

A CLUSTERED WIRELESS SENSOR NETWORK BASED AIR POLLUTION MONITORING SYSTEM WITH SWARM INTELLIGENCE BASED DATA AGGREGATION

Article history

Received
15 October 2015
Received in revised form
10 December 2015
Accepted
15 June 2016

Murali, S.*, Jaisankar, N.

School of Computing Science and Engineering, VIT University,
Vellore, Tamilnadu, India

*Corresponding author
murali.s@vit.ac.in

Graphical abstract



Abstract

Air pollution has significant influence on the concentration of constituents in the atmosphere leading to effects like global warming and acid rains. The disproportion of the constituents in the air or atmosphere is monitored using the air pollution monitoring system. The classical air pollution monitoring system uses the costly instruments for monitoring the environment at fixed locations. Most of the traditional monitoring system is coarse-grained and costlier during the real time implementation. Some system have problems such as communication overhead, time and power consuming. The efficient clustering based data aggregation is proposed in this paper for reducing the communication overhead and efficiently monitoring the environment. The sensor nodes in the networks are grouped into clusters and the cluster head is selected using the optimization algorithm such as firefly algorithm. The data aggregation using the hybrid genetic algorithm is also proposed in this paper for efficient data transmission by reducing the communication overhead. The simulation results shows that the performance of the proposed methodology is better than the existing one and the proposed system collects the reliable source of real time fine-grain pollution data.

Keywords: Air pollution monitoring system, Hybrid genetic algorithm, Firefly algorithm

© 2016 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

The wireless sensor network is composed of large number of sensor nodes which is mainly used for gathering the environmental data. The remote locations can be monitored effectively with the help of Wireless sensor networks and data can be gathered efficiently along with better accuracy [1]. Wireless sensor network is applied in different fields such as monitoring the environment, climate, structural monitoring, medical diagnostics, and emergency response, ambient air monitoring and gathering sensing information in hospitable locations [2, 3]. Many research works [11, 12, 13, and 14] have been conducted in order to improve the air pollution monitoring system by

using the efficient methods for routing and system design in wireless sensor networks.

Due to the rapid industrial growth in various parts of the world, air pollution becomes one of the important issues in the world. Road transport is the main reason for air pollutants which causes vulnerable climatic changes in the world [4].

Generation and transport of pollutant materials are governed not only by the distributions of their sources but also by the dynamics of the atmosphere. The dark clouds formed based on the pollutants are travelled in the wind directions [5]. The data based on the fine-grain pollutants and their distinction with time is required for through analysis. Many air pollution monitoring system based on the spatial and pollutant coverage

have problems such as expensive, time and power consuming.

The existing air pollution monitoring system uses costly equipments for monitoring the environment in fixed or movable manner. It is classified under category of coarse-grained system. The data obtained from the air pollution monitoring system is used for further analysis through the dispersion models. The main disadvantages of the existing system are poor measurement of environment data. In addition to this, the problems are arises during the real time implementation of air pollution monitoring system in fixed or movable locations. Currently, access to such data is limited [6] if not absent. It is available to and discernable by only a few who are well informed on the subject of pollution.

The equipments used in the existing systems are Fourier transform infrared (FTIR) instruments, gas chromatographs, and mass spectrometers. The main disadvantages of these instruments are high maintenance cost, less accuracy for large scale data [7, 8]. Some of the gases monitoring technologies are electrochemical, infrared, catalytic bead, photo ionization, and solid-state [7]. The existing monitoring system largely uses smart transducer interface module (STIM) with semiconductor gas sensors, which uses the 1451.2 standard. Although STIM was found to an efficient monitoring system, it has some disadvantages such as power requirements and inability to expand for large deployment. Environment Observation and Forecasting System (EOFS) is used for large scale sensor networks in order to monitoring and forecasting the environment effectively [9], but the size of the system and initial cost is too high. Air pollution monitoring system using geo sensor networks with control action and adaptive sampling rates is presented in [10] but it cannot used in vast deployment due to high cost.

Mobility is one of the major problems in sensor nodes. Air pollution monitoring is usually requires large number of movable sensor nodes. The main disadvantages of the wireless sensor nodes are data calibration during sensing, managing the operations of WSN, data collection and data presentation. Among the above challenges, especially address network-related issue such as how to adaptively adjust the reporting rates of mobile nodes to satisfy a target monitoring quality while reducing the communication overhead. In this paper clustering based data aggregation method is proposed to overcome the communication overhead and efficient monitoring of air pollution.

2.0 RELATED WORKS

Kavi et al (2010) presented an innovative system WAPMS in [11]. WAPMS is used for monitoring air pollution in Mauritius by using wireless sensors networks exploited in huge numbers around the island. In order to improve the WAPMS system the author uses the data aggregation algorithm called as recursive converging quartiles (RCQ) and air quality index (AQI). The data

aggregation algorithm is mainly used for eliminating the duplicates in the collected data by filtering process and summaries the collected data. The main problem in this system is implementation cost. Shu et al (2011) presented air pollution monitoring system which uses a micro-climate monitoring scenario. The system used here requires a large number of sensor nodes to capture environmental information accurately [12]. By utilizing vehicular sensor networks in air pollution monitoring system (VSNs), the author obtained the results in efficient manner. The sensor nodes are placed in the vehicles such as cars for obtaining the fine grained results. The main issues discussed in [12] are dynamic reporting rate and time-constrained opportunistic relay problem. In order to overcome the problems, the author presented algorithms and verifies their performances by simulations.

Umesh and Shah (2012) [13] are presented an air pollution monitoring system by using the association rule mining technique. The main of this method is to find the association patterns in various air pollutants parameters. The apriori algorithm is used for mining the associated patterns and it is applied to data gathered by sensor nodes placed in various places. The main advantage of this method is reproducibility, reliability and selectivity of air pollution sensor output. The main disadvantage of this method is large number of patterns are obtained and most of them non-interesting with low comprehensibility. A vehicular-based mobile approach is presented by Srinivas et al (2013) for measuring quality of air in real-time [14]. The author presented data farming models for accurate measuring such as one model is utilized for public transportation and the second model is used for personal sensing device. The real time simulation issues are discussed and preliminary prototypes are also presented.

