A Priority Based Congestion Avoidance Scheme for Healthcare Wireless Sensor Networks

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Abstract

The Wireless Sensor Network (WSN) is a self-organizing network consisting of a number of sensor nodes located in the monitoring area. One of the main applications of wireless sensor network is in the field of health care and remote patient monitoring. One of the most important challenges of such networks is controlling network congestion and transmitting data in a way that improves quality of service (QoS) parameters. Thus, it increasing grid performance and reducing energy consumption. Energy consumption increases due to various reasons such as unsuccessful delivery of packets to the receiver, congestion in the network, retransmission of packets, and delay in delivering packets to the base station, low received signal strength and so on. Given the importance of some data in the field of health, congestion should be avoided and secure data transmission should be ensured. This study divides the collected data into two groups based on their intrinsic characteristics by presenting a congestion management protocol: 1) critical data 2) non-critical data. The proposed protocol provides a dynamic routing algorithm based on the TOPSIS model for non-critical data transmission. In addition, an algorithm for transmitting critical data through the shortest possible path is also provided based on support vector machines. This improves the network performance through using multi-classification that is obtained from Support Vector Machines. The simulation results indicate that the proposed method works better than other methods and leads to better performance in delay, network performance and power consumption.

Keywords: Wireless Sensor Network (WSN); Priority-based congestion control; Transmission rate; Support Vector Machine (SVM); Topsis model.

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1) Introduction

Increasing advances in electronics, computers, and telecommunications have made it possible to build sensors with high power, reasonable prices, small dimensions, and very low consumption. Depending on their type and application, these sensors can sense information from the environment, collect them and then send these collected information to the sink [1]. Some of these sensor networks just receive information from the environment and transmit it to the analysis center, while others are intelligent and they are capable of cooperate and coordinate with each other. These smart sensors can apply processes to information and then send this semi-processed data to the base station [2]. These features of wireless sensor networks, make it possible to use them in various situations, even in dangerous and hardly access environments. Wireless sensor networks included a wide range of applications, from a simple detection sensor to healthcare applications [3], monitoring and control the traffic [4], industrial monitoring and automation [5], military [6], and Etc. By increasing development of such networks and technologies, the general use of WSNs is also increasing. However WSNs are widely used, they still have problems and challenges. Fig. 1 shows the classification of the WSN challenges and some of the proposed solutions to address these challenges [7-9].

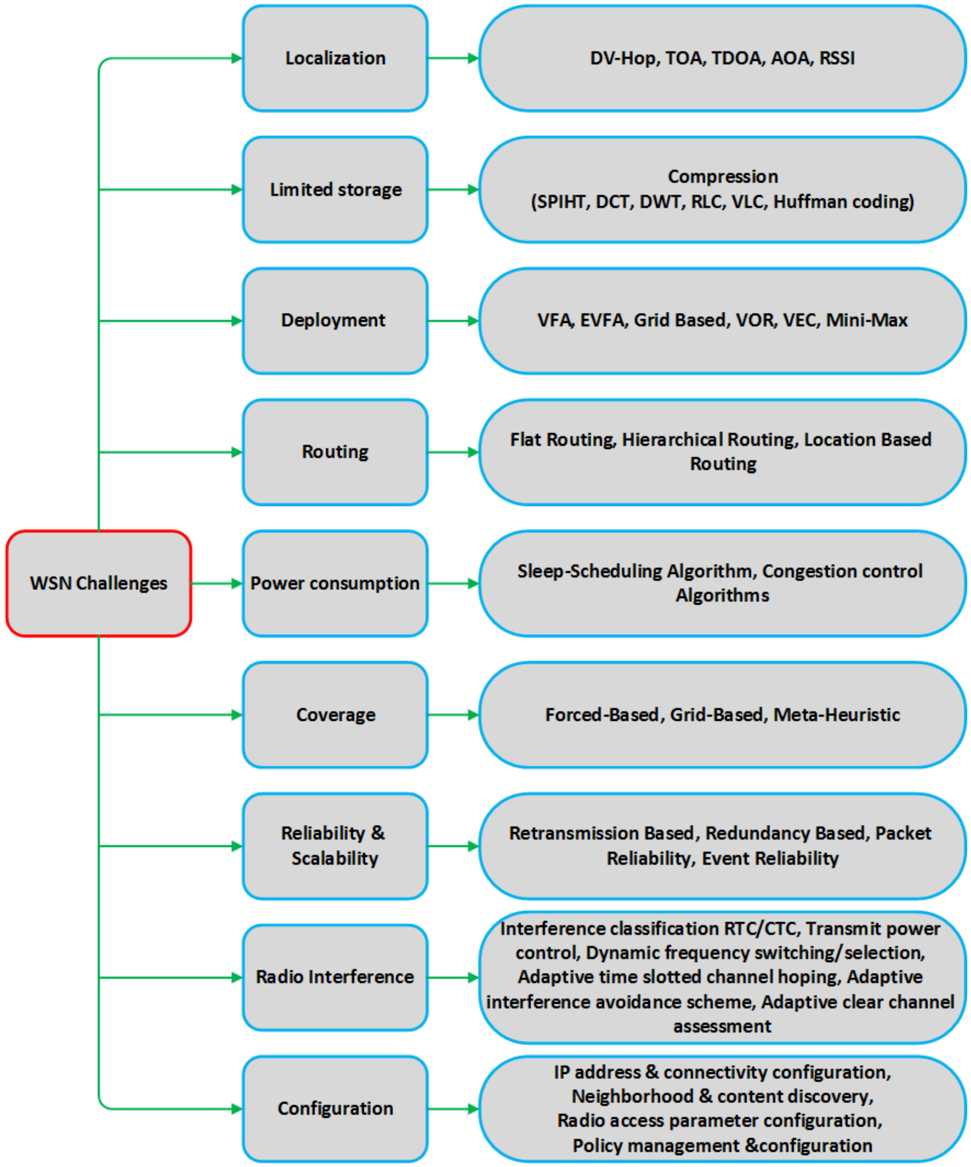

Fig.1. WSN Challenges

One of the most using areas of WSNs is healthcare and remote monitoring of patients performed by physicians and nurses [10]. This application reduces the need of presence doctors and nurses in the hospital to care of each patient. Implementation of patients remote monitoring shows that these patients will live more comfortably by using these new services. In addition, by implementing this system, the possibility of transmitting the virus to hospital staff is minimized. Although many wireless methods (such as Zigbee, Bluetooth, etc.) have been developed for remote monitoring of patients [10-11], The use of wireless sensor networks is the most common method according to their low cost and ease of use.

In general, two types of sensors are used in healthcare applications:

1- Body Area Network (BAN) sensors that connect to the human's body and collect sensed data. There are different types of these collected data. They range from vital signs such as heart rate, respiratory conditions to emergency medical conditions such as heart attack [12].

2- Relay nodes that are distributed in the monitored environment and transmit the collected data to the medical center or base station. These sensors are usually distributed in places such as hospitals to monitor patients for a long time.

