Multiple Mobile Agents based Data Dissemination Protocol for Wireless Sensor Networks

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Abstract. Energy Efficient and reliable data dissemination in wireless sensor network is an important research issue since the network consists of low cost nodes with limited resources. Mobile agent-based data dissemination (MADD) approach that deploys multiple mobile agents for the data gathering task is a flexible, robust, and distributed solution to the data dissemination problem in wireless sensor networks. However the manners in which mobile agents follow the itineraries (order of visited sensor nodes) have an impact on the efficiency of the data gathering. In this paper, we propose a multiple mobile agents with dynamic itineraries based data dissemination (MMADIDD) protocol that not only adapts to unexpected node failures but also prolongs the network lifetime.

Keywords: Wireless sensor network, Data Dissemination, Mobile agent.

1 Introduction

Recent advances in embedded micro-electro-mechanism system (MEMS) and wireless communication technologies have enabled the development of small size, low-cost sensor nodes with sensing, computation and wireless communication capabilities [1].Wireless sensor networks (WSNs) consist of a large number of these tiny sensor nodes that cooperatively monitor and react to physical or environmental phenomenon and send the collected data to a sink using wireless channels. WSNs have found many applications in areas such as battlefield surveillance, industrial process monitoring and control, environmental and habitat monitoring, home automation, traffic control, and healthcare applications [2], [3]. Sensor nodes are usually battery powered and they are left unattended after the initial deployment and it is difficult to recharge them. So an important issue in the design and efficient implementation of wireless sensor networks is to optimized energy consumption and keep the network functional for as long as possible.

Recently, mobile agent based computing paradigm has been proposed in the field of WSNs [4], [5], [6], [7], [12]. A mobile agent[7] is a special kind of software process that has ability to migrate from one node to another following certain itinerary and perform data aggregation locally at each node. Mobile agent based computing

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paradigm presents several important benefits [5]. First, it can significantly reduce bandwidth consumption by moving the computation process to the location of the sensed data; otherwise its transmission in raw form would consume more energy of the node. In addition, mobile agent computing paradigm also provides stability and fault-tolerance since it can be dispatched when the network connection is alive and return results when the connection is re-established. Finally, mobile agent can also extend the functionality of network by carry task-adaptive processing code [5], [6].

Mobile agent based data dissemination process in WSN largely depends on the planning of the mobile agent itinerary (order of sensor nodes to be visited during the mobile agent migration) [7].Itinerary planning can be classified as static or dynamic according to place where mobile agent routing decisions are made [7]. A dynamic itinerary planning scheme determines the route on the fly at each hop of the mobile agent, while a static scheme derives the route at the mobile agent dispatcher (i.e. sink) node before mobile agent is dispatched and it is based on global information of network topology. A mobile agent with dynamic itinerary is more flexible, and can adapt to faults during its traversal by changing its itinerary on the fly [7]. However, the node or link failures may invalidate the static itineraries determined centrally at the sink. In static scheme, sink node require to maintain global information of network topology for determining the itineraries of mobile agents. While in dynamic scheme, sink does not require to maintain global information of network topology [13].

In this paper, we propose a multiple mobile agents with dynamic itineraries based data dissemination protocol (MMADIDD) that uses multiple mobile agents for data dissemination task and each mobile agent is responsible for collecting sensed data from a particular area and determines its route on fly at each hop using local information. Our protocol not only adapts to unexpected node failures but also prolongs the network lifetime. The proposed protocol is designed for monitoring applications to obtain the periodically sensed data, such as temperature, humidity, and pressure, from the surrounding environments. The performance of our protocol is evaluated through a number of simulation results, which show that our protocol performs better than static itinerary based protocol when node or link failures occur en route.

The rest of the paper is organized as follows: we briefly describe works related to the research presented herein in Section 2. In Section 3, we present system model and list the assumptions in our work. In Section 4, we describe our proposed MMADIDD protocol in detail. Section 5 describes our simulation environment in detail and compares the performance of our protocol with other protocols with respect to the selected metrics of interest. Finally, Section 6 concludes this paper.