The system for estimating the pollution using wireless sensor networks (WSN) is developed by Aruljothi (2013) in [15]. The sensor nodes consist of ARM controller and GPS in user terminal for measuring the pollution in air accurately. The data aggregation techniques are used by author in this paper for measuring the parameters like temperature along with the gas pollutant.

Mujawar et al (2013) [16] presented a method for estimating the pollution in Sholapur city using wireless sensor network. The author mainly focused on the measuring the SPM (Suspended particular matter), NO_x and SO₂ in air. The author overcomes the problems in traditional air quality measurement by using the low cost sensor such as 15. 4 standards, high performance low power 8051 core acts as a node and CC2530ZDK board with 2. 4 GHz IEEE 802. A special program is created by author with LABVIEW for monitoring the networks and sensing measurements.

Madhusudhanan Baskaran and Chitra Sadagopan (2015) provide a CH conveys information gathered by cluster nodes and aggregates/compresses data before transmitting it to a sink. However, this additional responsibility of the node results in a higher energy drain leading to uneven network degradation. Low Energy Adaptive Clustering Hierarchy (LEACH) offsets this by probabilistically rotating cluster heads role among

nodes with energy above a set threshold. CH selection in WSN is NP-Hard as optimal data aggregation with efficient energy savings cannot be solved in polynomial time. The authors [17] presented a modified firefly heuristic, synchronous firefly algorithm, is proposed to improve the network performance. Extensive simulation shows the proposed technique to perform well compared to LEACH and energy-efficient hierarchical clustering.

The geographic information system along with the spatial interpolation is used for increasing the spatial coverage in the created network. The created network is used for monitoring the surrounding environment and data collected from the sensor nodes is analyzed through methods.

3.0 PROPOSED METHODOLOGY

The air pollution monitoring system is proposed in this paper using wireless sensor network based on the clustering formation. The nodes are grouped into clusters and the cluster head is selected based on the evaluation of node attributes in wireless sensor network.

The data aggregation algorithm using the hybrid genetic is proposed in this paper for reducing the communication overhead during the data transmission from the base station to cluster head or vice versa. And find the optimal path for send data to base station. The overall of process of proposed architecture diagram showed in fig 1.

3.1 System Model and Assumptions

The following assumptions are considered in the present study:

- The region considered for our simulation experiments is 100×100 square unit region where nodes are scattered randomly and it follows uniform distribution.
- All the 100 nodes send hello messages to the base station containing their local information.

3.2 Cluster Head Selection

The ID value is allotted to each and every node in the network and the ID values along with the information about the nodes are broadcasts to its neighbours. It creates the neighbourhood table based on the broadcast value. The weight value of each node is calculated based on the factors such as transmission range of the neighbourhood nodes, distance between the nodes, mobility of the node, and the residual energy.

3.2.1 Cluster Head Selection Algorithm

The cluster head is selected based on the calculation of following factors for each and every node in the wireless sensor network. The firefly algorithm is a metaheuristic optimization algorithm formulated by Xin-She Yang [18] and becomes favourable in WSN due to its attractiveness function. This includes self improving process for present and future space based on the previous stages. The firefly algorithm is used in this paper for selecting the cluster head in wireless sensor network. The main parameters considered in the firefly algorithm for selecting the cluster head is transmission range, distance between the nodes, mobility of the nodes and residual energy. These parameters are used to calculate the weight of each and every node in the network using iteration. The mobility and residual energy of the nodes is considered as objective function of the firefly algorithm. Sometimes the algorithm fails to remember the better situation due to memory loss property. The node first checks the transmission range of the neighbourhood nodes, if the neighbourhood is in transmission range it broadcast the ID along with the other information to the neighbourhood nodes. The objective function of each node is calculated based on the energy and mobility of the nodes. The light intensity is calculated based on the objective function and attractiveness. The light observation coefficient is considered as distance between the nodes and based on the light absorption coefficient; attractiveness of the firefly is evaluated. The process is continued for all nodes in the network until it reaches its maximum iteration value. The light intensity is calculated as

$$W_n = a_1 e - a_2 M + a_3 d \quad (1)$$

Where W_n represents weight of the each node, a_1, a_2, a_3 is used constant values, e and M are the objective function of the nodes and d is the light absorption coefficient in the algorithm.

The movement of the firefly from one node to another node is calculated based on the attractiveness of the node at distance $d=0$,

$$x_i = x_j + \beta_0 e^{-\gamma d_{i,j}^2} (x_j - x_i) + \alpha \epsilon_i \quad (2)$$

Where x_i, x_j are i^{th} and j^{th} nodes respectively, β_0 is attractiveness at the distance $d=0$, $e^{-\gamma d_{i,j}^2}$ is a light absorption coefficient, α is randomization parameter and ϵ_i is vector of random numbers of nodes being drawn from a non-uniform distribution.

