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Implementation framework for energy efficient routing in wireless sensor network

[1]S. Prithi, [2]S. Sumathi

[1]*Department of Computer Science and Engineering, Sri Rajalakshmi Engineering College, Chennai, INDIA*
[2] *Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, INDIA*
**Corresponding Author: e-mail: ssi.eee@psgtech.ac.in, Tel. No.: +99947 59330*
ORCID iDs: http:/orcid.org/0000-0001-5165-0212 (Sumathi)

Abstract

In recent years, designing of WSN becomes the leading domain for many researchers. In this paper an automaton system is suggested that dynamically monitors and studies the behaviors of the network environment to detect the malicious activities that occur in the network, to identify the attacked nodes and dead nodes in the wireless sensor network, and to transmit the message in the optimized route. The automaton system prevents the attacked and dead nodes from affecting the wireless sensor network. Computational Intelligence technique such as the PSO algorithm is used along with the automaton systemso as to obtain the optimized route from the set of available paths. Once the optimized route is obtained the message is transmitted through this optimized route. The transmission takes place at a high rate since the path does not containdead and attacked nodes, as well as the energy consumed by the optimal path will be minimal. Thus, the proposed model improves the utilization of energy,improves throughput, reduces end-to-end delay, and enhances the lifetime of the network.

Keywords: Wireless sensor network, energy efficient routing, computational intelligence, finite state automata, PSO

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1. Introduction

Energy consumption is one of the most essential factors and also plays a major part in deliberate the accomplishment of the sensor nodesdeployment owing to the uncompromising constrictions like the absence of thepower source, size of the sensors and the unreachability of the location stated by Akyildiz *et al.*, (2002). Once the nodes are deployed, these constrictions prevent the sensor devices to handle their activities and the main role among the sensor nodes is to transfer data (Elshakankiri 2008) which gets disturbed. In spite of these constrictions, the pervasiveness to design a WSN seemed to be a surfeit and it fascinated many researchers. Among the prevalence of various challenging issues such as power consumption, clustering, security, scalability related to WSN domain discussed by Yick *et al.* (2008), Jain (2011), Peter Schaffer *et al.* (2012) and Farzad Kiani (2016) the first predominant factor is to design an energy-efficient WSN so that energy consumed by each node is minimal which improves the lifetime of the networkand data transmission occurs with minimal energy. The second consideration is required for the energy-controlled sensor nodes to operate independently in the unattended area. Nevertheless, it might be cost-prohibitive to replace exhausted batteries or even impossible to replace batteries in a hostile environment. Hence, there arises a need to devise and deploy solutions to sustain the lifetime of the sensor nodes. Thirdly, the design of an energy- efficient routing in the wireless sensor network is focused on providing less end-to-end delay, and enhancing the throughput so that the packets are transferred faster with less interruption.

Thus, the primary objective of designing an energy-efficient wireless sensor network is to frequently observe and regulate the constraints and modifications that happen in the environment to avoid interrupting transmission and to decrease the utilization of the energy of the network. Hence, to do this, an automaton system is required which must be capable to dynamically learn the network environment and modify the variations according to the situations that occur in the network. Secondly, computational intelligence techniques could be used to obtain the optimal route so that the energy necessary to transmit the data could be minimized and throughput could be improved. Hence, this paper deals with the design of the learning dynamic deterministic finite automata which has the dynamic learning capability, and through its dynamic behavior, if any failure occurs in the sensor nodes the automata can handle it faster and can do the necessary changes. PSO algorithm is used along with the automata to obtain the optimal route from the set of all possible routes so that an uninterrupted transmission takes place at a faster rate. Therefore, in this paper a learning automata-based system is anticipated to learn the network environment dynamically, to efficiently utilize the energy, to extend the lifetime of the network, to enhance throughput, and to reduce end-to-end delay.

The rest of the paper is organized as follows. Section 2 presents the related work. Section 3 describes the proposed methodology. Section 4 shows experimental results and analysis, Section 5 illustrates performance comparison and Section 6 concludes the paper.

2. Related work

Clustering and Routing Algorithms

The communication protocol feature specified by Wendi Rabiner Heinzen et al (2000) showed a substantial influence on the overall utilization of energy of the wireless sensor networks. In accordance with the outcomes of Wendi Rabiner Heinzelman et.al (2000) static clustering, multi-hop routing, direct transmission through conventional bid protocols and transmission of minimum energy was not necessarily optimal for sensor networks, and therefore LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol was proposed by them which is a clustering-based protocol. The simulate results of LEACH prove that it can accomplish in dissipating the energy when compared with the conventional routing protocols. In addition, the LEACH enables to evenly distribute the energy dissipation throughout the sensor nodes, thus the protocol doubles the system lifetime of the networks. The energy among the network distributed is performed effectively in the network by reducing the dissipation of energy from a global perspective and enhancing system lifetime.

A novel cluster-based energy efficient routing algorithm was proposed by Li (2010) proposed in accordance with them to bring out a solution to optimize the lifetime of the network. Further, algorithm search the optimal inter- cluster mutiny path as well as to optimize the network lifetime. In the proposed approach, the utilization of energy in the wireless sensor network is balanced by applying the local competition mechanism while forming clusters as well as the periodic rotation of cluster head is been done. The simulation result reveals that it is better than LEACH in terms of energy efficiency, lifetime of network, and the stability of the algorithm proves the effectiveness of the algorithm. A cluster-based energy efficient routing algorithm was also proposed by Chen Chen and Chen (2010) which concentrates on improving the efficiency of energy by balancing the energy moreover prolonging the lifetime of the network. In this method the formation of cluster takes place by the approach of local competition and the hot spot problem is solved.

