A multi agent based energy and fault aware scheme for WSN of hard-to-reach territories

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Abstract: There are various applications of sensor networks in hard-to-reach territories. Sensor has limited energy. Therefore, several energy efficient methodologies have been devised to minimise the energy consumption. The manuscript discovers and resolves limitations of the existing multiple agent schemes which include energy consumption, fault handling, itinerary planning and positioning of sink. Existing protocols placed sink at centre of sensing area. This job is very difficult in hard-to-reach territories. So, a multi agent based energy and fault aware scheme for hard-to-reach territories (MAHT) has been devised. It provides a method of accumulated impact factor (AIF) for identifying the central node with high energy. Its novel agent migration scheme improves the energy efficiency. Planning the itinerary dynamically results in fault tolerance. Proposed protocol is simulated with Castalia simulator and its performance is evaluated on various metrics demonstrating that MAHT outperforms the existing schemes.

Keywords: mobile agents; fault tolerance; energy efficiency; WSN; wireless sensor network; AIF; accumulated impact factor.

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1 Introduction

Sensor networks are deployed in a region to sense various physical conditions viz., temperature, pressure, light, motion etc. These networks consist of various sensors which are interconnected wirelessly. Sensed data by these networks can be kept at cloud for further processing. This provides several services and facilities to the end users. These networks are the basis of various Internet of Things (IoT) applications viz., smart forest fire detection system, smart farming, smart healthcare, smart vehicular network systems etc. WSN are also used in many other areas viz., weather monitoring, disaster management, traffic monitoring, underground monitoring, underwater monitoring etc. (Cheng et al., 2012, 2019a; Chelbi et al., 2018; Khoufi et al., 2017; Verma and Dwivedi, 2017; Osamaa et al., 2016). Sensor nodes can be deployed in two ways: randomly or in fixed manner. In easy-to-reach areas, it is possible to deploy them in both ways but in hard-to-reach regions we have to deploy them randomly. These nodes are operated on batteries. It is very difficult to change the batteries in hard-to-reach areas. So, power efficiency becomes a big challenge with this network. There are many other challenges of WSN such as QoS, security, energy efficiency etc. (Cheng et al., 2016, 2019b; Mohamed et al., 2018; Shahbazian and Ghorashi, 2018; Wang et al., 2018; Dwivedi et al., 2012). Many protocols have been developed to solve these issues. This paper deals with the issue of energy efficiency and discusses some schemes to solve this issue. Energy efficient schemes of WSN can be categorised into two ways: one is non-agent based and the other is agent based (Kulik et al., 1999, 2002; Yu et al., 2001; Heinzelman et al., 2000; Intanagonwiwat et al., 2000; Chen et al., 2007). An agent based protocol uses mobile agent which is a program that migrates to the sensors for data collection. Few researches have shown that an agent helps to improve energy efficiency and minimise the cost of communication (Sasirekha and Swamynathan, 2017; Verma and Dwivedi, 2016; Chen and Leung, 2006). This paper presents a multi agent based fault aware and energy efficient protocol 'MAHT'. It plans the itineraries dynamically which in turn makes the system fault tolerant.

1.1 Motivation

Sensors work on batteries and it is very difficult to replace these batteries in hard-to-reach regions. So, energy saving became a primary concern in such sensor networks. It has been shown by several researches that agent based energy aware protocols perform better than non-agent based protocols (Jing et al., 2017; Vijayalakshmi and Bhuvaneswari, 2016; Chen et al., 2011). Agents implement data aggregation in which duplicate data is removed. It helps in energy saving. One or multiple agents can be used in agent based protocols. Single agent based protocols have some limitations in big networks such as data loss, delay and unbalanced load. Results indicate that multi agent based protocols outperform the single agent based protocols (Gupta and Mishra, 2015; Pantazis et al., 2013; Gupta et al., 2011). This paper deals with multi agent based energy efficient protocols. Few existing multi agent based protocols viz., multiple mobile agents with dynamic itineraries based data dissemination (MMADIDD) and tree based itinerary design (TBID) are outperforming in easy-to-reach regions but not suitable in hard-to-reach areas due to some limitations. These limitations include: problems in positioning sink at centre of the hard-to-reach sensing region, unnecessarily selecting all sensor nodes for data collection instead of only source sensors and weak agent migration procedure. This gives us motivation to do research for developing a fault aware and energy efficient protocol of WSN for hard-to-reach areas. Therefore, a multi agent based protocol called MAHT is devised and presented in this paper which satisfies the above requirements.