In addition, the generated data have different types and are divided into two groups: 1- Critical data 2- Non-Critical data. Critical data reports emergency situations such as heart attacks. As delay in transmitting this information can be life-threatening, this type of data should be reported to the medical center as soon as possible [13]. The next item is non-critical data that should be reported periodically and includes information about the patient's daily condition such as blood sugar, temperature and heart rate. This data should be registered in the patient's records so that physicians can refer to it if necessary. Obviously, there are more delays and more packet lost during the transmission of non-critical data.

BAN sensors transmit patients' daily signals continuously and simultaneously through relay nodes to the medical centers [14]. This increases the likelihood of congestion, packet lost, delays in receiving packets by the sinks, and energy consumption. Congestion in critical programs is very harmful because it may lead to the death of patients due to delay and packet lost [15]. As a result, congestion in the health sector is more challenging than other areas. This paper proposes a method that each node consists of two queue. One queue for transmitting critical data and the other one for non-critical data transmission. Obviously, the critical data queue has a high priority.

In addition, both critical and non-critical data have two separate algorithms for transferring packets to the sink and preventing congestion. Since packet delivery time is an essential factor in critical cases, the algorithm estimates the optimal transfer rate using the support vector machine [16-17]. For this purpose, the algorithm selects the packets with highest priority and sends them via the shortest path. To send non-critical data, each node sorts all its neighbors using the TOPSIS (Technique for Order of Performance by Similarity to Ideal Solution) model [18] and then send packets to the best neighbor. Thus, a node can scatter non-critical packets around congested areas and transfer them to the sink through idle or drained nodes. As the packets in each node have different priorities, a weighted scheduling algorithm is used to ensure the fairness of critical and non-critical data traffic.

Fig. 2 shows a system that BAN sensors are embedded in patients' bodies and relay nodes are randomly distributed in the environment. BAN sensors are responsible for collecting data from the patient's body, and relay nodes are responsible for sending the gathered information to the medical center. The red arrow indicates the shortest route to the medical center, which is dedicated to critical data. The green arrow indicates the path that non-critical data passes through it.

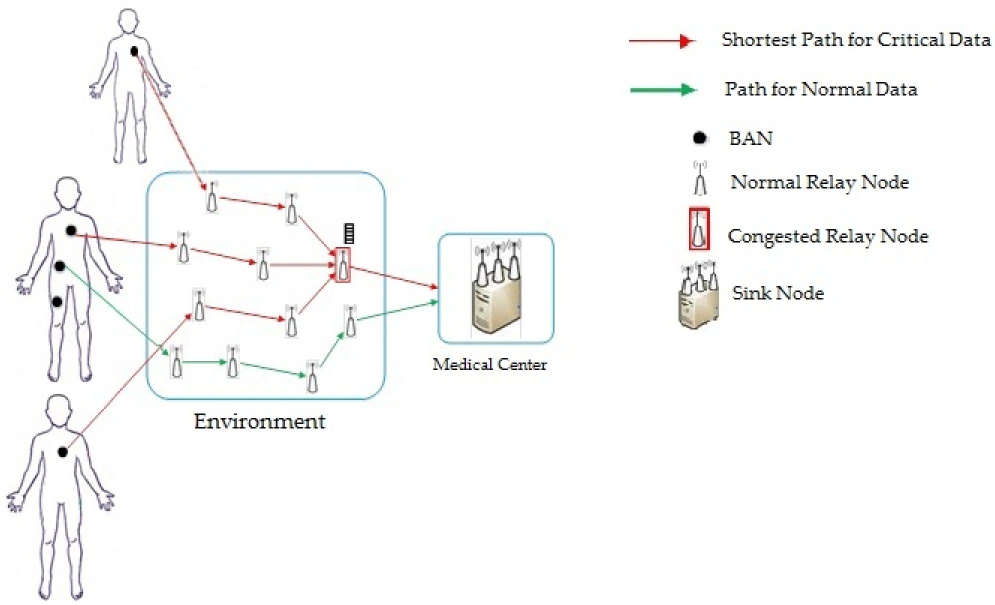

Fig.2. Congestion control in healthcare network

The novel contributions of proposed paper are as follows:

1. The proposed method divide patient data into two groups by providing a weighted congestion management protocol for health care applications based on their intrinsic characteristics: 1) critical data 2) non-critical data.
2. This is the first attempt to apply all SVM ,GA and TOPSIS model to address a WSN problem.
3. We choose SVMs instead of other traditional classification methods such as Naive Bayes classifier, Decision Tree and nearest neighbor classifiers. The results demonstrate that SVMs in this problem are Able to perform better than other methods.
4. In this problem, we propose a protocol offers a TOPSIS based dynamic routing algorithm for the transmission of non-critical data. In addition, present an algorithm for the transmission of critical data through the shortest possible route based on Support Vector Machines.

The structure of this article is organizing as bellow:
Part two is dedicated to reviewing the other works and solutions. Part three presents the proposed method, dividing into two parts: selecting the neighboring node and adjusting the transmission rate. Part four is dedicated to analyzing data and reviewing simulation results. Part five includes conclusions and future work.

2) Literature review

According to the constraints of WSNs, different methods have been developed to improve the performance of network in terms of delay reduction, packet lost reduction, packet retransmission reduction, network throughput increment, and so on. One of the most important ways to improve network performance is to control network congestion. Choosing a method to control the congestion is depending on the practical nature of the program. For instance, in event-based applications, phase shift methods generate better results than traffic-based techniques at the source node. It is because the number of packets per event is fairly small. The classification of different congestion control protocols is presented in Fig. 3 [19].

