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A NEW PREDICTIVE MODEL FOR CONGESTION CONTROL IN WIRELESS SENSOR NETWORKS

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Abstract

With the increase of various applications in the domain of wireless sensor networks, the tendency to use wireless sensors has gradually increased in different applications. On the other hand, diverse traffic with different priorities generated by these sensors requires providing adaptive quality of services based on users` needs. In this paper, a congestion control predictor model is proposed for wireless sensor networks, which considers parameters like network energy consumption, packet loss rate and percentage of delivered high and medium priority packets to the destination. This method consists of congestion prevention, congestion control, and energy control plans using shortest path selection algorithm. In the congestion prevention plan, congestion is prevented by investigating the queues length. In the congestion control plan, the congestion is controlled by reducing the transmission rate. Finally, the energy control plan aims to partially balance the energy of nodes to prevent network failures due to node energy outage. Simulation results indicated that the proposed method has a higher efficiency regarding the aforementioned parameters. In addition, comparisons with other well-known methods showed the effectiveness of the proposed method.

Keywords: Congestion prevention, Congestion control, Energy control, Wireless sensor networks.

1. Introduction

Congestion in a network occurs when an abundance of data is transmitted through the network which is above of packet handling capacity of network [1]. Since the characteristics of wireless sensor networks are affected by congestion, it is better to measure it under certain practical conditions [2]. One of the important goals of

Nomenclatures

Energy_i	The energy was consumed by node *i*
Queue_i	The queue length of node *i*
Si	A sensor node with index *i*

Greek Symbols

α_Energy	The first energy threshold
α_Queue	The first queue threshold
β_Energy	The second energy threshold
β _Queue	The second queue threshold

Abbreviations

CODA	Congestion Detection and Avoidance
ESRT	Event-to-Sink Reliable Transport
IFRC	Interference-aware Fair Rate Control
QoS	Quality of Service
RS	Reverse Signal

congestion control in wireless sensor networks is to provide a desired level of reliability in a target node, such that its efficient energy and reliability could insure the successful data delivery from the source to the sink [3]. Since one of the main goals of providing congestion control is to minimize energy consumption of the network, it is equally important to insure and focus on reliability with efficient energy for the protocols of wireless sensor networks [4]. In addition, congestion must be decreased in order to improve Quality of Service (QoS) [5] in a wireless sensor network.

In this paper, a congestion control predictor model is proposed for wireless sensor networks, in which three plans, energy control, congestion prevention, and congestion control plan are employed in conjunction with using shortest path algorithm. This method tries to prevent congestion, reduce the number of lost packets in routing, and in turn, increase the delivered high priority packets. The important point of the algorithm is to maintain the load balance in the network which prevents congestion occurrence in one point of network. Another important point is the relative balance of the energy of nodes is required to prevent network failure due to the energy outage of a few certain ones.

This paper is organized as follows: the second part some of the recent researches in congestion control protocols in wireless sensor networks are reviewed. The proposed method is discusses in the third section. The fourth section provides simulations and evaluation of the efficiency of the proposed approach and finally, the fifth part presents conclusions.

2. Literature Review

Recently many works have been carried out regarding congestion control in wireless sensor networks [6-9]. Here some of which are briefly reviewed.

Wan et al. [10] presented the first comprehensive research for detecting and preventing congestion in wireless sensor networks. The method is called CODA (Congestion Detection and Avoidance) in which congestion is detected by sampling wireless areas and supervising queue occupation. As soon as a node detects congestion, an upward inverse pressure message is propagated and the upward nodes reduce the traffic volume to mitigate congestion. In addition, CODA utilizes closed circuit resource adjustment in which end-to-end constant long-term feedback from the base station to source nodes requires adjusting the transmission rate by using additive gain and multiplicative reduction. Although CODA supports congestion reduction, it does not insure balance among resources.

