Society for Science and Education
United Kingdom
TMLAI Transactions on Machine Learning and Artificial Intelligence
Volume 5 No. 6
ISSN 2054-7390

Computational Intelligence for Congestion Control and Quality of Service Improvement in Wireless Sensor Networks

[1*]**Mukhdeep Singh Manshahia, [2]Mayank Dave, [3]S.B. Singh**
[1,3]Department of Mathematics, Punjabi University, Patiala, Punjab, India- 147002
[2]Department of Computer Engineering, NIT, Kurukshetra, Haryana, India- 136119
mukhdeep@gmail.com

ABSTRACT

Congestion and quality of service are widely researched topics in Wireless Sensor Networks in recent years. Many researchers proposed and compared the merits and demerits of various algorithms with the existing algorithms. The major challenge lies in developing an algorithm which optimizes the various performance parameters like packet drop ratio, residual energy and throughput of the network. Focus of the present work is to reduce congestion and improve quality of service by applying various metaheuristic or computational intelligence techniques which can optimize performance parameters. An objective function is formulated on the basis of factors like residual energy, throughput, distance between nodes and the number of retransmissions and its value is optimized by using various nature inspired computational intelligence techniques and their results are compared. Simulation results have shown that water wave algorithm outperforms all the other algorithms on the basis of packet drop ratio and throughput of wireless sensor network.

Keywords: Computational Intelligence, Congestion Control, Wireless Sensor Networks

1 Introduction

Congestion control in WSNs (Wireless Sensor Networks) means to improve the performance when demand for the finite transmission capacity exceeds the supply. There are mainly two causes for congestion in WSNs. First, packet arrival rate exceeds the packet service rate. Second is link level performance degradation due to contention, interference and bit-error rate. Increase in loss rate and starvation of most of the network due to traffic from nodes one hope away from sink are the basic symptoms of congestion in WSNs.

Congestion control is a core concept over the network for each and every type of media traffic, which has an active space of the analysis within the last decade. It can enhance the audio visual traffic of digital convergence [1]. Demand of the user for network applications is increasing boundlessly. Multiple users for network applications is endlessly growing therefore leading to congestion [2]. The major problem in congestion network is packet loss which gives transmission errors. TCP's congestion control mechanism reacts to packet loss to drop the amount of unacknowledged information segments allowed within the network [3]. All network applications do not used the TCP protocol. Therefore, the results of non- TCP applications are failed to have an abundant impact of most traffic within the network that uses TCP-based

DOI: 10.14738/tmlai.56.3689
Publication Date: 1ST Oct, 2017
URL: http://dx.doi.org/10.14738/tmlai.56.3689

protocols [4]. As the video and audio streaming applications like video players and web audio, video conferencing applications gives arise to non-TCP traffic. All the TCP-flows scale back their information rates to interrupt the congestion, wherever non-TCP flows maintains to transfer the actual rate [5]. It is extremely unfair that the condition can result in the starvation of TCP-traffic or congestion collapse. Congestion collapse can be described a state of the network when accessible data can be discarded the results of congestion before reaching the destination [6].

For this reason, it can be desirable to draw a fixed congestion management mechanism for the non-TCP traffic, which is compatible for the rate-adaptation mechanism for different kind of traffic. These mechanisms can be used to create the non-TCP application which is also TCP-friendly, and so result in distribution of information measure [7].

1.1 General Mechanisms for Congestion Control

Congestion should be controlled with efficiency. There are two basic approaches to control the congestion in WSNs. First approach of capacity provisioning means how to make the links wide enough to cope with traffic demand. The second approach is load control. WSNs nodes have very limited power due to hardware constraints. Packet losses and retransmissions resulting from congestion cost precious energy and shorten the lifetime of sensor nodes. This problem motivates the need for congestion control mechanisms in WSN. Congestion management protocol potency may depend on proportion it can do the subsequent objectives [8]:

i. Energy-efficiency requires to improved system life. Therefore, congestion management protocols have been compelled to avoid or cut back packet loss to buffer overflow, and stay lower to the management overhead that consumes less energy;
ii. Its conjointly necessary to support the ancient QoS metrics like packet delay, packet ratio, and throughput.
iii. Most of prevailing work guarantees straightforward fairness in each sensing node obtains an equivalent out turn to the sink. In fact, sensing nodes may be either outfitted with completely different sensing nodes or geographically deployed in several places and so they will have different importance or priority and want realize different out turn. Thus weighted fairness is needed.