2 Related Work

Recently, mobile agents [4], [5], [6], [8], [11], [12], [13] have been proposed for data dissemination task in wireless sensor networks. In [4], H. Qi et al. proposed two heuristic protocols, Local Closest First (LCF) and Global Closest First (GCF) to derive the itinerary of mobile agent for performing data gathering task. In LCF, mobile agent starts its route from the sink and searches for next destination with shortest distance to its current location. In GCF, each mobile agent also starts its route from the sink and selects the next closest node to the sink as its next destination. The performance of LCF depends on current location of mobile agent. Wu et al. [7] proposed a genetic algorithm (GA) for computing itinerary of mobile agent .It uses global network topology information to derive the static itinerary of mobile agent and provides better performance than LCF and GCF protocols in terms of energy consumption. The protocols proposed in [4] and [7] use single mobile agent to visit all sensor nodes and their performance is reasonable for small network; however, it declines as the network size grows. This is because mobile agent's size increases as network size increases resulting in more energy consumption and more time to finish the data gathering task.

In [11], M. Chen et al. proposed multi agent Itinerary Planning (MIP) algorithm. MIP is a centralized algorithm executed at sink and divides the deployed sensor nodes into different groups and in each group, single agent based protocol like LCF, GCF or GA is used to derive the itineraries of mobile agents. This approach reduces the task completion time than single agent based approach. In [13], Charalampos et al. proposed a tree based itinerary design (TBID) algorithm that employs multiple mobile agents for data gathering task in WSNs. In this method, it is assumed that sink knows the geographic location of all the sensor nodes. TBID algorithm is a centralized algorithm and is executed at sink. After processing, it determines the number of mobile agent used for data gathering and its itineraries. This algorithm follows greedy methods for grouping sensor nodes in multiple mobile agent itineraries. Basically, it builds a spanning forest of binary trees rooted at sink in network and calculates itineraries by post order traversal of binary trees and finally, assigns these itineraries to individual mobile agents. In this scheme, each mobile agent carries the pre-computed itinerary that determines the order of sensor nodes to be visited. The main limitation of static itinerary based approach is that mobile agent cannot complete its data dissemination task if a node or link fails en route.

3 System Model

In this paper, we consider a sensor network consisting of N sensor nodes uniformly distributed in a circular monitoring area of radius R, as in [16], as shown in Figure1(a). There is only one sink node that is located at the centre of the area. We make the following assumptions:

- All the sensor nodes are static, homogeneous and have the same computational and communication capabilities.
- Initially all nodes are charged with the same amount of energy.
- Wireless links are bidirectional.
- Sink node is static and uses a directional antenna for equiangular wedge setup and to dispatch mobile agent. However, its receiving antenna is omni-directional.
- Each node is assigned a unique identifier (ID).

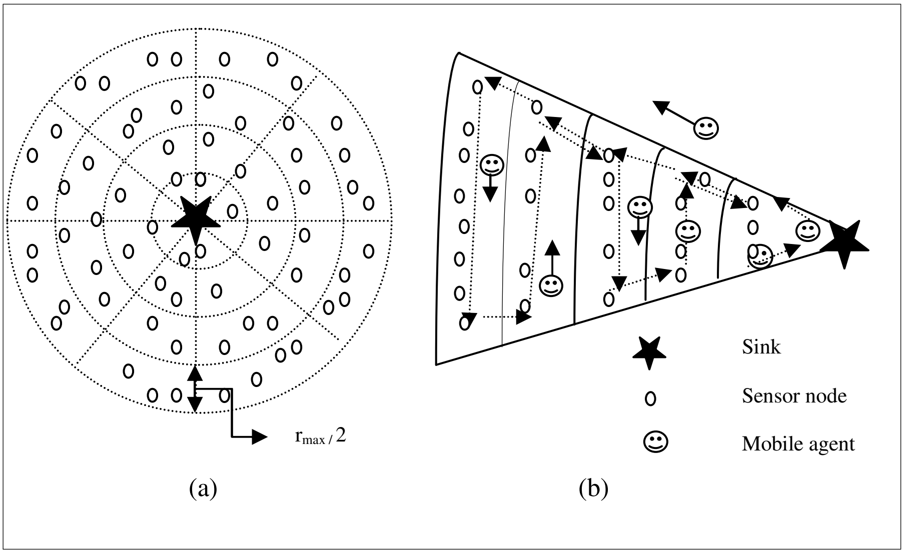

Fig. 1. (a) Network structure model. (b) Mobile Agent Migration Process

4 Proposed Data Dissemination Protocol

In this section, we present our proposed MMADIDD (multiple mobile agents with dynamic itinerary based data dissemination) protocol. Our protocol consists of two phases: initialization process and mobile agent migration process.

