Novel Architecture of Self- organized Wireless Sensor Network

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Abstract

Self-organization for Wireless Sensor Network (WSN) is critical issue because of each sensor node's limited energy, limited bandwidth and WSN's scalability. Therefore, how to manage wireless sensor networks effectively is a big challenge task. This paper presents a novel self-organized architecture which is capable to avoid these problems. In this architecture, we suppose that each node does not know its location (Random clustering). Random clustering is practical to implement on some applications which deploy nodes into inaccessible unknown environment. We propose two algorithms to divide sensor nodes into cells. The first algorithm Active-Tree uses tree topology assign different role and node ID to each sensor node. The second algorithm Drawn-Grid divides sensor nodes into cells according to the radio coverage and the roles get from the Active-Tree algorithm. Based on sensor nodes with different role play different tasks in WSN. The result of numerical simulations will show that our algorithm performs better.

Keywords component; formatting; self-organization; Wireless Sensor Network; self-organized architecture

1. Introduction

A Wireless Sensor Network consists of large number of sensor nodes. The sensor nodes are small, inexpensive, low power, distributive devices and have computation, sensing and wireless communication capabilities. But those sensor nodes are limited in resource i.e. memory, energy and computation power [1].The sensor nodes mainly use battery. Maybe some use solar battery or limited recharge. For the bandwidth of the sensor nodes, only have a few hundred kbps. WSN has been applied in many military and civilian applications such as machine monitoring, seismic detection, disaster recovery [3]. In some applications, sensor nodes are deployed predetermined like machine monitoring. This kind of applications is application-oriented deployment. And sensor nodes are mainly randomly deployed in most applications such as seismic detection, disaster recovery. It increases the complexity of design for WSN. This paper focuses on the WSN with randomly deployed sensor nodes.

WSN use sensor nodes to sensing the events and transmit it out to base stations. So the feature of the sensor nodes is the feature of the WSN which is limited resources. The challenge for WSN is to complete complex application based on the limited resources especially when the sensor nodes are randomly deployed.

Self-organization is involved to make sensor nodes used efficiently. Generally, Self-organization is the process of autonomous formation of connectivity, addressing and routing structures [1].As limited resource of the sensor nodes, and it is practical to distribute these management tasks to different sensor nodes. And there is no need to make every senor nodes to do management tasks, as sensor nodes only possess limited energy, computation power and limited bandwidth. So the sensor nodes must be clustered to a cell or a group [1, 2, 6, 7], to be an easily manageable network.

Another feature of clustered architecture WSN is that Well-Clustered architecture WSNs consume less energy than self-organization WSNs but only independent nodes [2].

A. Problem Identification

WSNs have following problems: collision, idle-listening, overhearing and disabled sensor nodes.Figure1 shows the collision. Idle-listening is the most power-intensive action. It could be solved by set sleep and wake model to sensor nodes [8].Sensor nodes will be set to sleep model when there is no events and it will wake up periodically or wake up by management nodes. When sensor nodes receive the sensing information not belongs to it, overhearing happens. Management nodes could use node ID to solve it [5].Disabled sensor nodes refer to the sensor nodes with low energy or damaged by environment. Clustered architecture WSN must be capable to avoid these problems to maximize the life time of the WSN [11]. And these problems are mainly solved by the management nodes.

A well-clustered WSN should divide into groups or cells and in a group or cell appropriate amount of sensor nodes are management nodes. As management sensor nodes in this paper are same devices as normal sensor nodes, so resource limited decides that management nodes cannot take much more tasks. Also, if more sensor nodes have chosen to be management nodes, then extra energy will be consumed for the communication between the management nodes. i.e. if 3 sensor nodes take one management task like recording the node ID which could be done by one sensor node, then when other sensor node needs the information about node ID the 3 sensor nodes need to communication to provide the information, so extra energy is wasted. So in a group or cell the management sensor nodes must be relatively appropriate, not less or more.