Wang & Chen (2013) devised a clustering mechanism called as Link-aware (LCM) for making the routing path efficient and trustworthy. A novel clustering metric has been used by the LCM approach to evaluate the selection of nodes for cluster heads in order to group the cluster. The simulation results shows that the LCM approach performs efficiently in clustering with the help of random selection and shows an improvement in packet delivery ratio, consumption of energy and delivery latency. The authors Danish et.al. (2013) have implemented few modifications in the LEACH protocol that has been devised by Wendi et.al. (2000). The modified LEACH which is termed as MODLEACH is done in order to replace the cluster head in an efficient manner and to maintain the dual transmission power levels. It has been observed from the investigational study that the modified LEACH algorithm has been recognized to be better in terms of the throughput, lifetime of the network and formation of cluster head.

Kuila and Jana (2014) proposed two formulations, for energy efficient clustering and routing problems. These two algorithms used PSO algorithm to provide energy efficient routing and clustering. They developed these algorithms in order to prove a tradeoff between the number of hop count and transmission distance. This approach balances the consumption of energy and also improves the network lifetime. The experimental result proves that the proposed algorithms outperforms the existing algorithms with respect to number of inactive sensor nodes, network lifetime and the transmission of total data packets. Azhvuddin and Jana (2017) presented a PSO based clustering an outing algorithm for WSNs. The clustering algorithm has been facilitated to minimize the consumption of energy among gateways and sensor nodes however the routing algorithm relies to compensate the energy efficiency and to balance the energy. These algorithms have the ability to tolerate the failure of cluster heads. Various experiments have been performed by the authors on two different scenarios of the WSN they have proved that the proposed schemes performs better with respect to lifetime of the network, utilization of energy, number of inactive sensor nodes, in comparison with the existing approaches like PSO based clustering proposed by PSO proposed by PrntyayKuila & Prasanta K. Jana (2014), GLBCA presented by Low et al (2008) and GA proposed by Kuila et al (20 l3). However, the authors have noticed that fault tolerance have occurred because of the failure of the cluster heads.

Energy Aware cluster Based Multi-hop (EACBM) a new routing protocol was proposed by Toor and Jain (2018) that makes use of the clustering principle and communication patted based on multi-hop to transfer information to base station. When comparing the performance of EACBM routing protocol with existing algorithms the proposed algorithm has shown betterment with respect stability among sensor nodes, throughput, lifetime of network and number of dead nodes per round for all the three different network sizes. It has been observed from the investigational study that the modified LEACH algorithm has been recognized to be better in terms of throughput, lifetime of the network and formation of cluster head. Hence in this paper, MODLEACH algorithm is used to cluster the nodes and to select cluster heads and helps in saving energy and also extends the network lifetime.

Optimization Algorithms for Energy Efficient Routing

Vimalarani et al. (2016) proposed algorithm in which they have used enhanced PSO algorithm for selecting the cluster head to minimize the consumption of power in wireless sensor network. The simulation results were evaluated on the performance metrics such as throughput, ratio of packet delivery, lifetime of the network, delay, remaining energy, normalized overhead, delay and consumption of total energy. The authors Singh and Sharma (2017) determined the programming formulation to improvise energy efficient cl uttering and proposed.PSO algorithm to provide efficient clustering. The proposed algorithm has been experimented and evaluated with various metrics such as number of alive nodes, consumption of energy, throughput and packet delivery ratio and compared with existing algorithms. The experimental results indicate that the proposed approach outperforms the other existing algorithms.

The authors Xiaoqiang Zhao et.al (2018) proposed a novel energy-efficient protocol The fitness value has been considered for improving the searching process of the optimal solution in GWO, which ensures a better distribution of CHs and a more balanced cluster structure. According to the instance to the BS and CHs, sensor nodes' transmission distance is recalculated to reduce the energy consumption. The results of simulation show that the proposed approach can prolong the stability period of the network in comparison to other algorithms, namely by 31.5% in comparison to SEP, and even by 57.8% when compared with LEACH protocol . The result also proves that the proposed protocol performs well over the above comparative protocols with respect to consumption of energy and throughput of the network. The Firefly algorithmic rule is implemented by the author Mukhdeep Singh Mans hahia (2015) that depends on the firefly attractiveness for improving the energy efficiency in routing. This simulation result of this approach shows an improvement in throughput and lifetime of the network. Okwori et al (2016) investigated the effectiveness of Ant Colony Optimization (ACO) and Firefly Algorithm (FA) meta-heuristic algorithms to detect the optimal route in a WSN. The performance of these two algorithms was tested on randomly deployed sensor networks that were placed in a clustered fashion. The simulation results show that proves that the Firefly algorithm had the capability to detect routes with minimum cost when compared with ACO algorithm in case of short routes while ACO algorithm performs better for longer routes.

The authors Al-Aboody et al (2016) developed a In Level One, the base station (BS) acts with a great role in selecting cluster heads along with a centralized selection. For data transfer GWO based routing is developed in Level Two, were the best mute to base station is selected to save the energy and in Level Three, The approach has been evaluated on various performance metrics such as energy consumption of the network, network lifetime, and the stability period of the network. The simulation results prove that the proposed approach achieves longer network lifetime, reduced utilization of energy and longer stability period in comparison with the existing algorithms.