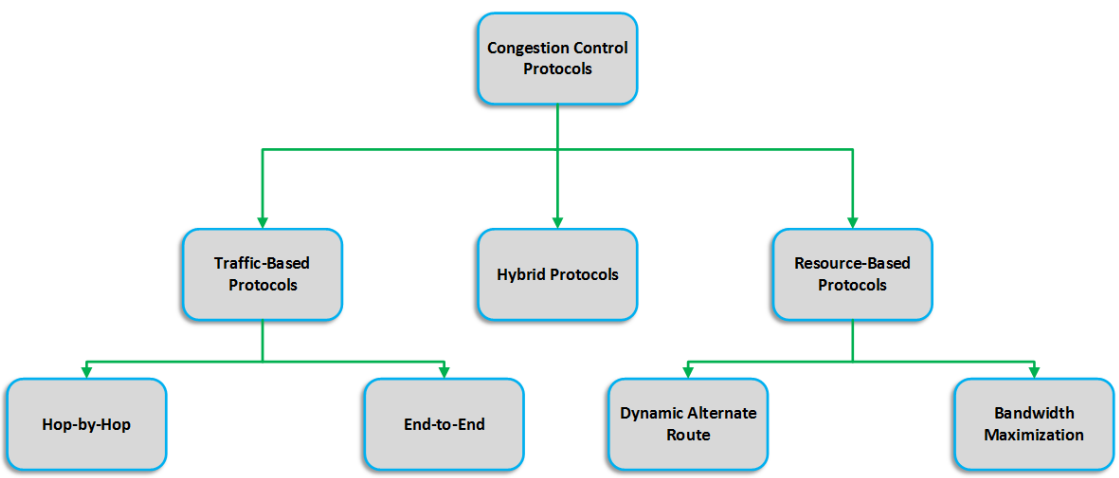

Fig.3. Classification of congestion control protocols

Previous research studies show that several congestion control methods have been developed using transmission rate adjustment [20]. Firstly, [21] was the first study in this area that called CODA (Congestion Detection and Avoidance). In CODA, after detecting congestion based on the number of received packets, the feedback is sent to the upstream nodes. The upstream node then adjusts its transmission rate according to the received feedback. This method has been very successful in controlling congestion in the data transmission path, but due to continuous channel monitoring, energy consumption in this method is very high. To improving the previous technique, another technique called ECODA (Enhanced congestion detection and avoidance) has been developed, which is used to detect and prevent congestion [22]. As an optimized version of CODA, ECODA detects congestion using dual buffer thresholds. This method prioritizes packets using specific criteria. When the number of packets exceeds the threshold, the low priority packets are deleted to maintain the high priority packets. This method uses the backpressure method to control congestion in each group. The transmission rate in each group is determined based on the congestion of neighboring nodes, which reduces packet lost compared to CODA. Another method that adjusts transmission rate to control the congestion is the DRR (Differed Reporting Rate) algorithm [23]. This method regulates the transfer rate by using the source node buffer occupancy ratio as an indicator of congestion. If the buffer occupancy exceeds the specified level, the congestion notification bit value becomes 1 and the packet transmission rate is reduced. If the nodes are closer to the sink, the transmission rate is lower. Nodes use the previous rate to transfer packets until a new congestion is detected. One of the disadvantages of the previous methods is that each node determines the amount of transmission based on the congestion of neighboring nodes. In this method, the congestion ratio of adjacent nodes does not help determine the amount of transmission.

Authors in [24] proposed a method for tree-based communications in WSNs assigning an efficient and fair transmission rate to each node. In this algorithm, each node controls its total amount of incoming and outgoing traffic. According to the distinction between the two traffic, each node decides to reduce or increase the allocated bandwidth. Since the application requirements in the wireless sensor networks do not follow a common feature, this design expresses the concept of fairness and allows the development of a general controlling module. These modules allow each node to use a control rule separately, resulting in more flexible design. Similarly, in [25], a Congestion control and Energy-balanced scheme based on Hierarchy (CcEbH) proposed to reducing congestion in wireless sensor networks. At first, CcEbH organizes the network into a hierarchical structure that start from the sink. In CcEbH, nodes are divided to three categories: nodes in the same hierarchy, downstream nodes and upstream nodes. When congestion is occurred, and while the downstream nodes are congested, sender nodes using lower hierarchical neighboring nodes to transmit data. Congestion at the node level is detected by the length of the queue, i.e. when the amount of incoming traffic exceeds the outgoing traffic of the node. Each node checks the next-hop node's buffer occupancy. If the buffer occupancy is bigger than twenty percent of the total, the upstream node will opt downstream nodes receiving data towards the base station to reduce congestion.

Congestion Control protocol based on Optimizing Routing (CCOR) [26] is a new method reducing congestion and maintaining fairness and energy efficiency simultaneously. Initially, a queue network model is constructed at the node level to detect congestion and congestion degree. Then, the CCOR considers two independent functions for routing purposes. These two functions are the link gradient and the traffic radius. These two functions are based on the location of each node and the service rate of the packets. For example, whenever the degree of congestion exceeds a certain threshold, the traffic radius function ensures that packets are sent to less congested areas to make more efficient use of available bandwidth. The proposed approach effectively reduces congestion and consequently conserves grid energy. However, CCOR does not perform well in heavy traffic. Moreover, Flock-based Congestion Control (Flock-CC) [27] is another protocol that is based on the collective behavior of birds, inspired by swarm intelligence. The proposed algorithm directs packets (synonymous with birds) to form flocks and forward them to the sink. The movement of a batch of packets depends on the forces of gravity and repulsion between adjacent packets, the field view, and the artificial magnetic field, which forward these packets toward the sink. As a result, idle network resources are used efficiently. Flock-CC can easily implement at the node level. The proposed protocol is highly scalable, and in addition, Flock-CC improves packet delivery rate, successful packet delivery rate, delay, and power consumption.

Healthcare aware Optimized Congestion Avoidance (HOCA) is a data-centric congestion control protocol proposed for healthcare applications [28]. This is a management protocol in the field of health care programs and includes a mechanism to prevent congestion using control components. HOCA uses a data-driven management protocol using AQM (Active Queue Management). In HOCA, the data is divided into two categories called sensitive and non-sensitive HOCA. Sensitive HOCA needs a higher data transmission rate while the non-sensitive HOCA requires a lower rate, depending on the priority of the data. HOCA operates in four various stages. Firstly, the request for information dissemination is made by the sink (medical center) to all nodes (patients) in the network. Patient's type, data priority, time and characteristics of the request are determined at this stage. In the second stage, the occurrence of event is reported to the sink by nodes located in the patient's body. In the third stage, the path is created by the sink node and by using multi-path and QoS-aware routing techniques to reduce congestion. Finally, the data is sent hop-by-hop by adjusting the source traffic rate. This traffic rate adjustment occurs specifically during congestion. HOCA prevents congestion by reducing end-to-end delay and extends network lifetime by saving energy. In addition, HOCA ensures fair use of network resources.

TABLE 1

CONGESTION CONTROL PROTOCOLS IN WSNS

protocol	Congestion detection	Congestion notification	Congestion control	Evaluating parameters
CODA	Queue Length, Channel Load	Explicit	Hop-by- Hop, End-to- End	Energy Tax, Fidelity Penalty
ECODA	Weighted Queue length, Delay dependent	Implicit	Hop-by- Hop	Throughput, E-to-E Delay, Weighted Fairness
DRR	Buffer Occupancy ratio	Explicit	Hop-by-Hop	Packet delivery rate, packet loss ratio, fairness index, average energy consumed
CCF2	Service rate, scheduling rate, buffer length	Implicit	Hop-by- Hop	Good put, Fairness, Data Generation Rate, Link Layer Retransmissions
CcEbH	Queue Length	Explicit	Dynamic Alternative Route	Packet loss Rate, Average End-To-End Delay, Throughput, and Average Residual Energy
CCOR	Queue Occupancy Rate	Explicit	Efficient Allocation of Bandwidth	Packet Loss Rate, Average Routing Hops, Energy Consumption per Packet Received
Flock-CC	Queue Load, MAC Layer Collisions and Retransmissions	Implicit	Efficient Allocation of Bandwidth	Packet Delivery Ratio, Packet Loss, Delay and, Energy Tax under low, high and extreme traffic loads
HOCA	Active Queue Mechanism at the relay nodes	Explicit	Hybrid	Network Lifetime, Remaining Average Energy, End–to-End Delay and Fairness
Our Work	Buffer Occupancy ratio, Congestion degree,	Implicit	Hop-by- Hop	packet loss, network throughput, energy consumed

3) Proposed method

Most health monitoring methods use only BAN sensors that attach to the patient's body. These sensors assess the patient's condition, as well as transmit packets to other nodes, which increases energy consumption. As managing energy consumption is critical in healthcare networks, it is important to propose a method to reduce energy consumption. This is important because the sensors are located in the body and have to work for months or even years, and replacing or recharging them is difficult and even impossible. Because in the proposed method, BAN sensors are responsible for estimating the patient's condition and the relay nodes are responsible for transmitting the packets, the energy is managed more efficiently.

