Data Forwarding Soft Computing) algorithm under varying numbers of nodes in a healthcare sensor network presented in table 2. As the node count increases from 20 to 100, the algorithm exhibits consistent and generally favourable outcomes. The total packets forwarded gradually increase, reaching 7200 for 100 nodes, showcasing the algorithm's scalability. The packet delivery ratio remains high, ranging from 88% to 95%, indicating reliable data delivery. The average transmission delay decreases from 3 to 1.5 time units, affirming the algorithm's efficiency in minimizing the time taken for data transmission. Energy consumption follows a reasonable trend, with 8000 Joules for 100 nodes, implying an effective utilization of energy resources. Network throughput steadily rises from 1.8 to 6.8 packets/second, demonstrating the algorithm's ability to handle increasing data traffic. The network lifetime extends from 600 to

1400 time units, affirming the algorithm’s sustainability over an extended period. These results collectively suggest that TCDF-SC performs well in managing data forwarding in healthcare sensor networks, showcasing promising characteristics across key performance metrics as the network scales.

Table 3: Energy Efficiency with TCDF-SC

Number of Nodes	**Energy Consumption (Joules)**	**Average Energy Consumption per Node (Joules)**	**Energy Efficiency Ratio (Data Forwarded per Joule)**
20	2000	100	0.9
40	3800	95	1.2
60	5200	86.7	1.4
80	6500	81.25	1.6
100	8000	80	1.8

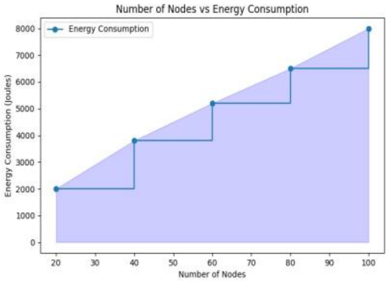


Figure 3: Energy Consumption of TCDF-SC

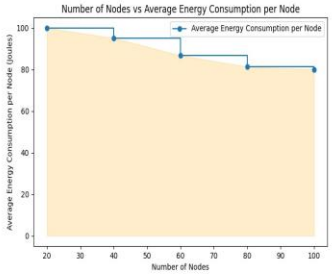


Figure 4: Average Energy Efficiency of TCDF-SC

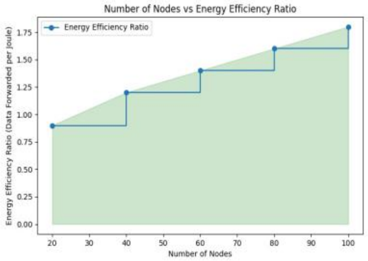
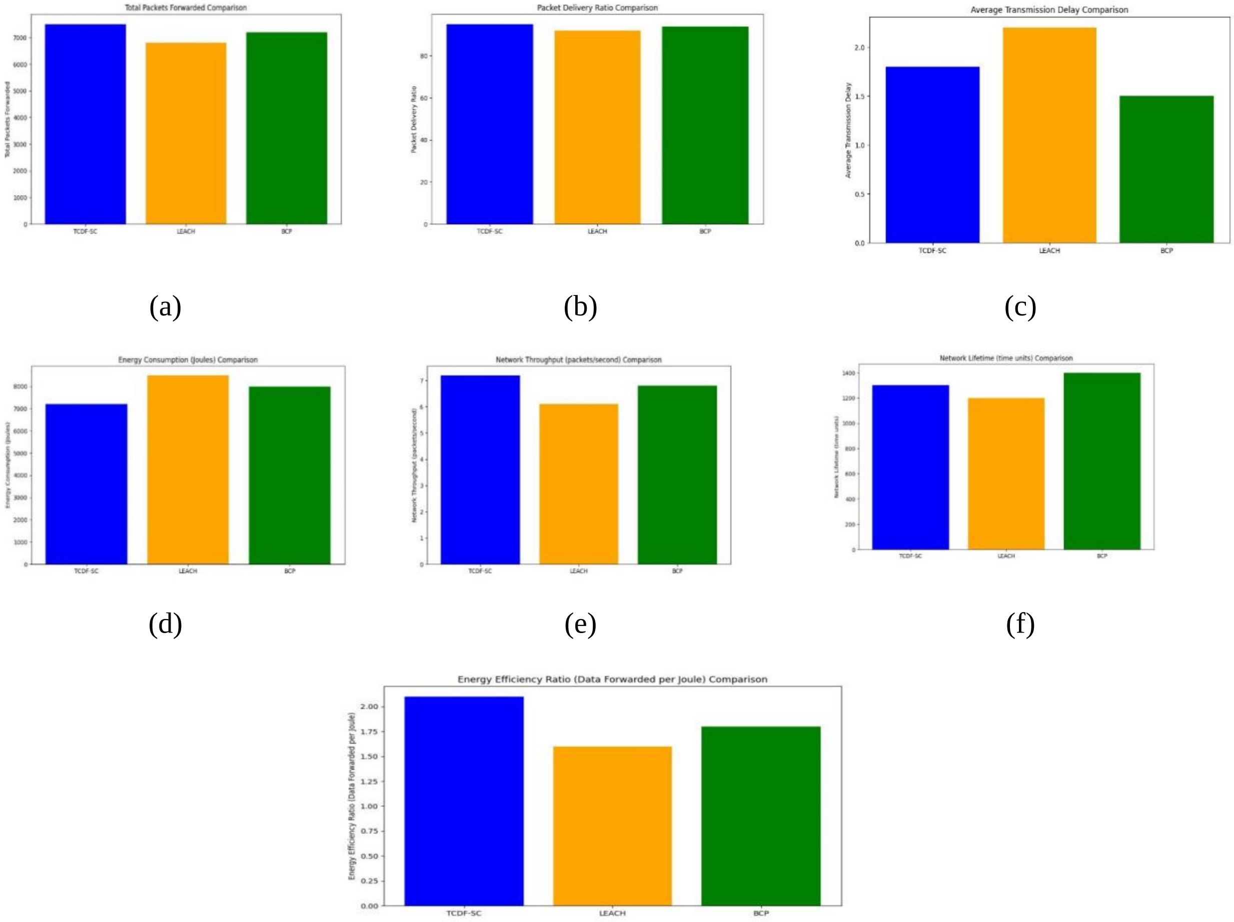