4.1 Initialization Process

This process is further divided into two sub processes: circular coronas and equiangular wedge setup process and neighbor discovery process. In circular coronas and equiangular wedge setup process, we aim to divide whole circular monitoring area into coronas and wedges. The width of each corona is $r_{max} / 2$ as shown in Figure 1(a), where r_{max} is the maximum transmission range of any sensor node. The angle of each wedge is 45 degree i.e. whole monitoring area is divided into eight equiangular wedges centered at sink. After this phase, each node knows its corona and wedge number and also sets its boundaryState field if it is located at boundary of wedge. The main aim of this process is to determine the visiting area of each mobile agent. Since circular sensing area is divided into eight equiangular wedges, for data gathering from each wedge, sink dispatches eight mobile agents in parallel, one for each corresponding wedge. The pseudo code for coronas and wedge construction phase is given in Algorithm 1 and 2.

Algorithm 1. Concentric Coronas Creation

For the Sink:

```
R = radius of circular monitoring area
r = the maximum transmission range of sensor node
CN = corona number
i=1
for R <= 0 do
   sink node create a CoronasCreationPkt packet with CN field set to i
   adjust the transmission power equivalent to transmission range i× r/2
   Broadcast   CoronasCreationPkt (sinkID, CN)
   R = R – r/2;
    i = i + 1
   wait for time t1
```

For any sensor node (i):

```
Initialize: corona state cn = 0
if (receive CoronasCreationPkt and cn = =0)
     set cn by CN field of received CoronasCreationPkt
```

Algorithm 2. Equiangular Wedge Creation

For the Sink:

```
WN = wedge number
j=1
θ = 45 // set angle of directional antenna
adjust the transmission power equivalent to transmission range R
while (θ < = 360)
   sink create a WedgeCreationPkt   packet with WN field set to j
   adjust angle of directional antenna by θ
   Broadcast WedgeCreationPkt (sinkID, WN)
   θ = θ + 45
   j = j+1
   wait for time t2
```

For any sensor node (i):

```
Initialize: wedgeNo state wn = 0
if (receive WedgeCreationPkt and wn = =0)
   set wn by WN field of received WedgeCreationPkt
```

In one-hop neighbor discovery process, each node is made to broadcast HELLO packets only once, which includes their nodeID, remaining energy, start time, wedge Number and coronas number. All one hope neighbors of any node that receive HELLO packet update their neighbor table. The neighbor table at each node maintains information – nodeID of the neighbor node from which it has received the Hello packet, the remaining energy at the neighbor node, distance of neighbor node, corona and wedge number of the neighbor node from which it has received the Hello packet. This phase is invoked by sink node. The pseudo code for neighbor discovery phase is given in Algorithm 3.

Algorithm 3. Neighbor Discovery

For the Sink:
1: sink node create a HELLO packet
2: Broadcast HELLO packet to its 1-hop neighbor
3: if (receive HELLO packet)
4: Update Neighbor table
For any sensor node (i):
1: Initialize: timeOn = false
2: boundaryNode = false
3: outerNode = false
4: if (receive HELLO packet from own Wedge)
5: Update Neighbor table
6: else
7: set boundaryNode = true
8: if (timeOn is false)
9: create HELLO packet
10: set timeOn = true
11. Broadcast HELLO packet

4.2 Mobile Agent Migration Process

Mobile agent migration process is divided into two phases. In first phase, mobile agent is forwarded by boundary nodes of wedge W_i until it reaches to outer ring or corona. In second phase, mobile agent starts its data aggregation and gathering task from sensor nodes of outer corona C_k to next inner corona C_{k-1} of same wedge W_i and so on until it reaches at sink as shown in Figure 1(b). In each sector S_{ij}, mobile agent starts its data collection from one boundary node to another by using least-cost based multi-hop routing scheme i.e. it migrates to node which is nearest and has highest enough node energy . The cost function for mobile agent forwarded from node N_i to node N_j is derived from [6]:

$$C_{ij} = w \cdot \frac{d}{R} + (1 - w) \cdot \frac{E}{E_{\max}} \tag{1}$$

Where d is the distance between sensor node N_i and N_j, R is the maximum transmission range of sensor node, E is the remaining energy of node N_j, E_{max} is the initial energy of sensor node, w is used to adjust the importance between distance and energy component, and $0 < w < 1$.The pseudo code for mobile agent itinerary computation phase is given in Algorithm 4.