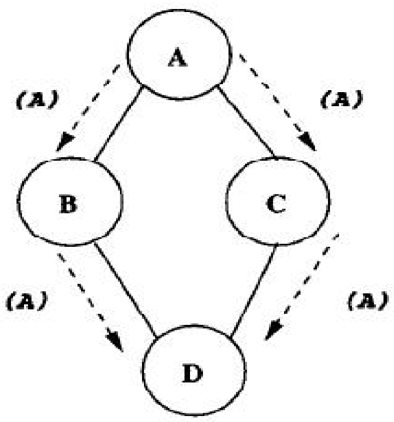

Figure 1: Both sensor nodes B and C desire to send message to sensor node D. Resource (energy, bandwidth) wasted.

As management nodes are same as normal nodes, so management nodes also have the chance of being damaged or low power. How to maintain the architecture of WSN also needs to be considered in our solution.

The rest of this paper is organized as follows. In Section 2, we review several related works, in Section 3 describes our proposed a novel tree self-organized architecture for Wireless Sensor Network is introduced here. Section 4. Finally, conclusions and future works are given in Section 5.

2. Related work

Self-organization has been an important research topic in wireless sensor networks, so there are many researchers who interested in solving its problems.

Duan and Yuan develop a task oriented Clustering algorithm to reduce the granularity of Wireless sensor networks. They assume that each sensor node has a unique ID and holds its one-hop neighbor list. Each sensor node in one sensor network runs a specific task including one or more data to form a task data pattern [8]. The clustering algorithm in this paper is clustering algorithm is designed based on data which related to the task code in each sensor node. It uses Vector Quantization Algorithm to divide the sensor nodes into cells, and choose the sensor node which has the minimum node id to be the cluster head but ignoring the radio coverage which would cause the cluster head may be not able to reach some of sensor nodes in its domain.

Hsu, King, and Banerjee propose that a scheme that is able to find the neighbors on the rim of the irregular radio coverage region to narrow down the choices of the forwarders [9].

Cell ID has been distributed to each node before deployment; it is impractical for some applications which deploy nodes into inaccessible environment [1], however, when the environment is unknown or hostile such as remote harsh fields, disaster areas and toxic urban regions, sensor deployment cannot be performed manually [10].

3. Proposed Solution and Simulation Modle

A. Proposed Solution

In this section, a novel tree self-organized architecture for Wireless Sensor Network is introduced here.

In this architecture, the nodes are clustered into cells. And each cell is based on a tree topology [12] which helps to initiate the cell size automatically. Not like [1] needs cell id predetermined. We assume the each node does not know its location. Figure2 shows the initial state of the nodes.

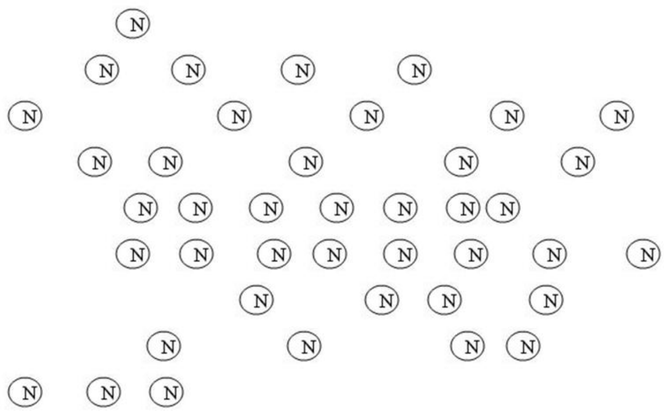

Figure 2: Initial State

The following process is called Active-Tree algorithm, all nodes will be processed to be a child of tree.

Step1. The Base Station which used to gather the information from the nodes will set up to active the closest nodes to be Root nodes. The level-id of the Root nodes is 0.

Step2. Root nodes gather the node id and signal length of the nodes which in their radio coverage and define this set as child-nodes. The level-id of these child-nodes is equal to the level-id of their parents' level-id plus 1.

Step3. Choose the longest child node as a child-root node. The level-id of these child-nodes is equal to the level-id of their parents' level-id plus 1.

Step4. The child-node use step2 to choose the longest node from it as the other child-root node.