In the current paper, a method is presenting for congestion management in healthcare sensor networks. Similar to other congestion control methods, the proposed method has been developed in several stages. The proposed method considers two types of data: 1- High priority packets for transmitting critical data (requires minimum delay), 2- Low priority packets for transmitting non-critical data. In the rest of this section, the flowchart of the proposed method is presented in Fig. 4 and the description of each section is also provided in the continuation of it. Table 2 also describes the abbreviations used in the proposed method.

TABLE 2

NOTATIONS DESCRIPTIONS

Abbreviation	Descriptions
P_i	packet $_p$ that located at node i
α_1 and α_2	weight factors
pr	packet priority queue value
t	elapsed time
$B_r(v)$	buffer occupancy
c_d	Congestion level
T_a	interval between two consecutive packets entering a node
T_s	Required time to process a packet
ΔB	buffer occupancy ratio
ΔC	Congestion degree
ΔR	Data transmission rate
F_i	i^{th} desired criteria
w_i	weight of i^{th} criterion
A_j	desired options
f_{ij}	The value of option A_i according to criterion F_j .
V_{ij}	final weight of each criterion
A^*	positive ideal vectors
A^-	Negative ideal vectors
I'	benefit criterion
I''	cost criterion
D_j^*	positive-ideal solution
D_j^-	negative-ideal solution
CC_j^*	shortest distance to ideal solution
$V_d(x)$	number of remaining steps that node x should take to reach the sink
V_q	buffer occupancy percentage
V_c	congestion degree of node x
V_a^i	distance that all nodes ahead from node x to sink i.

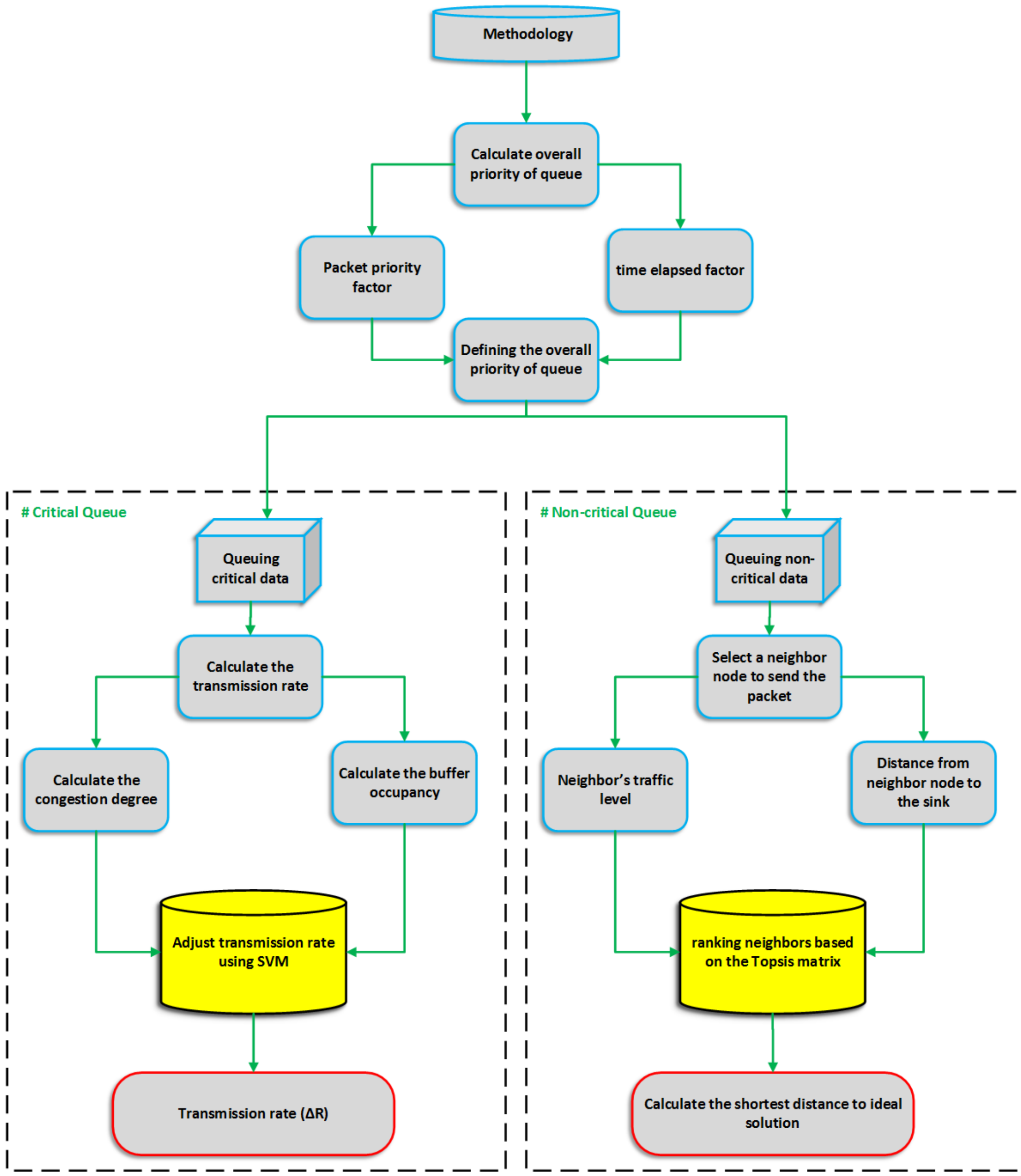

Fig.4. Proposed method flowchart

3.1) Fairness Weighted Scheduling Algorithm

Several existing congestion control protocols using in WSNs only support simple fairness, because all packets have equal priority [21-28]. As a result, each node provides services to incoming packets in the form of FIFO (First In First Out). But sometimes packets may have different priorities. In packets with different priorities, the maximum allowed delay in receiving the packets by the sink is various. In other words, each node requires weighted fairness to transmit to the sink according their priority.