Another method called FUSION, a hybrid congestion control algorithm for high-speed networks [11], introduced three congestion control techniques, hop-by-hop flow control, resource rate limitation and prioritized media aces control. In the ratio limitation mechanism, nodes should be constantly listen to the information sent by their parents to determine the sign generation time. This constant listening is very costly and consumes a large amount of energy.

Sankarasubramaniam et al. proposed a work called ESRT (Event-to-Sink Reliable Transport) presented in [12], in which the base station should reconfigure resource transmission rate periodically to prevent congestion. After detecting congestion, all data flows are transferred to a lower rate. Similarly, another method called IFRC (Interference-aware Fair Rate Control) [13] uses a static queue threshold to determine the congestion level and controls congestion by adjusting the output rate in each link. Although some of the routing protocols like MFR [14] find the routing path based on the node's position, these protocols do not consider the energy which is an important factor in wireless sensor networks.

Uthra and Raja [15] proposed a new method called *"congestion control and energy optimization in wireless sensor networks"*. By employing this method, sensor nodes are distributed in the environment with a predefined density. Sensor nodes transmit data packets to neighbour nodes based on the energy level of each node. Therefore, each node communicates with the farthest node (or the closest node to the destination from the sender).

This model uses a topology like the one shown in Fig. 1. Figure 1 shows all possible paths from each node to the destination node S_{10}. As it can be seen, if its energy level is high enough to communicate with S_5, S_6, or S_7, node S_1 can select any of these nodes for transmission. Consequently, the energy of nodes *S2*, *S3*, or *S4* is saved. This process is repeated for each node to find the farthest node (closest to the destination) to transmit the packets. After that, the method selects a path based on the energy level and the shortest path to transmit packets to the destination. However, any of the selected paths may face congestion along the way. Thus, the algorithm applies congestion control by employing divide and conquers (split) method. It means that the node which faces congestion in the path is replaced by its upward neighbour node [15, 16]. As mentioned before, this method contains of two main parts: distance finding and split algorithms. To calculate the overall time complexity of this method, time complexity of all parts are calculated which are shown in Table 1. It is obvious that, the overall time complexity of the this method is $O(n^2)$. This method is used as the counterpart of the approach proposed in our paper and the results are compared with this method.

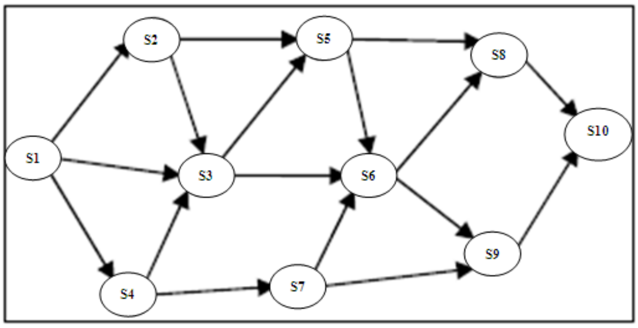

Fig. 1. The network model proposed by Uthra and Raja [15].

Table 1. Time complexity of the counterpart method.

	The main Parts of the program	**Time Complexity**
1	Find distance algorithm [15]	$O(n^2)$
2	Split algorithm	$O(n)$
3	Remain Codes	$O(1)$

3. The Proposed Method

The proposed method in this article tries to prevent congestion, reduce the number of lost packets during routing, and in turn increase the number of delivered high priority packets. Moreover, this method presents a plan to minimize energy consumption by considering congestion prevention and control, as well as shortest path algorithm and selecting the best transmission node at each stage. We will also show in the future works that this method will work for acoustic based underwater wireless sensor networks as substitutions for traditional underwater acoustic methods [17, 18]. In the proposed method, sensor nodes are deployed in the environment similar to the counterpart method of Uthra and Raja [15] shown in Fig. 1. However, this original algorithm is simulated for 50 nodes in order to check the reliability with the proposed method in this paper.