In order to control the congestion, Network resource management approach is used to increase the network resource to mitigate congestion. In wireless network, power management and multiple radio interfaces will be used to increase the information measure and congestion avoidance. Virtual sinks in radio interfaces can be used. One primary low-power speck radio with the smaller information measure and another long-rage radio with the larger information measure [9]. When congestion occurs, long-rage radio can be used as cut off to mitigate the congestion. With this method, it is vital to ensure the precise network resource adjustment to avoid congestion. Other approach tries to control and manage congestion through adjusting the traffic rate at supply nodes or intermediates nodes [10]. This approach can be useful to save several network resources and economical precise adjustment of the network resource becomes tough. Most existing congestion management protocols belong to present sort. To control the management behaviour, two ways are used end-to-end and hop-by hop. The end-to-end management will execute precise rate adjustment at every node and change will look at intermediate nodes. In distinction, the hop-by-hop congestion management has quicker response. However, it is sometimes tough to regulate packet forwarding rate at the intermediate nodes as a result of packet forwarding rate relies on MAC protocol and can be variable [11].

In Wireless Sensor Networks, each packet can possibly include helpful information, which may be utilised through packet-based computation, and utilised to reinforce the congestion management [12]. The packet-based computation may well be sensible for the Wireless Sensor Network considering:

1) Wireless Sensing Network typically has little packet forwarding rate and so unit time to forward one packet may well long enough for sensing node to perform the bound computation even supposing its computation capability is limited [13].
2) Though Wireless Sensing Network at most time are used with the restricted energy and lacks recharging approach. The packet-based computation continues to the most accepted for sensing node since typically acknowledges the computation consumes less energy than communication. Moreover packet-based computation may offer helpful information to the scale back or avoid useless communication and successively compensate the energy it consumes [14].

1.2 Focus of the Paper

The major focus area in the work is to reduce congestion and improve quality of service by applying various metaheuristic or machine learning algorithms which can optimize performance parameters. These algorithms then compared with each other on parameters like network lifetime, normalized system throughput and packet drop ratio. These algorithms work iteratively and try to optimize the result after each iteration. For detecting the congestion in the network queue length, window size, channel occupancy etc must be monitored periodically.

1.3 Paper outline

The whole work is divided into various sections which describes various aspects and phases of research. Section 2 provides the literature survey which is considered for the research. Section 3 describes the methodology used for the work which includes the derivation of objective function and the implementation of various proposed algorithms. The implementation of improved bat algorithm, firefly, water wave algorithm, PSO and ACO are also presented in this section. In Section 4, results of all the above implemented algorithms along with CODA are discussed. Conclusion and findings are given in Section 5. Finally, the limitation of the work, Suggestions and Future and acknowledgments are discussed in section 6, 7 and 8 respectively.

2 Literature Review

Chandrashekar et al. [15] proposed a transport protocol to control congestion. A fuzzy logic based congestion estimation and a congestion mitigation technique which decreases frame quality at an acceptable level is suggested. Congestion factor is calculated using fuzzy logic on the basis of frame size and buffer size. Frame rate based congestion controller has been used to maintain the rate of flow.

Cheng et al. [16] proposed a traffic regulation based approach to control congestion in wireless sensor networks. They have proposed to control congestion by forwarding the traffic regulating factors to children nodes. Traffic regulating factors are calculated from packet round trip delay and minimum event detection degree. Generation rate of source nodes are adjusted based on traffic regulations. Simulation results have shown that network throughput has increased with reduced packet loss rate and stabilize node queue length.

Meshram et al. [17] proposed an agent based upstream congestion control scheme for wireless sensor networks. Priority index and congestion degree is used to analyze the traffic rate. Upstream traffic of network is controlled by a new multi-agent system. Latency and throughput parameters are investigated during simulation.

Aghaei et al. [18] proposed an ant colony based routing technique for Wireless Sensor Networks. They have proposed a shortest path finding techniques based on ant colony intelligence and these intelligent paths avoids the probable collision with help of congestion control mechanism. They have mapped the shortest path with neighborhood information and a data ant can guess collision probability with help of this mapping. Simulation results have shown that this protocol performs better in finding the shortest path.

Saleem et al. [19] gave a cross layer design based self-optimized routing protocol for wireless sensor networks by using ACO. Optimal path finding mechanism from source to destination is proposed by using link quality, energy level and velocity as parameters. Signal strength, remaining power and timestamp metrics are used for cross layer communication. The proposed algorithm is capable of avoiding loops and deadlocks. Simulation results has shown that proposed protocol provides better delivery ratio over WSN.

Raha et al. [20] proposed a genetic algorithm based load balancing protocol for congestion control in wireless sensor networks. They have represented the fitness function as a function of the representative genes of chromosomes. A balanced distribution of traffic among alternate paths from source to destination has been proposed. Protocol targets the selection of reliable and trusted routes more frequently than unreliable routes. Simulation results have shown improvement in data delivery ration and network lifetime.

Verma et al. [21] gave an optimal path finding approach from source to destination with different source and sink node mobility scenario based on genetic algorithm with crossover and mutation. Connection value and localization region has been used to find an optimal path every time before sending data packet which reduces chances of congestion in network. Sensor nodes in localization region are supposed to be localized. Simulation results have indicated that genetic algorithm provides better results in case of complex and large networks.