Step5. Then the 2 child-root node repeats step2 and step3 and step5. Figure 3 shows the result after this process

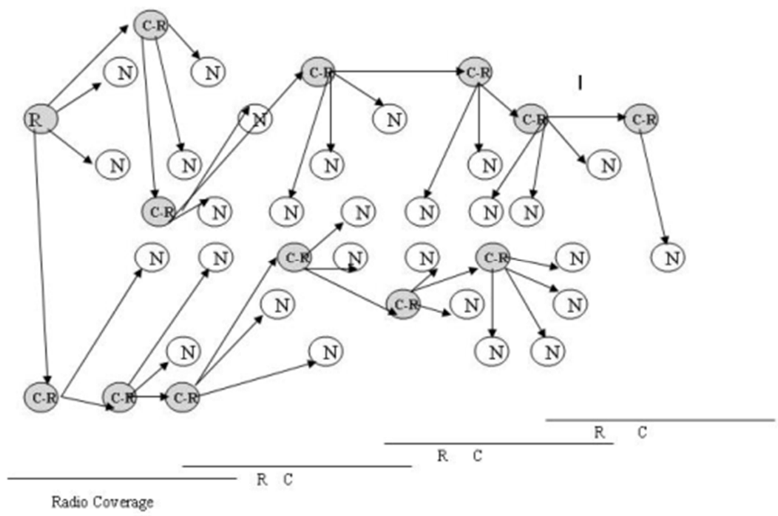

Figure 3: Shows the result after this process.

Active-Tree Algorithm:

Base Stations finds the closest sensor node

Sensor node = Root node;

Level-id = 0;

When still exist sensor node without Level-id

Do {**If** the length between Root node and Sensor node

<=Root node's radio coverage.

Then these sensor nodes Level-id = parent's Level-id + 1;

If the sensor node is the longest from its parent

The sensor node to be the childe-root node}

Till now, we could assume that each node has been classified as Root node, Child-Root node and Normal-Child node. We will use this hierarchy to clustering nodes to be cells. The clustering process is called Draw-Grid algorithm. However, in fact this algorithm is implemented into the step2 of Active-Tree algorithm, but not after the Active-Tree algorithm done. According to the radio coverage, each cell is an irregular grid from the Root node to the Child-Root node which is in its radio coverage but its children nodes are outside of radio coverage. If we get more than one Child-Root node like this, the one which is closest to Root will be the Root for the next cell. The And Root node will assign a cell-id to each node in the grid. The Figure4 shows how the nodes are clustered into cells.

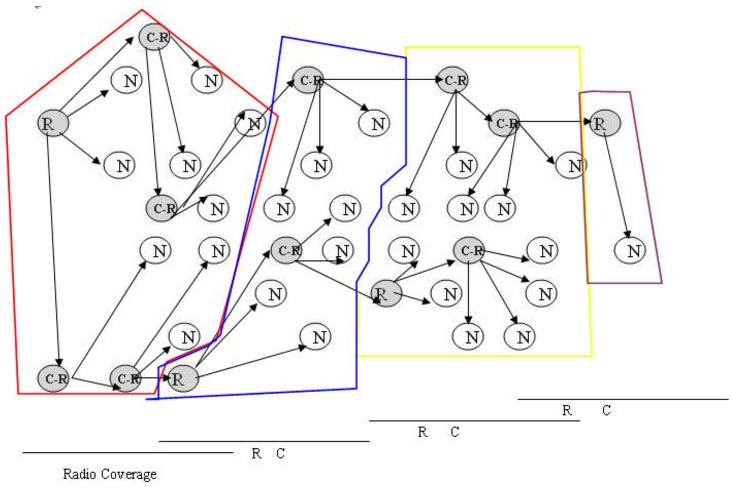

Figure 4: Clustered nodes

Draw-Grid Algorithm:

When still exists sensor node without Cell-id

Do {**If** (the child-root node is in the radio coverage of the cell's Root node) **&&** (the its child-root node is out of the radio coverage)

Then from Root node to this child-root node is a cell. Assign cell Id to each sensor node.}

According to the above algorithm, each cell's Root is in the radio coverage of the 'upper-level' cell's Root. The Root of each cell is the management node for this cell. In each cell, the Root node (R) is on the top of the hierarchy and Child-Root (C-R) node is the second in the hierarchy; the last level is the Normal-Child node (N).

