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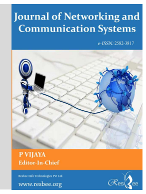

Performance Analysis of the Adaptive Cuckoo Search Rate Optimization Scheme for the Congestion Control in the WSN

Vinusha S

Department of Applied Electronics,
Regional Centre of Anna University
Tirunelveli, Tamil Nadu, India
s.vinu89@gmail.com

Abinaya J.S

Department of Communication and networking,
CSI Institute of Technology
Kanyakumari, Tamil Nadu, India
meabianu@gmail.com

Abstract: Congestion avoidance in the Wireless sensor networks (WSN) has gained research interest since the sensors in the WSN send and receive data rigorously. The presence of the congestion in the networks increases the retransmission of the information which effectively affects the network lifetime. Various literature works have introduced the congestion avoidance schemes for the WSN aiming for the congestion free transmission. These methods are affected by various network parameters. In this work, the performance of the Adaptive Cuckoo Search Based Rate Optimization (ACSRO) algorithm is studied based on the various network parameters. The ACSRO algorithm alters the share rate of the nodes whenever the congestion is detected in the network. The ACSRO model modifies the step size of the existing cuckoo search (CS) algorithm with the fitness function. This work analyzes the performance of the ACSRO algorithm by modifying the congestion threshold parameter. The simulation results obtained show that the ACSRO model has better performance with the values of 0.92038, 0.31057, 0.89948, 0.86449, and 0.86737 for the throughput, delay, normalized packet loss, normalized queue size, and congestion level metrics at the congestion threshold of 0.018.

Keywords: Wireless sensor networks, Cuckoo Search, rate optimization, Congestion avoidance, Congestion threshold.

1. Introduction

Wireless sensor networks (WSN) [3, 6, 11] contains a collection of sensor nodes for gathering the information from the remote environment. The WSN contains the child nodes, parent nodes, and the base station. Large distance separates the child nodes and they gather the information and send it to the parent node. If more than one child node communicates with the parent node, then the congestion will occur in the parent node. The occurrence of the congestion in the WSN primarily depends on the share rate of the child node and the service rate of the parent node. The occurrence of the congestion in the network halts the transmission and reduces the network lifetime. The congestion in the network can be broadly classified as location and packet based congestion. The location based congestion occurs at the sink, source, and the forwarder. The packet based congestion occurs at the node level and the sink level [9]. Each sensor node in the WSN is battery operated, and hence the congestion avoidance scheme needs to consider the energy of the network [12]. The energy of the sensor node gets deteriorated during the occurrence of the congestion [2].

The congestion in the WSN also depends on the flow of the data between the nodes. The traffic flow in the WSN may be unidirectional or bidirectional. The occurrence of the congestion in the WSN with the single sink differs from the conventional end-to-end strategies. The algorithm defined for the Congestion avoidance and control (CAC) manages the traffic flow in the WSN through the adjustment of the data flow between the nodes [5]. The increase in the number of resources in the network reduces the congestion of the network. The bulky nature of the network can result in increased delay, and hence the performance of the network gets affected [7]. Existing algorithms try to improve the energy efficiency of the network through the congestion control. Various qualities of service (QoS) requirements have not been satisfied by the existing models for the improved lifetime of the network [1]. Some techniques tend to overcome the congestion by increasing the buffer size of the node. The nodes with the larger buffer size have a large delay and higher packet loss. Besides, the collision of the packets increases during retransmission of the packets [8]. Retransmission of the packets during the packet collision requires high energy, and hence the construction of the energy efficient network is not possible with the retransmission

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of data [9]. The congestion control mechanism requires the mitigation technique to notify the nodes whenever the congestion occurs in the network [4].

In this work, the performance of the Adaptive Cuckoo Search Based Rate Optimization (ACSRO) scheme for the congestion avoidance in the WSN is analyzed. The ACSRO algorithm defines the presence of the congestion in the node based on the congestion threshold. Whenever the congestion level exceeds the congestion threshold, and then the node is declared to be congested. Initially, the ACSRO scheme opts for packet drop of the unimportant packets for avoiding the congestion. The packet with the more importance requires necessary transmission, and hence the ACSRO model defines a new share rate for the child node for avoiding the congestion. The performance of the ACSRO model is analyzed based on the various values of the congestion threshold. The network parameters congestion level, delay, packet loss, throughput, and the queue size analyze the performance of the ACSRO model.