The proposed method in this study uses two queues for each node. A queue for critical data and another queue for non-critical data. Obviously, critical data is more sensitive, and packets containing this data must be transmitted as quickly as possible. Queue priority is not the only factor determining packet transfer time. If high priority packets are always transmit earlier, low priority packets may wait in a node for a long time and never be transferred and cause starvation. Consequently, the packets prioritizing process should also consider the elapse time. The elapse time for a packet is the time interval between the creation of this packet in the BAN sensor and the current moment. Assume that packet *P* is located at node *i*. If *pr* represents the packet priority queue value and *t* represents the elapsed time, the overall priority of the queue will be as equation (1).

$$P_i = (\alpha_1 * pr) + (\alpha_2 * t) \tag{1}$$

α_1 and α_2 represent weight factors that directly influence decision making. The sum of the weights assigned should not exceed one, and each weight factor should take a value between zero and one. In other words, $\alpha_1 + \alpha_2 = 1$, $\alpha_1, \alpha_2 \in [0,1]$. All packets in a queue have equal priority. In addition, all packets are placed in each queue as FIFO. As a result, to determine the overall priority of packets and their transmission priority, just the front packets in each queue is needed to be compared.

3.2) Critical Data Traffic

Some remote monitoring applications require fast transfer of data to report functional disorders such as heart attack and respiratory complications. This type of data is very sensitive in terms of queue and content. Therefore, they should be taken to medical centers as soon as possible to save the patient's life. Each node can identify the data type according to the header of received packet and place it in the relevant queue for transmission.

Congestion avoidance is one of the important challenges in patient’s remote monitoring applications. In critical applications, congestion has devastating consequences. In other words, congestion in the middle nodes may prevent critical packets from entering the queue. As a result, these packets may be lost and patients may die. In fact, timely receipt of packets at the destination increases patient safety and survival. It is impossible to eliminate congestion, but it can be significantly reduced, meaning that there is a considerable reduction in the number of lost packets.

This study proposes a new method to prevent congestion in sending critical data and presents an algorithm that transmits critical packets to the sink via the shortest possible path.

Obviously, in critical data, choosing the shortest path and adjusting the packet transmission rate is very important. If the destination node has a high traffic load, the transmission rate should be reduced to prevent congestion in the upstream node. If the destination node has less traffic load, the speed of packet transmission to that node should be increased. Therefore, each node must be informed of the traffic status of its adjacent nodes.

For this purpose, each node attaches its Awareness Information (AI) in the header of the forwarding packets and then broadcast this information. The upstream node receives this information and is informed of the downstream node's traffic information. While the current node processes the AI information received from the downstream node, it must consider its traffic load and adjust the transmission rate using this information. For example, the *p* packet is located in the current node *v*, and node *v* must send it to the downstream node. We define the following metrics to determine the amount of traffic load and transmission rate in the current node:

Buffer occupancy rate is an important factor that is used to compare traffic load between the two groups. Equation (2) provides the calculation of the buffer occupancy percent.

$$B_r(v) = \left(\frac{Number \quad of \quad packet \quad \text{in} \quad the \quad queue \quad buffer}{Buffer \quad size \quad of \quad node \quad v}\right) \tag{2}$$

$B_r(v)$ shows the information of node's traffic and take a value between [0,1].

Obviously, when a node tends to transfer packets to a node with lower buffer occupancy, it increases the transmission rate. In addition, when the node tends to send packets to a node with a higher buffer occupancy rate, it must reduce its transmission rate because the receiving node has higher traffic.

Although the above factor plays an key role in determining the traffic load of nodes and packet transmission rate, there are other factors that should be considered. In other words, buffer occupancy is not the only factor that determines the amount of traffic in a node. The congestion degree is another important factor that should be considered when calculating the amount of traffic load. Equation (3) represents congestion level, which shows the ratio of the outgoing rate to the processing rate of the nodes. T_a represents the average interval between the entry of two successive packets to a node and T_s shows the average time required for processing a packet in the node.

$$C_d = (\frac{T_s}{T_a}) \quad (3)$$

Clearly, the transmission rate reduces when the sender has a lower occupancy percentage and congestion degree, compared to the receiver. The higher traffic load in the receiver node and high transmission rate will occupy the buffer rapidly and loss many packets (R represents the packet transmission rate and ΔR Indicates the amount of increase or decrease in packet transmission rate between two nodes). In contrast, the transmission rate increase when the sender has a higher occupancy percentage and congestion degree, compared to the receiver. The problem occurs when one of these two factors in the sending node is bigger than receiving node and the other factor is smaller. For example, a node has a lower occupancy percentage but a higher congestion degree. Therefore, it is difficult to explain exactly the decrease or the increase of transmission rate between the two nodes.

This article overcomes this problem by using SVM. More specifically, the following variables are considering as inputs and calculate the number of transmission packets: buffer occupancy rate (ΔB) ، Congestion degree (ΔC) ، Data transmission rate (ΔR).

SVMs receive this information. Then, the data is divided into the response variable and independent variable categories by a SVM. The response variable represents the number of retransmission packets, and independent variables are ΔB , ΔC and ΔR . One SVM is designing for each response variable. For example, label 1 and label -1 were implemented to denote data with zero retransmission value and other data, respectively. Similarly, the support vector machine was obtained for each retransmission variable. Then, in each node, the system derives the number of retransmitted packets, by considering the determined values of ΔB , ΔC and ΔR . Finally, the transmission rate (ΔR) that shows the minimum retransmission value is chosen as the final decision.

3.2.1) Support Vector Machine

Consider the data classification in a space X into one of two classes: G or ~G (not G). Also, assume that each data point x has a feature vector $\vec{x}$ in feature space $\vec{x} \in R^n$. k data points $X_1, X_2, \ldots, X_k$ (labeled as $y_1, y_2, \ldots, y_k$ respectively) which are called the "training points" are considered (where $y_1 = 1$ if $x_i \in G$ and -1 otherwise). The prediction should make to know whether a new data point x is in the G category or not.

For the limit data space (e.g., the retransmitted rate in each sensor network), the SVM steps are usually as follows:

- Define a kernel function $K : X \times X \rightarrow R$. This should be symmetric and the $k \times k$ matrix $[K(x_i; x_j)]_{i,j=1}^{k}$ should be positive semi-definite (i.e., has non-negative values)

- $$Maximize \quad W(\alpha) = \sum_{i=1}^{k} \alpha_i - \frac{1}{2} \sum_{i,j=1}^{k} y_i y_j \alpha_i \alpha_j k(x_i, x_j) \tag{4}$$

  Subject to

$$\sum_{i=1}^{k} y_i \alpha_i = 0 \tag{5}$$

$$0 \leq \alpha_i \leq C, i \in [i, k] \tag{6}$$

Assume $\{\alpha_1^*, \alpha_2^*, ..., \alpha_k^*\}$ is the solution of this optimization problem. $b = b^*$ is selected so that $y_i h_k(x_i) = 1$ for all i with $0 < \alpha_i^* < C$. The training points relevant to (i, α_i^*) support vectors. Then, $x \in G$ if $sign$ $(h_k(x)) = 1$ is determined based on decision-making rules where

$$h_k(x) = \sum_{i=1 \rightarrow k, x_i \ is \ a \ \sup port \ vector} \alpha_i^* y_i K(x, x_i) + b^* \tag{7}$$

Based on Mercer's theorem [29], a feature space $\vec{x}$ exists where the kernel k that mentioned above is the inner product of $\vec{x}$ ($i.e.$ $K(x,z) = <\vec{x}, \vec{z}>$ for each $x, z \in X$). The function $h_k(.)$ denotes the hyper-plane in $\vec{x}$ that separates the maximum training points in X (G points on the positive side of the plane, and ~G points on the negative side). When SVM is applied to test data, there is likely to be a classification error.