1.2 Contributions

There are several applications of WSN in hard-to-reach areas where energy of the nodes matters. To design an agent based energy efficient scheme of WSN, itinerary planning becomes a major challenge (Chen et al., 2010; Qi and Wang, 2001; Wu et al., 2004; Fissaoui et al., 2018). In this regard, we devised a multi agent based fault aware and energy efficient protocol for hard-to-reach areas called MAHT where we derived dynamic itineraries for data collection that also handles the faults. Considering these challenges, this paper makes the following contributions:

- computation of accumulated impact factor (AIF)
- identification of central node (CN) using AIF
- creation of various groups in the monitoring region that is centred at CN
- dispatch of agents into the created groups from CN
- migration of agents with dynamic itinerary planning
- data collection using agents.

1.3 Organisation of the paper

The rest of the paper is organised as follows. Section 2 describes related work in which two multi agent based protocols are taken into account. The proposed scheme is discussed in Section 3. Section 4 presents simulation results. It also compares the proposed MAHT protocol with the existing multi agent based protocols. Finally, Section 5 concludes the work along with offering some future directions.

2 Related work

Different groups of the sensors are created in multi agent based protocols and agents are migrated in each group separately. Agent's itinerary is obtained by using single agent based protocol in each group. Multi agent based schemes minimise the task completion time (Chen et al., 2009). This paper focuses on two such schemes viz., TBID and MMADIDD.

TBID is a multiple agent based protocol of WSN. Spanning forest of the binary trees rooted at the sink is created in this protocol. Use of multi agents makes this protocol better than the single agent based protocols (Konstantopoulos et al., 2010). This scheme plans the itinerary statically i.e., sink decides the itinerary before agent migration. Post order traversal is used in this protocol for migration of the agents. Post order traversal results in reverse trips which is unwanted. Protocol is not fault tolerant because of static itinerary planning. This protocol considers circular monitoring area of deployment where sink is situated at the centre of the region. So, it is suitable only for easy-to-reach areas and not for hard-to-reach territories because in hard-to-reach areas, it is not necessary that nodes are deployed exactly in circular region and sink is placed exactly at the centre position. All the sensor nodes may not contain the required data for a particular data collection application of the sensor networks. A fraction of nodes which participate in data collection for an application are called source sensor nodes. Itinerary must contain only these source nodes. How to find region of only source nodes is not discussed in this protocol. Agent migration process of this protocol can be made better for improvement of the results.

MMADIDD is also a multiple agent based protocol of WSN. This protocol implements dynamic itinerary planning which controls the unexpected node failures. Here, itinerary is planned at run time that makes the protocol fault tolerant. In this protocol, nodes are distributed uniformly to balance the energy usage. This protocol also uses circular monitoring region but here agent migration process is different. Here, region is divided into several sectors and agents are migrated for data collection in each of these sectors separately. This agent migration method produces better results and reduces the length of the itinerary (Gupta and Mishra, 2011, 2012). This protocol gives better results in easy-to-reach areas but has limitations for hard-to-reach areas because in hard-to-reach areas it is not certain that the monitoring area will be circular only and sink will be located precisely at its centre. In this protocol agent migrates to all the nodes. It is possible that different types of sensors are deployed in a region to sense the different type of data. So, at a particular instance all the nodes are not the nodes which are the source of data. Therefore, all the nodes must not be traversed. If only nodes which are the actual source of data are traversed by the agents then energy efficiency will be better. In agent migration process of this protocol, some nodes are traversed more than one time which can be optimised for better results in a way that all nodes are traversed only one time.