C-R node is responsible to gather messages from N nodes and to manage the N nodes. N nodes are used to process data, detect environment and set sleep and wakeup modes. When N nodes turn into the sleep mode, then it needed to be wake up by other N nodes with same cell-Id. C-R node will hold its N nodes' node id in its one-hop neighbor list [8]. C-R node will also hold the list of the N nodes' energy status. And N nodes have the responsibility to report their energy status to C-R nodes every certain time. If C-R nodes do not receive energy status from some N nodes, C-R nodes will declare them as died nodes and erase them from the one-hop neighbor list.

Root node is responsible to gather messages from C-R nodes and to manage the C-R nodes. As C-R nodes also need to do management tasks, so C-R nodes consume energy more quickly. Root nodes have the task to re-select C-R nodes. C-R nodes will report their energy status to Root nodes periodically. Once C-R nodes' energy status reaches the threshold, Root nodes will reselect C-R nodes from their N nodes which have the most energy in the energy list. The threshold must be enough for C-R nodes to send their N nodes' node id and one-hop neighbor list to their substitute C-R nodes. However, there is a situation that some C-R nodes go to dead as external environment damage. Root nodes will have a list of their C-R nodes' C-R nodes. So in this situation, Root nodes will directly link the dead C-R nodes' C-R nodes to the substitute C-R nodes. That means, the dead C-R nodes' other N nodes will be discarded.

B. Simulation Model

In our simulation model, we define a certain schema according to our algorithm with particular characteristics:

- The task of the certain application is pre-embedded into the sensor nodes.
- Radio coverage is equal to the sensing node. And radio coverage is constant.

- The communication protocol could be CAN protocol or dedicated one [2].
- In our proposed architecture, C-R node gather data from its child nodes no matter it is also a C-R node or Root node from another cell. So we can say, it is one-hop communication, collisions are largely reduced. So we assume the response time is constant.
- Our proposed architecture can be used on many applications, especially for remote harsh fields, disaster areas and toxic urban regions which sensor deployment cannot be performed manually. Like earthquake and disaster detection. We define one earthquake or one diction as an "event".
- We assume the transmitting, activating, receiving and managing energy consumption radio is 10:1:4.5:3.
- We assume the transmitting time from one node to the other nodes with closest level-id is 0.6sec. We ignore the receiving process time.
- We assume the damage probability is 10 among 100 sensor nodes.
- We assume sleep and wake up mode used periodically. When N nodes stay in wake-up node with no activity in 5secs, then turn to sleep mode until be woke up by other N nodes with same cell-Id for event happened. We the wake-up response time as 0.5 sec.
- We assume the total energy of each sensor node is 20.

Our architecture, each cell is a tree topology. For all sensor nodes, energy consumption are depends on the transmitting consumption, receiving consumption. For C-R nodes and Root nodes, energy consumption are also depends on management tasks. So frequency of event happens and management task frequency decides the whole energy consumption of the WSN.

We assume Eu represents utilized energy. E represents the whole energy of each sensor node. NC represents the number of the cells which we get after running our algorithms. In each cell, the response time to an event is:

TR = （wake-up time) 0.5sec × number of sensor nodes in the cell

$$Eu = \Sigma\, Cactive \times ER + \Sigma\, Cactive \times ET + Pdamage \times EM + \Sigma\, Cactive \times EA$$

C active represents the total number of the active sensor nodes in each cell. ER represents the energy used in receiving, here we assume the ER =4.5. ET represents the energy used in receiving, here we assume the ET =10. EM represents the energy used in receiving, here we assume the EM =3. EM is related to the probability of damage, also related to low energy pick up process which should be calculated in the whole process. Pdamage demonstrates the probability of damage.

Comparing with static architecture; static architecture has less flexibility. Especially, when damaging occurs, radio coverage constraints the backup nodes candidates. In our paper, the fixed size architecture also has Gateway same as R-node in our paper and they do the same management tasks. And Gateway of each cell could communicate. And each also has 1 Manager which is same as our C-R node and they do the same management tasks. We will use the same schema and parameters for fixed size architecture.

But as the cell size is fixed, so every node's back up must be picked from the same cell. The position of gateway and manager is determined randomly. Also as gateway and manager may be not a one-hop communication, the routing of the gateway is also determined randomly.

