Ph.D. Research Proposal

Doctoral Program in “Department Name”

Delay and Energy Aware Intelligent Agents based Refined Data Gathering Model for Wireless Sensor Networks

by

<Name of the Candidate>

<Reg. No of the Candidate>

<Supervisor Name>

<Date of Submission (DD MM 20YY>

phdprimehelp@gmail.com
+91-97 91 62 64 69

I. INTRODUCTION / BACKGROUND

Wireless Sensor Networks (WSN) is sustained for diverse of applications for monitoring of smart homes, health, agriculture, industries and many more. Each sensor node is working functionality differs with respect to their design and potentialities. WSN is categorized into two classes as homogeneous and heterogeneous. In this, the combination of using different type of sensors in WSN is called as heterogeneous networks. Briefly, this is practiced in the area of Internet of Things (IoT) where the diverse data is collected from large scale environment. However, IoT sensors are resource constrained they are majorly concentrated with the goal of maximizing network lifetime.

WSN IS BEHIND SUCCESS OF?

The processes of clustering and scheduling are performed for improving network lifetime. As well as the collected data is required to be transmitted effectively in an intelligently selected path. On the whole these three processes are handled in WSN IoT with the objective of reducing energy consumption [4]. Scheduling is an assignment of time slots in which the node is allowed to turn off its radio for a certain period of time. The activation of sleep and active modes of enabled to improve network lifetime [8].

WSN supported for IoT uses involve with the selection of efficient head for gathering the data. After collecting the data, it is routed to sink by means of selecting a path. Apart from this, the data collected from sensors are also subjected to be redundant. Hereby on eliminating the data redundancy, the energy consumption could be reduced during routing due to the transmission of smaller sized packets [9].

In recent days, intelligent agents (iAs) are presented for gathering data from sensors by planning their path in the network area. In most of the iAs employed network the sensors are clustered and so the data could be easily collected from the corresponding head. The agents in the network are capable to collect data from heads. However, in some work, the sensor node acts as agents which increases the energy consumption due to transmission of data to sink or base station (BS). Agents are the best solution to minimize energy consumption, but it needs to be a special entity with the intelligence to make decision and operated without any assistance. The main focus of our research is to improvement network lifetime by using intelligent agents in heterogeneous WSN IoT architecture.

II. PROBLEM DEFINITION & STATEMENT

2.1 Overall Problem Statement

Sensor node acting as an agent increases energy consumption and reduces network lifetime. Using single iA increases delay in delivering data to sink, these agents are not intelligent to make self-decision. Random movement of agents and selection of an entire path (Predefined paths) leads to poor performance when an event occurs in the network.

2.2 Specific Problem Definition

Authors of this paper [1] have designed an efficient honeycomb clustering algorithm (EHCA) with the aim of improving network lifetime in heterogeneous sensor environment. The proposed EHCA is operated successively from setup such as sensor localization, network partitioning and cell addressing to steady state CH selection and communication. The hexagonal cells (six) are constructed in the form of rings to cover the network area. Here, six sinks nodes are deployed which receives data from CHs.

Problems –

- As stated by this work, 37 adjacent hexagons are considered to be a cluster and selected with a CH. As per this work each hexagon is composed of many numbers of sensors. It is difficult for the CH to gather all the data from a cluster and also it consumes larger energy.
- However, the number of hops towards CH is lesser, the CH is responsible to collect data from the entire sensor hence it increases energy and latency.

Proposed Solutions –

- Two Dimensional Grid partitioning based clusters are constructed. Each cell is sub divided for reducing number hops thereby mitigates latency and energy consumption.
- Intelligent mobile agents are incorporated in proposed work for data gathering that reduces latency and energy consumption.

Authors have proposed [2] a hybrid optimization algorithm (Glowworm swarm (GSO) with fruitfly (FFOA)) for the selection of optimal cluster head to improve energy efficiency. The CH is selected by taking in account of *distance, delay and energy* parameters. The fitness values are computed and sorted, then best fitness (five) is chosen. The selected fitness is compared to index value and then the solution is updates using GSO or FFOA. Due to the less convergence in FFOA, the agents are randomly arranged for searching.