3 Proposed approach

This paper devises a protocol named as "multi agent based energy and fault aware protocol for hard-to-reach territories (MAHT)". It removes the limitations of the existing schemes. Finding central node for locating sink in any hard-to-reach area is a big issue. Proposed protocol solves this issue by giving the algorithm to identify the central node 'CN' using technique of AIF. CN may be connected with sink that might be kept anywhere. Proposed scheme assigns the impact factors only to the source nodes and not to all sensor nodes. Proposed protocol devises a better agent migration process in which the each node is traversed only one time in a particular round of data collection. It improves the energy efficiency. Thus, this approach solves the limitations of the existing protocols.

Algorithm 1 of the proposed scheme provides the computing procedure of AIF. AIF denotes the impact of other source nodes on a particular source node. It is computed with help of impact factor (*IF*). Impact Factor is a constant. Each source node has an impact to the other source nodes which can be decided on basis of hop distance between them. The nodes share the information of *IF* with each other. If there are k source nodes then each source node will receive information about k–1 impact factors. Source nodes with the largest hop count will have the smallest *IF* and vice versa. Impact Factor of node j at node i (IF_{ij}) is computed as given in equation (1). Here c is a constant and h_{ij} is hop count of the shortest path from node i to j. We assumed $c = 2$ in this paper.

$$IF_{ij} = \frac{c}{h_{ij}} \tag{1}$$

AIF of a node is summation of the impact factors of other nodes at that node. AIF at source node i AIF_i is computed according to equation (2). Here k is the total no. of source nodes.

$$AIF_i = \sum_{\substack{j=1 \\ j \neq i}}^{k} IF_{ij} = c \sum_{\substack{j=1 \\ j \neq i}}^{k} \frac{1}{h_{ij}} \tag{2}$$

Algorithm 2 identifies the central node 'CN' using method of AIF. Node which has energy more than a threshold value and maximum AIF is decided to become the central node. This algorithm finds central node of the monitoring region. Here, monitoring area appears almost circular and consists of only source nodes. If there are some source nodes which are not covered in the group then it finds the next CN by repeating the same procedure.

Algorithm 1: AIF computation at each source sensor node

Input: Sensor network with k source nodes (each node i maintaining a list of k-1 impact factors)
Output: AIF

Begin
Step 1: Find the minimum hop counts required to reach other source nodes
Step 2: Compute IF
// IF is decided on basis of hop count
Step 3: Inform its IF to other source nodes
Step 4: Record IF received from all other source nodes
Step 5: Compute AIF of the node from all received IF
// AIF is impact of other source nodes at a particular source node
Step 6: Broadcast its AIF to other source nodes
End

Algorithm 2: Central Node Identification

Input: AIF
Output: Identified CN

Begin
Step 1: Record AIF of all source nodes
Step 2: Sort these AIF in descending order and keep in list S
Step 3: **Loop** until CN is identified
Step 4: Get the first AIF from S // It is the highest AIF value of node F
Step 5: **If** (AIF of F is same with other nodes)
Step 6: Find list of nodes L having same AIF
Step 7: Remove it from sorted list and update S
Step 8: **Loop** for all elements of list L
Step 9: Find the node E from L having highest energy
Step 10: **If** (Energy of E > Threshold Energy)
Step 11: Notify it as CN
Step 12: **Else**
Step 13: go to Step 9 and find next node E of L with high energy
Step 14: **End of inner loop**
Step 15: **If** (CN is identified)
Step 16: go to Step 25 and end the procedure
Step 17: **Else**
Step 18: go to Step 3 to check next node with highest AIF
Step 19: **Else**
Step 20: Remove it from sorted list and update S
Step 21: **If** (Energy of F > Threshold Energy)
Step 22: Notify it as CN
Step 23: **Else**
Step 24: go to Step 3 to check next node with highest AIF
Step 25: End of outer loop
End

Algorithm 3 shows the procedure of dispatching agents in different groups of source sensors that are uniformly distributed. Route is decided dynamically at each hop of the agent and thus makes the protocol fault tolerant. Thus, Algorithm 3 produces dynamic itineraries of the agents. Here, each node is traversed only one time which helps in saving energy of the sensors. In this way, MAHT results in better network lifetime and energy efficiency than that of existing schemes.

