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KFOA: K-mean Clustering, Firefly Based Data Rate Optimization and ACO Routing for Congestion Control in WSN

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***Abstract*—Wireless sensor network (WSN) is assortment of sensor nodes proficient in environmental information sensing, refining it and transmitting it to base station in sovereign manner. The minute sensors communicate themselves to sense and monitor the environment. The main challenges are limited power, short communication range, low bandwidth and limited processing. The power source of these sensor nodes are the main hurdle in design of energy efficient network. The main objective of the proposed clustering and data transmission algorithm is to augment network performance by using swarm intelligence approach. This technique is based on K-mean based clustering, data rate optimization using firefly optimization algorithm and Ant colony optimization based data forwarding. The KFOA is divided in three parts: (1) Clustering of sensor nodes using K-mean technique and (2) data rate optimization for controlling congestion and (3) using shortest path for data transmission based on Ant colony optimization (ACO) technique. The performance is analyzed based on two scenarios as with rate optimization and without rate optimization. The first scenario consists of two operations as k-mean clustering and ACO based routing. The second scenario consists of three operations as mentioned in KFOA. The performance is evaluated in terms of throughput, packet delivery ratio, energy dissipation and residual energy analysis. The simulation results show improvement in performance by using with rate optimization technique.**

***Keywords*—Congestion control; WSN; Rate optimization; clustering; routing**

I. Introduction

WIRELESS Sensor Network is a network of large number of tiny, inexpensive and autonomous sensor nodes. The nodes are equipped with memory unit, power supply, processor and Transreceiver system. These resources constitute scarcity of bandwidth, processing speed, storage capacity and battery life. The main function of these sensors is to amass the data from environment and transmit it to one of powerful base station. Diverse applications of WSN include medical, industry production units, vehicle traffic managements, structural monitoring and habitat control. On the detection of event all sensors covering sensing range of event spot start simultaneous data transmissions towards sink node. This process causes collision of data packets and overflow of buffer results in congestion situation in the network. The high data transmission rate and longer delays due to retransmission diminish the network performance.

In WSNs, congestion happens when a sensor node or communication channel handles more data transmission rate than its capacity. The factors that cause the congestion are buffer overflow, interference, contention to access radio link, collision of packets, many to one data transmission nature, unfair utilization of resources and high data transmission rates on occurrence of event. Since congestion has significant impacts as degradation of channel quality, packets drops, increase in delay, wastage of bandwidth, increase of retransmission which leads to excess energy consumption it stimulates a pivotal necessity for a steadfast congestion control technique to mitigate the problem.

Following are some techniques in WSN aimed at controlling the congestion situation: Based on feedback system: Open loop congestion control (retransmission policy, window policy, acknowledgement, discarding policy, admission policy), closed loop congestion control (back pressure, chock packet, Implicit signaling, explicit signaling); congestion control manner (centralized, distributed, hybrid); network architecture based (e.g. block, tree, chain, hierarchical, topology, clustering); traffic type (source traffic, transit traffic); data flows (one packet, block of packets, stream of packets); congestion control approaches (e.g. using software tools, multi objective optimization, traditional methods); based on protocol operation (traffic based, resource based, priority based, queue based, hybrid); types of congestion (based on packet loss, congestion phase); based on performance matrix (network lifetime, energy consumption, network latency and throughput) node level, link level congestion. Congestion control algorithms can be classified into three phases: congestion detection, congestion notification and congestion reduction. For congestion detection the ratio or the number of received packets should be compared with the service packet rate. Then, in the congestion notification phase, at any given time, a bit is supposed to notify the upstream node about the occurrence or nonoccurrence of congestion. Congestion notification phase can be done in two ways, i.e. implicitly or explicitly. Finally, in the congestion reduction phase, the congestion problem will be sorted out by regulating and adjusting the transmission rate. Several methods for energy consumption improvement are presented to elude data losses throughout the communication process by development in network lifetime

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The main objective of KFOA is 1) to cluster the nodes using K-means algorithm, 2) to optimize the data transmission rate on receiving negative acknowledgement using active firefly optimization technique and 3) to enhance the throughput along with routing optimization using ant colony optimization algorithm. The performance evaluated based on with rate optimization and without rate optimization based results.

