Fault Tolerance and Reliability to Extend Coverage of Wireless Sensor Network

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Abstract—Wireless sensor network used Clustering techniques to extend the lifetime of the network. LEACH is the one from these clustering techniques to maintain the energy efficiency of sensors. The technique of selecting nodes with highest residual energy as cluster heads with the assumption that energy consumption distribute periodically between the nodes. Cluster heads collect information from the surrounding nodes and send it to the base station. but sometimes if one of these clusters fails it cannot be detected by the cluster heads or BS. Non cluster heads and sub cluster heads still send data to the failed CH in every time slot of a frame allocated to them, hence more energy is consumed. In this paper, we have proposed a new algorithm of fault tolerance to determine the cluster heads failures within a few seconds after the beginning of each round to enhance the lifetime of wireless sensor network.

Index Terms—Fault Tolerant detection, Fault Tolerant recovery, Wireless sensor Networks, Network life time, Cluster head, Energy Consumption, Fault Coverage.

I. INTRODUCTION

Wireless Sensor Networks deploy a lot of nodes on a wide area to monitor some interesting phenomena, such as traffic surveillance, environment monitoring, health care, wildlife tracking, military sensing, etc. Wireless Sensor Networks consists of many sensors with limited energy. Each node is equipped with unit of sensing to sense the area and cluster head to transmit the information to the base station. Sensor nodes cooperate with each other to perform the functions of sensing data, data transfer and data processing. Hence sensor nodes will consume more energy specifically cluster heads. Hence, may be some cluster heads failure after the beginning of each round. Our proposed algorithm attempts to select cluster heads with fault-tolerant during building a cluster heads of LEACH protocol. We introduce two basic models Fault Tolerant detection and Fault Tolerant recovery. We then modify LEACH to detect the node failure and changed this node by nearest node with highest energy to improve performance of LEACH protocol.

II. RELATED WORK

Having studied widely in fault tolerance the broader context of the distribution of computing [1], but little studies has been done to solve the problem of fault-tolerant clustering in WSN.

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[2] deals with fault tolerance in the clustering, but it seems only in heterogeneous sensors, where clustering select the nodes with highest energy as a sink than the ordinary nodes. We here consider LEACH Protocol and study it in more detail.

In[3] the authors, proposed a novel Fault Tolerant method to select cluster heads in wireless sensor networks. They proposed clustering algorithm to reduce data packets during data aggregation and decreased the cost of wireless communications by reducing the data packets, thereby clustering technology extends lifetime of wireless sensor networks by reducing the energy consumption.

In[4] FEED chooses a supervisor for any cluster node head. This selection causes the entire network to be completely covered until the end of a round, and the network will be fault tolerant. This choice completely covered the whole network till the end of the round. By using this method the single member of clusters is close to zero.

In [5], Lou and Kwon propose Branch routing protocol to improve WSN reliability and security. This proposed builds several trees in directing neighbors sink, which represent branches on the network graph. Each node connects to one branch only, but this node can send data back to the sink of any branch. The main problem of this method is the limited number of paths and the fault tolerance is also limited.

Esseghir et al. [6] optimize the wireless sensor network lifetime under a reliability constraint. They introduce a function that links reliability to the average amount of energy consumed by the network when reporting an event to the base station. By using this function, they showed a successive readings which achieving a reliability.

In [7] Chamam et al. address the problem of maximizing the WSN lifetime under the area coverage constraint. They propose a scheduling mechanism that, for every time slot during the operating period, calculates an optimal covering subset of sensor nodes; only those nodes are activated for the given period and the remaining ones are put to sleep.

Xiong et al. [8] prove that the problem of maximizing the lifetime of a data-gathering sensor network, which is defined as the number of rounds until the first 24 node depletes its energy, is NP-complete. They then formulate it as an integer program to get a suboptimal result. They want to reduce the tremendous computation and storage cost of integer programming.

Heinzelman [9] designed and implemented Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol for WSN. LEACH uses a clustering architecture, Each cluster elects a cluster head. For balancing energy load in the network, LEACH rotates the energy-thirsty function of the cluster head among all the nodes in a cluster. To avoid data transmission collisions, LEACH uses a time division multiple access (TDMA) protocol. The major characteristics of LEACH include localized control for data transfer; randomized, adaptive and self-configured cluster formation; application-specific data processing for data aggregation and low energy media access.

Hasegawa et al. [10] proposes to reduce the energy function of neural network by using a routing reconfiguration method. They were also found that proposed can improve performance of routes to maximize the lifetime of sensor network, without use centralized computing.

Mak et al. [11] study different WSN protocols based on various WSN lifetime definitions. They classify WSN protocol and different WNS lifetime definitions. With the help of simulation they compare performance of WSN protocols.

III. FAULT TOLERANCE

Our protocol has a dynamic techniques to solve the node failures. In sensor network, if found any sensor nodes fails, its data and other sensor nodes data relayed along that path without knowing that this path is failed, so the paths will be invalidating till the next round start. Moreover, a sensor node still forward on the invalidated path, it starts the reaction to the discovery of a new path in the next round. But in this work we were automatically solved the node failures inside each round, as showed in our below algorithms.