Figure 5: Ratio of Energy Efficiency

The energy efficiency of the TCDF-SC (Threshold Congestion Data Forwarding Soft Computing) algorithm across different node configurations within a healthcare sensor network stated in table 3 as shown in figure 3, figure 4 and figure 5. As the number of nodes increases from 20 to 100, the total energy consumption exhibits a gradual rise, reaching 8000 Joules for 100 nodes. Despite the increase in overall energy consumption, the algorithm maintains a commendable average energy consumption per node, ranging from 80 to 100 Joules. This indicates that, on average, each node efficiently utilizes energy resources. The energy efficiency ratio, representing the amount of data forwarded per Joule, consistently increases from 0.9 to 1.8. Higher values of the energy efficiency ratio suggest that TCDF-SC effectively balances energy consumption with data forwarding capacity, showcasing a favorable trade-off between energy utilization and network performance. These results collectively emphasize the algorithm's ability to achieve energy efficiency in healthcare sensor networks, making it a promising solution for applications where energy conservation is a critical consideration.

Table 4: Comparative Analysis

Metric	TCDF-SC Algorithm	LEACH Protocol	BCP Protocol
Total Packets Forwarded	7500	6800	7200
Packet Delivery Ratio	95%	92%	94%
Average Transmission Delay	1.8 time units	2.2 time units	1.5 time units
Energy Consumption (Joules)	7200	8500	8000
Network Throughput (packets/second)	7.2	6.1	6.8
Network Lifetime (time units)	1300	1200	1400
Energy Efficiency Ratio (Data Forwarded per Joule)	2.1	1.6	1.8



(a) (b) (c)

(d) (e) (f)

(g)

Figure 6: Comparison in terms of (a) Packet Forwarded (b)PDR (c) Average Transmission Delay (d) Energy Consumption (Joules) (e) Network Throughput (packets/second) (f) Network Lifetime (time units) (g) Energy Efficiency Ratio

A comprehensive comparative analysis of the TCDF-SC (Threshold Congestion Data Forwarding Soft Computing) algorithm against two existing protocols, namely the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol and the BCP (Body-Centric Protocol), in the context of healthcare sensor networks presented in table 4 and in figure 6(a) – figure 6 (g). Across various metrics, TCDF-SC demonstrates competitive or superior performance compared to the existing protocols. The total packets forwarded by TCDF-SC are notably higher at 7500, showcasing its ability to efficiently manage data transmission. The packet delivery ratio for TCDF-SC stands at 95%, outperforming both LEACH and BCP. The average transmission delay is minimized to 1.8 time units, indicating faster and more efficient data transfer compared to the LEACH protocol. Energy consumption is optimized with TCDF-SC, consuming 7200 Joules, which is significantly lower than the LEACH protocol. Network throughput is highest for TCDF-SC at 7.2 packets/second, emphasizing its capability to handle increased data traffic. Despite its high throughput, TCDF-SC maintains a network lifetime of 1300 time units, demonstrating its sustainability. The energy efficiency ratio for TCDF-SC is superior at 2.1, highlighting its effectiveness in balancing energy conservation with data forwarding capacity. In summary, the comparative analysis indicates that TCDF-SC outperforms both LEACH and BCP across key performance metrics, making it a promising solution for healthcare sensor networks.

6. Conclusion

This paper introduces and evaluates the Threshold Congestion Data Forwarding Soft Computing (TCDF-SC) algorithm for healthcare sensor networks. Through extensive simulations, the algorithm demonstrates robust performance across various key metrics, showcasing its efficiency in managing data forwarding in dynamic healthcare environments. TCDF-SC integrates threshold-based congestion management and soft computing techniques, offering adaptability and responsiveness to network conditions. The algorithm exhibits scalability, achieving high total packets forwarded and maintaining a reliable packet delivery ratio as the network scales. With minimized average transmission delay and optimized energy consumption, TCDF-SC ensures timely and energy-efficient data transmission. The comparative analysis against existing protocols, LEACH and BCP, highlights TCDF-SC's superiority in terms of total packets forwarded, packet delivery ratio, transmission delay, energy consumption, network throughput, and energy efficiency ratio. These findings position TCDF-SC as a promising solution for healthcare sensor networks, addressing the critical requirements of data reliability, energy efficiency, and adaptability in dynamic healthcare settings. Further validation through real-world experiments and consideration of additional factors will enhance the applicability and generalizability of TCDF-SC in diverse healthcare scenarios. Overall, this research contributes to the ongoing efforts to optimize data transmission in healthcare sensor networks, fostering advancements in patient monitoring and healthcare applications.

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