The paper organization is done as follows: Section 1 provides the introduction to the congestion avoidance scheme in the WSN. Section 2 defines the architecture of the ACSRO model. Section 3 explains the various analysis parameters used for the measuring the performance of the ACSRO model. Section 4 provides the simulation results for the various values of the congestion threshold, and the section5 concludes the work.

2. Adaptive Cuckoo Search Based Rate Optimization (ACSRO) Scheme in the Wireless Sensor Networks

This section provides a brief explanation of the ACSRO algorithm for the congestion avoidance in the WSN. Figure 1 briefs the architecture of the ACSRO model. The ACSRO algorithm uses the existing CS algorithm for modifying the share rate of the child nodes in the WSN. In the WSN, a group of child nodes communicates with the single parent node. The ACSRO algorithm uses the user defined value of congestion threshold. The algorithm declares a node to be congested when the congestion level exceeds the defined congestion threshold. Thus to avoid the congestion in the network, the average share rate of the child nodes should be made minimal than the service rate of the parent node. The ACSRO finds the optimal share rate based on the fitness function and the CS optimization steps. Whenever the congestion is detected in the network, the old share rate of the child nodes is replaced with the optimal new share rate.

The optimization process requires modification of the share rate of the nodes to avoid the congestion in the network [15].The ACSRO algorithm constantly checks for the congestion occurrence in the WSN. If the each node in the WSN is free from the congestion, then the old share rate of the child node is used for the transmission of the data packets. When the congestion is detected in the WSN, the level of the congestion is measured, and then the ACSRO algorithm is called. The ACSRO algorithm finds the new share rate through the optimization process and the fitness function. Then, the optimal share rate from the ACSRO algorithm replaces the old share rate. Now, for the congestion free transmission, the data transfer is done with the new share rate. The iteration continues until the network is free from the congestion.

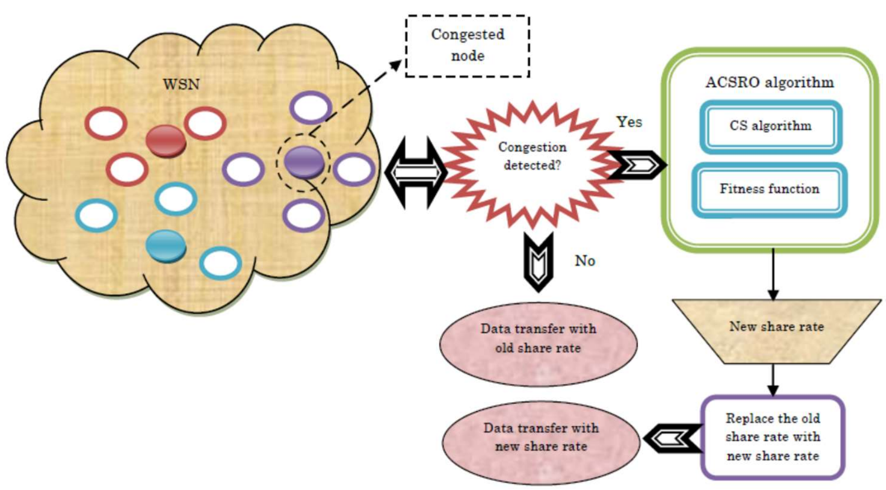

Fig.1 *Architecture of the ACSRO model for congestion avoidance*

2.1 Fitness Function for the ACSRO Algorithm

The AQCSRO algorithm uses the multi-objective fitness function to find the optimal share rate for the congestion free transmission. The fitness function utilized in the [5] uses share rate of the child nodes and the bandwidth of the network as the parameters. But, the other QoS parameters such as congestion level, service rate, and queue length are utilized by the ACSRO model for the congestion avoidance. The equation 1 expresses the expression for the fitness function of the ACSRO model.

$$\mathbf{F}itness = \mathbf{f(share\,rate) + f(Bandwidth) + f(Service\,rate) +} \\ \mathbf{(Congestion\ level) + f\ (Queue\ Length)} \quad (1)$$

where, the each term in the above expression define the fitness function regarding the share rate of the child node, the bandwidth of the network, service rate of the parent node, congestion level, and the queue length. The fitness function defined by the equation 1 is the maximization function. The fitness function regarding the share rate is expressed by the equation 2. When the congestion occurs in the WSN, the share rate of the ACSRO algorithm needs to be less than the old share rate.