3.2.2) Adjusting Data Transmission Rate Based on GA-SVM

As already mentioned, the problem was solved by using SVM. 80% and 20% of date are considered as train and test data, respectively. The retransmission rate is obtained based on buffer occupancy rate (ΔB), transmission rate (ΔR), Congestion degree (ΔC). Here, retransmission is assumed 0,1,2,3 to solve SVM5. For example, for an SVM that is equal to zero, the data with zero responses is labeled 1 and the rest of the data is labeled -1. A similar labeling method is followed for SVM5.

Testing may reveal that the data belongs to more than one SVM (i.e. it is labeled 1 for more than one SVM). Therefore, the data belongs to the SVM that has the longest distance from the support vector. If the data belongs to none of the SVMs (i.e. it is labeled -1 for all SVMs, then, the data belongs to the SVM that has the closest distance from the support vector).
In this study, these parameters are adjusting by using uniform mutation and uniform crossover. The correct adjustment is considered as one of the main factors in efficient classification of SVM: Penalty rate (C) ،Acceptable error (ε) and the deviation of the Gaussian kernel function (δ).
In the implementation phase, the designed GA-SVM is inserted inside all sensor nodes. In each step, the values of ΔC and ΔB are known and the best value of ΔR should figure out. Then, the algorithm was running by using the values of ΔC, ΔB and seven values of ΔR (the values ranged from -3 to 3). Eventually, the lowest retransmission value of ΔR was selected as the final value.
According to the limit range of buffer size in each node, the packet transmission rate is set in the range [-3, 3]. This means that if the number of transmitted packets increases by more than three packets, some packets would drop due to the limited buffer size. Moreover, if the number of transmitted packets reduces by more than three packets, the number of transmitted packets may reduce to the extent that there would be no packet to transmit. Therefore, the amount of increase or decrease of sent packets is one of the following numbers: (-3, -2, -1, 0, 1, 2, 3).
Clearly, as the classification phase is done in offline mode, this method is energy efficient in the wireless sensor network.

3.3) Non-critical Data Traffic

In some patient remote monitoring programs, such as daily reports of patients' conditions and locations, information must send to the sink at regular intervals. In fact, delays are somewhat tolerable when it comes to transferring non-critical data to medical centers. When the header of a received packet represents the non-critical type, a node will place it in the non-critical queue. Because the time factor can be ignored in this type of data, the data can bypass congested places to prevent packets from being lost. In fact, the data pass through a longer, yet less congested, path to avoid congestion.
In non-critical queue, the next receiver node is obtaining based on two factors: 1-distance from the neighboring node to the sink 2- the node's traffic level.
The distance between the sink and the neighboring node factor represents the shortest distance. The second factor shows the traffic level of the upper nodes. Clearly, there is a tendency to transmit the packets through the shortest path that causes the closest node to

the sink has a high priority. Therefore, the route ahead sometimes has a high level of traffic, so we have to move packets through a longer route to bypass the traffic. In other words, there is a trade-off between the distance to the sink and the traffic level while choosing the next receiver node, and the destination node should select based on a balanced combination of these two factors.
A node should choose one of its neighboring nodes as the next receiver node. The neighbors are ranking by using the TOPSIS matrix.

3.3.1) TOPSIS

TOPSIS was first proposed by Hwang and Yoon [30] and is commonly using for Multi-Attribute Decision Making (MADM). In this method, a positive-ideal solution is calculating based on the shortest distance to the ideal position and the longest distance to the negative position. TOPSIS is used to solve many MADM problems [31-33]. Equation (8) presents the ranking TOPSIS matrix:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_J \end{array} \begin{array}{c} \begin{array}{cccccc} F_1 & F_2 & \cdots & F_j & \cdots & F_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{J1} & f_{J2} & \cdots & f_{Jj} & \cdots & f_{Jn} \end{bmatrix} \end{array} \tag{8}$$

Where F_i denotes i^{th} desired criteria ($i = 1, 2, ..., n$), A_j represents the desired options j ($j = 1, 2, ..., J$), and f_{ij} is the amount of option A_i according to criterion F_j.

Following the formation of ranking matrix, the normalized decision matric $R = | r_{ij} |$ is forming as equation (9):

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}} \; j = 1, 2, ..., n; \tag{9}$$

Then, equation (10) calculate the final weight of each criterion:

$$V_{ij} = w_i \times r_{ij} \qquad j = 1,2,...,J; \quad i = 1,2,...,n; \tag{10}$$

w_i denotes the weight of the i^{th} criterion.

In next step, the values of positive and negative ideal vectors are obtained according to Equations (11) and (12):

$$A^* = \{v_1^*, v_2^*, ..., v_i^*\} = \{(\min_j v_{ij} \mid i \in I')\}, \tag{11}$$

$$A^- = \{v_1^-, v_2^-, ..., v_i^-\} = \{(\max_j v_{ij} \mid i \in I'')\}, \tag{12}$$

Where, I' and I'' presented the benefit and the cost criterions, respectively.
Then the value of positive-ideal and negative-ideal solutions are calculating by equations (13) and (14) respectively:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^*)^2} \qquad j = 1,2,...,J \tag{13}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \qquad j = 1,2,...,J \tag{14}$$

CC_j^* in equation (15) represents the shortest distance to ideal solution, ranging from 0 to 1. The higher CC_j^* shows more alternative performance. Therefore, all alternatives are ranking based on this value.

$$CC_j^* = \frac{D_j^-}{D_j^* + D_j^-} \qquad j = 1,2,...,J \tag{15}$$

In this study, decision matrix has four columns (V_d, V_q, V_c, V_a^i). It should be noted that the number of rows is different and had examined according to the number of each node's neighbors. For example, a node with three neighbors x, y, z will present as the matrix (16).

$$D_v = \begin{array}{c} \\ x \\ y \\ z \end{array} \begin{array}{c} \begin{array}{cccc} V_d & V_q & V_c & V_a^i \end{array} \\ \begin{bmatrix} f_{xd} & f_{xq} & f_{xc} & f_{xa} \\ f_{yd} & f_{yq} & f_{yc} & f_{ya} \\ f_{zd} & f_{zq} & f_{zc} & f_{za} \end{bmatrix} \end{array} \tag{16}$$

In above matrix, $V_d(x)$ represents the number of remaining steps that node x should take to reach the sink. Actually, this factor represents the distance factor.