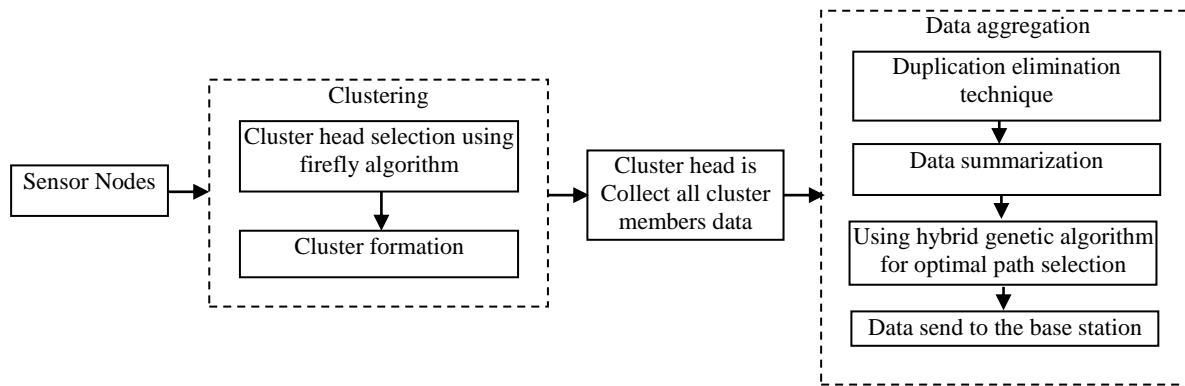


Figure 1 Proposed overall architecture diagram

The distance between the node and cluster head is calculated

$$D(C, N) = \sqrt{\sum_{i=1}^n (C_i - N_i)^2} \quad (3)$$

Where,
C=cluster head,
N=node

3.2.2 Cluster Head Selection Pseudo Code

Initialize n number of nodes i.e., $x = (x_1, \dots, x_n)$
Initially $t=0$ where t is a number of iteration till the cluster head is selected
Check whether the node is in transmission range or not
If node is in transmission range then determine the objective function
Else eliminate the node
Define the objective function of $f(x)$ i.e., calculation of energy, mobility for the n number of nodes
Determine the light intensity I_i of x_i i.e., calculation of weight of the nodes using $f(x_i)$
Define γ : the light absorption coefficient i.e., distance between the nodes

While ($t \geq \text{maxgeneration}$)
For $i = 1$ to n for all n nodes
For $j = 1$ to i for all n nodes
If ($I_j > I_i$),

move firefly i towards j by using $x_i = x_j + \beta_0 e^{-\gamma r_{ij}^2} (x_j - x_i) + \alpha \epsilon_i$
End-if

Attractiveness varies with distance r via $\exp[-\gamma r^2]$

Evaluate new solutions and update weight of the node
End for j ;
End for i ;

Rank the nodes based on the weight and find the current best node;

End while
Update maximum weighted node as cluster head after the process;

3.3 Cluster Formation

The cluster head is selected using the firefly algorithm. The elected cluster head is used to broadcast the message to non cluster head nodes for cluster formation. The non cluster head node is decided to join the cluster based on received message from the cluster head and the cluster is formed.

3.4 Data Aggregation

During the transmission of the data's from the cluster head to base station, some problem such as communication overhead is arise in the network. Data aggregation algorithm is used for reducing communication overhead in the networks. In this paper data aggregation using hybrid genetic algorithm is proposed.