Algorithm 3: Dispatching Agents

Input: Source sensor nodes, agents
Output: Agent allocation to different groups of source sensors

Begin
Step 1: Create different groups of uniformly distributed source sensors
Step 2: Allocate individual agents to each group
Step 3: Assign information of nodes of the group to its respective agent
Step 4: Dispatch the agent to its corresponding group for data collection
End

Algorithm 4 presents the procedure of data collection using mobile agents. The monitoring region is divided into various groups. Multiple agents are migrated (one in each group) for data collection. It reduces the task completion time. These agents also implement aggregation during their migration. Redundant data is filtered or removed during aggregation. The proposed procedure of data aggregation reduces the power consumption and makes the protocol better in terms of power efficiency.

Algorithm 4: Data Collection

Input: Source sensor nodes of a group, allocated agent to that group
Output: Collected data with dynamic itinerary

Begin
Step 1: Create multiple narrow linear subgroups from the CN to the end node within the group
Step 2: Start agent migration from CN and perform Step 3 to 6 until all source nodes are traversed
Step 3: Migrate to first nearest node
Step 4: Receives data
Step 5: Remove the redundancy if any
Step 6: Migrate to the next nearest node
Step 7: Report CN with all collected data
End

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4 Performance evaluation

MAHT is simulated on i7 processor with Castalia Simulator (Castalia Simulator: Last Accessed 2019).

4.1 Simulation setup

Simulation environment is setup for 50 to 300 sensors for 1000 s in monitoring region of 500×500. The range of transmission is set to 25 m. Table 1 shows various simulation parameters of the proposed scheme.

Table 1 Simulation parameters

Parameter name	*Value*
Sensors	50–300
Monitoring region size	500 × 500
Range of transmission	25 m
Time for Simulation	1000 s
Initial power of the battery	18720 J
Energy consumed by agent processing	5 nJ
Size of processing code of the agent	1024 B
Data size at every sensor (d)	100 B
MAC Protocol	IEEE 802.15.4

4.2 Performance metrics

We have considered two performance metrics namely average energy consumption and response time for evaluating the performance of the proposed scheme. We define them as follows:

4.2.1 Average energy consumption

Average Energy Consumption (E_{avg}) is defined as the ratio of total energy (E_{total}) to total nodes (N) as shown in equation (3).

$$E_{avg} = \frac{E_{total}}{N} \tag{3}$$

4.2.2 Response time

Response time ($T_{response}$) is defined as the average time needed for completing one round of data collection. We can represent it as ratio of the sum of maximum time of data collection in each round (max_T_i) to the total rounds (x) as shown in equation (4).

$$T_{response} = \frac{\sum_{i=1}^{x} \max\_T_i}{x} \tag{4}$$

4.3 Results and analysis

We compare our protocol MAHT with the existing protocols TBID and MMADIDD. On basis of simulation results, it can be analysed that proposed protocol outperforms over existing ones.

4.3.1 Effect of data payload on energy consumption and response time

The effect of data payload size (d) on average energy consumption and response time are described as follows:

Figure 1 Average energy consumption vs. data payload size (see online version for colours)