Traffic level factor (x) calculated by using the following criteria: V_q is the buffer occupancy percentage in node x, V_c is the congestion degree of node x and (V_a^i) is the distance of all nodes ahead from node x to sink i. Clearly, node v should choose the next receiver node by considering the four factors in each neighbor. In fact, each node forms the above matrix according to the data of adjacent nodes and opts the best neighbor as the next destination using the TOPSIS matrix.

Weight factors considered to decide according to distance and traffic information to forward a packet. Obviously, w is a factor affecting routing. Weight factors take the depth of the node as the basis of the proposed scheme.

According to the research of Georgiou et al [34], TOPSIS is a method with $O(m \times n)$ complexity, where n represents the number of the neighbors and m denotes the number of criteria. Therefore, the computation of TOPSIS is not a complex one, which is appropriate for wireless sensor networks with limited energy.

4) Results and Discussion

The wireless sensor network was implemented using NS2 simulation software and the performance of SVM and TOPSIS was evaluated using Matlab version 2019b. Table 3 shows the simulation parameters. The parameters proposed in this paper are the same as the parameters in [28, 35] to make an accurate and fair comparison.

TABLE 3
SIMULATION PARAMETERS

Parameter	**Value**
Number of sensors	100
Terrain Dimension	100*100m^2
Mobility	None
Node's Communication Radius	20m
Transmission Rate	250kbps
Channel Connection Window range	[1,63]
Total Buffer Size	20 packet
Percentage of Critical Data	50%
Packet Sent Energy	15 mJ
Packet receive Energy	7 mJ

The most optimal weight factors are obtained by performing multiple simulations using a genetic algorithm.

$$W_1 = 0.3,\ \ W_2 = 0.4,\ \ W_3 = 0.2,\ \ W_4 = 0.1$$

We set the final parameters for genetic algorithm according to table 4.

TABLE 4
PARAMETERS OF GENETIC ALGORITHM

Parameter	VALUE
SIZE OF POPULATION	50
NUMBER OF ITERATION	50
MUTATION RATE	0.25
CROSSOVER RATE	0.6

uniform crossover and uniform mutation methods have been used to performing genetic algorithm [36]. Based on multiple simulations, the best values for α_1 and α_2 are 0.2 and 0.8, respectively. The proposed method is compared with sensitive HOCA, non-sensitive HOCA and LACAS in term of efficiency.

4.1) Efficiency of Support Vector Machine Classification

Fig. 5 illustrate the genetic algorithm convergence diagram. As it can be seen, after 21 iterations with 79% correct responses, the algorithm attained convergence. Total iterations is 50 times.

Table 5 displays the coefficient of each SVM, calculated using a genetic algorithm.

TABLE5
COEFFICIENT PARAMETERS FOR SUPPORT VECTOR MACHINES

δ	ε	C	Parameter / SVM
1.1467	0.05405	143.2403	SVM_0
0.8478	0.0434	155.1789	SVM_1
0.4518	0.0688	7.0814	SVM_2
1.8396	0.01736	149.5184	SVM_3
0.3682	0.07647	34.3063	SVM_4

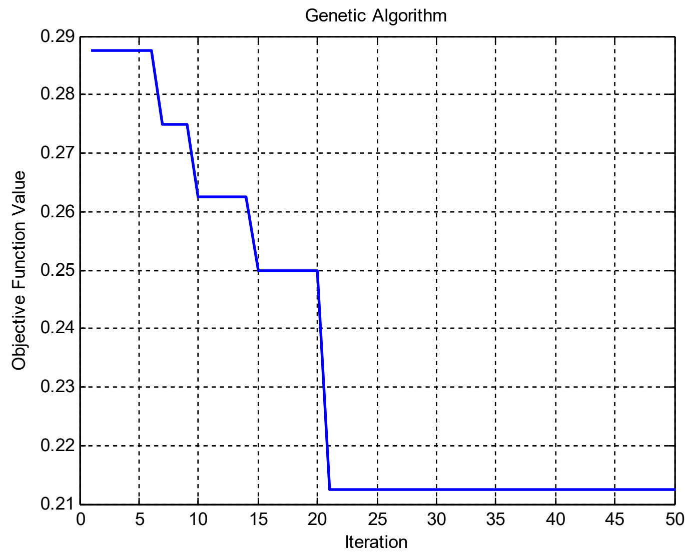

Fig. 5. Convergence diagram of genetic algorithm

The mean square errors (MSE) for each SVM are according to table 6. The error in each SVM is negligible, indicating the high accuracy of the proposed algorithm.

TABLE6

MEAN SQUARE ERRORS FOR EACH SVM

MSE Test	SVM
0.0875	SVM_0
0.2000	SVM_1
0.1250	SVM_2
0.2500	SVM_3
0.0625	SVM_4

4.1.1) SVM's Diagrams

The comparison of the results gathered from the support vector machine with the actual data is illustrated in Fig. 6. The red lines are the data gathered from the support vector machine (in training and testing phase), and the blue lines are the values of actual data which are normalized. As it shows, in the most of points, the red and blue lines overlap, which indicates the quality of the system estimation.

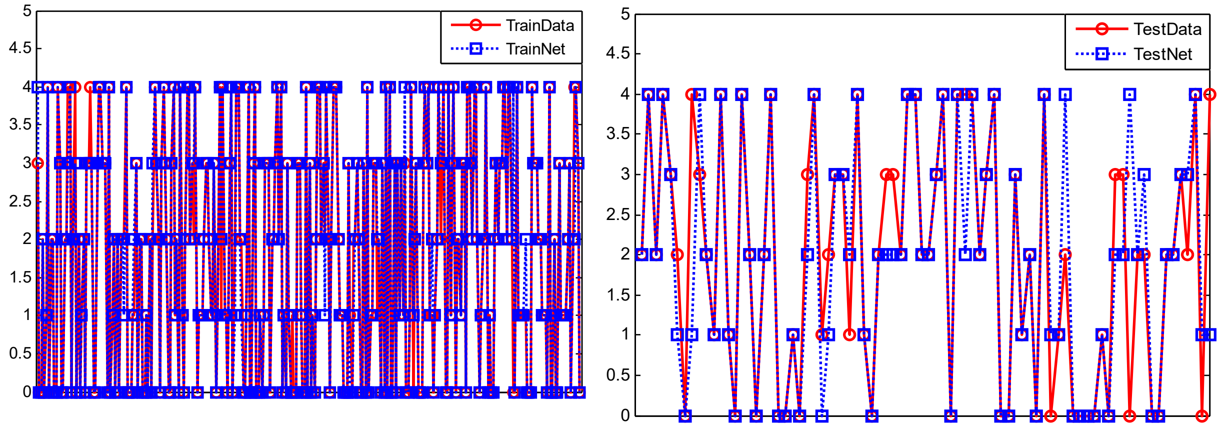

Fig. 6. The convergence of actual data and training and testing data

4.2) Packet Loss Comparison

Network problems such as congestion and buffer overflow may result in packet loss. The rate of packet reception is an important factor in remote patient monitoring and it should be maximized. Fig. 7 displays the rate of packet lost based on various traffic levels. In the proposed method and HOCA, two traffic flows, namely, non-critical flow and critical flow are considered. In contrast, LACAS does not consider any prioritization of data and responding to the data regardless of the priorities.