Algorithm 4. Mobile Agent Migration

```
Initialize: sink know its 1-hop neighbor say N1
k: no of mobile agent used for data collection task, initial value is 1
CN: concentric coronas number
C: no of coronas
i=1
For the Sink:
1: while (k <=8)
2:      sink create mobile agent packet with MA-id = k
3:      send to Groupleader of wedge k
For any sensor node (i)
1: if (receive MobileAgentpkt packet )
2:    {   if (node is Groupleader and MA_direction is DOWN)
3:           send   MobileAgentpkt to boundary node of next corona
4:         else {  if (boundaryNode and CN < = C)
5:                      send   MobileAgentpkt to boundary node of
                         next  corona
6:                      else   set MA_direction to UP
7:                             send MobileAgentpkt to its
                               nearest neighbor of  same CNi
8:               }
9:      if (receive MobileAgentpkt packet and MA_direction is UP
           and !boundaryNode)
10:        send MobileAgentpkt to its nearest neighbor of same CNi
11       else   send MobileAgentpkt to its nearest neighbor node
                of   CNi-1 coronas
```

5 Simulation Results and Discussion

In this section, we present and discuss simulation results of our proposed data gathering protocol MMADIDD and compare the performance of MMADIDD with TBID, LCF and GCF algorithms in terms of total energy consumption, response time.We used Castalia [19] simulator to implement and conduct a set of simulation experiments. Castalia is a simulator for wireless sensor network and body area network which is built and based on the OMNeT++ [18] discrete event simulation platform.

Our simulation scenarios consist of a circular monitoring area of radius 100 m containing five different scales (25, 50,100,150, and 200) of sensor nodes randomly deployed. All nodes are identical with a radio transmission range set to 25m. The sink node is situated at the centre of the simulation field. The simulation time was set to 1000s.

5.1 Performance Metrics

We use three metrics, energy consumption, response time and success rate of itinerary of mobile agent, to compare the performance of the protocols.

a) *Energy consumption:* A sensor node has three main units [14] namely the processing units (PU), the transceiver unit (TU) and the sensor board unit (SU). Each of these units consumes a certain amount of energy while operating. The energy consumed by a sensor node can be defined as[14][17]:

$$E_{SN} = E_{PU} + E_{TU} + E_{SU} \tag{2}$$

Where E_{PU} , E_{TU} and E_{SU} represent the energy consumed by the processing unit, the transceiver unit and the sensor board unit respectively. Energy consumed [9], [14] by the transceiver unit (E_{TU}) can be further defined as

$$E_{TU} = E_{TU_{TX}}(d) + E_{TU_{RX}} \tag{3}$$

Where E_{TUtx} represents the energy consumed by the transceiver unit (TU) to transmit a bit of data for a distance d and E_{TUrx} represents the energy consumed by the transceiver unit (TU) to receive a bit of data. The total energy consumed by a sensor node is represented as [14],[17]:

$$E_{SN} = E_{PU} + E_{TU_{TX}}(d) + E_{TU_{RX}} + E_{SU} \tag{4}$$

Generally, E_{PU}, E_{TUrx} and E_{SU} are constant and sum of these represented as C and E_{TUtx} is a function of d which depends on network topology. In other way, equation (6) can be written as:

$$E_{SN} = C + E_{TU_{TX}}(d) \tag{5}$$

For mobile agent based data dissemination protocols, energy consumption at a sensor node i (E_{SN_MAi}) can be represented as

$$E_{SN\_MA_i} = E_{DA} + E_{Rx\_MA} + E_{Tx\_MA} \tag{6}$$

Where E_{DA} is energy spent for data aggregation at sensor node, $E_{Rx\text{-}MA}$ is energy spent at a node by receiving mobile agent and $E_{Tx\text{-}MA}$ for energy required to transmit mobile agent. So for mobile agent based data dissemination protocols, total energy consumption E_{total_MA} can be represented as

$$E_{total\_MA} = \sum_{i=1}^{N} E_{SN\_MA_i} = \sum_{i=1}^{N} \left(E_{DA} + E_{Rx\_MA} + E_{Tx\_MA}\right) \tag{7}$$