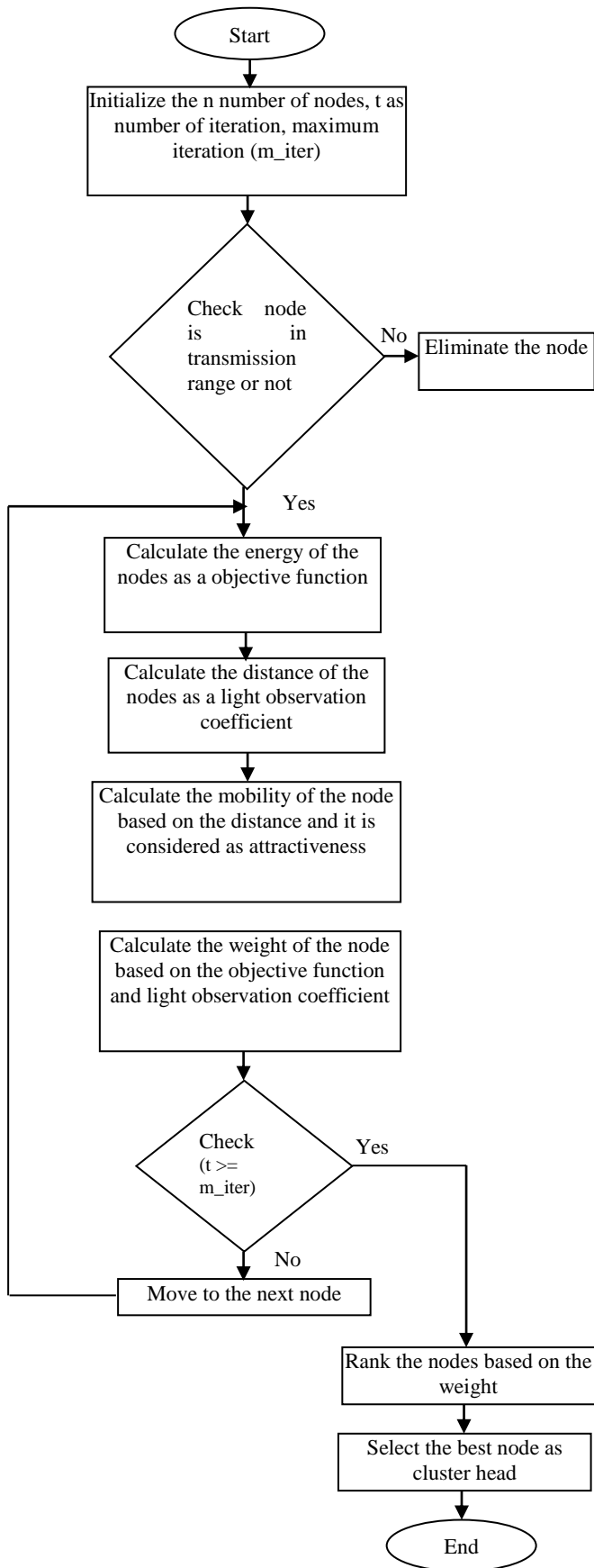


Figure 2 Cluster head selection using firefly algorithm

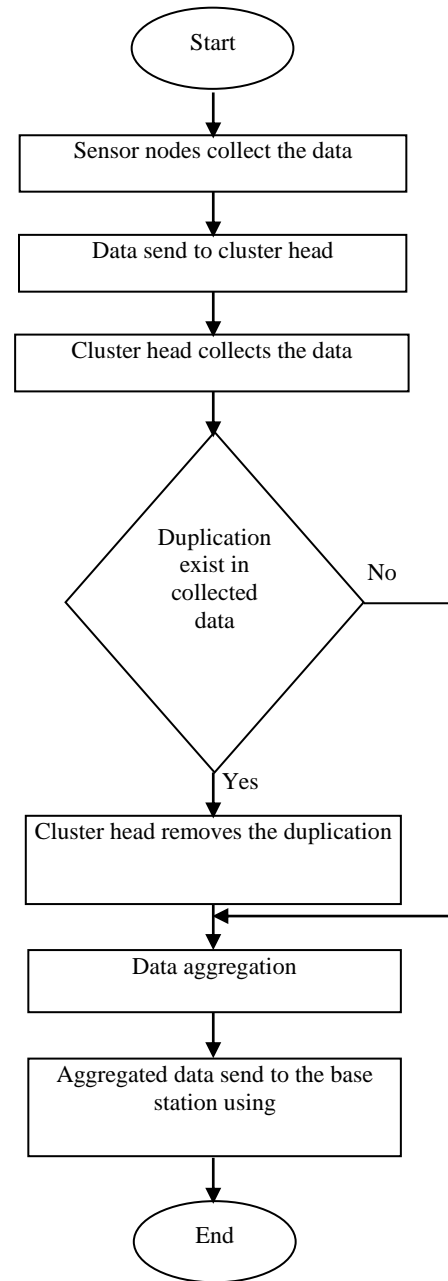


Figure 3 Data aggregation diagram

After the cluster formation in the networks, sensor nodes start to collect the environmental data. The gathered data from the sensor nodes are send to the cluster head for further operations. In cluster head two operations are performed when it receives the data from the nodes in the cluster. They are duplication removal and data aggregation.

The sensor nodes send the data as a packet to the cluster head where it consists of two parts. They are data and a node ID for identification of node in the network. The table is created based on the data gathered from all nodes in the network.

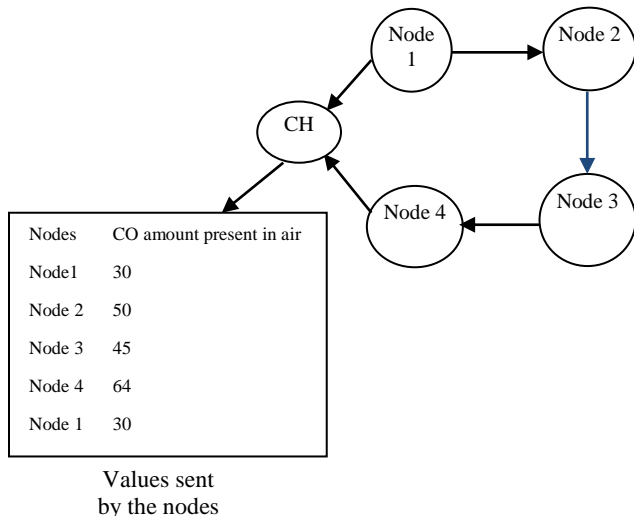


Figure 4 Table creation using data gathered from all nodes in CH

After the table creation, each and every data in the table is evaluated and find the redundant data with same id. As a result the cluster head will keep its only one instance in the table.

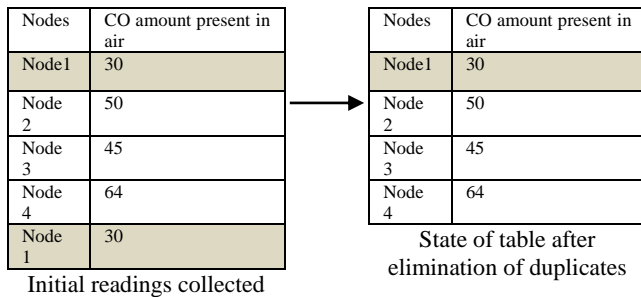


Figure 5 Illustration of redundant elimination technique

3.5 Optimal Path Selection Using Hybrid Genetic Algorithm Based on Fuzzy Logic

3.5.1 Traditional Genetic Algorithm

The traditional genetic algorithm is used to resolve the problems in many fields. The set of population is represented as a chromosome in the beginning of the algorithm. The new solutions are formed from the old population using fitness value of the solution, crossover, and mutation. The main parameters used in the genetic algorithm are explained below

Initial population: An initial population is created from a random selection of solutions.

Fitness function: During the search procedure, each individual node is evaluated using the fitness function. In this paper fitness function is calculated based on the

mobility, distance, energy and transmission range of the nodes.

Selection: For selection, two individuals are randomly chosen from the population based on different probability distributions and it is mainly used for generating a new solutions. The probability distributions, such as uniform distribution or a random selection from a population based on fitness values is used in the algorithms.

Crossover: The crossover operator is used for generating a new solution based on the selected pairs of existing solutions. In this paper, 2 individual paths are selected as an input to crossover and it exchanges the column behind this point as a whole. The impossible solutions are eliminated during the crossover.

Mutation: The mutation operation is mainly used for changing individual path. The individual path must be a feasible solution for optimal path selection and it is considered as important criteria.

3.5.2 Hybrid Genetic Algorithm

Applications of Fuzzy logic for optimal path selection from cluster head to base station of GAs are to be found in [19]. The fuzzy logic is mainly used for controlling the convergence of the genetic algorithm by performance measure as an input. The output is parameters of genetic algorithm such fitness, distance of the nodes. The performance measures are used to find the optimal parameter and it is mainly used to controlling convergence of the genetic parameters. Many FLCs are used for defining the crossover probability P_c and mutation probability P_m on specific individuals by considering the fitness values of the individuals and distances.

The fuzzy logic is mainly used in GA for

- 1) Choosing the parameters for genetic algorithm such as fitness value, crossover, mutation so on
- 2) Adjust the control parameters of genetic algorithm in order to controlling convergence of the GA. In this paper crossover P_c and mutation probability P_m calculation is controlled by FLC.

The crossover probability and mutation probability is modified using the maximum and average fitness of the populations of two continuous generations. The maximum fitness and average fitness is represented using $f_{ave}(t)$ and $f_{max}(t)$. If average fitness value of the nodes is increased and it attains the maximum value means then the probability of crossover for path selection is decreased and probability of mutation for path selection is increased.