Abhishek Agnihotri et al (2018) used Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) to develop an energy efficient routing algorithm. The authors developed four types of routing approaches namely shortest path approach, GA approach, PSO approach and Hybrid based PSO-GA approach for both large size as well as small size wireless sensor networks. The simulation results show that the Hybrid based PSO-GA routing approach has increased from 12% to 23% network lifetime in comparison with shortest path approach, 8%r to 15% network lifetime when compared with PSO approach and 5% to l 3% lifetime in comparison with GA approach for large sized network. The packet delivery ratio of Hybrid based PSO-GA has increased from 9% to l 6% when compared with shortest path approach, 6% to l l % in comparison with PSO approach, 5% to 9% when compared with GA approach.

An energy efficient routing protocol using hybrid optimization technique was proposed by Logambigai et al (2018). The author has used the nature inspired hybrid optimization approach bacterial swarm optimization (BSO) to optimize the energy in WSN. For each gateway, the optimal next node is identified and the final result will be an optimized route. The simulation results prove that the proposed BSO based algorithm can improve the network lifetime by 50 rounds, can increase the utilization of energy upto 15% and the hop count used for routing can be improved by 2 to 5 when compared with the existing algorithms.

Therefore in this paper the PSO and Grey Wolf Optimizer (GWO) algorithm has been hybridized to form an hybrid optimization algorithm to obtain an optimal path for transmitting the data packets to sustain the network lifetime to increase the flow rate and to proficiently utilize the energy in the wireless sensor network.

3. The proposed scheme

In this paper, an overall framework has been devised for energy- efficient routing in wireless sensor networks using Learning Dynamic Deterministic Finite Automata (LD^2FA) and Particle Swarm Optimization. Figure 1 portrays the overall framework of the proposed LD^2FA-PSO model. The network has been created with a group of sensor nodes and it hasbeen positioned in an audacious environment. Cluster formation is done by combining the nodes and from that group, the Cluster Head (CH) is chosen using geographical based clustering. Once the nodes are deployed the segment table is formed with the parameters such as node id, location of the nodes, node's energy, neighbor node, cluster head number, the status of the dead and malicious node, and timestamp of the sensornodes. Soon after the creation and placement of nodes in an audacious environment, LD^2FA is activated and it starts to monitor and learn the networkenvironment. The automata studies about the structure of the network and the node's information get updated sporadically in the segment table. The LD^2FApt path table stores information about all the possible paththat occurs between the starting node and final node and also stores the status of the path whether accepted or rejected. Path validation is done by LD^2FA andif any changes in the path, LD^2FA updates it in the path table accordingly. If LD^2FA detects malicious or dead node the path containing the corresponding malicious or dead node becomes rejected.

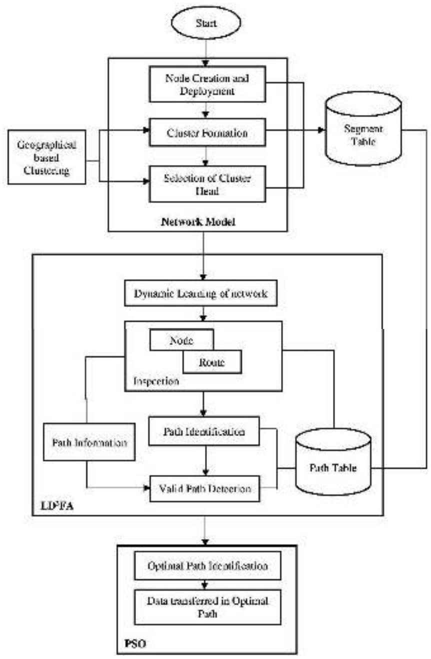


Fig 1. Overall framework for energy efficient routing using LD^2FA-PSO

The set of all possible paths from the source node to the sink node isavailable in the LD^2FApt path table. When a node needs to transmit the data packets to the destination it becomes ambiguous to choose the path which needsless energy and needs to select the uninterrupted path. So, an optimization algorithm is implemented to choose the optimized route from the set of all possible paths. In this proposed model PSO algorithm is implemented and incorporated with LD^2FA to obtain the optimized path. As soon as the optimalpath is determined, the packet transmission gets initiated with the help of the existing information of the path that is stored in the LD^2FApt path table in an effectual manner.

The proposed model contains the following features: Node inspection, Path table analysis, Route information updates. The node is dynamically monitored by LD^2FA and if any of the node's energy gets completely exhausted then it will be considered as the dead node. The node is also inspected by LD^2FA to identify any suspicious activities that occur in the node. If it finds such a malicious activity, the node will be treated as malicious node and the state of the malicious node are set in the segment table. In LD^2FApt path table, the path that contains dead and malicious nodes will be assigned as rejected. The LD^2FApt path table is analyzed periodically to check whether the path is accepted or not. If any of the nodes is detected as malicious or dead nodethen the path containing that node will be rejected. Through the route information updates, the unsolicited intruders could be eradicated in the network. The optimality in the path information is performed by frequently updating the route information.

The overall flowchart for energy-efficient routing using LD^2FA andPSO is shown in Figure 2.