Normally, E_{DA} is constant for all source nodes visited by the mobile agent. $E_{Rx\text{-}MA}$ and $E_{Tx\text{-}MA}$ depends on size of mobile agent received and transmit respectively. This metric is important because the energy level that a network uses is proportional to the network's lifetime. The lower the energy consumption the longer is the network's lifetime. E_{total_MA} depends on itinerary length traveled by mobile agent during data dissemination process.

b) *Response time:* Response time is calculated as the time spent to finish a data collection task from all source nodes to sink. For agent-based data dissemination protocols, it consist of four components [12], [13],[17] time spent in mobile agent instantiation (T_{inst}), time spent for mobile agent to complete its data aggregation task at a node (T_{proc}), time spent in mobile agent transmission (T_{trans}) and time spent in mobile agent propagation (T_{prop}). So response time ($T_{responsetime\_MA}$) is represented as :

$$T_{responsetime_{MA}} = T_{inst} + \left(T_{proc} + T_{trans} + T_{prop}\right) \times n \tag{8}$$

Where n is number of sensor nodes visited by mobile agent. In general, T_{inst} is constant and assumed as 5 ms in our experiments. T_{proc} is also constant and assumed as 25ms. T_{trans} depends on the mobile agent size and network transfer rate. T_{prop} depends on the overall itinerary length that is the distance covered in successive mobile agent migrations. In a single agent based protocol, the response time is equivalent to the average reporting delay, from the time when a mobile agent is dispatched by the sink to the time when mobile agent returns to the sink. In a multi agent based protocol, since multiple agents is used for data gathering in parallel, there must be a mobile agent which is last one to return to the sink. Then, the response time of multi agent based protocol is delay of that mobile agent.

c) *Success rate of itinerary:* This metrics is used to evaluate the reliability of mobile agent's data collection process in presence of faulty or dead nodes. It is evaluated as percentage ratio of number of sensor nodes visited by mobile agent to total number of nodes.

5.2 Performance Analysis

In this section, we investigate the performance of the protocols in a multi-hop network topology. We study the impact of the number of deployed sensor nodes on energy consumption per round, overall response time and success rate of itinerary of mobile agent in presence of faulty or dead nodes. From the analysis of the simulation results, we have the following observations:

Figure 2 shows the performance comparison of the two single agent based data gathering protocol (LCF and GCF) and the two multi agent based protocol (TBID and MMADIDD) in terms of overall energy consumption per round .When the number of nodes is increased, energy consumption per round is also increases in all of the four protocols as shown in Fig. 2. Our proposed MMADIDD protocol consumes slightly (approx. 5%) more energy than TBID. This is due to the use of dynamic itinerary where mobile agent uses local information to determine the next source node. However, MMADIDD performs better than single agent based data gathering protocols (LCF and GCF) in terms of energy consumption. The reason of this outcome is that in LCF and GCF, a single mobile agent has to visit all nodes distributed in the network.