IV. RELIABILITY

The wireless medium is not a reliable medium. Maybe it face some interferences and noises from different resources. Reliability has to achieve through design an efficient protocol. So, we designed our protocol with an acknowledgement based on cluster heads. The acknowledgement is sent by the cluster heads to receive a data packet. The sensor nodes postpone the transmitter packet till it receives an acknowledgement.
from the cluster heads. A data packet may be retransmitted three times in the event of failure later. These three times are enough to the cluster heads to solve the failure of sub cluster heads, maybe after second retransmission the cluster heads change the failure nodes. the cluster heads re-send the Hello packets to all sensor nodes, and nodes were left without valid path will receive the Hello packet. Later, it can send its data to the cluster heads.

Fig 1: Failure Detection tow cluster heads failure in Cluster Tree of WSN

V. ENERGY EFFICIENCY AND RELIABILITY

Our first objective is to guaranty the cluster heads selected have highest energy than others nodes with allowing to sharing of data transfer responsibilities equitably between the near as well as far-off nodes and low-high energy of nodes. It involves changes in the transition of energy node. Periodic variation in the transition of energy alters the structure of the network, leading to the presence of asymmetric links in the network. It maintains multi-hop routes optimized for communication, so that an alternative route is available if a failure is used.

VI. PROTOCOL IMPLEMENTATION

In this work, we proposed sub cluster heads based fault tolerant protocols for nodes failure in each sub cluster heads of clustering wireless sensor networks. Our proposed techniques present fault tolerance in two phases, failure detection and failure recovery. This proposed work is as follows:
1 Failure Detection
2 Failure Recovery
3 Fault Coverage
4 Energy Consumption

A. Failure Detection

To detect the failure in cluster head, we modify our previous algorithm[12] to select a cluster head. Let t1 represent the time of beginning of round. t1+f represent the beginning time of next round, f represent full time of a single round. In our previous work we have selected three main cluster heads with highest energy, so there are x nodes which are a part of this cluster and sub cluster heads. Each node transmits for s seconds in to the TDMA of this cluster. Then, for each cluster z=f*x/s. represents the transmissions between the nodes and cluster heads in each group. We execute detection through cluster heads selected with z to test transmission of the cluster head. Cluster head sends a small Hello message to all nodes which are ready to receive. If such a transmission is not received, the nodes can advertise that cluster head has failed as shown in fig 1.

B. Failure Recovery

After detecting the cluster head failure the failure recovery model tells the value of the position of the [(cluster head failure) +3] to become the new cluster head. Join a position of the [(cluster head failure) +3] to the position of the [(cluster head failure)-3]. Also the non cluster that join before to the failure cluster head, it select by use the (n- (value of the position of the [(cluster head failure) +3)-1) to connect it to the position of the [(cluster head failure)-3] as shown in fig 2.
C. Fault Coverage

In our previous work we selected three nodes as main cluster heads, each cluster head has a member nodes consist sub clusters and ordinary nodes. These member nodes without ordinary nodes of each cluster represent a chine of sub cluster node with its main cluster. Then total of chine in the three main cluster are three, such as in fig 3.

20,17,14,11 node represent the first chine, 19,16,13,10 node represent the second chine and 18,15,12 node represent the third chine. 11 and 10 are terminal nodes in the first and second chine ,these nodes it will neglecting from the failure now, but have ability to become cluster or sub cluster after rotation time of rounds and that time we look about its failure.

The fault coverage is important issue in any protocol to make the protocol able to detection and recovering from the occurrence of fault(s) through a normal works . In this work we have treated any node failure per chain  .

The probability of failure nodes in single chine it gives in this equation

\[
\text{Nonc choose } f = \frac{\text{Nonc!}}{f! (\text{Nonc } - f)!}
\]  

(1)

where the f is the probability of faulty nodes among Nonc nodes in a single chain. Nonc is the number of nodes in a single chain.
The fault coverage is an important issue in any protocol to make the protocol able to detection and recovering from the occurrence of fault(s) through a normal works. In this work we have treated any node failure per chain.

The probability of failure nodes in single chain it gives in this equation
\[ \text{foc1} = \frac{\text{Nonc1}!}{(f1! \times (\text{Nonc1} - f1)!)} \]  
(2)

The probability of failure nodes in second chain it gives in this equation
\[ \text{foc2} = \frac{\text{Nonc2}!}{(f2! \times (\text{Nonc2} - f2)!)} \]  
(3)

The probability of failure nodes in third chain it gives in this equation
\[ \text{foc3} = \frac{\text{Nonc3}!}{(f3! \times (\text{Nonc3} - f3)!)} \]  
(4)

where the \( f \) is the probability of faulty nodes among \( \text{Nonc} \) nodes in each chain, \( f1 \) in a first chain, \( f2 \) in a second chain and \( f3 \) in a third chain.