In the counterpart work of Uthra and Raja [15], after investigating the network topology and routes between the origin and the destination nodes and selecting the best route which is the shortest path, each source node transmits the packet through this route as soon as it generates that. This process continues until this route is not usable due to factors such as energy. During the working time, this route is frequently used and congestion occurs due to the increase of the number of packets. Consequently, some packets are eliminated. On the other hand, frequent usage of this route creates an imbalance between the load of the current path and the other routes in the network. Moreover, when this route is removed, the network topology will be changed and the shortest path process should be executed again. Due to these drawbacks of the previous method, three new plans in our method are proposed for congestion control, load balance and energy consumption improvements. Figure 2 shows the general work flow diagram of the proposed method. Different parts of the proposed method will be explained in the following subsections.

3.1. Energy control plan

Energy Control Plan of the proposed method consists of three parts. In this scenario, each node has an initial amount of energy and two energy thresholds *α_Energy* and *β_Energy* are used to participate in routing. The reason for using two thresholds is to maintain the nodes` energy at about the same level at any time and prevent changing network topology due to energy outage of a few nodes.

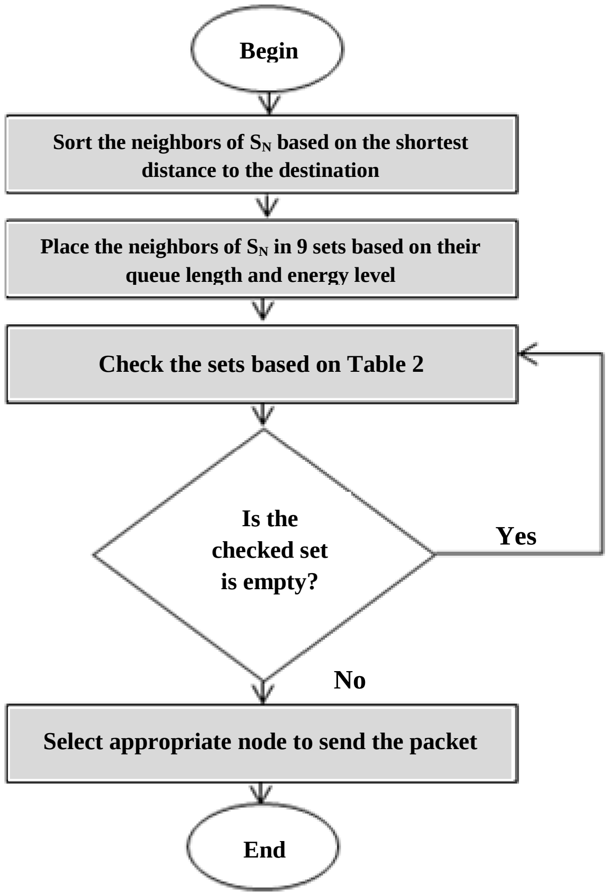

Fig. 2. The workflow of the proposed method.

In order to solve the energy problem, node S_N, which intends to transmit information, refers to candidate node S_i for routing according to the shortest path algorithm and congestion control and prevention plans, which are used together with the energy control plan. Subsequently, it checks the energy consumed by that node, *Energy _i*, and if this value is less than the first threshold, that node is selected as an appropriate node to transmit the packet to it. Otherwise, that node will be ignored and the next candidate node will be checked. Figure 3 shows the pseudo code for this energy control plan.

```
For (i=1 to n-1)
        If (Energy_i < α_Energy) Then
        {       I is the Optimal Node;
                Find_Optimal_Node=True;
                Exit For; }
```

Fig. 3. The pseudo code of the energy control plan (part 1).

If none of the nodes to which the packet can be sent satisfies this condition, may occur when their consumed energy is less than the first threshold, the other nodes will be checked whose consumed energy levels are between the first and the second threshold. Figure 4 shows the pseudo code for the second part of energy plan.

```
Lable1: For (i=1 to n-1)
        If (α_Energy < Energy_i < β_Energy) Then
        {       I is the Optimal Node;
                Find_Optimal_Node=True;
                Exit For; }
```

Fig. 4. The pseudo code of the energy control plan (part 2).