Naveena et al. [22] gave a cross layer dynamic adaptation mechanism for wireless ad hoc networks. A joint congestion control scheme with scheduling algorithm is proposed for dynamic networks by changing scheduling scheme with adaptation model. They have generalized the channel access management and routing process with management of traffic, connection maintenance and distributed scheduling for concurrent transmission. Simulation results have proved that the proposed protocol is highly stable and robust for unicast data and it improves the packet relay in all mobility situations.

3 Proposed Methodology

Nature inspired computational intelligence techniques are implemented in the work to control congestion in the Wireless Sensor Networks. The clustering operation is performed using firefly algorithm [23]. A fitness function is derived for clustering which is based on the values of residual energy and the distance between the nodes. Each node in the cluster shares its information like number of packets lost, its residual energy, queue size etc to every other node in the cluster. Number of retransmissions of every node and the distance value between any two nodes in the cluster is calculated. This data is used by the proposed approaches to route the packets by calculating the optimum route.

An objective function based on various parameters like residual energy, packet loss ratio, throughput, distance has been proposed in the present work to control congestion in wireless sensor networks. The Improved Bat Algorithm which is based on the echolocation of bats, Firefly algorithm that relies on the attractiveness issue of the firefly, water-wave algorithm which works on the propagation, refraction and breaking of the waves, Particle swarm optimisation (PSO), and Ant Colony Optimization (ACO) are applied on the objective function to find the optimum solution. NS-2.35 based simulation results of implementation of all five algorithms are presented and compared with the Collision Detection and Avoidance algorithm (CODA). The analysis of the simulation results have shown that the computational intelligence techniques perform better on many parameters.

Figure 3.1 shows the flow diagram of proposed methodology. The proposed methodology is for all the five algorithms i.e. Improved Bat Algorithm, Firefly Algorithm, Water wave Algorithm, PSO and ACO. The result of the global best will be calculated after every iteration and compared with the previous global best solution.

3.1 Derivation of Fitness Function

The problem of congestion control in WSN is a very wide area of research. From the past few years many researchers use various algorithms to solve the same problem. Among the many reasons of congestion, Buffer overflow, Channel contention and packet collision are considered as the major focus areas. A fitness function is considered based on various parameters like throughput of the network, packet lost rate and residual energy. These parameters are:

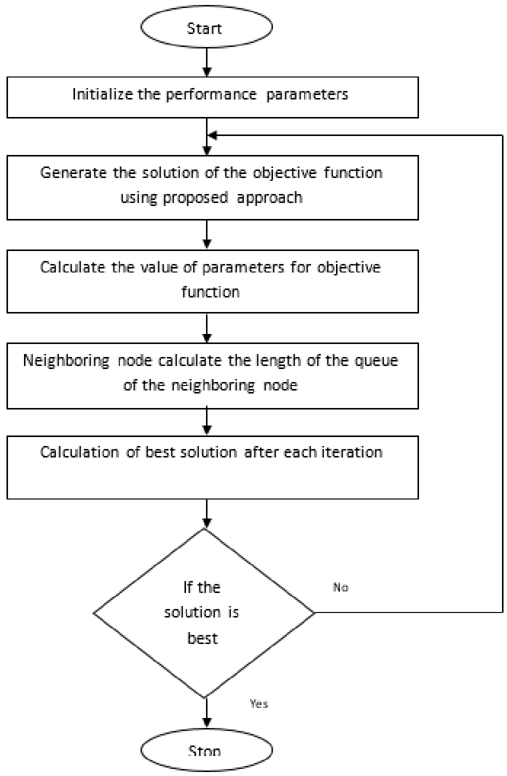

Figure 1: Flow Diagram of Proposed Methodology

The fitness function considered in the research work is a combination of the above written parameters along with the numerical weight given to each parameter. The numerical values will be given according to the contribution of each parameter in the optimum result of the algorithm. To improve the performance of the network and to reduce the congestion we need to optimize the fitness function.

$$\textit{Fitness Function}\ (F_j) = \sum_{i=1}^{n}(w_1 * \tau_i + w_2 * (1 - P_{L_i}) + w_3 * E_i + w_4 * d_{i,j}) \quad (1)$$

Where, i is the iteration which ranges from 1 to N (total number of nodes),

w_1, w_2, w_3 and w_4 are the weights supplied to the algorithm,

τ is the throughput of the network,

P_L is the normalized Packet lost rate in the network

$d_{j,i}$ is the distance between node i and j and

E is the residual energy of each node in the network.