II. Literature Survey

In [1] the cluster routing based rate optimization congestion control technique is presented for reducing energy consumption. In AWF (RBCC) nodes are clustered using hybrid k-means clustering algorithm. As the congestion triggers queue length is compared with threshold value. If buffer size exceeds the threshold value it set acknowledgement as zero. Zero indicates negative acknowledgement and it minimizes the data transmission rate using adaptive weighted firefly optimization. For the controlled data rate packets are transmitted using Ant colony optimization algorithm with maximum throughput. The end to end delay is reduced to extend network life time. Congestion is detected through queue length and sends notification implicitly. AWF (RBCC) gives energy efficient transmission but this should require improvement in balancing traffic load or reliability along the selected paths.

Packet Priority Intimation (PPI): PPI guarantees congestion control using Packet Priority Intimation [2]. Every packet carries a PPI bit to examine congestion. The PPI is installed in AODV routing protocol to work it as congestion aware routing. PPI is built on the basis of bandwidth, allocation of schedules and assignment of priorities to reduce the overhead and overhearing by the network. The major challenges are data transmission and network mobility which results in high average delay.

Congestion Detection Technique for Multipath Routing and Load Balancing (CDTMRLB): CDTMRLB depict congestion prevention along with power wastage challenge in WSN. If distance between nodes is used for selecting the routes, then there could be repeated utilization of same paths in a static network. Due to this node closer to BS will die out of energy soon. There exists consistent energy wastage when routes are chosen randomly, but it leads to reduced data success rate [3]. In this protocol the distance between source and sink node, relative success rate (RSR) value and buffer tenure of a node are used for selecting routes. A utility function is defined based on these three parameters and employed to all adjacent nodes. The next hop node is selected based on highest utility value.

Split Protocol determines the appropriate path for data transmission incorporating congestion control mechanism in all the nodes. Congestion level is detected by observing the queue size. For controlling the congestion SP protocol uses rate control and selects best forwarding node for data transmission. The use of this technique reduces the power consumption. The major concern is the given power level of transmitting node and the load balancing at each node depending upon the energy level of that node [4].

Congestion control and energy-balanced scheme based on the hierarchy (CCEbH) [5] for WSNs uses queue length, forwarding and receiving rate for congestion detection. It provides this information to its upstream nodes to find other next hop so that congestion can be easily avoided. The energy balancing scheme provides nodes with maximum remaining energy. This technique effectively deals with the network congestion and unbalanced energy consumption. The lack of fairness and less attention on energy consumption of lower hierarchy nodes are the limitation of this technique.

PASCCC: priority-based application-specific congestion control clustering protocol assimilate the mobility and heterogeneity of the nodes for congestion detection [6]. The cluster head gives first priority to the packets of distant nodes by effectively utilizing queue scheduling approach. In this way it achieves coverage fidelity. The mobility feature is retained only to ensure reporting of critical events. The design of queuing model is based on time critical data. Many other factors like threshold for queues, number of queues and probability of blocking can be used for modeling the queue. The limitation of this study is that it takes extreme delay in establishing network setup phase.

Fast Congestion control (FCC) [7]: This protocol introduces routing through a hybrid optimization algorithm. The work is divided in to two tasks. For selection of forwarder node with lowest queuing delay in first stage it presents a multi-input time on task optimization algorithm. In second stage an energy efficient route is established between source node to destination node using an altered gravitational search algorithm. In this technique congestion is controlled by multipath routing. FCC efficiently decreases data loss, energy utilization and increases average hop count to extend the network lifetime but multiple hops consume more energy.

An optimizing routing algorithm based on congestion control (CCOR)[8]: This protocol works in three stages. In first stage for detection of congestion CCOR presents a queuing network model. With the help of node position, congestion status and packet service rate CCOR finds best routing decision to increase energy efficiency in second stage. In last stage based on hydraulics principle the traffic is distributed among multiple paths so that it ensures effective recourse utilization. The limitations of this technique are degraded performance under heavy traffic, lack of choosing the shortest path and high delay under heavy traffic load.

The estimating of round-trip-time, forecasting of lagged packets, announcing the channel status, differencing of loss and controlling congestion window are the major constituents of this algorithm. The variation in round trip time is founded on the ARIMA (2,1,1) [9] model. Further received signal strength indicator is used to discriminate the packet losses which control the window size to avoid congestion situation of network. This technique performs well in heterogeneous networks. The major drawback of this method is that it does not support a balanced energy among nodes.