Finally, if there are not any nodes satisfying this condition and if the packet has a medium priority, in order to store the energy of the nodes for high priority packets, it will be dropped. Otherwise, if the packet has a high priority, the second energy threshold will be increased by one unit (the amount of energy necessary to transmit the packet) and it will be checked again to recognize whether there is any node whose consumed energy is between the first and the second energy threshold. If so, the packet will be sent to that node and otherwise, the second threshold will be increased by one again. This process continues until a node is found to transmit the packet to it or the energy of all nodes to which the packet can be sent is finished. The corresponding pseudo code for this part of energy plan is presented in Fig. 5.

```
If Priority of Packet is Medium, Drop It;
Else
{       If (β_Energy <= Full_Energy) Then
                β_Energy += Send_Packet_Energy;
                GOTO Label 1; }
```

Fig. 5. The pseudo code of the energy control plan (part 3).

3.2. Congestion prevention plan

Congestion prevention plan of the proposed method also consists of three parts. In this scheme the next parameter in selecting a route is the queue length. In this scenario, two thresholds *α_Queue* and *β_Queue* are considered for the queue length. The queue length, the buffer length of intermediate nodes, is defined with a specific size in the simulations.

In order to investigate the queue length, node S_N, which intends to transmit information, refers to routing candidate node S_i considering the path length and energy control plan that are used along with congestion control and prevention. If the queue length of that node is less than the first threshold, the packet is transmitted to that node (Fig. 6). Among the nodes satisfying this condition, the priority belongs to the node with the shortest path to the destination.

```
For (i=1 to n-1)
        If (Queue_i < α_Queue) Then
        {       I is the Optimal Node;
                Find_Optimal_Node=True;
                Exit For; }
```

Fig. 6. The pseudo code of congestion prevention plan (part 1).

If there is no node satisfying this condition, the nodes will be checked, whose queue length is between the first and second thresholds and the appropriate node is searched to transmit the packet. The corresponding pseudo code is presented in Fig. 7.

```
Lable2: For (i=1 to n-1)
        If (α_Queue < Queue_i < β_Queue) Then
        {       I is the Optimal Node;
                Find_Optimal_Node=True;
                Exit For; }
```

Fig. 7. The pseudo code of congestion prevention plan (part 2).

If there is still no node satisfying this condition and if the packet has a medium priority, it will be dropped in order to save the queue of nodes for high priority packets. Otherwise, if the packet has a high priority, a decision should be made for its transmission. Under such circumstances, the second threshold is increased by one unit and it will be checked to see whether there is a node whose queue length is between the first and the second queue threshold. If so, the packet will be sent to that node and otherwise, the second threshold will be increased by one unit again. This process continues until a node is found to send the packet or the queue lengths of all nodes to which the packet can be sent become full. Figure 8 shows the corresponding pseudo code for the last part.

```
If Priority of Packet is Medium, Drop It;
Else
{       If (β_Queue <= Queue_Size) Then
                β_Queue ++;     count++;
                GOTO Label 2; }
```

Fig. 8. The pseudo code of congestion prevention plan (part 3).

3.3. Congestion control plan

In this section of the proposed method, congestion control plan is described. If the queue length of sensor node S_N which intends to transmit a packet is less than or equal to the second threshold, there is no need to change the transmission rate. Under these circumstances, the packet is transmitted by the initial transmission rate. If the queue length of the node is larger than the second threshold (the initial second threshold, since the second threshold is variable), an inverse signal is sent to the parent node *(RS=1)*, which indicates the state of the node`s queue. By receiving this signal, the parent node according to Eq. (1) reduces its transmission rate to half.

$$Rate=Rate/2 \tag{1}$$

Until it receives signal *RS=0*, the parent node maintains this transmission rate and according to Eq. (2) resets to the initial value as soon as it receives the signal. This signal is generated when the second threshold of the queue length is equal to its initial value.

$$Rate=Rate*2 \tag{2}$$

The congestion is controlled through this reduction in packet transmission rate and when the nodes` queues are about full, the transmission rate reduction prevents losing and removing packets.