3.2 Routing Technique

Reactive routing technique is used in the proposed methodology [25]. In reactive routing technique the route is determined in the real time. RREQ message is generated when a node wants to transfer the information or data which simply defines as the route request message. In reactive routing single hop or multi hop route is considered on the basis of RREQ message. In these types of protocol there is a provision of route recovery also and many routing schemes consider the following three route recovery mechanisms:

RREQ - Source node initiates the route request message to the destination node. These requests generally have a time to live (TTL) parameter which is initially set as a predefined value and can be increased when there is a loss of packets in the network.

RREP- It is unidirectional message targeted towards the source node from the destination node. Route Reply message is used to inform the source node about the route to the destination node.

RERR- RERR message notifies the other nodes for the loss of the link. Nodes in the network monitor the link status and update the next hop information in the network.

3.3 Performance Metric

There are many factors responsible for the congestion in WSN. Congestion can be detected in WSN by tracking various parameters which gives a clear insight view of the congestion in WSN [26]. These factors are:

Channel Occupancy: It is defined as the number of active packets in the network which will occupy the network or channel resources. It is an important parameter as it describes the channel usage by the nodes transferring the packets in the network.

Reporting Rate: Reporting rate is defined as the number of packets reaching the destination over a specified period of time. It depends on the sub tree value of each node.

Queue Length: The length of the queue of each node also plays an important role in congestion detection in the network. It is the parameter associated with each node and the number of packets that a node can store is termed as its queue length. A node can store only a fixed number of packets and if the queue is full then packets started to overflow and thus lead to extra packets in the network which can cause congestion.

Packet Loss and Window Size: Window size is associated with the network and is defined as the number of packets that can flow in the network on a particular moment of time. This parameter is also related to the channel capacity of the network and only a fixed number of packets can be handled by the network at a particular time. If the number of packets increases in the network at that time then it lead to the loss of the packets and these packets also cause congestion in the network. So a network is designed to handle the packets in an optimum way by distributing the load to all the nodes in the network.

The congestion is detected by monitoring the queue length and the window size of each node in the proposed work.

3.4 Proposed Congestion Control Approaches

The objective of the congestion control is to increase the throughput of the network. So the problem of congestion becomes a multi objective constraint optimization problem. Nature-inspired algorithms Improved Bat Algorithm, Firefly Algorithm and Water wave Algorithm, PSO, ACO are implemented to optimize the objective function. These algorithms are based on iterations and an optimal route is calculated based on iterative analysis.

Improved Bat Algorithm: The algorithm is based on the concept of echolocation of bats [27, 28, 29]. For obstacle detection and avoidance, bats use sonar echoes which reflect from obstacle and are transformed to frequency. They use time delay between the emission and reflection and use that delay for navigation. This can be implemented in the proposed work by using simple rules proposed in the algorithm. Packets will go randomly in any direction towards their destination node and use the value of packet lost rate and residual energy of the target node to decide which node they will choose to go further. This selection is based on the fitness function value.

Firefly Algorithm: Firefly is an insect that mostly produces short and rhythmic flashes that produced by a process of bioluminescence [24, 30, 31]. The function of the flashing light is to attract partners (communication) or attract potential prey and as a protective warning toward the predator. Thus, the intensity of light is the factor of the other fireflies to move toward the other firefly. This algorithm can be implemented in this work by taking advantage of the attractiveness factor of the fireflies. Packets will follow the path through those nodes which have high residual energy value. The node can broadcast the value of the fitness function along with the residual energy to their neighbouring nodes in the network. Packets will follow the path which has the most optimized set of fitness values.

Water Wave Algorithm: Water Wave algorithm is based on the shallow water wave models for solving optimization problems [32,33]. When a wave travels from deep water to shallow water, its wave height increases and its wavelength decreases and vice versa. In Water Wave Optimization, the solution space and the fitness of a point is inversely proportion to its seabed depth. It means the shorter the distance to the still water level, the higher will be the fitness function $f(x)$. This algorithm is implemented in this work by considering the fitness function and performing all the three operations i.e. propagation, refraction and breaking.

Particle Swarm Optimization (PSO): Particle Swarm Optimization (PSO) is a metaheuristic algorithm which computes the mathematical solution depicting the particles in the search space [34, 35, 36]. PSO calculates the solution of the moving particles in the search space in terms of velocity and position. It iteratively computes the best solution of the problem. Swarm and data packets will follow search space path computed by the algorithm.

Ant Colony Optimization (ACO): Ant Colony Optimization (ACO) is a method for finding the solution in terms of optimal routes based on the behavior of ants searching for food [37, 38]. Firstly ants wander randomly and when they find the food they walks back to the colony leaving the traces called the pheromones for other ants to get the path to the food. This model is used by packets to select path for transmission.

3.5 Congestion Detection and Avoidance (CODA)

We have compared our approach with Collision Detection and Avoidance (CODA).Collision Detection and Avoidance (CODA) is a congestion control mechanism which works on the energy efficiency parameter [39, 40]:

- Closed-loop multisource regulation
- Open loop hop-by-hop backpressure
- Receiver based congestion detection

MAC layer is used in the performance of the algorithm and management of data in the network. CSMA is used for detection and avoidance of congestion.