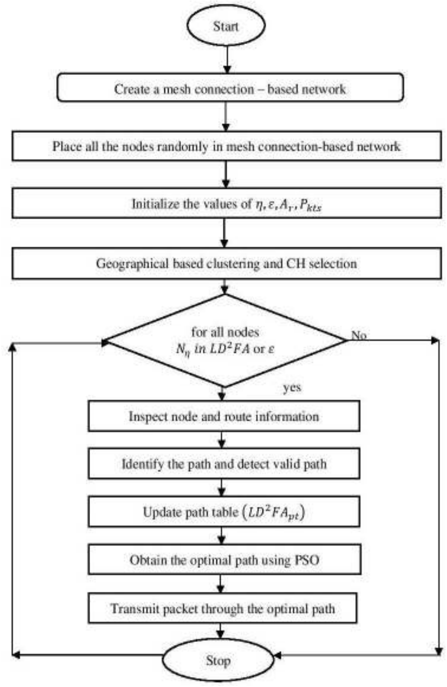


Fig.2. Proposed Flowchart for energy efficient routing using LD^2FA-PSO

Initialization of the network is done in which the nodes are positioned arbitrarily in a mesh network. The parameters such as message size (M_{size}), size of packets (P_{kts}), number of sensor nodes (η), nodes initial energy (ε), and acknowledgement size (A_r) are assigned with initial values. The cluster is formed among nodes and cluster head is selected using geographical based clustering. The nodes are selected dynamically and the various possible paths needed for transmission are allocated. LD^2FA investigates the nodes and the route information periodically and updates the value in the segment table and LD^2FA_{pt} path table. Path validation is done by LD^2FA and the automata stores thevalidated path in the LD^2FA_{pt} path table. In addition, the automata also inspectthe node and route information that has been stored in the segment table and LD^2FA_{pt} path table for eliminating the intruders. The objective of the PSO algorithm is to attain the optimized route from the existing paths in the LD^2FA_{pt}path table. Once the PSO algorithm finds the optimized route the packet transmission takes place in this optimized route.

Network Model

A network is constructed with a set of 'n' nodes that are arbitrarily located in the environment. The properties of a node are the message size (M_{size}), the threshold value (Th), maximum packet size (P_{kts}), and initial energy(ε). All these properties are assigned an initial value and it is illustrated in Table 1.

Table 1. Assignment of initial values in the network

Input parameters	Values initialized
Initial Energy (ε)	200 Joules
Packet size (P_{kts})	4000 bits
Message size (M_{size})	200 bits
Threshold Value (Th)	50

In this proposed model, the cluster is formed by combining nodes into small groups. From this group, a node would be chosen as Cluster Head (CH). The accountability of the cluster head is the communication of the essential data tothe Base Station (BS) or to next cluster head that is located near the CH. Hence,the node which has to play as the CH needs the minimum transmission energy. The data transmission and collection process lead to the exhaustion of the energy in the CH. This could be avoided by making the CH selection as a cyclicprocess so that all the sensor nodes get the chance of acting as a CH. In each transmission round, choosing of the CH is done at the beginning stage. The main aspect that contributes to the selection is the new computational value ofthe energy that is found at each round. Hence, this results in the utilization of energy in a minimum way which in turn prolongs the network lifetime.

Cluster Head Selection

In this phase, the CH is elected after the formation of the clusters. The node that acts as the CH should have the least transmission energy level insuch a way that the information must be transmitted to the nearest BS or the subsequent hop for a particular transmission round.

The selection of CH is done as stated below:

The elementary energy level of a node is represented as E0(n).

The distance from the BS to each node or the consistent high- level CH has to be measured and it is denoted as d(n).

The computation for the energy required by the nodes for the transmission process is given by Equation (1). Here the transmission might be either to the next level CH or among the cluster.

$$E_{TX} = (E_{amp} * n * d) + E_{elec} \quad (1)$$

From the above equation, 'n' is used to denote the number of data bits that are transmitted. 'd' designates the distance among the CH and the sensor nodeor the CH to the next level CH or between the CH and BS. Eelec signifies the cost of the circuit energy that is been spent during the transmission or receiving of one-bit data and Eamp exemplifies the transmitter amplifier. The maximum energy that has been spent subsequently is computed and the CH selection is performed based on it. The formula is denoted in Equation (2)

$$Max(E_0(n) – E_{amp} * n * d) \quad (2)$$

As soon as the selection of CH is done, the selection process of the next CH will be commenced once the current round gets completed.

4. Practical perspective

In this section, an energy-efficient routing using LD^2FA-PSO is proposed that minimizes the utilization of the energy, extends the network lifetime, improves throughput and end-to-end delay. Various tools used for simulation are NS-2, NS-3, GloMoSim, OMENT++, J-Sim, MATLAB exists for authenticating the behavioral pattern of a WSN. In this work, MATLAB (Matrix Laboratory) is chosen as the tool in simulating the proposed model. In this section, the simulation environment, experimental scenario, results, and performance comparison with existing algorithms are discussed.

Simulation Environment

The work has been deployed in the Intel® core™i5-7200CPU @ 2.50 GHz processor in a 64-bit operating system with 8 GB of RAM and x64- based processor with the installation of MATLAB R2018b. To carry out the operations, the sensor nodes range from 100-700 in a space of 500 * 500 m^2. The simulated environment is installed for 50 sensor nodes which have been positioned in the x and the y-axis in a random manner. A primary energy level of 200 Joules is set for all sensor nodes and Transmitter and Receiver Electronics (EElec) has been assigned a value of 50 nJ/bit. The other values such as d0 which is the critical value for dividing the spatial model is initialized with 87.0m, transmitter amplifier (Eamp) is assigneda value of 100 pJ/bit/m^2, energy level of data aggregation (EDA) is set to 5nJ/bit,message size is set to 200 bits and the packet size is set to 4000 bits for a simulation round of 200-5000 and communication range of about 150m. The initial values that are assigned to the input parameters are depicted in Table 2.