Problem –

- Index value is given based on the smell concentration that is reciprocal to the distance. Setting up pre-defined index value for the entire network leads to poor selection of CH in the network.
- In GSO the agents as glowworms are randomly distributed, if there are nil neighbors then the agent randomly moves to next location. Due to random movement, it consumes time to select CH.
- In this work, base station is employed at the center of the network, so obviously the far distanced CH with larger number of members consumes larger energy for transmission.

Proposed Solutions –

- CH selection threshold is vigorously calculated using Tsallis Entropy based on the sensor's connectivity distance in core ring, since this is a heterogeneous network.
- HyCO for head selection is processed faster and produces efficient solutions. The fitness value for head selection is estimated from node's energy, distance, centrality and speed.

- Intelligent agents are used so, the CH aggregated data will be collected by those entities. Hence, the farthest CH is capable to sustain for longer time.

Author proposes [3] a combination of ant colony optimization (ACO) and particle swarm optimization (PSO) as a hybrid method HM-ACOPSO for defining moving path for mobile agents. For clustering, the virtual grids are equally divided into sub domains and CH is selected based on the weight (*residual energy and distance*). Each anchor node is selected for individual CH with respect to the mobile agent's path. A mobile agent path selected using ACO is optimized by PSO with the selection of anchors. Undirected graphs are constructed using the CHs and then a shorted path is chosen from the graph.

Problem –

- Single mobile agent is used which does not support immediate data transmission in emergency events.
- For initial path in ACO, distance is the only metric that is used and for optimized path distance and speed is used. Selection of complete path for mobile agent traverse leads to fails to gather emergency event message which is delay sensitive.
- ACO and PSO are slower in convergence.

Proposed Solutions –

- Two intelligent mobile agents are used to gather data and in case an emergency data is identified, then the CH forwards it directly to sink. In order to achieve density of each cell in the grid is portioned into four equal parts and each portion forms a cluster.
- The use of intelligent agents selects dynamic next hop data gathering point with respect to significant constraints of CH. Since intelligent agents are used, a powerful deep deterministic policy gradient is used for decision making.

In [4] the proposed work is employed with manifold mobile agents for data collection. The key processes handled in this work are clustering, cluster head selection, itinerary planning and fault management. CH is selected based on the sensor node which has higher accumulated impact factors such as hop count and sensor strength. The itineraries for mobile agents are planned using minimum spanning tree in which the weights (*hop count between two CHs and hop count towards sink*) for CHs are computed. Later, an alternate CH is selected to mitigate fault that happens due to malfunctioning.

Problem –

- The path planning based on minimum spanning tree becomes tedious when multiple CHs have similar weights.
- However, an alternate CH is selected to avoid faults, however the data from members will be initially collected by the primary CH and hence unnecessary drain of energy occurs due to transmission of gathered data from primary CH to alternate CH.

Solution –

- The next position of intelligent agents is chosen using deep deterministic policy gradient.
- The selected CH in this proposed work is based on optimization algorithm and hence the failure of CH will not occur.

A cooperative agent's geographic adaptive fidelity (CAGAF) [5] is proposed for data transmission. To reduce the energy consumption, the sensor nodes are operated either in active mode or sleep mode. A set of active nodes are selected in each grid based on *residual energy, information importance and distance to BS*. In this work, each sensor node is adapted with the potentialities of an agent. The shortest path is determined based on Dijkstra's algorithm based on cooperation parameters (*Density & Position*).

Problem –

- According to the energy level, the sensor nodes are operated itself by active mode or sleep mode based on their remaining energy level. In case, if most of the nodes in a grid are in sleep state, then selection of path becomes tedious.