3.6 Simulation Environment

For creating the simulation environment, a 1000*1000 grid is considered in ns- 2.35. 50 nodes are placed in the network grid. Wireless parameters like antenna type, channel type and propagation model are defined for each node. MAC layer is used for the extraction of energy from each node with standard IEEE 802.11 and the radio model has been adopted [41,42,43,44].

Table 1. Simulation Parameters

Parameter	Value
No. of Nodes	50
X dimension	1000
Y dimension	1000
Grid Area	1000*1000
Mac Protocol	IEEE 802.11
Propagation Model	Two-Ray Ground Model
Transmission Range	200m (approx.)
Antenna type	Omni-Antenna
Channel type	Wireless Channel
Routing Protocol	AODV
Simulation time	60
Interface Queue type	Prequeue

4 Results and Discussions

A comparative analysis is performed between Improved Bat Algorithm, Firefly Algorithm, Water Wave Algorithm, Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and CODA. The factors of comparison are the throughput of the network, network lifetime and the packet loss ratio. The proposed approaches which are implemented on an objective function to resolve the problem of congestion follow different approaches to solve the problem. While CODA (Congestion detection and Avoidance) is also implemented on similar environment and compared to our proposed approaches.

Figure 7.7 shows the graph of Normalized system throughput. Throughput of a network is defined as the ratio of packet size and the time required transferring the packet from source to destination. System throughput as shown in the graph is best for Water wave Algorithm while performance of firefly algorithm is also better than CODA, Improved Bat algorithm, PSO and ACO. Improved Bat algorithm, PSO and ACO performs almost same in this case. The performance of CODA is worst because there is a decrease in value for CODA at around 30 seconds of simulation

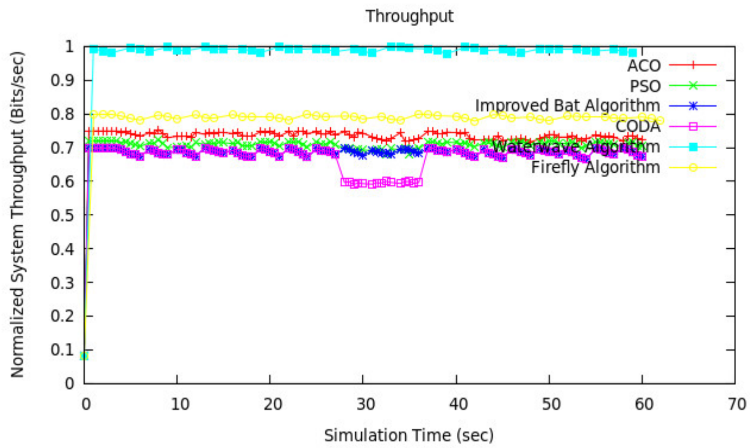

Figure 2: Graph between Simulation Time and Normalized System Throughput

Figure 7.8 shows the graph of Network lifetime plotted against the simulation time. In this graph the network lifetime in case of Improved Bat Algorithm is better as compared to the other algorithms. CODA has the worst performance as the residual energy is less and exhausted very quickly. While the performance of Firefly and Water wave algorithm, PSO is almost same and better than ACO

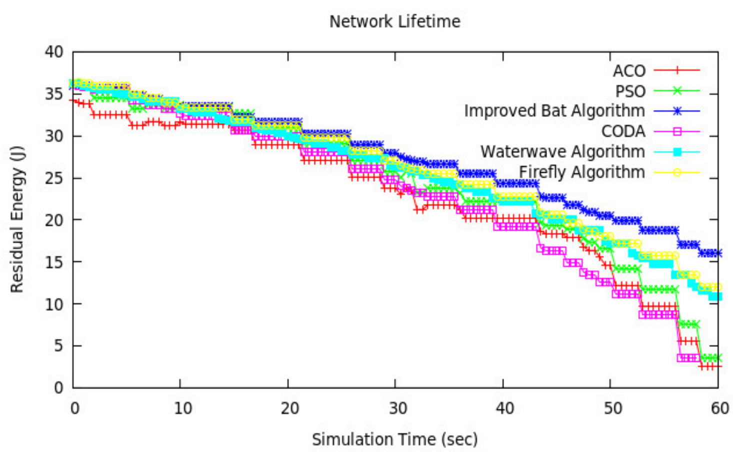

Figure 3: Graph between Simulation Time and Network Lifetime

Figure 7.9 shows the graph of packet loss (drop) ratio. In this graph packet loss ratio of all four algorithms is considered and compared with each other. , Water wave algorithm performs better than other algorithms. Packet loss rate of CODA and PSO is almost equal while it is on higher side in case of Improved Bat algorithm, Firefly algorithm and ACO.