$$f(Share\,rate) = 1 \quad \frac{\left(H_{old}^{m} \quad H_{new}^{m}\right)}{H_{old}^{m}} \quad (2)$$

where, the term H_{old}^{m} expresses the old share rate of the node m, and the term H_{new}^{m} expresses the new share rate from the ACSRO algorithm for the node m. The equation 3 expresses the fitness function regarding the bandwidth of the network. It depends on the value of the difference in the available bandwidth and the new share rate from the ACSRO.

$$f(Bandwidth) = (B \quad H_{new}^{m}) \quad (3)$$

where, the term B expresses the available bandwidth. The nest factor for defining the fitness function is the fitness regarding the service rate of the parent node. To avoid the congestion in the network, the share rate of the node holds less than the service rate of the parent node. Thus, the fitness regarding the service rate depends on the difference in the old share rate and the new share rate. The equation 4 expresses the fitness based on the service rate of the parent node.

$$f(Service\,rate) = 1 \quad \frac{\left(H_{old}^{m} \quad H_{new}^{m}\right)}{H_{r}} \quad (4)$$

where, the term H_r expresses the service rate of the parent node. The share rate defined by the ACSRO algorithm needs to reduce the congestion level in the network. Thus the fitness function based on the congestion level is expressed by the equation 5.

$$f(Congestion\,level) = \frac{1 \quad C_{L}^{m}}{H_{new}^{m}} \quad (5)$$

where, the term C_L^m expresses the overall congestion level at the node m. The nest parameter for defining the fitness of the ACSRO algorithm is the queue length. The equation 6 expresses the fitness based on the queue length.

$$f(Queue\,length) = \frac{\left(q_{L}^{m} \quad H_{old}^{m}\right)}{V_{L}} \quad \frac{\left(q_{L}^{m} \quad H_{new}^{m}\right)}{V_{L}} \quad (6)$$

where, the terms q_L^m and V_L expresses the physical size and the virtual length of the queue.

2.2 Steps Involved in the ACSRO Algorithm for the Congestion Avoidance

The ACSRO algorithm is the modification of the CS algorithm [10]. This section explains the steps involved in the ACSRO algorithm for the providing the optimized share rate.

Step 1: Initialization of the population size of the ACSRO

Initially, the population of the host best of the ACSRO is chosen. Equation 7 expresses the population of the host nest. If the WSN contains n number of the parent node, then the size of the population will be $T \times n$. where, T represents the total nodes in the WSN.

$$X_p = \left(X_1, \ldots X_a \ldots X_p\right) \quad (7)$$

where, the term X_a represents the a^{th} host nest.

Step 2: Generation of the adaptive step size (ACS)

The cuckoo bird searches for the host nest and places its egg in the best host nest. The cuckoo uses the adaptive step size for identifying the host nest. The host nest chosen by the cuckoo in the nest iteration is expressed in the equation 8.

$$\mathbf{X}_{\mathbf{a}}^{(\mathbf{t+1})} = X_{\mathbf{a}}^{\mathbf{t}} + \eta \oplus \Psi(a) \tag{8}$$

where, the term $\Psi(a)$ represents the levy flight function, and it is expressed as follows,

$$\Psi \sim u = t^{\ a}, \qquad (1 < a \leq 3) \tag{9}$$

where, the term $\mathbf{X}_{\mathbf{a}}^{(\mathbf{t+1})}$ represents the new solution obtained by the cuckoo. The ACSRO uses the adaptive step size for the finding the host next. The step size η expressed in the equation eight is replaced by the adaptive step size η_A and it is expressed as,

$$\mathbf{X}_{\mathbf{a}}^{(\mathbf{t+1})} = \mathbf{X}_{\mathbf{a}}^{\mathbf{t}} + \eta_A \oplus \Psi(a) \tag{10}$$

The equation 11 expresses the adaptive step size of the ACSRO model.

$$\eta_A = \frac{X_{best}}{H_{old} \times 10} \tag{11}$$

where, the term X_{best} represents the best solution obtained, and the term H_{old} represents the old share rate. The expression of the levy flight is provided by the equation 12.

$$\Psi\ (a) = \left| \frac{\Gamma\left(1 + a \times \sin\left(\Pi a/2\right)\right)}{\Gamma((1+a)/2) \times a \times 2^{((a\ \ 1)/2)}} \right|^{1/a} \tag{12}$$

where, the term $\Gamma(z)$ represents the gamma function and it has the values of $\Gamma(z) = \int_0^{\infty} e^{\ t} t^{z\ \ 1} dt$.