The multi-objective optimization algorithm is used to control congestion problem .To optimization the data transmission rate from every child node to the parent node PSOGSA is proposed in [10]. The energy of the node is considered as fitness function in multi-objective based optimization algorithm. To optimization the data transmission rate the priority based approach is used. The different arrival rate, output available bandwidth and energy of the child node are inputs to the optimizer. To improvement load balancing problem & security issues is the future scope.

The study [11] maximizes the throughput by proposing an efficient congestion control-based schedule algorithm, dubbed REFIACC (Reliable, Efficient, Fair and Interference-Aware

Congestion Control) protocol. By scheduling the communications REFIACC prevents the interferences and ensures a high fairness of bandwidth utilization between sensor nodes. Findings are improved throughput and reception ratio that can scale for large scale networks. Future work will enhance REFIACC with a better reliable and recovery scheme for loss-intolerant applications.

To control the congestion situation the current node adjusts the transmission rate. Support Vector Machines (SVMs) by using multi-classification improves the network throughput in [12]. SVM parameters are tuned, using genetic algorithm. It decrease energy consumed, Packet loss, delay; improve throughput & network lifetime under different traffic conditions, especially in heavy traffic areas.

A congestion control protocol (CCP) [13] for HTWSNs which can estimate the congestion control degree (CCD) at each node prior to identify the future congested nodes in the network is proposed in [16]. To achieve high-quality data transmission in HTWSN the CCP facilitate its load balancing technique effectively and balance the data traffic between the futures congested nodes and source node. It gives satisfactory performance even with lower bandwidth. Future scope is to make CCP an energy efficient protocol.

In paper [14], two algorithms for mitigating query hotspots, distance-based mobile agent selection (DMAS) and greedy-based mobile agent selection (GMAS) are proposed. The boundary node equipped with mobile node which moves around the hotspot. In the future work the proposed algorithms will enhance to deal with the problem of query hotspot and storage hotspot. The load balancing and spam attacks are resolved effectively by this technique.

In paper [15], a new duty cycle based congestion aware algorithm known as Dynamic Agile Congestion Control (DACC) designed to overcome the limitations of FIFO based sensor motes at the gateways. The DACC uses two sub-algorithms one at the gateway that intelligently senses congestion during its initial stage and another at the sensor node that dynamically alters the duty cycle based on packet marking field. The DACC improves the stability and reduces congestion in wireless sensor network. The drawback of this method is that it does not consider energy factor. In future it is customized to meet the challenges of mobile sensor node & sensor cloud environment.

AODV with mobile node [16]: Mobile nodes move around the nodes whose power consumption is very high. By adjusting the reporting rates of buffer the mobile nodes control the congestion. Performance of network with and without mobile nodes is checked for observing energy consumption and network lifetime. For this number of mobile nodes, location and speed of mobile nodes are varied to enhance the lifetime of nodes and entire network. This system is only suitable for event driven applications also it requires extra overhead to move the mobile node.

III. The Problem Statement and System Block Diagram

The formation of sensor nodes for inter cluster data transmission in WSN is presented in Fig.1. The packets are transmitted from one cluster head to another cluster head or directly transferred to sink node. In data transmission process nodes starts loosing energy and discarding important information. The sensor nodes are represented as x1, x2, x3, …xn which are deployed in random manner in the network. The c1, c2, c3…..cn represents cluster heads. The base station node (BS) is the high power node located at center in the network. The network design is homogeneous in which all nodes are with uniform energy and computational ability. The data transmission takes place using simple first order communication model and the nodes positions are stationary.

The radio dissipates E_{elec}=60 nJ/bit energy to activate transmitter and receiver circuitry. The $\mathcal{E}_{fs}$ =15 pJ/bit/m2 is amplifier energy consumption per bit in a free space model and $\mathcal{E}_{mp}$ = 0.0013 pJ/bit/m4 is multipath fading channel model. The ds is the threshold distance. To transmit k bit message over distance d the radio model is given by Eq. (1).