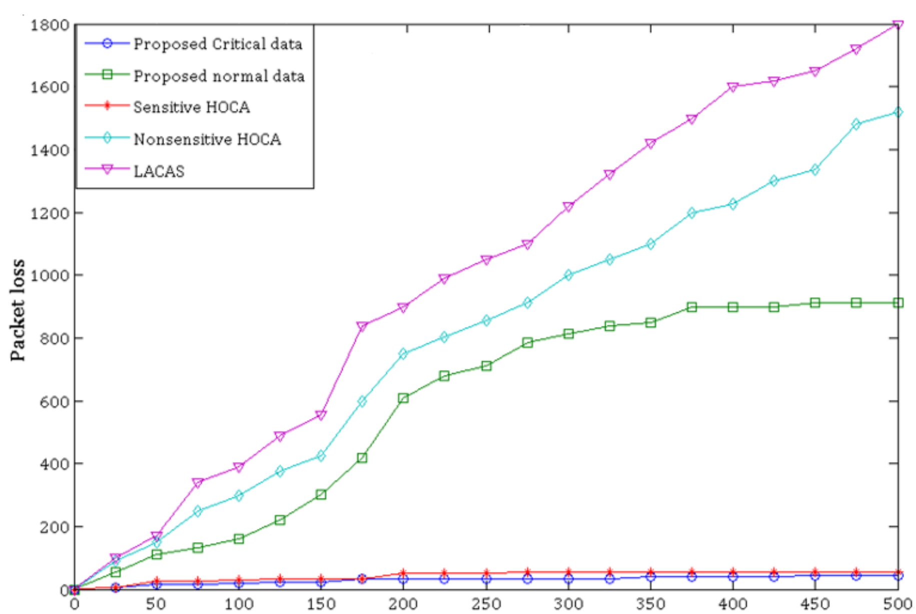

Fig. 7. Packet loss over traffic load (Kbps)

As Fig. 7 shows, the proposed method works better than other methods because it can predict network conditions in the next step and prevent congestion more effectively. According to the proposed method, non-critical data passes through multi-hops and avoids packet loss by bypassing congestion. In addition, the maximum node buffer capacity in the shortest path is allocated to critical data, thus reducing the likelihood of packet loss. Because it is difficult to control the transmission rate during the production of control packets in HOCA, the proposed method works better than HOCA. In addition, the hop-by-hop transfer from the congested node to the source node in HOCA has delay. It is clear that when the traffic load is low, adjusting the transmission rate is easy in all methods, and due to the lack of congestion, these values are close to each other.

4.3) End-to-End Delay

In healthcare applications and specifically, in transferring critical data, the delay is an important parameter that should be minimize. High levels of delay may have irreparable consequences, such as patient death.

End-to-end delay is the time duration to transfer a packet from sender to reciever. Fig. 8 displays the amount of end-to-end delay in various methods.

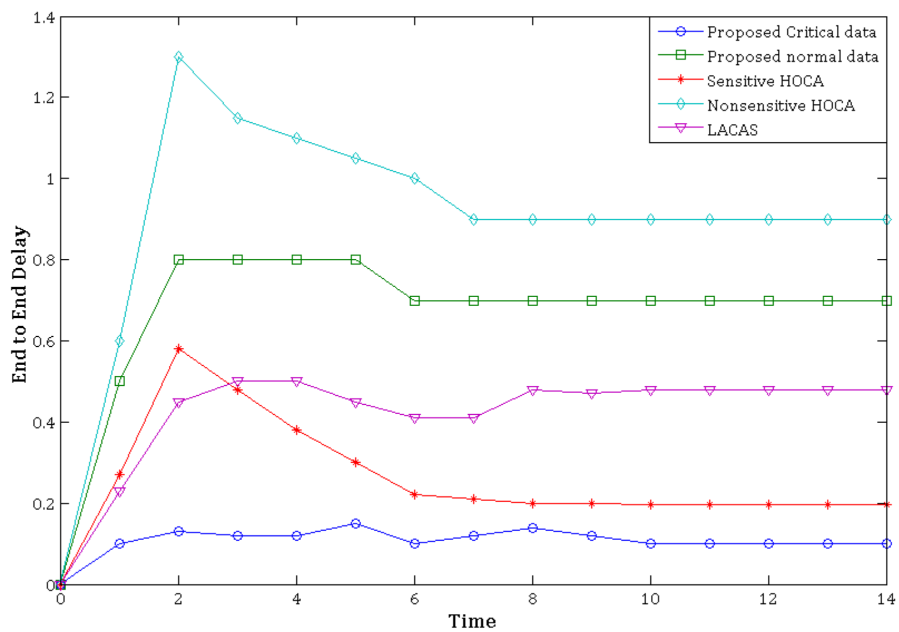

Fig. 8. End-to-end delay in various methods

Because LACAS is not able to distinguish between various types of traffic, only one type of delay is considered. Fig. 8 shows the end-to-end delay for critical and non-critical data in Sensitive HOCA, Non-Sensitive HOCA and LACAS. Because the proposed method passes critical data through the shortest path, the end-to-end delay in the proposed method is minimized. Transmitting non-critical data take longer because they have to avoid congestion and go through multi hops. However, this data is not critical and it's delay can be ignored. The HOCA protocol transmits control packets in phases 1 and 2 of the algorithm implementation and increases the end-to-end delay. However, the delay in HOCA is reduced after completing the transmission of control packets and the packet transmission rate is adjusted.

5) Conclusion and Future Work

In remote patient monitoring systems, some data is critical. Therefore, they should send to medical centers with the least delay. During these transmissions, there is a possibility of congestion because different patients send various packets to the medical center. By dividing the data into two groups, critical data and non-critical data, this paper presents an algorithm for transmitting each group of data to medical centers. In addition, by using the weight scheduling mechanism, each data is prioritized and high-priority data is transmitted in the fastest possible time.

The proposed method uses the shortest path to transmit critical data. In addition, the transmission rate of critical data is regulated using GA-SVM. Transmitting non-critical data to the medical center is done by bypassing traffic and through farther routes, using idle or unloaded nodes. The next receiving node is selected using the TOPSIS method. The results demonstrate that the proposed method has more efficiency than other methods.

In the future, we plan to cluster the network to achieve more accurate classification of information. Then, in each cluster, a support vector machine is used for more accurate classification. In addition, we try to improve the proposed algorithm by using a simple linear function and creating a precise formula for queuing priority.

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