- The network is portioned into 3×3 grid cells is composed of decentralized sensor nodes which increases number of hops to reach BS. However the agents were employed in sensors, the increase in hops for transmission consumes energy in the entire active node present in the route.
- Dijkstra algorithm was not able to obtain shortest path at all instances due to blind search that leads to higher time consumption to identify a path.

Solution –

- Sensor nodes are scheduled only, if its energy goes below the threshold value. This is verified by the node itself by using Bayes rule and then the super node takes responsibility to assign schedules for requested nodes. The schedules are given with respect to energy and discharge rate so all the sensor in an area will be in sleep state at a time.
- The 3×3 portioned grid is sub divided into four partitions and constructed as an individual clusters. Deployment of multiple intelligent agents gathers data promptly.
- In proposed, the best next position is determined using deep deterministic policy gradient.

Author proposes [6] a rendezvous-based approach in which a rendezvous points (RP) are for data collection. Then the collected data is gathered by the mobile element (ME) from the RP. This RP is selected using minimal constrained RP (MCRP) algorithm that computes *number of affiliation nodes, relay hop and location of RP*. A shortest path tree (SPT) is constructed based on the number of hop counts with respect to the BS. The selected rendezvous node is always situated at lowest distance from the BS from which the ME gathers the sensed information.

Problem –

- A sensor node is selected as rendezvous node based on its distance, due to this the sensors nearer to the BS will drain larger energy in short period of time.
- However the rendezvous node supports for per round, it will be continuously selected for the future rounds since they satisfy the distance constraint.

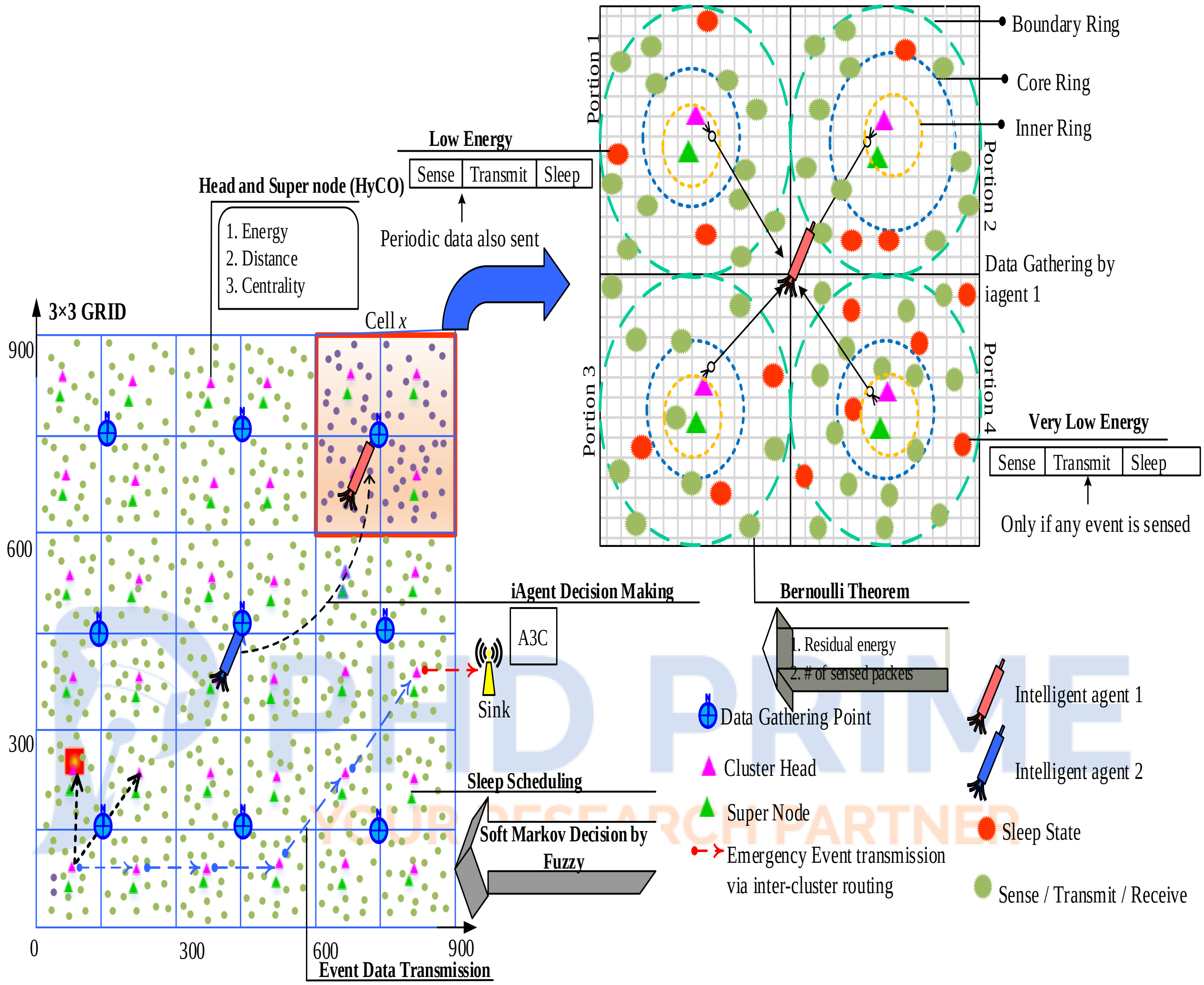
- Only single mobile element is used to traverse over the entire network and hence this is not suitable for large scale network.