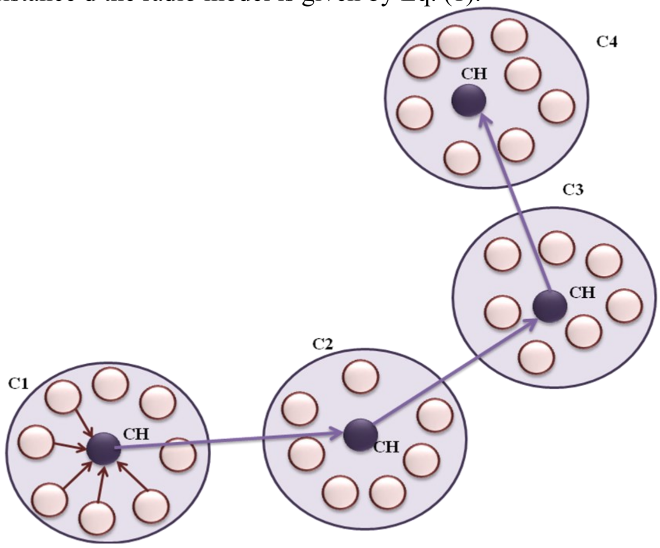

Fig. 1. Inter cluster data transmission between sensor nodes in WSN

$$ETx = \begin{cases} k\,Eelec + k\,\mathcal{E}fsd2\ , & d \le ds \\ k\,Eelec + k\,\mathcal{E}mpd4\ , & d > ds \end{cases} \qquad (1)$$

The threshold distance is expressed by Eq. (2).

$$ds = \sqrt{\frac{\mathcal{E}fs}{\mathcal{E}mp}} \qquad (2)$$

And to receive the message, the radio expands as Eq. (3)

$$ERx\,(k) = k\,Eelec. \qquad (3)$$

The two sensor nodes x and y has fixed buffer length (BL) which shows variation through receiving packets and transmission rate at every node. This buffer length is presented by Eq. (4), where P_i^{QB} is amount of data at node i in queue buffer, P_i^{TB} is amount of data in entire buffer size. The buffer length varies in between $0 \le BL\,(i) \le 1$. If BL (i) = 1 the buffer crosses threshold value. In this way buffer occupancy level functions in congestion detection.

$$BL\,(i)=PiQB/PiTB \qquad (4)$$

Initially this buffer size is circulated in the entire network. It checks first the buffer size of the node while transmitting the packets from source node to next hop node. The overflow of buffer size indicates the acknowledgement as zero, so that packet rate will be minimized through firefly optimization. The core conception is to optimize the data rate and to accomplish entire information at the receiver. At the end the data packets are routed using Ant Colony Optimization (ACO). The schematic representation for KFOA is shown in Fig.2. The system is divided into two scenarios. In the without rate optimization method if the number of bits in the buffer are greater than the buffer size packets are dropped else packets are transferred using ant colony optimization based routing. In second scenario packet transmission rate is decided first and after that packet rate is optimized using firefly optimization algorithm. At the end packets are routed using ACO and performance of with rate optimization and without rate optimization methods are evaluated.

IV. K-MEANS CLUSTERING FRAMEWORK

The clustering technique provides efficient data load management and uniform network lifetime. Initially, all the nodes are clustered using K-means algorithm [19]. The algorithm works as follows:

(1) All the nodes in the network are divided in k number of random clusters.
(2) The sensor node locations in the network are represented as data samples x1, x2, x3….xn.
(3) In the first iteration k centroid are selected in random way as c1, c2, c3…..cn.
(4) The distance between each of sensor nodes and centroid is obtained.
(5) Based on minimum distance revise the sensor nodes to new clusters.
(6) In next iteration with new centroid repeat step (4) and (5) till there is no change in centroid.
(7) End the process when nodes in the cluster stops there movement.
(8) The distance between the nodes is calculated using Euclidean distance defined by Eq. (5)