Below is the assumption for our architecture:

Cell_Id	Role	Node_Id	Level_Id	Active or not	When be damaged
1	R	1	1	N/A	N/A
1	C-R	3	2	N/A	N/A
1	N	4	2	N/A	N/A
1	N	5	2	N/A	N/A
2	R	2	2	N/A	N/A
2	C-R	6	3	N/A	N/A
2	N	8	3	N/A	N/A
2	N	10	4	N/A	N/A
2	N	11	4	A	N/A
3	R	7	3	N/A	N/A
3	C-R	9	4	N/A	After 1sec
3	N	12	5	N/A	N/A
3	N	13	6	N/A	N/A
3	N	14	6	N/A	N/A
3	N	15	5	A	N/A

The architecture will be shown as below:

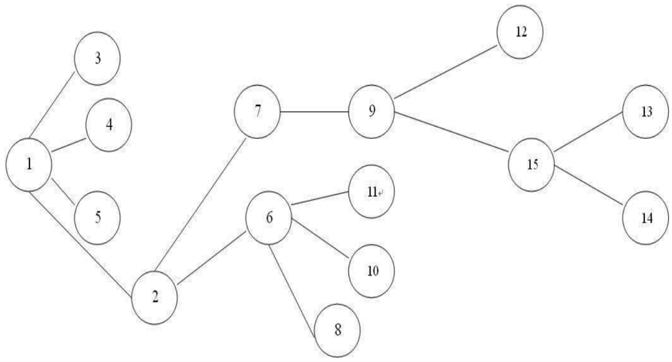

Figure 5: Scenario 1 Proposed architecture

Below is the assumption for our architecture:

Cell_Id	Role	Node_Id	Active or not	When be damaged
1	G	1	N/A	N/A
1	M	3	N/A	N/A
1	N	4	N/A	N/A
1	N	5	N/A	N/A
2	G	2	N/A	N/A
2	M	6	N/A	N/A
2	N	8	N/A	N/A
2	N	10	N/A	N/A
2	N	11	A	N/A
3	G	7	N/A	N/A
3	M	9	N/A	After 1sec
3	N	12	N/A	N/A
3	N	13	N/A	N/A
3	N	14	N/A	N/A
3	N	15	A	N/A

The architecture will be shown as below:

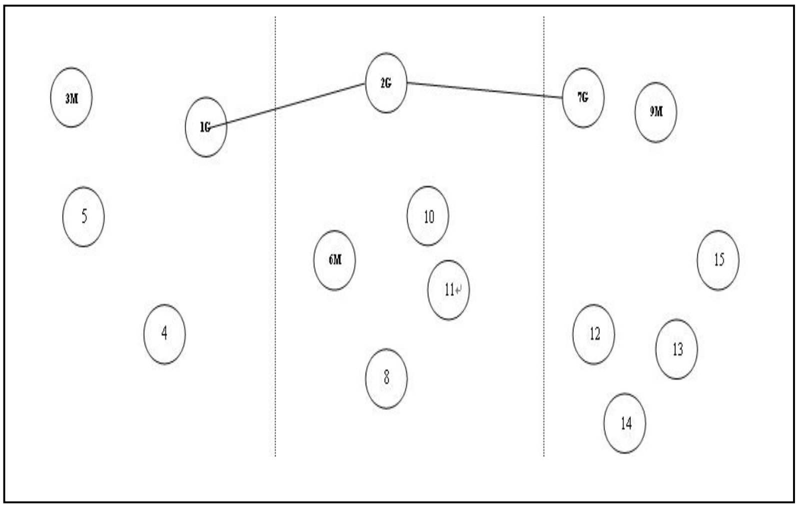

Figure 6: Scenario 2 (Static architecture)

4. Simulation Result

According to our assumption and the table shows above.In the first senario which is played by our architecture, the sensor node 11 and 15 are actived by the event. And sensor node 1 is the closest one to the base station. Firstly, 15 and 11 will active the other normal sensor nodes in the same cell, like 15 will active 12, 13, and 14 from the sleep node.And 11 will active 10 and 8,as 6 is the C-R node which is responsible to gather the data from 10,11 and 8. This action will take TR =3× 0.5sec+2×0.5sec =2.5sec. Eu=4×ER +3×ER =31.5.Sensor nodes 8, 10, 11, 13, 14 and 15 use energy 4.5 to receive to the data respectively.This action takes same time and energy for both senarios.After 1second from the beginning, the sensor node 9 is damaged.13,14 have been active.