Step 3: Choose the random host nest based on the fitness function

In this step, the host nest is chosen based on the following steps,

i) Take a host nest X_a from the population X.

ii) Calculate the fitness value of the host nest X_a based on the equation1.

iii) Calculate the fitness of the current best solution X_d.

iv) If the fitness value of the $f(X_d) > f(X_a)$, then replace the best solution with the a^{th} solution.

Step 4: Rejection of the Worst nest

The congestion avoidance scheme requires the new share rate less than the old share rate. Hence, the host nest with the large share rate than the old share rate is rejected. The rejection of the host nests depends on the discovery rate with the range of $Pa \in [0,1]$.

Step 5: Ranking of the host nests based on the fitness function

In this step, the best possible solution is found through the ranking of the host nest based on their fitness value. The nest with the best fitness is kept at the top, and another nest is placed next to the best value.

Keep the best solution and rank it.

Step 6: Iteration

This is the final step of the ACSRO algorithm. When the iteration reaches the maximum value the host nest with the reduced share rate is provided as the optimal solution.

3. Analysis Parameters

The performance of the ACSRO algorithm depends on the congestion threshold value defined by the user. The performance of the model varies for the varying values of the congestion threshold. Various evaluation metrics such as congestion level, throughput, delay, packet loss, and the queue size analyze the performance of the ACSRO model.

(i)Throughput:

Throughput defines the ratio of the packet receiving rate and the bandwidth of the node. Equation 13 expresses the throughput of the node.

$$Throughput = \frac{R}{B} \tag{13}$$

where, the term R defines the packet receiving rate. The term B defines the available bandwidth of the node. The model with the higher throughput indicates better performance with a low level of congestion.

(ii) Delay:

Delay defines the ratio of the total data packets in the transmission to the transmission rate. Equation 14 expresses the delay rate of the WSN.

$$Delay = \frac{D_P}{R_T} \tag{14}$$

Where, the term D_p indicates the data packets required for the communication. The term R_T represents the transmission rate in seconds.

(iii) Normalized Packet Loss:

The presence of the congestion in the node results in the packet loss. The packet loss defines the ratio of the difference in the data packets send and the data packets received during the transmission of the total time elapsed in seconds. Equation 15 expresses the normalized packet loss.

$$Packet\ loss = \frac{D_P^{send} \quad D_P^{reieve}}{T_{elapsed}} \tag{15}$$

where, the term D_P^{send} indicates the data packets send by the nodes, and the term D_P^{reieve} represents the total data packet received by the nodes. The term $T_{elapsed}$ represents the time required for the data transmission process.

(iv) Normalized Queue Size:

The queue size represents the waiting packets in the node that needs to be processed. Larger value of the queue size increases the end to end delay of the system. The normalized queue size takes the value of between 0 and 1. The value 1 indicates the all the data packets involved in the communication process are waiting in the queue.

(v) Congestion Level:

The congestion level of the node depends on the priority of the data packets received by the node and the length of the queue of that particular node.

4. Results and Discussion

This section briefs the various simulation results obtained by the ACSRO model for the various values of the congestion threshold. The effectiveness of the ACSRO scheme for avoiding the congestion in the WSN is measured based on the various analysis parameters discussed in the previous section.

4.1 Performance Analysis of the ACSRO

The ACSRO model for the congestion avoidance primarily depends on the congestion threshold value defined by the user. This work analyzes the ACSRO model for the various values of the congestion threshold. The congestion threshold values for the analysis are chosen as 0.018, 0.02, 0.022, 0.024, and 0.026.

4.1.1 Analysis based on the congestion level

Here, the performance of the ACSRO model is measured based on the congestion level for the various congestion threshold values. Figure 2 shows the performance analysis graph for the simulation time vs. congestion level for different congestion threshold. For the simulation time of 10 sec, the ACSRO model has the congestion level of 0.92038 for the congestion threshold of 0.018. For the increase in the congestion threshold to 0.02, the congestion level increases to 1.0124. For the congestion threshold values of 0.022, and 0.024, the ACSRO scheme has the congestion level of 1.1045 and 0.92959. For the maximum value of the congestion threshold, the ACSRO model has the highest congestion level of 1.1965. From the analysis, the ACSRO model has lower congestion level for small values of congestion threshold.