$$ED = \sqrt{(xc - xi)^2 \quad - (yc - yi)^2} \tag{5}$$

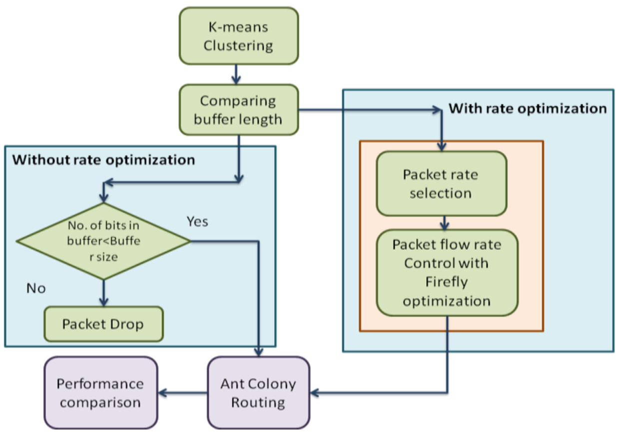

Fig. 2. Schematic representation of the KFOA

V. FIREFLY OPTIMIZATION ALGORITHM FOR PACKET RATE REGULATION

The Fig. 3 shows the system for controlling the congestion situation. If the data rate is increased on detection of events buffer size of sensor nodes become full. In this case congestion is indicated by sending acknowledgement. For positive acknowledgement there is no need to reduce the packet transmission rate but on reception of negative acknowledgement packet rate is regulated using firefly optimization algorithm. The firefly optimization algorithm is based on flashing behavior of fireflies. The fireflies are attracted o each other and attractiveness is directly proportional to brightness. Less bright firefly is attracted to the brighter firefly and attractiveness decreases as distance between two firefly's increases. For equal brightness fireflies move randomly. New solutions are generated by random walk and attraction of fireflies [17, 18]. Here in this case the main objective is to minimize the packet transmission rate. It is mathematically expressed by Eq. 6.

$$\text{Obj (i)} = \min \{x\} \tag{6}$$

The factor x in Eq. 6 represents packet transmission rate.
The algorithm works as follows:

(1) Initialize the parameters.
(2) Generate population of n fireflies.
(3) Calculate fitness value (light intensity) for each firefly such as Ii at xi.
(4) Check if (t:=1 to M_{axt})
(5) Update position and light intensity of each firefly.
(6) The movement of firefly (i) towards firefly (j) is given by Eq.7

$$xi(t+1)=xi(t) + \beta 0e\text{-}\gamma rij2\ (xj\text{-}\ xi) + \alpha\ \epsilon i \tag{7}$$

(7) The attractiveness β of a firefly is given by Eq. (8)

$$\beta = \beta 0e\text{-}\gamma r2 \tag{8}$$

Where
β0 is the attractiveness at zero distance (i.e., rij = 0),
γ is the absorption coefficient,
α is randomization parameter,
ϵ is random number obtained through normal distribution.

(8) The random movement is represented by Eq. 9 as New solution= Current position + Step size.\
(9) $$xi(t+1)= xi(t)+ \alpha\ \epsilon i \tag{9}$$
(10) Update new position. The distance between two fireflies at position xi & xj is given by Eq. 10 as rij=||xit-xjt|| (10)
(11) Report the best solution.

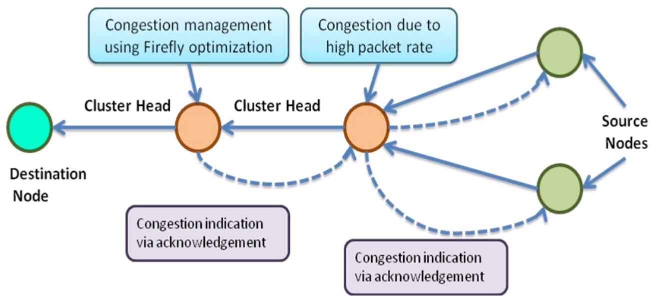

Fig. 3. Congestion control based on Firefly Optimization

VI. ACO FOR IMPROVING THE THROUGHPUT

Ant colony routing enhances the throughput by updating pheromone value in every routing path by the objective function. To reduce time delay in processing, on pheromone based, an arbitrary path is selected for routing to update minor distance path to enhance throughput in WSN. Ant Colony Optimization (ACO) has to find the lowest path for transmission of information. On the basis of information from its neighboring ants (through pheromone), a number of ants (i.e. packets) has been simulated from one point to another.