Table 2. Network Simulation Parameters

Input parameters	Network 1 and 2
Area (A)	500 * 500 m^2
Sensor Nodes (η)	100 – 700
Initial Energy of SNs (E_0)	200 J
Simulation Rounds (S_R)	200 – 5000
Communication Range (C_R)	150 m
Packet Size (P_{kts})	4000 bits
Message Size (M_{size})	200 bts
Transmitter and Receiver Electronics (E_{elec})	50 nJ/bit
Critical Value for Dividing Spartial Model (d_0)	87.0 m
Data Aggregation (E_{DA})	5 nJ/bit
Transmitter Amplifier (E_{amp})	100 pJ/bit/m^2

Simulation Setup and Results

The experiment has been evaluated by simulating the network environment for network setups namely, Network 1. The network setup differs only in the location of the base station whereas the otherparameters like area of the network environment, sensor nodes, initial energy of the node, simulation rounds, communication rounds, packet, and message size and the rest of parameters depicted in Table 2 remains the same for bothnetwork scenarios. The base station is placed in one side of the region where its coordinates are denoted by (500,250) in Network 1 which is depicted in Figure 3. The base station is placed at different locations so as to evaluate the effectiveness of the proposedwork. The measurement of the coordinates is done in meters.

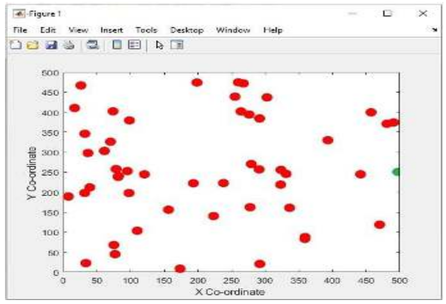


Fig.3.Creation and Deployment of 50 nodes for Network 1

As soon as the nodes are positioned in the network environment, clusters are grouped using geographical based clustering. The clusters that are formed is depended on the whole coverage area space. However, if there is an increase in clusters, then the area which is to be considered as a cluster must bedivided in an equal manner. This method of division depends on space. In this simulation, the cluster formation is done with 50 sensor nodes for Network1 which is grouped into three clusters and it is revealed in Figure 4.

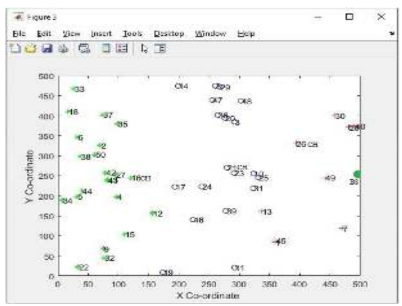
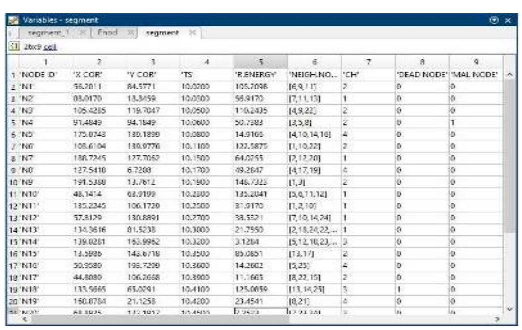


Fig.4. Formation of 3 clusters with 50 nodes for Network 1



	1	2	3	4	5	6	7	8	9
1	'NODE ID'	'X COR'	'Y COR'	'TS	'R.ENERGY'	'NEIGH.NO...	'CH'	'DEAD NODE'	'MAL NODE'
2	'N1'	56.2011	84.5771	10.0200	105.7098	[6,9,11]	2	0	0
3	'N2'	88.0170	13.8459	10.0300	56.9170	[7,11,13]	1	0	0
4	'N3'	105.4285	119.7047	10.0500	110.2435	[4,9,22]	2	0	0
5	'N4'	91.4849	94.1849	10.0600	50.7383	[3,5,8]	2	0	1
6	'N5'	175.0743	180.1899	10.0800	14.9106	[4,10,14,16]	4	0	0
7	'N6'	106.6104	139.9776	10.1100	122.5875	[1,10,22]	2	0	0
8	'N7'	188.7245	127.7062	10.1500	64.0255	[2,12,20]	1	0	0
9	'N8'	127.5410	6.7208	10.1700	49.2847	[4,17,19]	4	0	0
10	'N9'	191.5388	13.7612	10.1900	148.7323	[1,3]	2	0	0
11	'N10'	48.1414	63.9199	10.2300	135.2041	[5,6,11,12]	1	0	0
12	'N11'	185.2245	106.1720	10.2500	31.9170	[1,2,10]	1	0	0
13	'N12'	57.8129	130.8891	10.2700	38.5321	[7,10,14,24]	1	0	0
14	'N13'	134.3616	81.5238	10.3000	21.7550	[2,18,24,22,...	1	0	0
15	'N14'	139.0281	163.9962	10.3200	3.1284	[5,12,18,23,...	3	0	0
16	'N15'	13.5986	143.6718	10.3500	85.0651	[13,17]	2	0	0
17	'N16'	30.9580	198.7290	10.3600	14.2602	[5,23]	4	0	0
18	'N17'	44.8080	106.2668	10.3900	11.1665	[8,22,15]	2	0	0
19	'N18'	133.5665	65.0291	10.4100	125.0859	[13,14,25]	3	1	0
20	'N19'	160.0784	21.1258	10.4200	23.4541	[8,21]	4	0	0

Figure 5. Cluster Head Selection for Network 1

Figure 5 illustrates the selection of cluster head for Network 1. From Figure 5, it is observed that the selection of the CH is done as per the steps mentioned before.In the case of Network 1, node 16 acts as the CH for the first cluster, node 21 acts as the CH in the second cluster, and node 26 has been elected as the CH in the third cluster which is presented in Figure 5. As soon as the deployment of the node takes place and the clusterformation is done, the following information are stored in the segment table. Identifier of the node, Position of the node through its x and y coordinates, Timestamp (TS), Its neighbor nodes, CH number, Residual energy, Status of the dead node, Information about the malicious node. Figure 6 indicates the parameters and their corresponding valuesthat are stored in the segment table for the deployed nodes in Network 1.