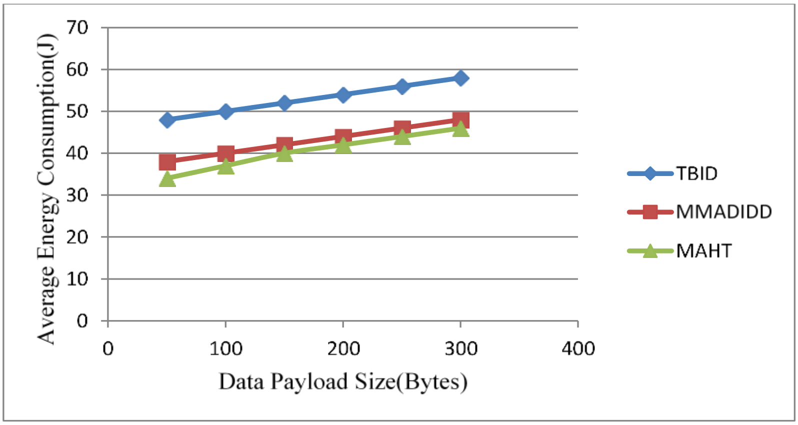


Figure 1 confirms that average energy consumption in MAHT as well as in the existing schemes increases when data payload size is increased. Energy consumption in MAHT is lower than that of the existing schemes. It is the result of a novel agent migration scheme of MAHT as well as uniform node distribution.

Figure 2 displays that response time in MAHT as well as in the existing schemes increases when data payload size is increased. Response time of MAHT is lower as compared to the existing schemes. This is due to new agent migration scheme of the proposed scheme.

Figure 2 Response time vs. data payload size (see online version for colours)

4.3.2 Effect of network size on energy consumption and response time

The effect of number of the nodes in the network on average energy consumption and response time are described as follows:

Figure 3 Average energy consumption vs. network size (see online version for colours)

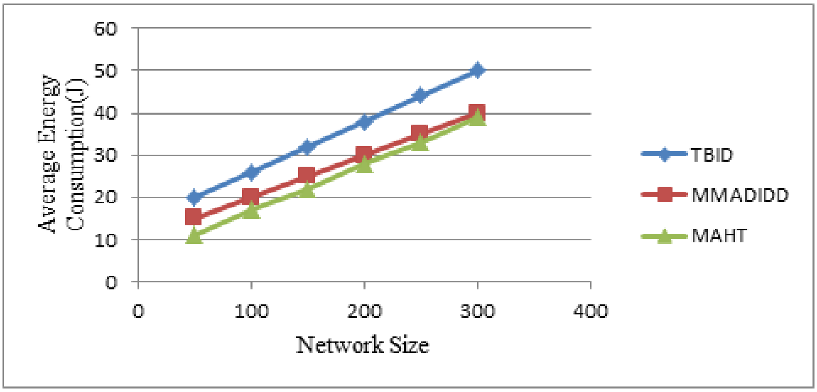
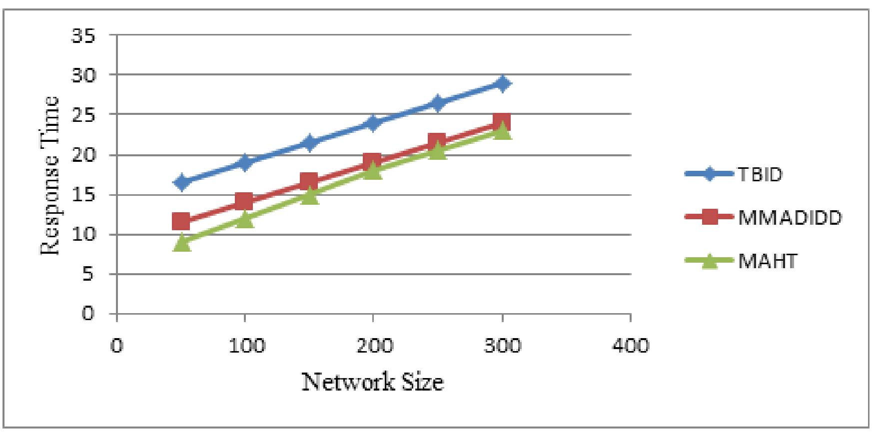


Figure 3 indicates that average energy consumption in MAHT as well as in the existing approaches increases when network size is increased. This consumption is lower in MAHT as compared to the existing schemes. This is due to uniform distribution of the sensors and optimised agent migration scheme of MAHT.

Figure 4 illustrates that response time in MAHT and in the existing methodologies increases when network size is increased. It is lower in MAHT than that of the existing schemes. This is due to the novel agent migration technique used in MAHT.