The Δτijk gives the amount of pheromone deposited by k^{th} ant along the path from node i to node j as shown in Eq. 11. The Lk is the length of path travelled by kth ant and 1/Lk indicates shortest path.

$$\Delta\tau ijk = 1/ Lk \quad (11)$$

The total amount of pheromone deposited by all the ants travelling on path from node i to j is represented by Eq. 12.

$$\tau ijk = \Sigma\, \Delta\tau ijk \quad (12)$$

The pheromone on the path gets evaporated due to change in environmental conditions so this change is represented by Eq. 13 where ρ indicates pheromone evaporation on each path. ρ=0 means no evaporation and ρ=1 indicates evaporation at maximum level.

$$\tau ijk = (1 - \rho)\, \tau ij + \Sigma\, \Delta\tau ijk \quad (13)$$

The probability of selecting the shortest path from all the paths is given by Eq. 14 where ηij is reciprocal of distance (Lk) so ηij =1/ Lk, α is pheromone exponential weight and β is heuristic exponential weight.

$$Pij = \frac{[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}}{\Sigma[\tau(i,j)]^{\alpha}[\Upsilon(i,j)]^{\beta}} \quad (14)$$

VII. Results of the Work Done: Performance Analysis

The proposed work is executed in MATLAB simulation tool with the total of 100 nodes. Additional parameters are explained in Table I. Two different scenarios are created to compare the results as shown in Fig. 4.

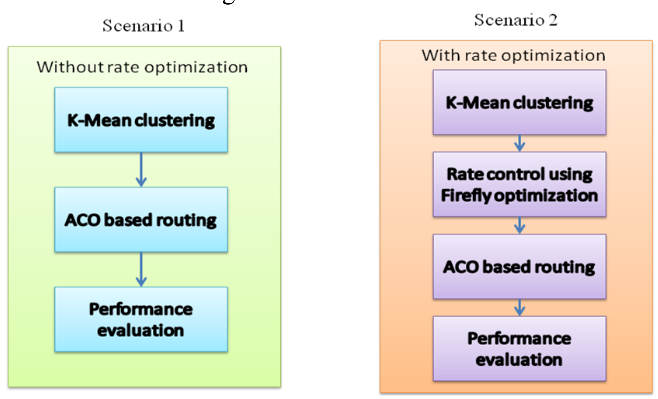

Fig. 4. Two Scenarios to compare the results

TABLE I
SIMULATION PARAMETERS

Type	Parameter	Values
Network topology	Network size	200x200
	Total number of relay nodes	85
	Source node	15
	Sink node	1
	Number of nodes	100
	Number of cluster	6
	Base station position	100 ×100 m
	Node distribution	Random
	Number of bits per packet	5000 bits
	Packet sending rate	1 packet/s
	Buffer size	8 packets
Radio model	Initial energy of normal nodes(Eo)	1 J
	Free space energy loss (εfs)	15 pJ/bit/m2
	Multipath energy loss(εmp)	0.0013 pJ/bit/m4
	Degeneration energy (Eelect)	60 nJ/bit

The scenario 1 contains of k mean clustering and data transmission using ACO routing. In scenario 2 firefly optimization algorithm is added to regulate the data rate. The sensor node deployment is shown in Fig. 5. The nodes are clustered using K-mean clustering algorithm in which total six clusters are formed and cluster heads are shown in Fig. 6. after regulating the data rate the path travelled by nodes is shown in Fig. 7. The data rate values obtained from firefly rate optimization algorithm and rate without optimization are shown in Fig. 8. The following graphs show the comparison of results obtained from data rate optimization and without rate optimization techniques.

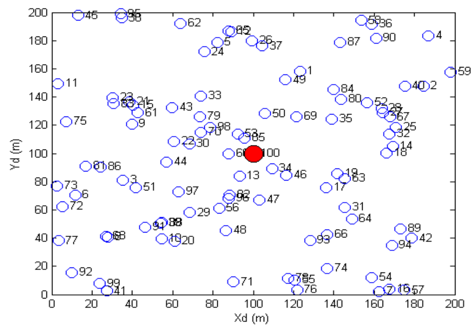

Fig. 5. Initial network design with 100 nodes

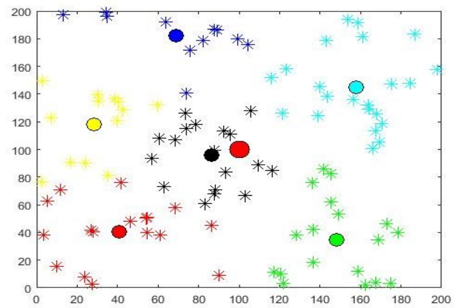

Fig. 6. Nodes are clustered using k-means algorithm.