This method is mainly used for selection of suitable path for data transmission and eliminating the remaining paths during the recombination process such as

crossover and mutation. The two inputs are used for proposed fuzzy logic system. They are e_1 and e_2

$$e_1(t) = \frac{f_{max}(t) - f_{ave}(t)}{f_{max}(t)} \quad (4)$$

$$e_2(t) = \frac{f_{ave}(t) - f_{ave}(t-1)}{f_{max}(t)} \quad (5)$$

Where

t is timestamp

$f_{max}(t)$ is the best fitness at iteration t

$f_{ave}(t)$ is the average fitness at iteration t

$f_{ave}(t-1)$ is the average fitness at iteration $(t-1)$

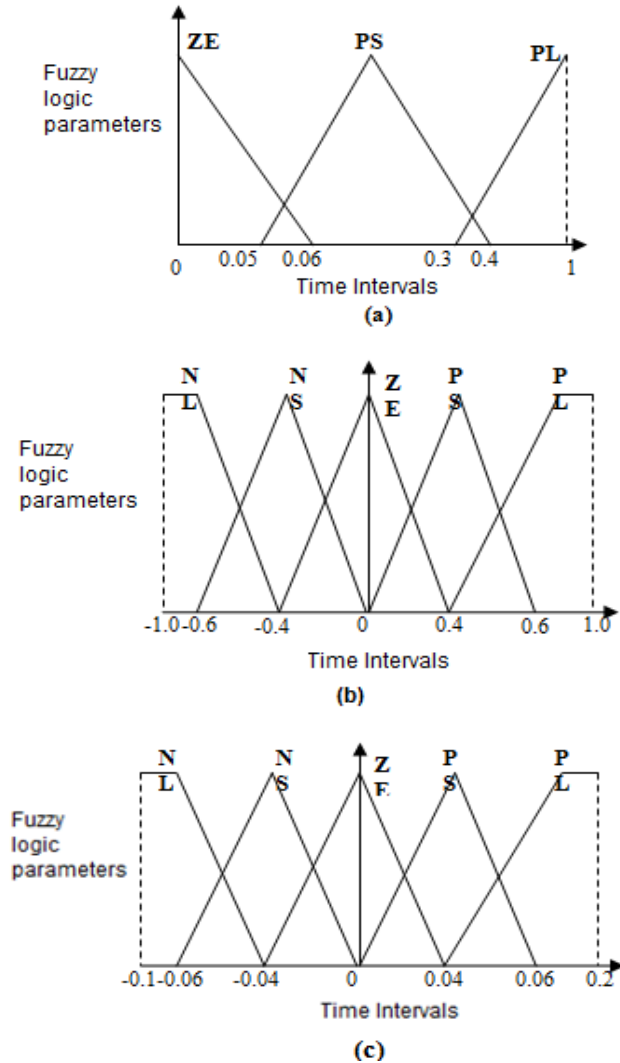


Figure 6 Membership functions. (a) for e_1 , (b) e_2 , (c) for $\Delta P_c(t)$

The membership function used in fuzzy logic is explained in the figure 6. The terms used in the fuzzy logic is NL means Negative large, NS means Negative small, ZE is Zero, PS is Positive small and PL is Positive large. Table 1 and Table 2 shows the fuzzy rules used for crossover and mutation probability calculation for each path in networks. The output of the fuzzy logic controllers

are $\Delta P_c(t)$ and $\Delta P_m(t)$. Then the crisp value is used to modify the parameters P_c and P_m as follows:

$$P_c(t) = P_c(t-1) + \Delta P_c(t) \quad (6)$$

$$P_m(t) = P_m(t-1) + \Delta P_m(t) \quad (7)$$

Table 1 Fuzzy rules for crossover operation ($\Delta P_c(t)$)

e_1	e_2				
	NL	NS	ZE	PS	PL
PL	NS	ZE	NS	PS	PL
PS	ZE	ZE	NL	ZE	ZE
ZE	NS	NL	NL	NL	NL

Table 2 Fuzzy rules for mutation operation ($\Delta P_m(t)$)

e_1	e_2				
	NL	NS	ZE	PS	PL
PL	PS	ZE	PS	NS	NL
PS	ZE	ZE	PL	ZE	NS
ZE	PS	PL	PL	PL	PS

Algorithm

Input : path for data transmission

Output: best path for efficient transmission

Begin HGA

$t = 0$ iteration counter

Initialize the population as set of nodes

Calculate the fitness value for each and every node based on mobility, distance, energy and transmission range

While (the end criterion is not met) do

$t = t + 1$

Select $n(t)$ node from $n-1$ nodes

Crossover $n(t)$

Mutate $n(t)$

Evaluate $n(t)$

Evaluating the GA parameters

{

Call fuzzy logic controller (e_1, e_2)

Update according to $P_c(t)$ and $P_m(t)$

}

End while

best path is selected

End

4.0 EXPERIMENTAL RESULTS

In this the section, proposed method is evaluated using MATLAB 12. The proposed clustered with swarm

intelligence is compared with existing distributed weighted cluster [21] with water drops algorithm [20].

An Air Quality Index (AQI) is used in air pollution monitoring system for measuring the air quality. The pollutants are ozone, fine particulate matter, nitrogen dioxide, carbon monoxide, sulphur dioxide and total reduced sulphur compounds. Figure 7 and figure 8 illustrates the AQI range.

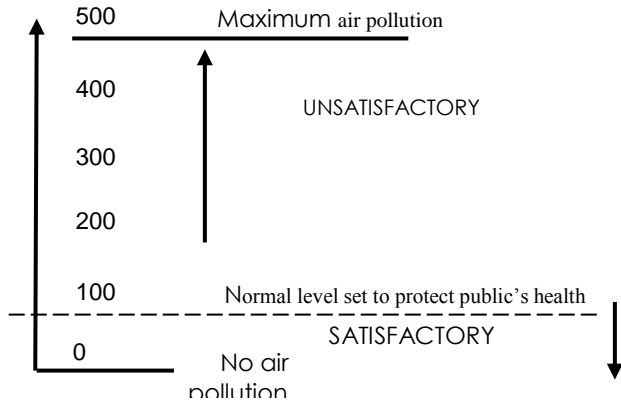


Figure 7 The range of AQI values

The categories used in AQI are represented by different colors and each color indicating the level of health concern. The figure 8 explained categories in the AQI.