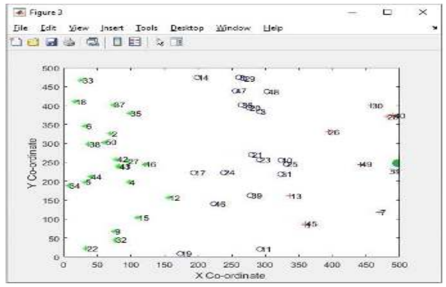
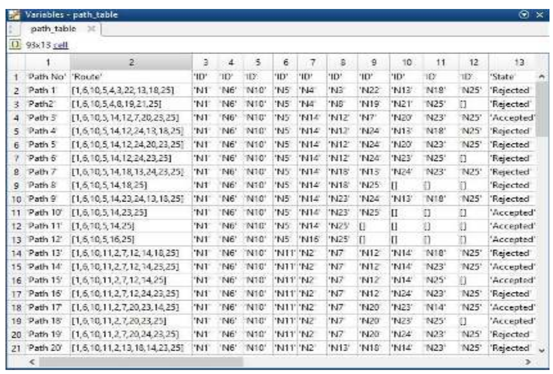


Fig. 6. Segment Table for Network 1

When a source node (S) in a network initiates the data transmission process to the destination (D), it has to determine all the paths and the information about the paths must be stored in the LD^2FApt path table. The paths are identified with the help of the values that are stored in the LD^2FApt table shown in Figure 7. Figure 7 demonstrates all the possible paths beginning at source node 1 and ending at destination node 25 that are stored in the LD^2FApt path table for Network 1. LD^2FA learns the network dynamically and if it identifies any dead node or malicious node the path containing the respective node ID becomes rejected and if there is no problem in the route LD^2FA returns as accepted. As per the simulation scenario, it can be noticed from Figure 6 that node 4 is recognized as the malicious node and in addition, node 18 becomes dead. Therefore, the paths that comprises all these nodes are rejected and it is shown in Figure 7. Before transmitting the data, the PSO algorithm is invoked to determine the optimized route from the set of all probable paths that are available in LD^2FApt path table. The parameters that are initialized in order to deploy PSO are tabulated in Table 3.



Variables - path_table

path_table

93x13 cell

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	'Path No'	'Route'	'ID'	'ID'	'ID'	'ID'	'ID'	'ID'	'ID'	'ID'	'ID'	'ID'	'State'
2	'Path 1'	[1,6,10,5,4,3,22,13,18,25]	'N1'	'N6'	'N10'	'N5'	'N4'	'N3'	'N22'	'N13'	'N18'	'N25'	'Rejected'
3	'Path2'	[1,6,10,5,4,8,19,21,25]	'N1'	'N6'	'N10'	'N5'	'N4'	'N8'	'N19'	'N21'	'N25'	[]	'Rejected'
4	'Path 3'	[1,6,10,5,14,12,7,20,23,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N12'	'N7'	'N20'	'N23'	'N25'	'Accepted'
5	'Path 4'	[1,6,10,5,14,12,24,13,18,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N12'	'N24'	'N13'	'N18'	'N25'	'Rejected'
6	'Path 5'	[1,6,10,5,14,12,24,20,23,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N12'	'N24'	'N20'	'N23'	'N25'	'Rejected'
7	'Path 6'	[1,6,10,5,14,12,24,23,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N12'	'N24'	'N23'	'N25'	[]	'Rejected'
8	'Path 7'	[1,6,10,5,14,18,13,24,23,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N18'	'N13'	'N24'	'N23'	'N25'	'Rejected'
9	'Path 8'	[1,6,10,5,14,18,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N18'	'N25'	[]	[]	[]	'Rejected'
10	'Path 9'	[1,6,10,5,14,23,24,13,18,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N23'	'N24'	'N13'	'N18'	'N25'	'Rejected'
11	'Path 10'	[1,6,10,5,14,23,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N23'	'N25'	[]	[]	[]	'Accepted'
12	'Path 11'	[1,6,10,5,14,25]	'N1'	'N6'	'N10'	'N5'	'N14'	'N25'	[]	[]	[]	[]	'Accepted'
13	'Path 12'	[1,6,10,5,16,25]	'N1'	'N6'	'N10'	'N5'	'N16'	'N25'	[]	[]	[]	[]	'Accepted'
14	'Path 13'	[1,6,10,11,2,7,12,14,18,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N12'	'N14'	'N18'	'N25'	'Rejected'
15	'Path 14'	[1,6,10,11,2,7,12,14,23,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N12'	'N14'	'N23'	'N25'	'Accepted'
16	'Path 15'	[1,6,10,11,2,7,12,14,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N12'	'N14'	'N25'	[]	'Accepted'
17	'Path 16'	[1,6,10,11,2,7,12,24,23,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N12'	'N24'	'N23'	'N25'	'Rejected'
18	'Path 17'	[1,6,10,11,2,7,20,23,14,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N20'	'N23'	'N14'	'N25'	'Accepted'
19	'Path 18'	[1,6,10,11,2,7,20,23,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N20'	'N23'	'N25'	[]	'Accepted'
20	'Path 19'	[1,6,10,11,2,7,20,24,23,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N7'	'N20'	'N24'	'N23'	'N25'	'Rejected'
21	'Path 20'	[1,6,10,11,2,13,18,14,23,25]	'N1'	'N6'	'N10'	'N11'	'N2'	'N13'	'N18'	'N14'	'N23'	'N25'	'Rejected'