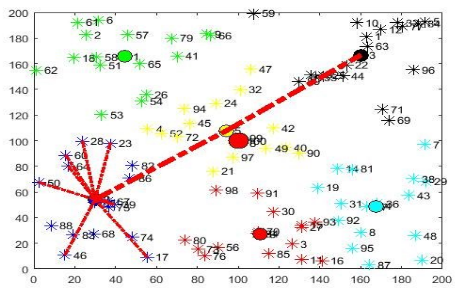

Fig. 7(a). Routing path using ACO algorithm between source nodes and Cluster Head 3

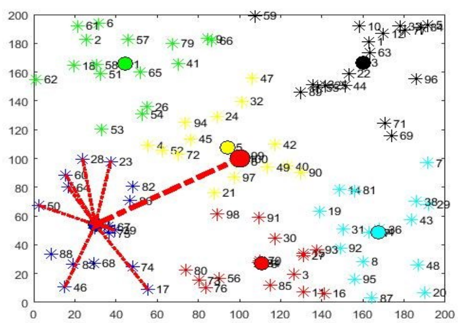

Fig. 7(b). Routing path using ACO algorithm between source nodes and base station node

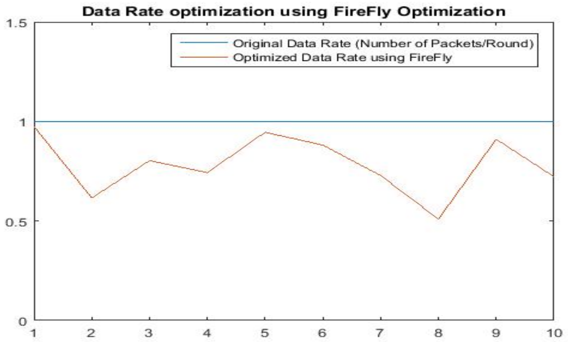

Fig. 8. Data rate optimization using firefly algorithm

Average throughput analysis: This is the ratio of number of packets received at the receiver to the packet transmission delay in the process. The Fig. 9 shows throughput analysis with rate optimization and without rate optimization technique. By optimizing the data rate using firefly algorithm gives higher results.

$$\text{Throughput} = \frac{\text{number of packets received}}{\text{delay}} \qquad (15)$$

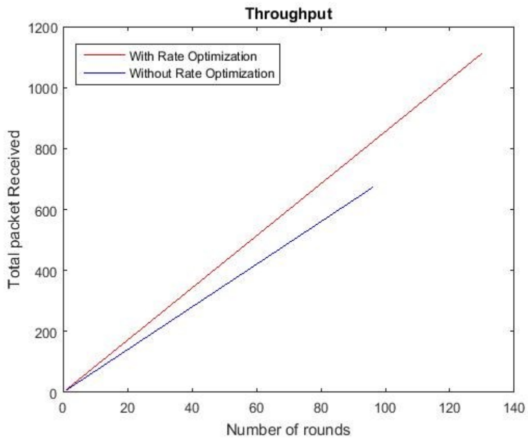

Fig. 9. Packets transmitted from source to base station

Packet delivery proportion analysis: Packet conveyance proportion characterizes as the percentage of the sum of data packets received by the receiver to the sum of data packets transmitted by the transmitter. Fig. 10 shows improvement in packet delivery ratio while using data rate optimization technique.

$$packet\ delivery\ ratio = \frac{sum\ of\ packets\ received\ by\ receiver}{sum\ of\ data\ packets\ transmitted\ by\ transmitter} \qquad (16)$$

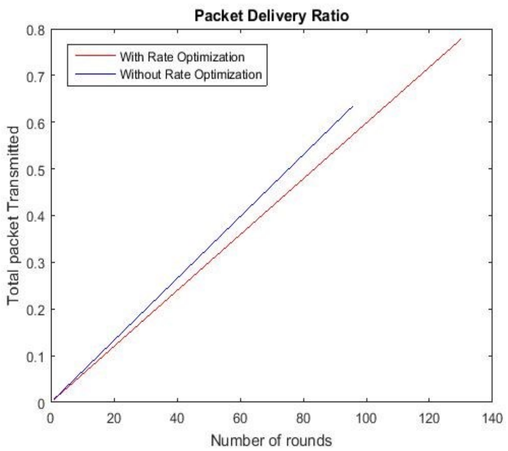

Fig 10. Packets Delivery Ratio

Energy Dissipation: It indicates energy consumption of sensor nodes and measures the amount of energy consumed for sending and receiving packets. It is defined as the sum of receiving energy with the number of nodes and the transmitted energy. Fig. 11 shows the energy dissipation analysis and Fig. 12 gives residual energy up to 130 iteration using rate optimization.