Air quality index	CO (8hr)	Associated Health Impacts
Good(0-50)	0-1.0	Minimal impact
Satisfactory (51-100)	1.1-2.0	May cause minor breathing discomfort to sensitive people.
Moderately polluted (101-200)	2.1-10	May cause breathing discomfort to people with lung disease such as asthma, and discomfort to people with heart disease, children and older adults.
Poor (201-300)	10-17	May cause breathing discomfort to people on prolonged exposure, and discomfort to people with heart disease.
Very poor (301-400)	17-34	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.
Severe (401-500)	34+	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

Figure 8 Description of AQI categories for Indian scenarios

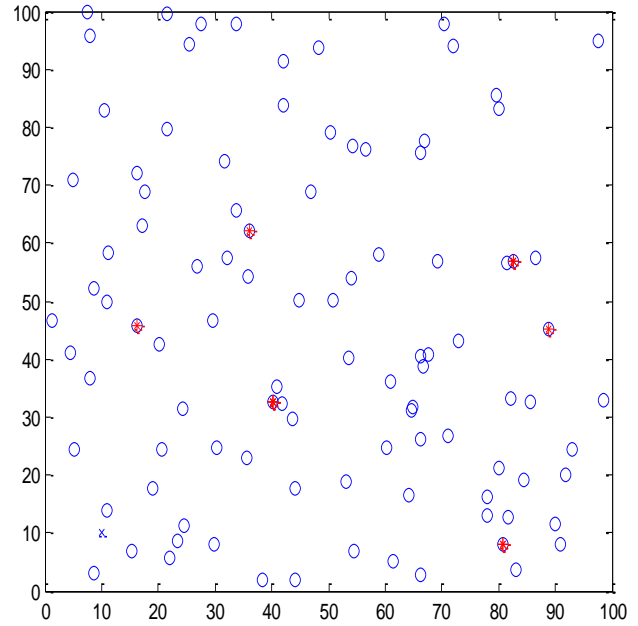


Figure 9 Node Creation

Figure 9 shows the node creation of the wireless sensor network. And the red color of the node indicates the cluster head of the network.

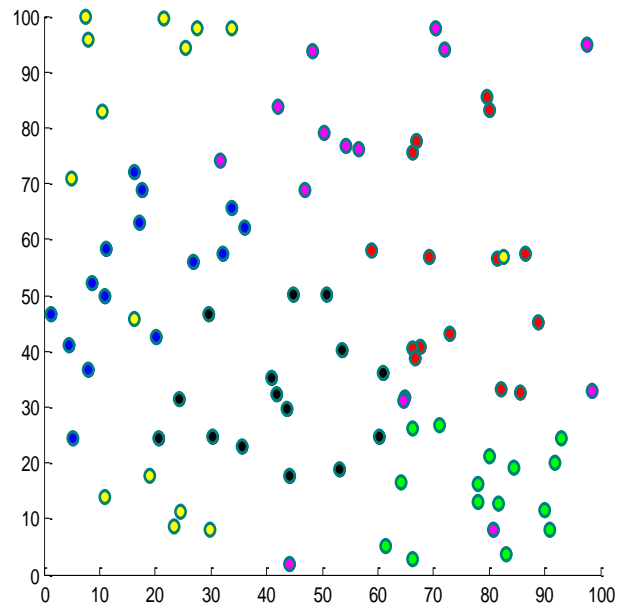


Figure 10 Cluster Selection

Figure 10 shows the cluster selection of the nodes in wireless sensor network. The figure shows that different colors, that the each color represents the various number of cluster formation of nodes in the network.

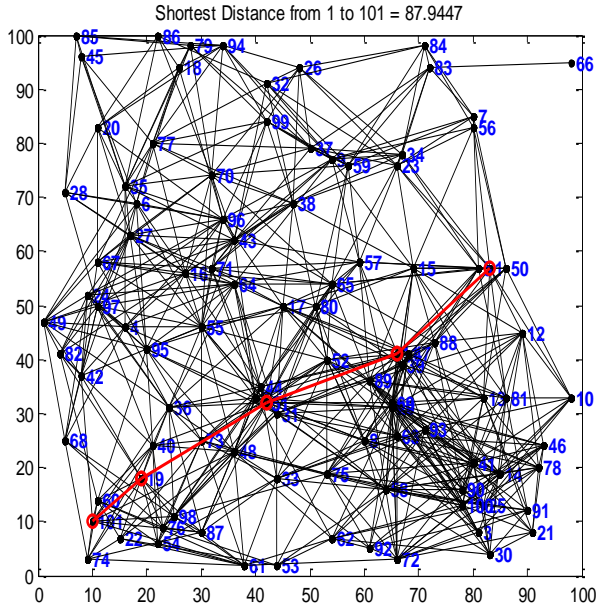


Figure 11 Shortest Distance graph from 1 to 101

Figure 11 shows the Shortest Distance graph from 1 to 101. The source nodes 1 to destination node 101 of all possible paths are defined as blue and the optimal or shortest path is generated as red.

Figure 12 shows the Shortest Distance graph from node 42 to node 4. The source nodes 42 to destination node 4 of all possible paths are defined as blue and the optimal or shortest path is generated as red.