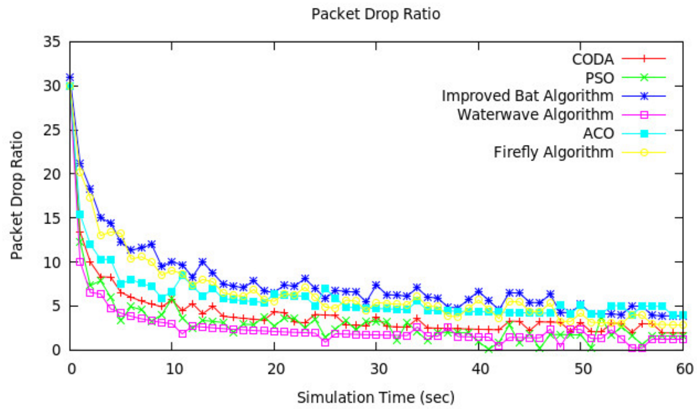

Figure 4: Graph between Simulation Time and Packet Drop Ratio

Table 2. Comparison of Various Techniques

Algorithm	Throughput	Network Lifetime	Packet Drop Ratio
BAT	M	H	H
Firefly	H	M	M
Water Wave	VH	M	L
PSO	M	M	M
CODA	L	L	L
ACO	M	L	M

The values for input linguistic variables are Low (L), Medium (M), High (H) and Very High (VH).

5 Conclusion and Findings

To solve the problem of congestion various machine learning algorithms have been proposed in recent past. In this work we have implemented five of the recognized machine learning algorithms. The results of various performance parameters are compared with each other and their approximation for the best value is carried out. Few important findings are drawn from this work which is well suited with their theoretical explanation. Number of packets stored by the sensor node directly depends on the hop count. It is also evident from the graphs of all the proposed approaches that the number of packets in the queue decreases with the increase in the number of hops. It means that while transferring the packets from source to destination the number of hops encountered in the route depicts the congestion in the network.

All the proposed algorithms are also compared on the basis of three other performance parameters which are:

Normalized System Throughput: Throughput value is normalized to 1 and Water wave algorithm outperforms all the other algorithms and maintains its value close to 1. In case of firefly throughput is better as compared to the PSO, ACO, CODA and Improved Bat Algorithm. The performance of CODA is worst due fluctuation at 30 sec.

Network Lifetime: Network lifetime of nodes in the network is an important parameter of comparison as it decides the active period of network. It directly depends on the residual energy of all the nodes in the network. The network lifetime in case of Improved Bat Algorithm is better as compared to the other algorithms. In case of CODA the energy of all the nodes exhausted very rapidly and the network which works on CODA algorithm becomes inactive in a short period of time. While in case of Water Wave, Firefly and PSO the network lifetime is better as compared ACO.

Packet Drop Ratio: While transferring the packets from source to destination, Packets can be lost due collisions and network congestion. Water wave algorithm performs better than other algorithms on packet loss ratio. Packet loss rate of CODA and PSO is almost equal while it is on higher side in case of Improved Bat algorithm, Firefly algorithm and ACO.

6 Limitations

Major limitation of this work is that all the algorithms used in optimizing the fitness function are not showing the better results in every performance parameter considered. Bat algorithm performs better in case network lifetime but performs badly in case of packet drop ratio. The performance of Firefly algorithm is average. Water wave algorithm shows best performance in case of normalized system throughput and packet drop ratio parameter while in case of remaining parameter other algorithms perform slightly better.

7 Suggestions and Future Scope

Congestion in the Wireless Sensor Network is dealt by implementing various machine learning algorithms and their results are compared. In future the problem may be dealt by implementing various other algorithms which can perform best in almost all the considered performance parameters. Also performance of algorithms present in this work may be tested on various other parameters by varying the size of the network, as the performance of the given parameters can be changed by increasing the number of nodes in the network.

ACKNOWLEDGEMENTS

Authors are grateful to Punjabi University Patiala and NIT, Kurukshetra for providing adequate library and internet facility

REFERENCES

[1] J. Long, H. Zhang, O. W.W. Yang, *A Queueing performance comparison of Extended proportional controller in TCP Traffic Control*, Proceedings of IEEE Canadian Conference on Electrical and Computer Engineering, IEEE, vol.2, Montréal , 4-7 May 2003. p. 973 – 976.

[2] Zhai. H, Chen. X, Fang. Y, *Rate-Based Transport control for Mobile Ad Hoc Networks*, Proceedings of 2005 IEEE Wireless Communications and Networking Conference, WCNC 2005. 4:p. 2264 - 2269

[3] G. Anastasi, E. Anallatti, M. Conti, A. Passarella, *TPA: a Transpart Protocol for AD hoc Networks*, Proceedings of 10th IEEE symposium on computers and communications, IEEE, 27-30 June 2005. p. 51-56.