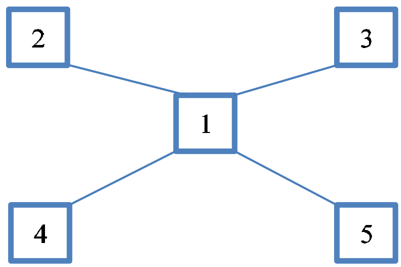
Figure 4 Response time vs. network size (see online version for colours)



4.4 Discussion

Let us consider a typical sensor network as shown in Figure 5 in which there are five sensor nodes. Now compute AIF for all the nodes. The node, whose AIF is highest, will be decided as the central node. Assume that, IF for 1 hop and 2 hops are 2 and 1 respectively. Now compute AIF for each node one by one. First, check the impact of all nodes on node 1. All nodes are at one hop count from node 1. So, AIF of node 1 will be sum of impact factors of all nodes at this node that is 8 (2+2+2+2). Now, compute AIF of node 2. Here, we can see that node 1 is at 1 hop count to this node while other nodes are at 2 hop count. So, AIF of node 2 will be 5 (2+1+1+1). Now, let us check the AIF of node 3. Node 3 is at 1 hop distance from node 1 while it is at 2 hop distance from other nodes. Therefore, AIF of node 3 will also be 5 (2+1+1+1). Similarly, AIF of node 4 and node 5 are also computed and found 5 for each of them. Here, it is observed that node 1 has the highest AIF. Therefore, node 1 will be decided as CN in this case. Here, we assumed that all nodes are having distinct values of energy which is more than the threshold value.

Figure 5 A typical sensor network (see online version for colours)



4.5 Salient features of MAHT

MAHT implements data aggregation in which it removes the redundant data during data collection. Agent migration technique of MAHT is also better than that of the existing schemes. It results in better energy efficiency. It is observed that MAHT outperforms the existing protocols. Proposed protocol is a fault aware and energy efficient multi agent based scheme which is fit for hard-to-reach territories. Some salient features of MAHT are discussed as follows:

4.5.1 Fault tolerance

MAHT uses dynamic itinerary planning in which route is decided at run time. The dynamic itinerary planning helps in rejection or handling of the faulty nodes which results in fault tolerance.

4.5.2 Energy efficiency

Itinerary length in MAHT is shorter than the existing schemes. It results in better energy efficiency than TBID and MMADIDD. Better energy efficient solution of the protocol also increases the network life time.

4.5.3 Suitability in hard-to-reach territories

Placing sink at centre of the sensing region in hard-to-reach areas is a tough job. To handle this problem, MAHT provides a technique to identify the central node using AIF. This makes the proposed protocol suitable for hard-to-reach territories.

5 Conclusions and future work

A novel fault tolerant and energy efficient multi agent based scheme named as MAHT is devised and presented in this paper. This scheme is fit for hard-to-reach regions. Existing researches have shown that if sensing region is circular and sink node is placed at its centre then energy efficiency is improved. But, it is too difficult to place sink at centre of the region in hard-to-reach areas. MAHT provides techniques to deal with this problem. In this direction, the paper demonstrates four main algorithms of MAHT. First and second algorithms help in identification of the central node 'CN' with help of AIF. Third and fourth algorithms contribute in data collection process by performing the mobile agent migration in a better way. MAHT uses technique of AIF to find CN that has higher energy than other source sensors of the network. CN identification process is also justified in this paper by providing a typical scenario of a WSN. The sensing region centred at CN is divided into different groups of source nodes. CN dispatches one agent in each group of sensors to collect the sensed data. These agents also implement data aggregation during data collection in which redundant data is filtered or removed. Agent migration scheme of MAHT improves the energy usage which results in a better network lifetime. MAHT uses dynamic itinerary planning which results in fault tolerance. We have compared MAHT with MMADIDD and TBID on various performance metrics and observed that MAHT outperforms the existing schemes.

In future, some security mechanisms over various network attacks can be added with this protocol. To reduce the agents' overhead, we can add some new works too.

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