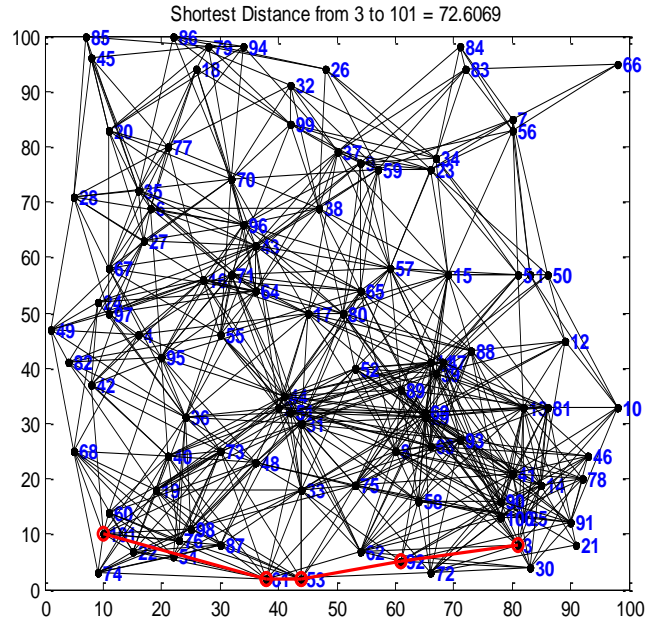


Figure 13 Shortest Distance graph from 3 to 101

Figure 13 shows the Shortest Distance graph from 3 to 101. The source nodes 3 to destination node 101 of all possible paths are defined as blue and the optimal or shortest path is generated as red. In Figure 11, 12 and 13 distances between the nodes calculated by using equation (2) and equation (3).

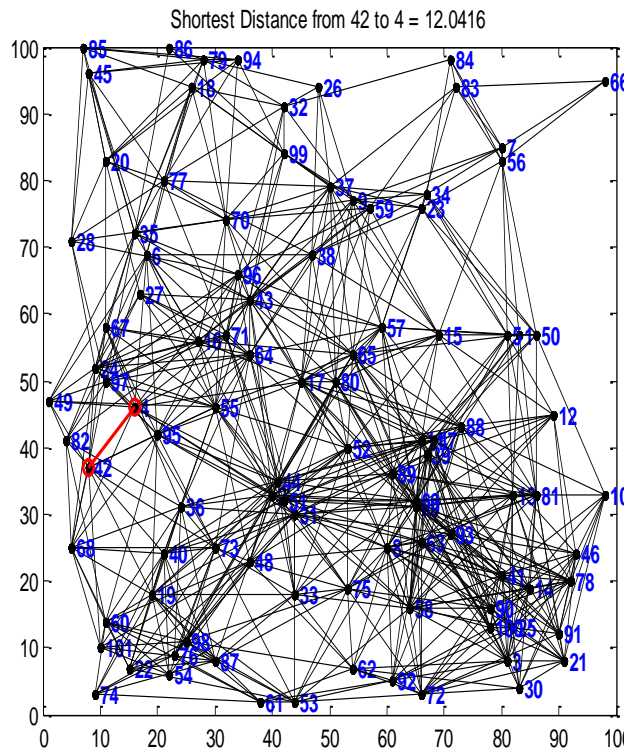


Figure 12 Shortest Distance graph from 42 to 4

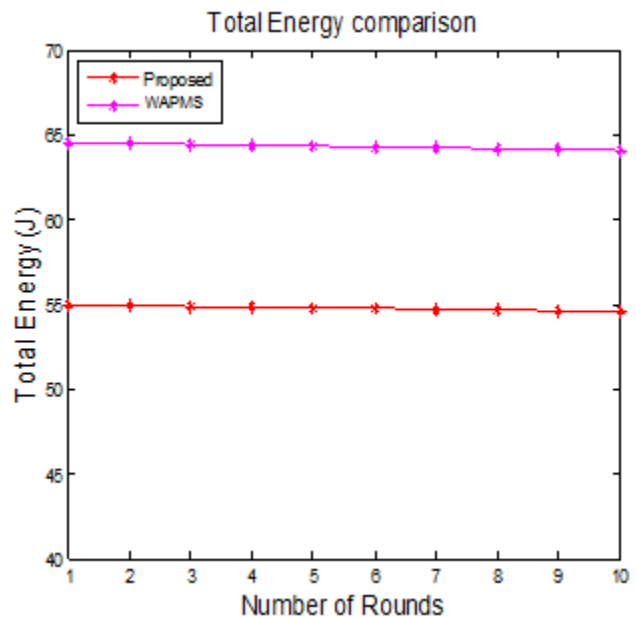


Figure 14 Total Energy Comparison Graph

The figure 14 is drawn for the Total Energy Comparison Vs Number of nodes. From the figure the proposed system which as lesser value of Throughput when compared with WAPMS. The results illustrates that the proposed approach performs better when compared to other algorithm.

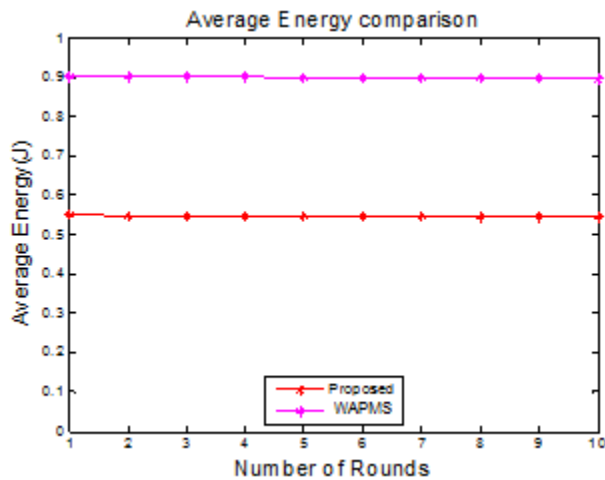


Figure 15 Average Energy Comparisons

The Figure 15 is drawn for the Average Energy Comparison Vs Number of nodes. From the figure the proposed system which as lesser value of Throughput when compared with another existing techniques. The results illustrates that the proposed approach performs better when compared to other algorithm.