Fig. 7. Path LD^2FApt Table for Network 1

Table 3. Initial PSO parameter values for Network 1

Input parameters	Values Initialized
Number of Particles (N_p)	100
Maximum length of the string (Str_{len})	10
Number of Iterations ($iter_{max}$)	50
Acceleration Constant c_1 and c_2	1.4962
Inertia weight (w)	0.7968
Maximum Velocity (V_{max})	0.5
Minimum Velocity (V_{min})	-0.5

LD^2FA produces the LD^2FApt path table which provides informationabout the valid possible paths. PSO accepts the LD^2FApt path table as the inputand starts analyzing the path. The fitness value is computed for each and everyvalid path. If the path in LD^2FApt path table is rejected then the Pbesti will not be calculated. Based on the fitness value, the values for the metrics such as Pbesti, Gbesti are computed and the optimal pathis returned through the variable Gbesti. In this simulation for Network 1, 93 possible paths are available from source node N1 to destination node N25 which is stored in LD^2FApt path table. From these 93 paths, a path no 31 (N1- N6-N10-N5-N16-N25) is found to be the global best value through the implementation of the PSO algorithm and is depicted in Figure 8. Thus, theGbest31 is considered as the optimal route from source node 1 to destination node 25.

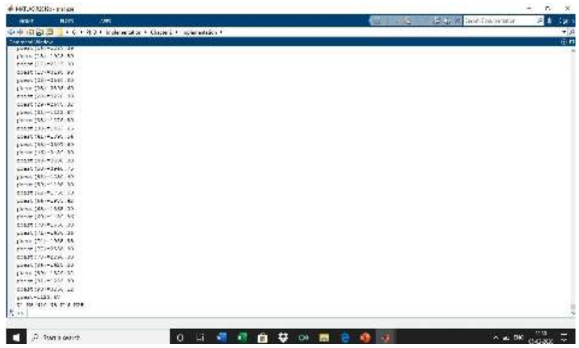


Fig 8. Optimal path selection using PSO algorithm for Network 1

5. Performance comparison with existing algorithms

The performance measures such as consumption of the energy, lifetime of the network, throughput, statistics of alive nodes, and end-to end delay are evaluated and analyzed. These metrics are compared with the existing algorithms like PSO proposed by Pratyay Kuila & Prasanta K Jana (2014), Greedy Load Balanced Clustering Algorithm (GLBCA) presented by Chor Ping Low *et al.* (2008) and Genetic Algorithm based clustering (GA) proposed by Pratyay Kuila *et al.* (2014) and are described in this section. Figure 9 showcase the comparison of network lifetime for Network 1. For the proposed network containing 200 nodes, the first node is alive until the 899th round. For a network which comprises of 300 nodes, the node goes down at the 880th round. It can be noticed from the figure that a network with 500 the first node loses its complete energy at 740th round. From Figure 9, it is inferred that there is an increase of 6% and 32% in the network epoch when compared with the PSO and GLBCA and nearly 30% of increase than GA. From the inference it is found that the LD^{2}FA-PSO is comparatively effective than that of the prevailing algorithms like PSO, GLBCA and GA as mentioned in recommendations given by Pratyay Kuila & Prasanta K Jana (2014), Chor Ping Low *et al.* (2008), Pratyay Kuila *et al.* (2014). The automaton dynamically monitors the network and avoids the malicious activities that occurin the network and restricts the malicious node to take part in routing and sustains the network lifetime.

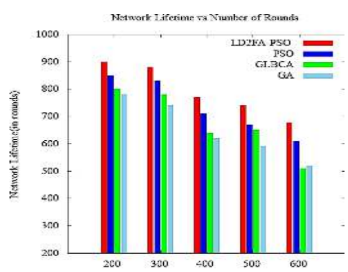


Fig. 9. Network Lifetime for Network 1

Figure 10 shows an evaluation of energy consumption for the Network 1 according to each round for 200 - 1600 sensor nodes. It can be noticed from Figure 10 that 3% less energy is utilized when compared with PSO proposed by Pratyay Kuila & Prasanta K.Jana (2014) and 5% lesser energy is utilized than GLBCA developed by Chor Ping Low et al. (2008) and 6% lesser energy consumption than GA deployed by Pratyay Kuila et al. (2014). Less energy is consumed by the proposed LD^{2}FA-PSO when compared to the existing algorithms such as PSO, GLBCA, and GA because the energy needed for transmitting the messages is minimized by choosing the optimalroute and malicious node's energy utilization is avoided in transmission.