[4] M. Elshakankiri, Y. Damroury, *A quality of service protocol for Mobile Ad hoc Networks*, Proceedings of IEEE 46th Midwest Symposium on Circuits and Systems, IEEE, Vol. 1, 27-30 Dec. 2003. p. 490-495.

[5] K. Chen, Y. Xue, K. Nahrstedt, *On setting TCP's congestion window limit in Mobile Ad Hoc Networks*, Proceedings of IEEE International Conference on Communications, Vol. 2 , IEEE, 11-15 May 2003. p. 1080 - 1084.

[6] H. Xu. H, X. Wang, C.K. Toh, *Comparative analysis of scheduling algorithms in Ad Hoc Mobile Networking*, Proceedings of Sixth international conference on parallel and distributed computing, Applications and Technologies, IEEE, Dec. 2005. p.639 - 643.

[7] A. Legout, E.W. Biersack, *Revisiting the fair queueing paradigm for End to End congestion control*, IEEE Network, 2002. 16(5): p. 38 - 46.

[8] D. Kim, C. K. Toh, H. J. Jeong, *An early Retransmission Technique to improve TCP performance for Mobile Ad Hoc Networks*, Proceedings of 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2004. 4: p. 2695 – 2699.

[9] A. Kumar, L. Jacold, A. L. Ananda, *SCTP Vs TCP: Performance comparison in MANETs*, Proceedings of 29th Annual IEEE International Conference on Local Computer Networks, IEEE, 16-18 Nov. 2004. p. 431 – 432.

[10] D. Kim, H. Bae, C.K. Toh*, Improving TCP-vegas performance over MANET Routing protocols*, IEEE Transactions on Vehicular Technology, 2007. 56(1): p. 372 – 377

[11] A.A. Abouzeid, M. Azizoglu , *Comprehensive performance analysis of a TCP session over a Wireless Fading Link with Queueing*, IEEE Transactions on Wireless Communication, 2003. 2(2): p. 344 - 356

[12] V.S. Mansouri, B. Afsari, H. Shahmansouri, *A simple Transport protocol for wireless sensor Networks*, Proceedings of the 2005 International Conference on Intelligent Sensors, Sensor Networks and Information Processing Conference, IEEE, 5-8 Dec. 2005. p. 127 - 131.

[13] S. Hashmi, H. T. Mouftah, N. D. Georganas, *A New Transport layer Sensor network protocol*, Proceedings of IEEE Canadian Conference on electrical and Computer Engineering, Ottawa, May 2006. p. 1116 - 1119.

[14] I. Stoica, S. Shenker, H. Zhang, *Core-Stateless Fair Queueing : Achieving approximately fair bandwidth allocations in high speed Networks*, IEEE/ACM Transactions on Networking , 2003. 11(1): p. 33 – 46

[15] G. Chandrashekar, S. S. Manvi, *Fuzzy Logic based Congestion control in Wireless Multimedia Sensor Networks*, International Journal of Latest Trends in Engineering and Technology, 2014. 4(2):p.216-221

[16] L. Cheng, Z. Yong, X. Wei-xin, Traffic Regulation based Congestion Control Algorithm in Sensor Networks, Journal of Information Hiding and Multimedia Signal Processing, 2014. 5(2): p. 187-198

[17] S. Meshram, R. V. Bobate, S. Chaturvedi, *Congestion Control by Multiagent in Wireless Sensor Network*, International Journal of Software and Web Sciences, 2013. 5(1): p. 37-41

[18] R.G. Aghaei, A.M. Rahman, M.A. Rahman, W. Gueaieb, *Ant Colony-Based Many-to-One Sensory Data Routing in Wireless Sensor Networks*, Proceedings of IEEE/ACS International Conference on Computer Systems and Applications, IEEE, Doha , March 31- April 4 2008. p. 1005 - 1010.

[19] K. Saleem, N. Fisal, M.A. Baharudin, A.A. Ahmed, S. Hafizah, S. Kamilah, *Ant Colony inspired Self-Optimized Routing Protocol based on Cross Layer Architecture for Wireless Sensor Networks*, WSEAS transactions on communications, 2010. 9(10): p.669-678

[20] A. Raha, M.K. Naskar, A. Paul, A. Chakraborty, A. Karmakar, *A Genetic Algorithm Inspired Load Balancing Protocol for Congestion Control in Wireless Sensor Networks using Trust Based Routing Framework*, I.J. Computer Network and Information Security, 2013. 9: p. 9-20

[21] A. Verma, N. Mittal, *Congestion Controlled WSN using Genetic Algorithm with different Source and Sink Mobility Scenarios*, International Journal of Computer Applications, 2014. 101(13):p. 8-15

[22] G. Naveena, H. H. Babu, *Dynamic Congestion Control with Multihop Scheduling Algorithm For Mobile Ad-Hoc Network*, International Journal of Innovative Research in Computer and Communication Engineering, 2014. 2(1): p. 2011-2015

[23] Manshahia, M.S., Dave, M. and Singh, S.B., *Firefly algorithm based clustering technique for Wireless Sensor Networks*, in: Proceedings of International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), 23-25 March 2016.