Proposed Solutions –

- The movement of agents is made by itself, since mobile agents are used. These intelligent agents are capable to gather data from more than one sensor, so in this proposed work the iagents gather aggregated data from four CHs at a time.
- Two intelligent agents are used to cover the entire sensor environment and hence our proposed work supports for large scale network. As per the increase in size of the network environment, the number of agents can be increased.

III. RESEARCH CONTRIBUTIONS

To overwhelm the problems defined in the previous section, in this proposed heterogeneous WSN IoT is designed. The use of agents without intelligent is identified to be operated with the assistance of sink node for data gathering. To break through the limitations of such agents the proposed heterogeneous WSN IoT is modeled. This research work concentrates on efficient data gathering using goal based intelligent agents (iagents) with the aim of improving network lifetime. The major potentialities of this iagents are robust to collaborative signals and capable to collect data from more than one sensor node at a time.



In order to increase network lifetime, the proposed network is composed to perform following process as,

- Network Building
- Cluster Formation
- Node Scheduling
- Data gathering by CH and iagents

The proposed network is composed of heterogeneous IoT sensor devices, two iagents and one sink node. Sensors are responsible to sense the environment and report sensed information to head sensors. The key process handled in this proposed research are detailed in the following,

(i) Network building – A distributed heterogeneous network is deployed with IoT sensors to sense the environment. In this work a 3×3 grid based network is constructed with 9 cells, in which each cell is further divided into four equal portions (portion 1 to portion 4). Each individual portion in the cell is considered to be a cluster in which cluster heads are selection. The cells are split into four to reduce the energy consumption by minimizing the cluster area.

(ii) Cluster formation – The cluster heads (CH) are selected in each portion of the cell, so totally 4 CHs will exists in each cell. The CH selection need to,

- Cover the complete cluster area
- Reduce message exchange during CH selection

To achieve these constraints, the ring partitioning is performed to shrink the number of competitors in CH election and also to select a CH at centered position. A number of two rings are constructed as core ring and boundary ring. The IoT sensors within the core ring participate in CH selection. An optimal CH is selected using **Hydrological Cycle Optimization algorithm** by computing fitness with energy, distance and centrality degree. The topmost solution will be selected as CH and the second topmost node will be super node.