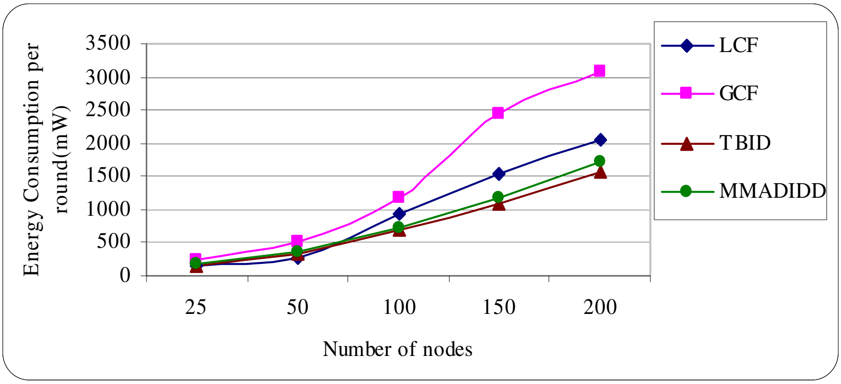

Fig. 2. Energy consumption per round

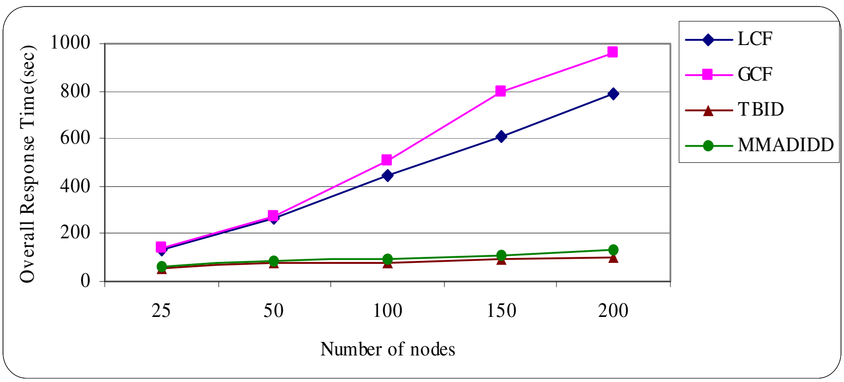

Fig. 3. Overall response time

Figure 3 shows the performance of LCF, GCF, TBID and MMADIDD protocols in terms of their respective overall response time. Overall response time increases as the number of deployed sensor nodes increases. Our proposed MMADIDG protocol takes slightly (approx. 3%) more time to complete the data dissemination task than TBID. This is because MMADIDD derives next destination of mobile agent on the fly based on local information. However, overall response time of MMADIDD and TBID are much lower than LCF and GCF. This is because of MMADIDD and TBID both dispatch multiple mobile agents in parallel to complete data dissemination task and each of them visits a small number of sensor nodes. While, LCF and GCF employ a single mobile agent to visit all deployed sensor nodes thereby increasing mobile agent's state size, significantly increasing the associated transmission delay.

As shown in Figure 4, MMADIDD protocol has absolute gain in terms of success rate of itinerary. The performance of MMADIDD protocol is better than static itinerary based protocol (LCF, GCF and TBID) because statically determined order of sensor nodes to be visited during the mobile agent migration may fail when node or link failure occurs on some nodes en route.

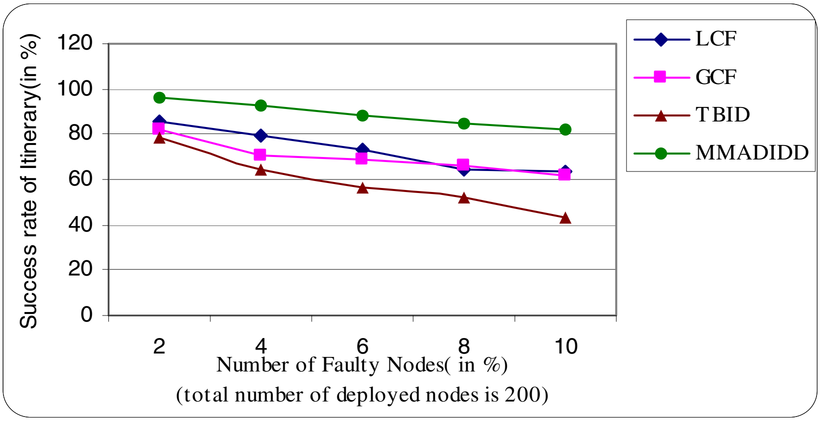

Fig. 4. Success rate of itinerary

6 Conclusion

In this paper, we have proposed a multiple mobile agent based data dissemination protocol that dynamically determines the order of sensor nodes to be visited during the mobile agent migration. It divides the circular sensing area into number of equiangular wedge centred at sink. In each wedge, we employ a mobile agent for data dissemination task. We have demonstrated through simulation results that our proposed protocol performs better than static itinerary based protocol when node or link failure occurs en route.

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