[24] Manshahia, M.S., Dave, M. and Singh, S.B., *Congestion Control in Wireless Sensor Networks Based on Bioluminescent Firefly Behavior*, Wireless Sensor Network , 2015. 7: p. 149-156

[25] R. Ding, L. Yang, *A Reactive Geographic Routing Protocol for Wireless Sensor Networks*, Proceeding of 6th International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), Brisbane, 7-10 December 2010. p. 31-36.

[26] L. Alazzawi, A. Elkateeb, *Performance Evaluation of the WSN Routing Protocols Scalability*, Journal of Computer Systems, Networks, and Communications, Vol. 2008 , 2008.

[27] X..S. Yang, A. H. Gandomi, *Bat algorithm: a novel approach for global engineering optimization*, Engineering Computations, 2012. 29(5): p. 464-483

[28] A. H. Gandomi , X.S. Yang, *Chaotic Bat Algorithm*, Journal of Computational Science, 2014: 5(2): p. 224–232

[29] Manshahia, M.S., Dave, M. and Singh, S.B., *Bio Inspired Congestion Control Mechanism for Wireless Sensor Networks*, in: Proceedings. of 2015 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC), Madurai, India , December, 2015.

[30] X..S. Yang, Xingshi He, *Firefly Algorithm: Recent Advances and Applications*, Int. J. of Swarm Intelligence, 2013. 1(1): p. 36-50

[31] X..S. Yang, *Firefly algorithms for multimodal optimization*, Stochastic Algorithms: Foundations and Applications, Lecture Notes in Computer Sciences, 2009. 5792: p. 169–178

[32] Y.J. Zheng, Water wave optimization: A New Nature-inspired Metaheuristic, Computers & Operations Research, 2015. 55: p. 1–11

[33] Manshahia, M.S., *Water Wave Optimization Algorithm based Congestion Control and Quality of Service Improvement in Wireless Sensor Networks*, Transactions on Networks and Communications, 2017. 5(4): p .31-39

[34] P. Antoniou, A. Pitsillides, T. Blackwell, A. Engelbrecht and L. Michael, *Congestion Control in Wireless Sensor Networks based on Bird Flocking Behavior*, Computer Networks, 2013. 57(5): p. 1167–1191

[35] R. C. Eberhart, J. A Kennedy, *New optimizer using particle swarm theory*, Proceedings of the Sixth International Symposium on Micromachine and Human Science, Nagoya, Japan, 1995. p. 39-43

[36] J. Kennedy, R.C. Eberhart, *Particle swarm optimization*, Proceedings of IEEE International Conference on Neural Networks, Piscataway, NJ, 1995. p. 1942-1948

[37] Marco Dorigo, Thomas Stützle, *The Ant Colony Optimization Metaheuristic: Algorithms, Applications, and Advances*, Handbook of Metaheuristics, Volume 57 of the series International Series in Operations Research & Management Science, 2003. p. 250-285, (ISBN: 978-0-306-48056-0)

[38] Marco Dorigo, Gianni Di Caro, *The ant colony optimization meta-heuristic, New ideas in optimization*, McGraw-Hill Ltd., UK Maidenhead, UK, England, 1999. p.11-32 (ISBN: 0-07-709506-5)

[39] C.Y. Wan, S.B. Eisenman and A.T. Campbell, *CODA: Congestion Detection and Avoidance in Sensor Networks*, Proceedings of the 1st international conference on Embedded networked sensor systems, sensys 03, Los Angels, USA, Nov 5-7, 2003. p. 266-279

[40] Mukhdeep Singh, S.B. Singh, Mayank Dave, *Congestion Control in Computer Networks*, Ultrascientist: International Journal of Physical Sciences, 2008. 20(2m)

[41] F. Paganini, Z. Wang, J.C. Doyle,S.H. Low, *Congestion control for high performance, stability and fairness in general networks*, IEEE/ACM Transactions on Networking Los Angeles, 2005. 13: p. 43-56

[42] Manshahia, M.S., *Wireless Sensor Networks: A Survey*, International Journal of Scientific & Engineering Research, 2016. 7(4): p. 710-716

[43] Manshahia, M.S., *A Firefly Based Energy Efficient Routing in Wireless Sensor Networks*, African Journal of Computing & ICT, 2015. 8(4): p. 27-32

[44] Manshahia, M.S., Dave, M. and Singh, S.B, *Improved Bat Algorithm Based Energy Efficient Congestion Control Scheme for Wireless Sensor Networks*, Wireless Sensor Network, 2016. 8: p. 229-241