(iii) Node Scheduling

The selected super node is responsible to assign schedules to the cluster members. In most of the research work, the schedules are allotted by the CH, but to enrich the lifetime of CH the super node is used for scheduling. The super node uses **Soft Markov Decision Model** for schedule allotment. This is activated only when the sensor node requests for sleep time. In this work **Fuzzy Rules with Bernoulli Theorem** is once in a while verified by the sensors using residual energy and number of sensed packets. If the probability exceed beyond the threshold, then the member requests for sleep time to super node. On receiving the schedule request, the super node evaluates node's *residual energy* and *discharge rate* to assign schedules.

(iv) Data Gathering by CH

The sensed data from members are collected by selected CH and the redundancy data are reduced by using **Noise Elimination based Redundant Check Bits Algorithm (NER-CBA)**. This is a stream cipher method that converts the sensed data into hash values before sending it to CH. If more than one hash value is similar, then they are ignored and then the single data is taken in account. Once the data is received from a sensor, the flag is checked. If the flag value is 1, then the data is identified as emergency. If emergency data is received then immediately inter cluster routing is performed to transmit the data to sink.

Inter cluster routing between CHs is handled only for emergency data; else the CH waits for iagent to reach its position. The best neighboring CH is selected by determining Triset-level objective functions as: (1). *Energy* and *throughput*, (2). *link lifetime* and *sensor failure rate*, (3). *Expected transmission count* (ETX) and Expected Delay. The best objective function satisfying node will be chosen as CH as next hop and then the data reached sink.

(v) Data Gathering by iagents

The deployed goal based iagents are operated for the goal of effective data gathering from the CHs. Asynchronous Advantage Actor Critic (A3C) is used for decision making regarding the movement of iagent. In this work, the maximum number of visiting points of the iagents is 4 i.e. once if the iagent have gather data from four visiting points then returns back to sink for delivering the gathered data. Hereby the decision of iagents is given based on *last visit time*, *energy* of CH and *data packets* at CH. In this work, last visit time is taken in account, so that the other iagent will not visit that CH if it is recently visited.

Performance Evaluation

From the proposed heterogeneous system model the following metrics are evaluated to ensure the better efficiencies with respect to previous research works. The evaluation metrics are,

- Simulation time vs. Alive nodes
- Number of Sensors vs. Network Lifetime
- Simulation time vs. Energy consumption
- Number of Sensors vs. Residual Energy
- Number of Packets vs. End-to-End delay
- Number of Sensors vs. Path length
- Number of Sensors vs. Redundancy check

The above simulation metrics are evaluated and experiments conducted for two kinds of scenarios as follows,

(1). with the use of mobile intelligent agents

(2). without the use of mobile intelligent agents

Finally, it is concluded that with the use of mobile intelligent agents, the performance of network model has improved exponentially for all performance metrics.

IV. Research Highlights

- The designed mixed WSN with IoT sensors are fused with the aim of effective data gathering by improving the network lifetime using goal based intelligent agents. The grid-ring partitioning based head selection mitigates the number of packet exchange between sensors that reflects on reduction of energy consumption.
- Data in WSN is also sensitive at times and hence this work does not wait for the iagent until it reaches the position for data collecting. If the data is sensitive, the CHs pick up a route and forward the data to sink node.
- Super node is selected in each cluster for providing schedules to members using Soft Markov Decision Model. The schedules are provided only for the IoT sensors that are below energy threshold. This is done so, for minimizing the energy consumption in CH and increases the sustainability of the CH.

V. PRIOR WORKS

In this section, what are the works have been previously released in the field of energy aware and delay tolerant sensor network design for wide variety of applications.

Paper 7

Title – An Enhanced Energy-Aware Cluster-Based Routing Algorithm in Wireless Sensor Networks

Concept –

Optimal routing is one of the most important methods in WSN. For this purpose, in this paper authors proposed an enhanced energy aware routing in cluster-based WSN. Firstly a network is divided into cells and then the genetic algorithm is applied to find the optimum number of nodes. To increase the speed of clustering, K-means algorithm is proposed.