Energy dissipation=(ERX* number of nodes) + ETX (17)

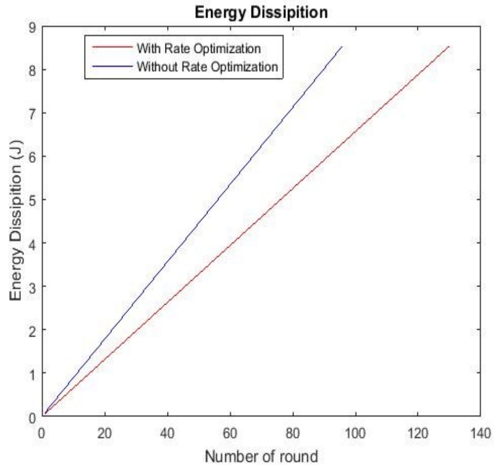

Fig. 11. Energy dissipation analysis

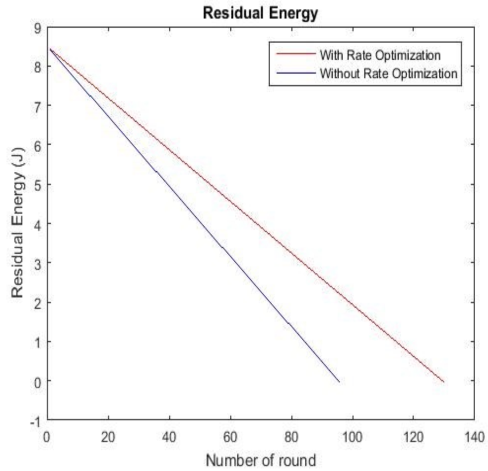

Fig. 12. Residual Energy

Packet Loss Rate: It is the ratio of number of packets dropped to total number of packets delivered to the sink. Fig. 13 gives packet loss ratio analysis.

$$Packet\ Loss\ ratio = \frac{Number\ of\ packets\ dropped}{Total\ number\ of\ packets\ produced\ in\ the\ network} \qquad (18)$$

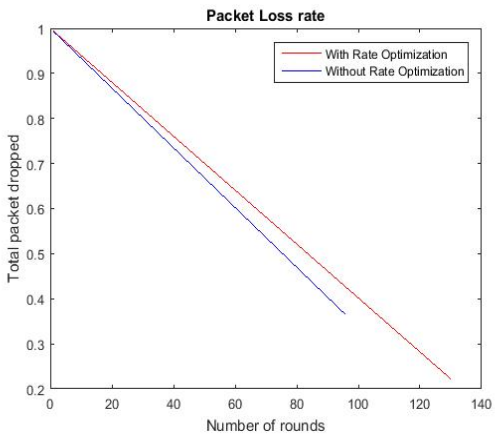

Fig. 13. Packet Loss rate.

Simulation Results: Table II shows the summary of results obtained through with rate optimization and without rate optimization method.

TABLE II
SUMMARY OF RESULTS FOR TWO SCENARIOS

Parameter Name	Without Rate control	With Rate control
Packet Delivery Ratio	63.63 %	77.78 %
Packet Loss Ratio	36.36 %	22.21 %
Total Packet transmitted	665	1112
Energy consumption	At 96 iteration: 8.52J	At 96 iteration: 6.3031 J At 130 iteration: 8.52 J
Residual Energy	At 96 iteration : 0 J	At 96 iteration: 2.19 J At 130 iteration: 0 J

CONCLUSION

This method presents a traffic rate-based congestion control method for WSN. The K-means algorithm provides clustering over a hierarchical wireless sensor network. The Ant Colony Optimization is used for data transmission. The data rate optimization is obtained through Firefly optimization algorithm. Energy efficient transmission is achieved with this technique. The performance result shows analysis for with rate optimization and without rate optimization technique. It has been concluded that the KFOA is the best suited for wireless applications with congestion control and maximum packet delivery ratio.

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