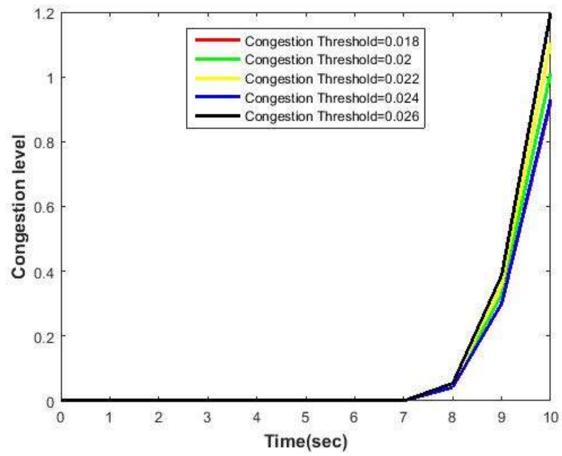

Fig. 2. *Performance evaluation for the varying congestion threshold vs. congestion level*

4.1.2 Analysis based on the Throughput

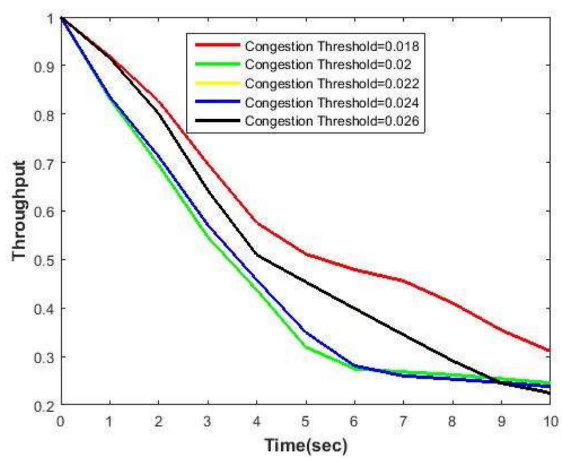

Fig. 3. *Performance evaluation for the varying congestion threshold vs. Throughput*

This analysis explains the performance of the ACSRO model based on the throughput parameter for the various values of the congestion threshold. Figure 3 shows the performance analysis graph for the simulation time vs. throughput for different congestion threshold. For the simulation time of 10 sec, the ACSRO model has the throughput of 0.31057 for the congestion threshold of 0.018. The throughput of the ACSRO model reduced for the increase in the simulation time and achieved the lowest throughput for the simulation time of 10 sec. For the increase in the congestion threshold to 0.02, the throughput value reduces to 0.2453. For the congestion threshold values of 0.022, and 0.024, the ACSRO scheme has the throughput value of 0.22438 and 0.23793. For the maximum value of the congestion threshold, the ACSRO model has the throughput of 0.22445. The performance of the ACSRO model is better at the congestion threshold value of 0.018 based on the throughput.

4.1.3 Analysis based on the Delay

This analysis explains the performance of the ACSRO model based on the delay parameter for the various values of the congestion threshold. Figure 4 shows the performance analysis graph for the simulation time vs. delay for different congestion threshold. For the simulation time of 10 sec, the ACSRO model has the delay of 0.89948 for the congestion threshold of 0.018. For the increase in the congestion threshold to 0.02, the delay increases to 0.96868. For the congestion threshold values of 0.022, and 0.024, the ACSRO scheme has the delay of 1.0823 and 0.89071. For the maximum value of the congestion threshold, the ACSRO model has the highest delay of 1.1725. Hence for better performance of the ACSRO model, congestion threshold should be chosen as small value.

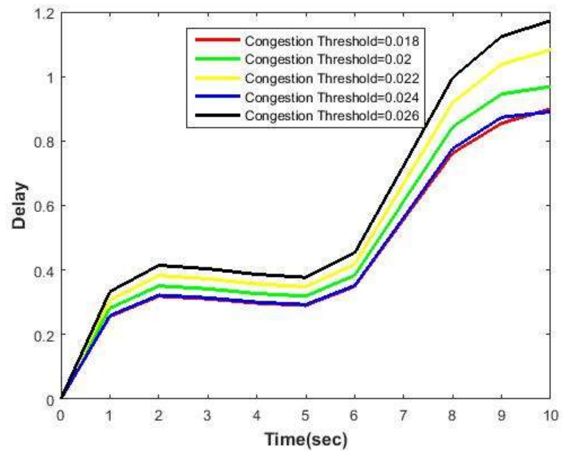

Fig. 4. *Performance evaluation for the varying congestion threshold vs. Delay*

4.1.4 Analysis based on the Packet loss

This analysis explains the performance of the ACSRO model based on the packet loss parameter for the various values of the congestion threshold. Figure 5 shows the performance analysis graph for the simulation time vs. packet loss for different congestion threshold. For the simulation time of 10 sec, the ACSRO model has the packet loss of 0.86449 for the congestion threshold of 0.018. For the increase in the congestion threshold to 0.02, the packet loss increases to 0.9707. For the congestion threshold values of 0.022, and 0.024, the ACSRO scheme has the packet loss of 1.0567 and 0.8932. For the congestion threshold of 0.026, the ACSRO model has the highest packet loss of 1.1448. Same as the analysis based on the delay, the ACSRO model has the worst performance for the higher values of the congestion threshold.