Limitations

- Both genetic algorithm and k-means algorithms are time consuming process

Paper 8

Title - A Heterogeneous Energy Wireless Sensor Network Clustering Protocol

Concept –

In this paper, the authors have proposed an energy-coverage ratio clustering protocol for minimizing the energy consumption. According the minimum energy consumption, the optimal number of clusters is determined and then head in cluster is determined from regional coverage maximization. In this work, the initial cluster head is selected randomly and then the total number of heads in the network is determined. By optimal selection of cluster head the energy consumption is reduced.

Paper 9

Title - Big Data Collection in Large-Scale Wireless Sensor Networks

Concept –

In this work the authors have discussed about the incorporation of IoT into heterogeneous WSN where the amount of data from sensors is in larger amount. A big data will be collected due to its supportability on wide range of applications. Energy is one of the key challenge that exist in sensors due to the limitations of battery. Hence this research area focuses on the idea of balancing energy consumption along with the improvement in data transmission.

Paper 10

Title – A forwarding strategy based on ANFIS in internet-of-things-oriented wireless sensor network (WSN) using a novel fuzzy-based cluster head protocol

Concept -

Authors have presented an artificial neural network and fuzzy inference system (ANFIS) for optimal route selection. Along with the ANFIS model, the fuzzy-based CH selection also presented. The major objective of this work is to improve the QoS performance of IoT-oriented WSN networks. For that, multiple parameters such as link bandwidth, centrality, latency, channel state information, SNR, and packet loss ratio are fused by ANFIS model to select optimal route. Here, the ANFIS model is trained by Particle Swarm Optimization (PSO) algorithm.

Limitations

- Typically, PSO has convergence issues and falls in local optimal solutions. Thus, PSO-trained ANFIS algorithm degrades the efficiency of route selection.

Paper 11

Title – Survivable Path Routing in WSN for IoT applications

Concept –

In this paper, authors have proposed a survivable path-based routing in WSN for IoT applications. Authors focus on the performance improvement through optimal route selection. Optimal route is selected based on multiple criteria such as signal-to-noise ratio (SNR), survivability factor, and congestion level. The survivability factor is derived as the ratio of minimum value of available residual energy among every node along that path to the total consumed energy for communication through that path. However, network management is not considered in this work.

Limitations

- To improve the network performance it is also necessary to handle the large scale network since the node located far away from the sink will have large energy consumption and loss rate.

Paper 12

Title - Energy-Efficient Multilevel Heterogeneous Routing Protocol for Wireless Sensor Networks

Concept –

An enhanced balanced energy efficient network-integrated super-heterogeneous (E-BEENISH) is a routing protocol that is presented for balancing energy using cluster based routing. The developed heterogeneous network is operated in four levels. Cluster head is selected based on a weighted probability with is given based on *remaining energy* and *distance*. Hereby, the efficient selection of cluster head enables to reduce energy consumption by gathering the data and transferring it to sink node.

Paper 13

Title - Energy-efficient modified LEACH protocol for IoT application

Concept –

The authors of this paper have developed a modified LEACH protocol for reducing energy consumption. As per LEACH, the CHs are newly selected for each round and so even eligible node is not selected as a CH for next round. In this work, a modified LEACH protocol is presented with a threshold limit and so, if the CH obeys the constraint they it will be re-activated as CH. After electing CH, the data is aggregated from cluster members in the basis of TDMA schedules.

Paper 14

Title – An energy-efficient sleep scheduling mechanism with similarity measure for wireless sensor networks

Concept –

In this proposed work the authors have determined a competition radius for balancing the energy consumption. Initially, the sensors are clustered and the head is selected using distance and residual energy. The cluster members request to join cluster based on TDMA with the request of received signal strength indicator (RSSI). This is followed by the measurement of similarity using fuzzy matrix for identifying the redundant nodes and then put them into sleep state for the next round.