In senario1, 9 damaged, sensor node 7 will choose 12 to be the C-R node. As 12 has more engery at that time. Then 12 will start to gather data from 13,14,15. 12 needs to take 3×ER=13.5 to receive data from 13,14 and 15.Then 12 sends data to 7, 7 takes ET=10 to receive the data. Next 0.5 second, 7 detects 12 is in low energy, at that time 7 has energy 6. Sending data to 2 has higher priority, so 7 sends the data out firstly. After that, 7 only has engery 3.Then 2 detects 7 in low energy. In the cell which R node is 2, 11uses 1 second active the 8 and 10. 6 gathers data from 8 and 10. And 6 has enough energy to send data to the 2. So when 2 detects 7 in low energy, 2still has energy 15.5 to do management task. So 2 takes engery 3 to choose 10 which left energy 5 to replace 7. Then 10 picks up 13 which left 5.5 as the C-R node. After that, 2 sends the data to the Root node 1 which will send the data directly to the Base station.

The Figure 7 below will show the energy consumption with time.

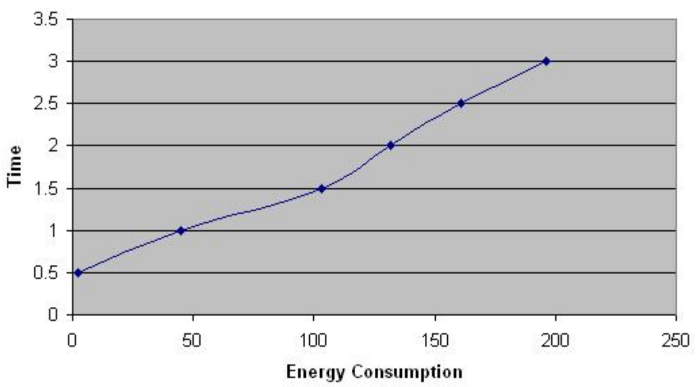

Figure7: Energy Consumption for senario1

In senario2 has the same energy consumption with senario 1 before 3 senconds. After 2 sends data to 1,2 needs to pick up Gateway to cell3 to replace 7. 13,14,15 are the candidates. 13 has more energy comparint with 14 and 15. But 13 in our assumption is out of the radio coverage of 2 and 10.So there generates 2-hop communication. 2 will choose 10 and then 10 chooses 14 and 14 chooses 13.As we set a low total energy to each sensor node, so in this situation, we will lose cell3 to investigate its region. We will put this lose to the energy consumption as this energy is unable to be used.

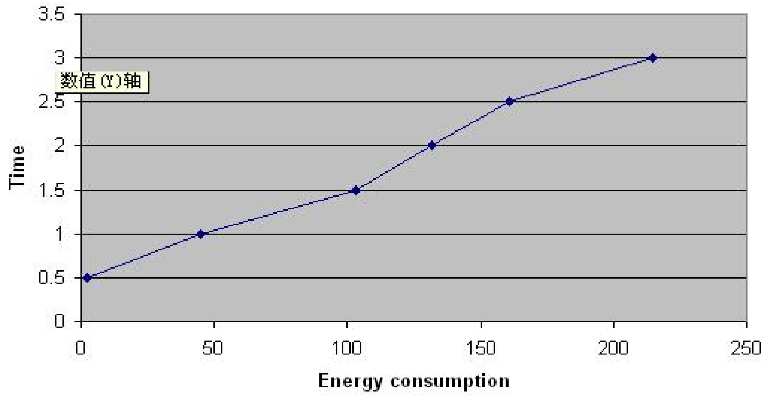

Figure 8: Energy Consumption for Scenario 2

From the simulation results, as the flexibility of our proposed architecture, we could archive less energy consumption.

5. Conclusion

This paper proposes a novel architecture for WSN. Although there are many researches for this aspect, our architecture is suitable for more applications especially for the applications apply for harsh environment situation. Our architecture is a dynamic architecture and changes with time changes. Simulation results shows that our dynamic architecture with appropriate management tasks distribution could archive a better energy saving in given time than static architecture. Future work will be focused on investigate the MAC (Medium Access Control) protocols to optimize our solution.

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