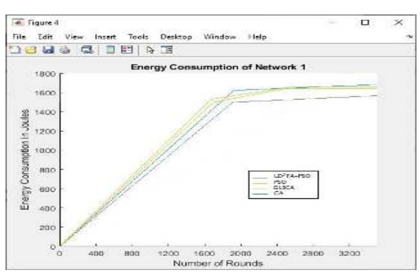


Fig 10. Energy Consumption of Network 1

Cluster-based Intrusion Detection System (IDS) adopted by Singh *et al.* (2016) and Light weight IDS suggested by Michael Riecker *et al.* (2014) is used for the comparison of the parameter throughput with the proposed model. The proposed method illustrated in Figure 11 for Network 1 depicts that the parameter throughput has an improvement of 16% when compared with the Cluster-based IDS and a vast variation of 70% when compared with the Light weight IDS after the completion of 5000 rounds. Thethroughput is improved in the proposed system due to the detection of dead and malicious nodes and minimum hop is chosen by the optimal route through PSOalgorithm. The packets that are transmitted across the network travel in an uninterrupted path which are monitored by the automata. If the automaton encounters a dead node it does not allow the node to be involved in the transmission. Therefore, the packets are transmitted at a higher rate when compared with existing algorithms.

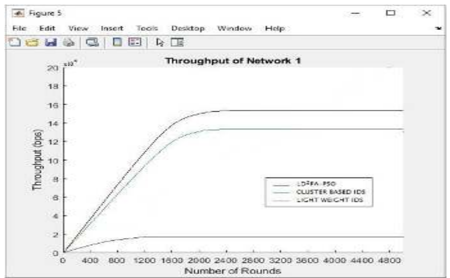


Fig. 11. Throughput Vs Number of Rounds of Network 1

A clear illustration of the performance measure in relation with the alive node's energy for a period of operation for network 1 is depicted in Figure 12. It is observed that only after the 2600 rounds, the alive nodes get disappeared whereas in Light weight IDS there are no alive nodes after the completion of 1400 rounds and in case of Cluster-based IDS, there is no possibility of presence of alive nodes after the 2000 rounds. From Figure 12 it can be inferred that the lifetime of the Network 1 is prolonged for a longer period which shows that the nodes are alive for a longer period.

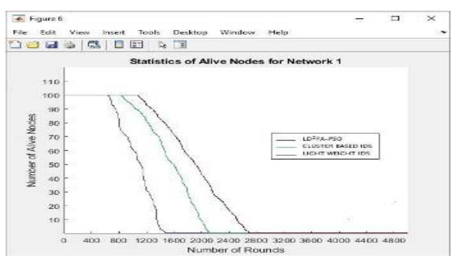


Fig. 12. Statistics of Alive Nodes for Network 1

The performance comparison of end-to-end delay parameter for the proposed and prevailing approaches for Network 1 are depicted in Figure 13.

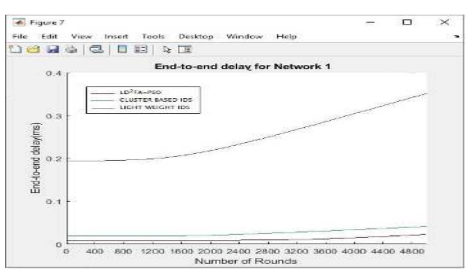


Fig.13. End-to-End Delay versus Number of rounds for Network 1

When compared with the prevailing system such as Cluster based IDS deployedby Shubhangi Singh *et al.* (2016) and Light weight IDS proposed by Michael Riecker (2014) the time delay taken by proposed model to transmit packet is less. After 5000 rounds the proposed model takes only 0.03ms delay in transmitting packets, whereas cluster-based IDS takes 0.05ms end-to-end delay, and light-weight IDS takes up to 0.35ms time end-to-end delay. Since inthe proposed model the automaton along with PSO algorithm has chosen the optimal path which has a high possibility for an uninterrupted transmission. The packets are transmitted in an uninterrupted route that is free from dead andmalicious node which avoids any delay in the transmission.

6. Conclusion

Thus, the proposed model designed in this paper has made use of the features of automata to dynamically learn the wireless sensor network environment and used the benefits of computational intelligence techniques for optimizing the transmission route. The proposed LD2FA-PSO adopts the concept of dynamic learning of the network so that it is capable of providing aforementioned knowledge about the node, path and the network. Moreover the lively details about the sensor nodes and the route information are periodically stored in the segment table and LD2FApt path table. These two tables are continuously monitored by the automata to detect any malicious or dead node that occur in the network. The proposed model evaluates the path, the nodes and identifies the malicious activities that occur in the network as well as detects the dead node and eliminates them from taking part in routing. The set of all the possible paths are determined by the automata and path validation is done to remove the invalid path and finally the PSO algorithm is implemented to determine the optimum path. With the help of the PSO obtaining the optimal route the automaton obtains better performance. The performance of the proposed model is evaluated and analyzed for the metrics like network lifetime, consumption of the energy, alive nodes status, throughput and end-to-end delay. From the outcome it can be noticed that there is an improvement in utilization of the energy, enhancement in the lifetime of the network, increase in throughput and takes less end-to-end delay. With the integration of the route examination and node evaluation, the LD2FA with PSO is considered to be the suitable model for energy efficient optimized routing in WSN.

The automata-based system proposed has not given its attention towards the security of the sensor nodes besides, the routing process could be improved further to enhance the lifetime of the network and minimizes the utilization of the energy by applying hybrid optimization algorithms. Thus, in the future work, the security of the network is taken into account and routing has been improved further to sustain the network lifetime, reduce the utilization of the energy, improve throughput and reduce the end-to-end delay.

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Bibliographical notes

Dr. S. Prithi is of the Department of Computer Science and Engineering, Sri Rajalakshmi Engineering College Chennai, India while **Professor S. Sumathi** is a Professor at the Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, India