Paper 15

Title – Residual Energy Based Cluster-head Selection in WSNs for IoT Application

Concept –

In this paper the CH is selected and then their position is rotated based on the available energy level in sensor nodes. The residual energy of each sensor node is estimated and compared with other sensor nodes. If it is higher, then the particular sensor will be selected as optimal CH and perform data aggregation based on TDMA. If the energy is lesser, then that node will be as a cluster member.

Paper 16

Title – Intelligent Sensing in Multiagent-based Wireless Sensor Network for Bridge Condition Monitoring System

Concept –

In this work, the authors have proposed agents-based processing for in-network processing in the system. This research is especially developed for bridge condition monitoring. According to this work, an employed sensor announces itself as a CH to the sink node. The migration of agent is determined by the sink node based on the signal strength and energy level. If the sensor node requests for MA, then the sink dispatches a MA into the network.

Paper 17

Title – An empower Hamilton loop based data collection algorithm with mobile agent for WSNs

Concept –

This paper proposes power efficient gathering in sensor information system (PEGASIS) with Hamilton loop algorithm. A mobile agent in the system moves and gathers collected packets from the CH. The Hamilton algorithm is applied to identify a loop for MA to visit all the CHs and reach sink. In this, if any CHs is left out, then they are reconnected and a complete loop is formed. According to the constructed loop, the MA moves on and collects the data from individual CH.

Paper 18

Title – Travel Route Planning with Optimal Coverage in Difficult Wireless Sensor Network Environment

Concept –

The authors of this paper have proposed a travel route planning schema using mobile collector. In this work for route planning the sojourn points are fixed using PSO and then shortest route is preferred using ACO. Sojourn points are predicted by splitting the network area into hexagons. These points are determined from the fitness function (*coverage area and overlapping coverage area*).

Paper 19

Title – iAgent: When AI Meets Mobile Agent

Concept –

In this paper, the authors have detailed with the use of mobile agents as an intelligent agents. These iagents are broadly categorized into four types as simple – reflex iagent, model based iagent, goal based iagent and utility based iagent. Each type has their own procedure and the energy consumption is evaluated for each type that is deployed in WSN. Among four types, the simple-reflex iagent consumes higher energy. Also this paper compares the use of single iagent and multi iagent, from which the multi-iagent comparatively consumes lesser energy than single iagent in the network.

Paper 20

Title – Mobile agents-based data aggregation in WSNs: benchmarking itinerary planning approaches

Concept –

This paper discusses about the idea of extending network lifetime by using mobile agents. These MAs are incorporated for handling the data process of data aggregation effectively by prolonging network lifetime. Heuristic algorithms are used for itinerary planning of MAs path to gather sensed data.

BIBILIOGRAPPHY

Amine Rais, Khalid Bouragba, Mohammed Ouzzif, "Routing and Clustering of sensor Nodes in the Honeycomb Architecture", Journal of Computer Networks and Communications, 2019.

Kale Navnath Dattatraya K. Raghava Rao, "Hybrid based cluster head selection for maximizing network lifetime and energy efficiency in WSN", Journal of King Saud University - Computer and Information Sciences, 2019.

Yu Gao, Jin Wang, Wenbing Wu, Arun Kumar Sangaiah, Se-Jung Lim, "A Hybrid Method for Mobile Agent Moving Trajectory Scheduling using ACO and PSO in WSNs", Sensors, Vol.19, No. 3, 2019.

Mohamed El Fissaoui, Abderrahim Beni-hssane, Mostafa Saadi, "Multi-mobile agent itinerary planning-based energy and fault aware data aggregation in wireless sensor networks", EURASIP Journal on Wireless Communications and Networking, 2018.

Hanane Aznaoui, Said Raghay, Youssef Ouakrim, Layla Aziz, "A Heuristic Algorithm of Cooperative Agents Communication for Enhanced GAF Routing Protocol in WSNs", Wireless Communications and Mobile Computing, 2019.

Mukhtar Ghaleb, Shamala Subramaniam, Safwan M. Ghaleb, "An Adaptive Data Gathering Algorithm for Minimum Travel Route Planning in WSNs Based on Rendezvous Points", Symmetry, Vol. 11, No. 11, 2019.