3.4. Combining of energy control, congestion prevention, and congestion control plans

Now, in order to complete the proposed method, the shortest path algorithm is used in combination with the energy control and congestion prevention and control plans. Then, an optimal route is selected to transmit the information. The combination scheme was shown in Fig. 2 and the details of the complete model are explained as follows:

Assuming that S_N intends to transmit a packet, nodes S_i $(1< i <N-1)$, indicate the set of all neighbour nodes of node S_N which the packet can be sent to. First, sensor node S_N sorts its neighbour nodes based on the distance of the nodes to the destination from the best to worst neighbour so that S_1 has the smallest and S_{N-1} has the largest distance to the destination. This is the first box of Fig. 2.

After that, as the second box of Fig. 2, neighbour nodes (S_i) are divided into sets based on their energy and queue length as shown in Table 2. As mentioned so far, if the first and the second energy thresholds are considered, nodes will be in one of these three sets: less than the first energy threshold, between the first and the second energy thresholds, and higher than the second energy threshold. Moreover, if the first and the second queue thresholds are considered, nodes will be also in one of these three sets: less than the first queue threshold, between the first and the second queue thresholds, and higher than the second queue threshold. If these two energy and queue groups combine with each other, totally 9 sets will be created as depicted in Table 2. Moreover, the energy problem is considered more important than the queue overflow problem.

After placing the neighbours of S_N in 9 sets based on their queue length and energy level, the sets should be checked according to Table 2 (the third box of Fig. 2). Each of these sets may be empty, include only one node, or have more than one node. For the first set the following cases may occur:

- The set is empty: it checks the next set.
- The set only has one node: this node is selected as the next node to send the packet to.
- The set has more than one node: the node with the least distance to the destination is selected as the next node.

By checking each set, it is investigated whether the queue length or consumed energy of the nodes of that set is higher than the second threshold. If so, the packet will be sent according to its priority as described in the following subsections (the forth box in Fig. 2).

Table 2. Dividing nodes based on their energy and queue length.

Set	Queue length	Consumed energy	The next appropriate node
1	Less than the first threshold	Less than the first threshold	Select the node with the least distance to the destination
2	Between the first and second threshold	Less than the first threshold	Select the node with the least distance to the destination
3	Higher than the second threshold	Less than the first threshold	Go to set 2 after changing the second threshold
4	Less than the first threshold	Between the first and second threshold	Select the node with the least distance to the destination
5	Between the first and second threshold	Between the first and second threshold	Select the node with the least distance to the destination
6	Higher than the second threshold	Between the first and second threshold	Go to set 5 after changing the second threshold
7	Less than the first threshold	Higher than the second threshold	Go to set 4 after changing the second threshold
8	Between the first and second threshold	Higher than the second threshold	Go to set 5 after changing the second threshold
9	Higher than the second threshold	Higher than the second threshold	Go to set 5 after changing the second threshold

3.4.1. Medium priority packets

For medium priority packets, if the consumed energy or queue length is higher than the second threshold, the packet will be dropped in order to save nodes energy and queue for high priority packets.

3.4.2. High priority packets

For high priority packets, as mentioned in the energy control plan, if the consumed energy of the nodes of that set is higher than the second energy threshold, the second energy threshold is increased by one (a unit of necessary energy to transmit one packet). The next set mentioned in the third column of Table 2 is checked after increasing the second threshold. If it is not empty, an appropriate node is selected and if it is empty, the next set is checked, the second energy threshold is increased, and this process continues until a non-empty set is found.