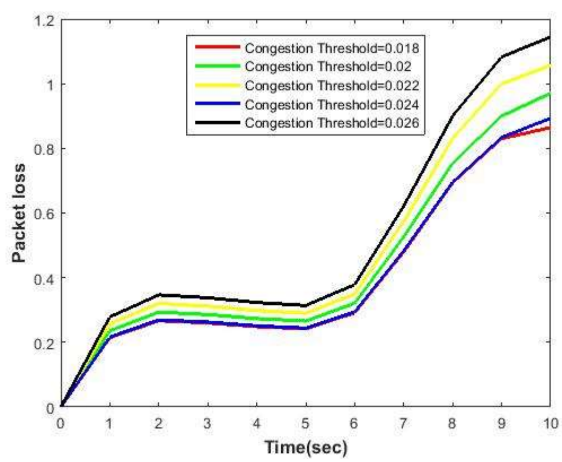

Fig. 5. *Performance evaluation for the varying congestion threshold vs. Packet loss*

4.1.5 Analysis based on the Queue size

This analysis explains the performance of the ACSRO model based on the queue size parameter for the various values of the congestion threshold. Figure 6 shows the performance analysis graph for the simulation time vs. queue size for different congestion threshold. A Larger value of the queue size reduces the congestion, but the speed of the ACSRO model gets reduced. For the simulation time of 10 sec, the ACSRO model has the queue size of 0.86737 for the congestion threshold of 0.018. For the increase in the congestion threshold to 0.02, the queue size increases to 0.97286. For the congestion threshold values of 0.022, and 0.024, the ACSRO scheme has the queue size of 1.0637 and 0.89525. For the maximum value of the congestion threshold, the ACSRO model has the highest queue size of 1.1523.

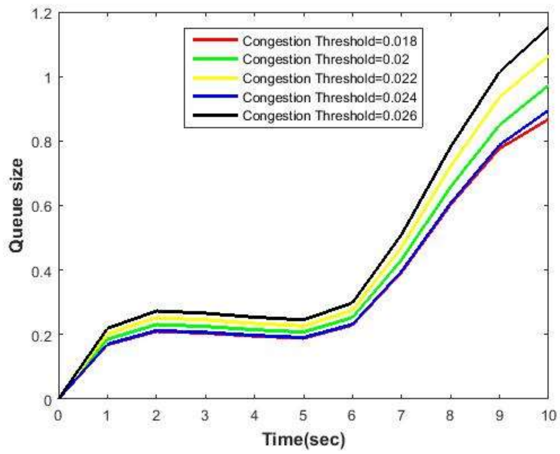

Fig. 6. *Performance evaluation for the varying congestion threshold vs. Queue size*

5. Conclusion

This paper presents the analysis of the ACSRO algorithm for congestion avoidance. The ACSRO algorithm uses a congestion threshold value to determine the congestion in the node. Initially, it opts for the packet drop, and then the important packets are transmitted with the optimal share rate. The ACSRO finds the optimal share rate by modifying the CS algorithm. It uses the fitness function with the various network parameters for the optimization process. The performance of the ACSRO algorithm is found by choosing random values of congestion threshold. Evaluation metrics such as congestion level, throughput, delay, packet loss, and queue size measure the performance of the proposed model. From the performance analysis, it is evident that the ACSRO algorithm has better performance at the minimum value of the congestion threshold. From the simulation results, the ACSRO model has the values of 0.9203, 0.31057, 0.89948, 0.86449, and 0.86737 for the congestion threshold of 0.018 for the congestion level, throughput, delay, packet loss, and queue size respectively. Increasing the congestion threshold has reduced the throughput, and increased the other parameters such as congestion level, delay, packet loss, and queue size. Thus, the ACSRO scheme is more suitable for the congestion avoidance if the congestion threshold is optimally chosen with any algorithms.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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