Dehghani, S., Barekatain, B., & Pourzaferani, M. (2017). An Enhanced Energy-Aware Cluster-Based Routing Algorithm in Wireless Sensor Networks. Wireless Personal Communications, Vol. 98(1), PP.1605–1635.

Mengjia Zeng, Xu Huang, Bo Zheng, Xiangxiang Fan, "A Heterogeneous Energy Wireless Sensor Network Clustering Protocol", Wireless Communication and Mobile Computing, 2019.

Asside Christian Djedouboum, Ado Adamou Abba Ari, Abdelhak Mourad Guroui, Alidou Mohamadou, Zibouda Aliouat, "Big Data Collection in Large-Scale Wireless Sensor Networks", Sensors, 2018.

Kumar, S., Lal, N., & Chaurasiya, V.K. (2018). A forwarding strategy based on ANFIS in internet-of-things-oriented wireless sensor network (WSN) using a novel fuzzy-based cluster head protocol. Annals of Telecommunications, 73, 627-638

Elappila, M., Chinara, S., & Parhi, D.R. (2018). Survivable Path Routing in WSN for IoT applications. Pervasive and Mobile Computing, 43, 49-63.

Yinghui Zhang, Xiaolu Zhang, Shuang Ning, Jing Gao, Yang Liu, "Energy-Efficient Multilevel Heterogeneous Routing Protocol for Wireless Sensor Networks", IEEE Access, Vol. 7, pp. 55873 – 55884, 2019.

Trupti, Mayee Bahera, Umesh Changdra Samai, Sushanta Kumar Mohapatra, "Energy-efficient modified LEACH protocol for IoT application", IET Wireless Sensor systems, Vol. 8, No. 5, pp. 222 – 228, 2018.

Runze Wan, Naixue Xiong, Nguyen The Loc, "An energy-efficient sleep scheduling mechanism with similarity measure for wireless sensor networks", Human-centric Computing and Information Sciences, 2018.

Trupti Mayee Behera, Sushanta Kumar Mohapatra, Umesh Chandra Samal, Mohammas S. Khan, Mahmoud Daneshmand, Amir H. Gandomi, "Residual Energy Based Cluster-head Selection in WSNs for IoT Application", IEEE Internet of Things Journal, Vol. 6, No. 3, pp. 5132 – 5139, 2019.

Seno Adi Putra, Bambang Riyanto Trilaksono, Muhammad Riyansyah, Dina Shona Laila, Agung Harsoya, Achmad Imam Kistijantoro, "Intelligent Sensing in Multiagent-based Wireless Sensor Network for Bridge Condition Monitoring System", IEEE Internet of Things Journal, Vol. 6, No. 3, pp. 5397 – 5410, 2019.

Jin Wang, Xiujian Gu, Wei Liu, Arun Kumar Sangaiah, Hye-Jin Kim, "An empower Hamilton loop based data collection algorithm with mobile agent for WSNs", Human-centric Computing and Information Sciences, No. 18, 2019.

Yu Gao, Jin Wang, Wenbing Wu, Arun Kumar Sangaiah, Se-Jung Lim, "Travel Route Planning with Optimal Coverage in Difficult Wireless Sensor Network Environment", Sensors, Vol. 19, No. 8, 2019.

Jiayi Lu, Wenjing Xiao, Enmin Song, Mohammad Mehedi Hassan, Ahmad Almogren, Ayman Altameem, "iAgent: When AI meets Mobile Agent", IEEE Access, Vol. 7, pp. 97032 – 97040, 2019.

Ioannis E. Venetis, Damianos Gavalas , Grammati E. Pantziou, Charalampos Konstantopoulos, "Mobile agents-based data aggregation in WSNs: benchmarking itinerary planning approaches", Wireless Networks, Vol. 24, No. 6, pp. 2111 – 2132, 2018.