Regarding the queue length threshold, as mentioned in the congestion prevention plan, if the queue length of the nodes of that set is higher than the second queue threshold, the second queue threshold is increased by one. The next set mentioned in the third column of Table 1 is checked after increasing the second queue threshold. If it is not empty, an appropriate node is selected and if it is empty, the next set is checked, the second threshold is increased and this process continues until a non-empty set is found. It must be noted that after increasing the second queue threshold and transmitting the packet, the second queue threshold may be decreased due to the reduction in the queue length of the nodes. The maximum decrease is equal to the initial value of the second queue length threshold. It must be noted that the second energy threshold does not change after increasing, since the nodes energy is not returnable.

3.4.3. Time complexity of the proposed method

To calculate time complexity of the program, the time complexity of all parts of the program are calculated and shown in Table 3. It is cleared that, time complexity of the complete proposed method is *O(n log n)* which is better in comparison with Counterpart Method mentioned so far in Table 1.

Table 3. Time complexity of the proposed method.

	The main Parts of the program	Time Complexity
1	Find shortest path algorithm (For the first time and when ever a node dropped, it will be ran.)	*O(n)*
2	Sorting nodes	*O(n log n)*
3	Sending low priority packets	*O(1)*
4	Sending high priority packets	*O(n)*

4. Discussion

The attributes of the system that programs ran on it are shown in Table 4. In addition, the list of parameters values for simulations and evaluations are outlined in Table 5. Different scenarios are implemented and the results are compared with the base article of Uthra and Raja [15] as a counterpart method.

Table 4. The attributes of the system that programs ran on it.

parameter	model
OS	Win 7 (32 bit)
Motherboard	ASUS N82JQ
Processor	Intel Core i7- 720QM
Graphic Card	Nvidia Geforce GT335M
RAM	4 Giga Byte

4.1. Performance analysis for a scenario with 10 nodes

In this part the original topology based on Fig. 1 is used. After 30 consecutive simulations run with changing the seed, the obtained results for 270 seconds are outlined as follows: 2236 packets are sent in 270 seconds in the network by the proposed method while in counterpart method (Uthra and Raja [15]) 2700 packets are sent. The packet sending rate in their method is fixed whereas in the proposed method it is variable, as it was mentioned in the congestion control plan; and this is the reason for the difference between the numbers of sent packets by these two methods.

Table 5. Selected values for parameters used in proposed method.

Parameter	value
Energy of Each Sensor	18720J
Length Buffer of Each Sensor	32 Packets×32 bit
α_Queue (The First Queue Threshold)	16 Packets
β_Queue (The Second Queue Threshold)	28 Packets
α_Energy (The First Energy Threshold)	9000J
β_Energy (The Second Energy Threshold)	17000J

4.1.1. The percentage of lost packets

As it is shown in Fig. 9, the average percentage of lost packets in the proposed method is reduced compared to the counterpart base method.

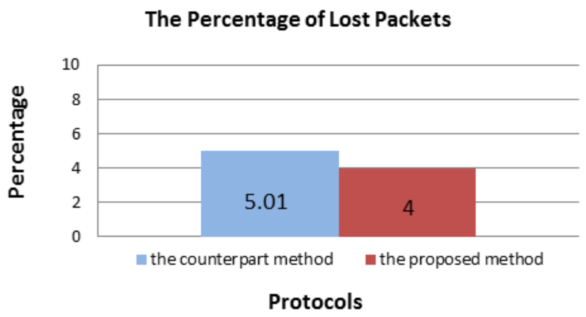

Fig. 9. The percentage of lost packets in scenario with 10 nodes.

4.1.2. The percentage of delivered packets with a high priority

As we can see in Fig. 10, the percentage of delivered high priority packets in the proposed method is increased compared to the counterpart base method.

4.1.3. The percentage of delivered packets with a medium priority

As it is shown in Fig. 11, the average percentage of delivered packets with medium priority in the proposed method is reduced compared to the counterpart method. If there was no difference between high priority packets and medium priority packets, the counterpart base method would be preferable.