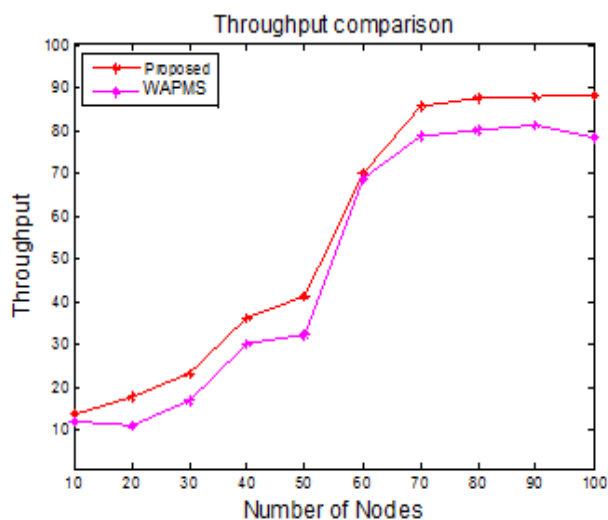


Figure 16 Throughput Comparison

The figure 16 is drawn for the Throughput Vs Number of nodes. From the figure the proposed system which as higher value of Throughput when compared with another existing techniques. The results illustrates that the

proposed approach performs better when compared to other algorithm.

5.0 CONCLUSION

Since the rapid technological developments leads to the usage of wireless sensor networks (WSN). The wireless sensor networks are mainly used for enhancing environmental monitoring system. Each and every sensors present in the networks is used for the collecting the environmental data. The sensor nodes in the network are grouped into clusters and through the cluster head, the data's are transmitted to the base station. The firefly optimization algorithm is proposed in this paper for efficient cluster head selection and cluster formation. During the data transmission from cluster head to base station, the problems such as communication overhead are araised. The data aggregation method is used in this paper for reducing the communication overhead. The hybrid genetic algorithm is proposed for efficient data aggregation based on the fuzzy logic. The experimental results are produced and it is compared with the existing system such as distributed weighted cluster with water drops algorithm. The simulation results show that performance of the proposed methodology is better than the existing one.

References

- [1] H. Karl and A. Willig. 2005. *Protocols and Architectures for Wireless Sensor Networks*. John Wiley and Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, England.
- [2] D. Culler, D. Estrin, and M. Srivastava. 2004. Overview of Sensor Networks. *IEEE Computer*, August.
- [3] I. F. Akyildiz, D. Pompili and T. Melodia. 2005. Underwater Acoustic Sensor Networks: Research Challenges. *Ad Hoc Networks*. 3(3): 257-279.
- [4] Department of Transport. 2000. Transport Ten Year PlanII . The Stationary Office, London.
- [5] J. C. St. John and W. L. Chameides. 1997. *Environmental Science & Technology*. 31: 2797-2804.
- [6] AirData web portal Retrieved May 2013 from <http://www.epa.gov/airdata/>.
- [7] IST. Chapter 1—Introduction —International Sensor Technology, 1-4.
- [8] D. D. Lee and D. S. Lee. 2001. Environmental Gas Sensors. *IEEE Sensors J.* 1(3): 214-215.
- [9] Xu, N. 2002. A Survey of Sensor Network Applications. *IEEE Communications Magazine*. 40(8): 102-114.
- [10] Young Jin Jung, Yang Koo Lee, Dong Gyu Lee, Keun Ho Ryu, Silvia Nittel. 2008. Air Pollution Monitoring System Based On Geosensor Network. *IEEE International Geoscience and Remote Sensing Symposium*. III-1370-III-1373.
- [11] Kavi, K. Khedo, Rajiv Perseedoss and Avinash Mungur 2010. A Wireless Sensor Network Air Pollution Monitoring System" *International Journal Of Wireless And Mobile Networks*. 2(2).
- [12] Shu-Chiung Hu, You-Chiun Wang, Chiuan-Yu Huang, Yu-Chee Tseng. 2011. Measuring Air Quality In City Areas By Vehicular Wireless Sensor Networks. *The Journal of Systems and Software*.
- [13] Umesh, M. Lanjewar, J. J. Shah. 2012. Air Pollution Monitoring & Tracking System Using Mobile Sensors and Analysis of Data Using Data Mining. *International Journal of Advanced Computer Research*. 2(4): 6.

- [14] Srinivas Devarakonda, Parveen Sevusu, Hongzhang Liu, Ruilin Liu, Liviu Iftode, Badri Nath. 2013. Real-time Air Quality Monitoring Through Mobile Sensing in Metropolitan Areas. www.cs.uic.edu/.../Paper%2019_Devara.
- [15] Aruljothi. R. 2013. Air Pollution Measuring System with Mobile Sensor Arrays. *International Journal of Scientific & Engineering Research*. 4(5).
- [16] T. H. Mujawar, V. D. Bachuwar and S. S. Suryavanshi. 2013. Article: Air Pollution Monitoring System in Solapur City using Wireless Sensor Network. *IJCA Proceedings on Computing Communication and Sensor Network 2013 CCSN*. 2013(1): 11-15.
- [17] Madhusudhanan Baskaran and Chitra Sadagopan. 2015. Synchronous Firefly Algorithm for Cluster Head Selection in WSN. *The Scientific World Journal*. 7.
- [18] Xin-She Yang. 2011. Chaos-Enhanced Firefly Algorithm with Automatic Parameter Tuning. *International Journal of Swarm Intelligence Research*.
- [19] Hongbo Liu, Zhanguo Xu, Abraham, A. 2005. Hybrid Fuzzy-Genetic Algorithm Approach For Crew Grouping. *5th International Conference on Intelligent Systems Design and Applications*. PP: 332-337.
- [20] Naveen Chauhan, Lalit Kumar Awasthi, Narottam Chand, Vivek Katiyar, Ankit Chugh. 2011. A Distributed Weighted Cluster Based Routing Protocol for MANETs. *Wireless Sensor Network*. 3: 54-60.
- [21] D. Chinh Hoang R. Kumar S. Kumar Panda. 2012. Optimal Data Aggregation Tree In Wireless Sensor Networks Based On Intelligent Water Drops Algorithm. *IET Wireless Sensor Systems*. 2(3): 282–292.