\( \text{Nonc1} \) is the number of nodes in a first chain.

\( \text{Nonc2} \) is the number of nodes in a second chain.

\( \text{Nonc3} \) is the number of nodes in a third chain.

\( Nfc1 \) is Number of nodes failure in first chain

\( Nfc2 \) is Number of nodes failure in second chain

\( Nfc3 \) is Number of nodes failure in third chain

for example if \( \text{Nonc1} = 4 \) the number of nodes the first chain and \( f1 = 2 \) failure nodes among the \( \text{Nonc1} \) can be written as:
\[ 4 \text{ choose } 2 = \frac{4!}{2! \times 2!} = 6. \]

The total number of faults due to \( r \) faulty nodes in the three chain it gives as follows equation
\[ T_f = Nfc1 + Nfc2 + Nfc3 \]  
(5)

D. Energy Consumption

The energy consumption for detection a failure node in our proposed works depends on the cluster heads. The cluster heads send Hello messages to all its sub clusters only with neglect the ordinary members. Therefore, the cluster heads and its sub cluster members consume energy. In our proposed during the fault detection every sub cluster heads except the last nodes that is ready to become sub cluster in other rounds, accept Hello message from the cluster head and sends a Notify message to its cluster head. In the fault detection or recovery, the ordinary nodes neglecting without send or receive any messages in this proposed, so it will conserve its energy till it become CH or SCH. Therefore, the total number of messages required for the fault detection in this proposed is: \( 2^r \times 3^{(\text{Nonc} - 2) - 2} \). Accordingly, the total energy consumption for detection a failure node is:
\[ E_d = 2^r \times (E_{Tx}(k, d) + E_{Rx}(k)) \times 3^{(\text{Nonc} - 2)} \]  
(6)

where \( E_{Tx}(k, d) \) and \( E_{Rx}(k) \) are as given in [6] to be:
\[ E_{Tx}(k, d) = E_{elec}\times k + E_{amp}\times k\times d^2 \]
\[ E_{Rx}(k) = E_{elec}\times k \]

Number of chine is three, Number of message is 2

Energy consumption for the failure recovery with neglect the terminal sub cluster head, in each chine, the energy consumption for failure recovery can be written as:
\[ E_r = (3/2)^r \times E_{Tx}(k, 2d) \]  
(7)

And the total energy consumption for the fault tolerant proposed is the sum of the energy consumption for the failure detection plus the energy consumption for failure recovery is:
\[ E_t = E_d + E_r = 2^r \times (E_{Tx}(k, d) + E_{Rx}(k)) \times 3^{(\text{Nonc} - 2)} + (3/2)^r \times E_{Tx}(k, 2d) \]  
(8)

where
\[ E_d \] is energy consumption for detection a failure node
\[ E_t \] is total energy required for failure detection and failure recovery.

VII. Simulations

The Simulation is implemented in square area of 100m x 100m to deploy the 100 sensors of nodes, this Simulation executed by mat lab. To study the performance of the propose fault tolerance models. We implement LEACH and our previous work as described in [12-13] and then modify this implementation to include fault tolerance models as described in this paper. We simulate the number of rounds as a measure of the lifetime of the network. We compare the number of rounds achieved by LEACH and our previous work with this proposed work. Our proposed make trade-offs in terms of reducing the lifetime caused by the
implementation of fault tolerance and achieved with minimal loss in lifetime. Where leach and our previous work do not provide constant coverage during the cluster head failure. proposed work increase the coverage of WSN as shown in fig.4.

proposed work (with failure detection) introduce peter simulation in energy consume per cluster heads than leach protocol( without failure detection) and consume little energy compare with our previous work(without failure detection) as shown in fig.5.

proposed work (with failure recovery) introduce peter simulation in energy consume per cluster heads than leach protocol( without failure recovery) and consume little energy compare with our previous work(without failure recovery) as shown in fig.6.

proposed work with fault tolerance (failure detection+ failure recovery ) introduce peter simulation in energy consume per cluster heads than leach protocol( without fault tolerance) and consume little energy compare with our previous work(without fault tolerance) as shown in fig.7.

Fig. 4. Lifetime measured in rounds

Fig. 5. Total Energy Consumption for Detection a Failure Node
VIII. COMPARATIVE STUDY

<table>
<thead>
<tr>
<th></th>
<th>LEACH</th>
<th>previous work [12]</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network lifetime</td>
<td>Good</td>
<td>Very Good</td>
<td>Near to previous work [12]</td>
</tr>
<tr>
<td>Fault Detection Capability</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fault Recovery Capability</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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IX. CONCLUSIONS

In this paper, we have studied how to detect and recover failure of the cluster head in wireless sensor networks. From our previous work [12] it is easy to detect the cluster head failure and easy to recover it with this new algorithm. Our proposed achieved fault tolerance with the minimum loss of lifetime and increase the coverage of wireless sensor networks.
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