4.1.4. The total energy consumption

As shown in Fig. 12, the average total consumed energy in the proposed method is reduced compared to the counterpart base method. However, it should be mentioned that due to the reduction in the packet sending rate in congestion control plan in the proposed method, the number of sending packets in the proposed method is less than the number of sending packets in the counterpart base method.

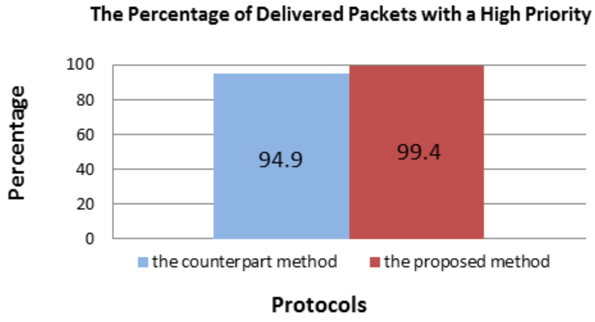

Fig. 10. The percentage of delivered packets with high priority in the scenario with 10 nodes.

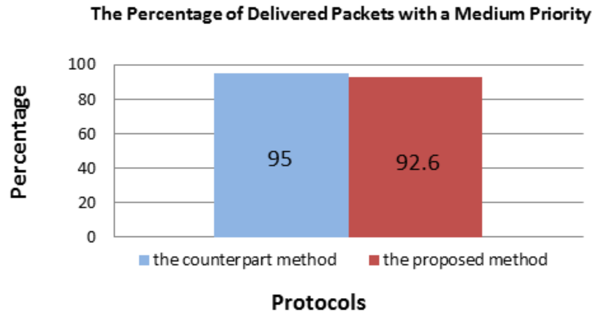

Fig. 11. The percentage of delivered packets with a medium priority in scenario with 10 nodes.

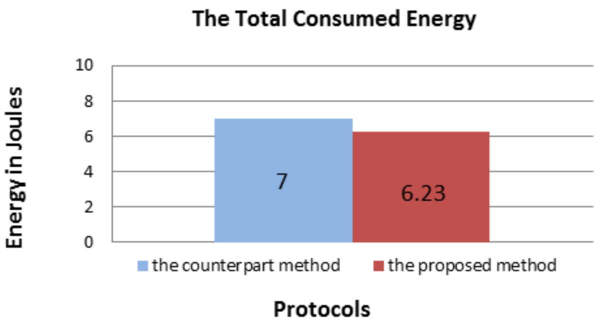

Fig. 12. The total consumed energy in scenario with 10 nodes.

4.2. Performance analysis for scenario with 50 nodes

Here, the base counterpart algorithm is simulated for more nodes (50 nodes) in order to check the reliability of the algorithm and the results of that are to be projected in this paper. After 30 consecutive simulation runs with changing the seed, the results are obtained in 270 seconds as follows: 2208 packets are sent in 270 seconds in the network in the proposed method and 2700 packets are sent by the counterpart base method. The packet sending rate in the counterpart base method is fixed while in the proposed method is variable (as it was mentioned in the congestion control plan) and it is the reason for the difference between the number of the sent packets by these two methods.

4.2.1. The percentage of lost packets

As we can see in Fig. 13, the average percentage of lost packets in the proposed method is reduced compared to the counterpart base method.

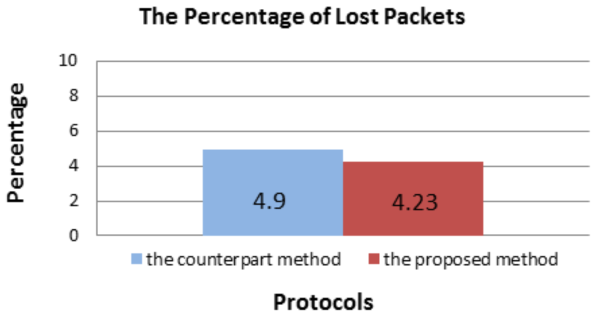

Fig. 13. The percentage of lost packets in scenario with 50 nodes.

4.2.2. The percentage of delivered packets with high priority

As it shown in Fig. 14, the average percentage of delivered packets with a high priority in the proposed method is increased compared to the counterpart method.

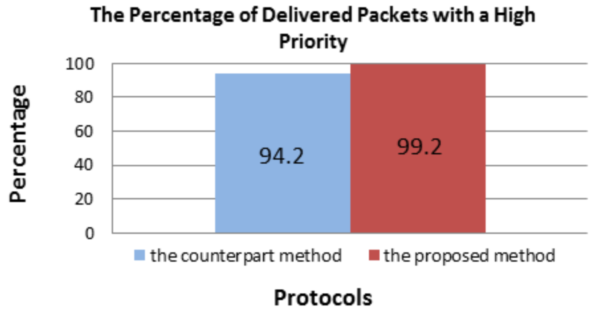

Fig. 14. The percentage of delivered packets with a high priority in scenario with 50 nodes.

4.2.3. The percentage of delivered packets with a medium priority

It is shown in Fig. 15 that the average percentage of delivered packets with a medium priority in the proposed method is reduced compared to the counterpart base method. If there was no difference between high priority packets and medium priority packets in the network, the counterpart base method would be preferable.

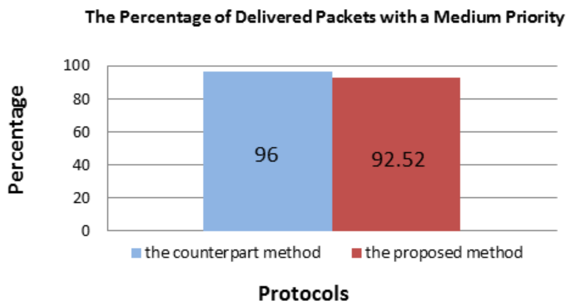

Fig. 15. The percentage of delivered packets with a medium priority in scenario with 50 nodes.

4.2.4. The total consumed energy

As it shown in Fig. 16, the average total consumed energy by the proposed method is reduced compared to the counterpart base method. However, it should be noted that due to the reduction in the packet sending rate in congestion control plan by the proposed method, the number of the sent packets by the proposed method is less than the number of the sent packets in the counterpart base method.

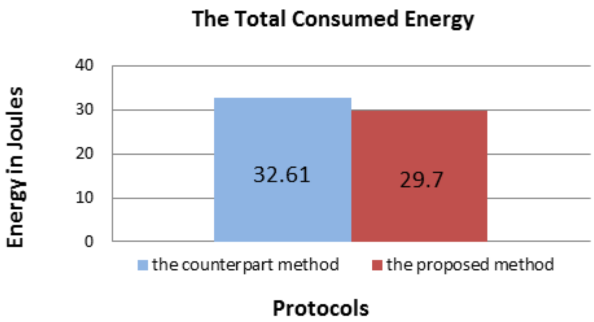

Fig. 16. The total consumed energy in scenario with 50 nodes.

5. Conclusions

In this paper, a new congestion control predictor model is proposed for wireless sensor networks. In the proposed method, parameters like energy consumption, packet loss rate, percentage of delivered packets with high and medium priority are considered. In addition, energy control and congestion prevention and control plans were used simultaneously with the shortest path algorithm to complete the proposed model. Many Simulation scenarios are implemented and comparisons are provided with other well-known methods. The final results indicated that the proposed method exhibits better performance regarding the packet loss rate, percentage of delivered packets with high priority and energy consumption parameters. Although the proposed method is reliable for delivering high priority packets, it is not suitable for the networks in which there is not a difference between high priority packets and medium priority packets. In the end, the proposed method time complexity *(O(n log n))* is less than counterpart method time complexity *(O(n2))*.

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