Proposing a Method to Increase Fault Tolerance in Wireless Sensor Networks Using Fuzzy Logic

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Abstract: - Considering the capabilities of fuzzy logic (such as low computational load, usability in distributed environments with inaccurate information, full compliance with the universe, etc.), it appears to be appropriate to be used to optimize energy consumption and fault tolerance in wireless sensor networks. The proposed protocol is called FFT-LEACH. The purpose of using this protocol is to increase fault tolerance and network lifetime and reduce energy consumption.

Keywords: Wireless sensor networks; Fuzzy logic; Energy consumption; Fault tolerance.

1. Introduction

Recent advances in electronics and wireless communications have provided the possibility to produce multifunctional, low energy consumption and low cost sensors. These sensors are able to communicate with each other over short distances. A very small sensor node has the equipments for data sensing and processing and wireless communication. A sensor network is actually a series of a large number of sensor nodes scattered in the environment that each autonomously pursues a specific purpose and in collaboration with other nodes. The nodes are close together and each node can communicate with other nodes and provide its information to other nodes. Finally, the situation of the observed environment is reported to a central point [1].

In the same area, a distributed clustering mechanism based on LEACH protocol is proposed. Fuzzy logic and zoning is used in the mechanism to reduce energy consumption and fault tolerance. The proposed protocol (FFT-
LEACH) is simulated using NS2 simulation software, and the behavior of the protocol is evaluated against the FT-LEACH basic protocol based on this simulation results.

This paper is organized in five sections. In the second part of the paper, the key concepts are provided. The third part reviews the research literature. In the fourth part, the proposed algorithm and simulation are described, and the fifth section examines the conclusions.

2. Key concepts
2.1. Sensor Network

Wireless sensor network is a special type of Ad hoc networks, which includes a set of small nodes with the capability to sense the environment around with a certain target, data processing, storage, exchanging information with other nodes as well as adaptability against changes (topology, etc.). Usually, all nodes are identical and satisfy the general purpose network in effectively collaborating together. The main objective in wireless sensor networks is to supervise and control the conditions and climate, physical or chemical changes in an environment with a given range [2].

Each sensor node is equipped with a series of internal equipment that each is required according to the possible task and the conditions of each node potential. The connections of internal components of a sensor node are presented in Figure [3].

![Figure 1: Internal Components of a Sensor](image)

be recharged. Thus, clearly the energy-based routing and data collection protocols in these large-scale networks should be specific to maintain the lifetime of the network in an acceptable manner. The grouping of nodes in clusters has been widely accepted by research communities to realize scalability objective and overall achieving of greater energy efficiency and longer life in WSN networks environments. Hierarchical routing protocols and data collection imply on cluster-based organizing of sensors to make possible to combine and integrate the data, leading to a considerable energy saving. In the hierarchical structure of the network, each cluster has a leader called cluster head (CH), which normally performs special tasks (such as combining and aggregating data). There are also some regular sensor nodes (SN) in each cluster as the cluster members. The cluster forming process develops a two-level hierarchy that its higher level is formed by CH nodes, while its lower level is formed by the cluster membered sensors. The sensor nodes send their data periodically to their own cluster head. The CH nodes collect the data (and thus, the number of retransmitting packets reduces) and send them to the base station (BS). Sending to BS can be done directly or intermediarily with other CHs [4].

2.3. Protocol (LEACH)
Low-energy adaptive clustering hierarchy protocol (LEACH) is one of the earliest and most famous hierarchical protocols provided for sensor networks. In this protocol, the time of network activity is divided into periods (equation 1). At the beginning of each period, a number of nodes are randomly selected as cluster heads. To do this, each node generates a random number between 0 and 1. If the number is lower than the \( T(n) \) value obtained using the following equation, the mentioned node will be introduced as the cluster head. In the following equation, \( P, r \) and \( G \) are respectively the ratio of number of clusters to the total number of network nodes, the number of period and the number of nodes not selected as cluster head in the last period [5].

\[
T(n) = \begin{cases} 
  \frac{P}{1 - P \times (r \mod \frac{1}{p})}, & \text{if } n \in G \\
  0, & \text{otherwise}
\end{cases}
\]

After defining the cluster head nodes, other groups decided to become a member of one cluster based on the received signal strength from each cluster head. The cluster head node divides its responsibility range to a number of
time cuts. These time cuts are shared based on TDMA mechanism among the cluster members. In each time cut, the cluster head communicates with one of the cluster members and receives the information packets of that member. In every several time cuts, the cluster head sends the received data from its members to the central node. To distribute the load on different nodes after a period completion, the cluster heads are changed based on the mechanism described above for a new period.

2.4. Fuzzy Logic

Fuzzy logic was introduced in the mid-1960s by Professor Lotfi Zadeh. The concept has introduced a method for managing data through uncertain or partial membership in a set instead of definitive or complete membership. According to Professor Lotfi Zadeh, if someone looks closer to the universe problems, he would find the fuzzy logic as a solution.

Fuzzy logic can be used described as a super-set of the traditional (Boolean) logic. The fuzzy logic has been developed to demonstrate the detailed accuracy. This means the accuracy value is between completely correct and completely wrong. In other words, classical Boolean logic has only two values, true or false. However, the fuzzy logic has extended these two values to obtain the degree of membership.

2.4.1. Fuzzy Set

As stated, the fuzzy logic is an extension of classical logic. Thus, the fuzzy set definition is extending the definition of sets in classical logic. In classical logic, the distinct function returns a value of zero or one, but it returns a number in the [1, 0] range in the fuzzy logic.

\[
A = \{(x, \mu_A(x)) | x \in U\}
\]

\[
\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in U\}
\]

A fuzzy system consists of the fuzzy making, inference engine and non-fuzzy making parts. First, the numeric inputs are converted to fuzzy variables. Then, in the inference engine section, the outputs are produced based on fuzzy inputs and rules in the knowledge base. Since the outputs are fuzzy type, in the non-fuzzy section, the fuzzy output is converted to of non-fuzzy variable [6].

The conversion of system inputs to numeric variables is the first stage of the system process. In this stage, the numeric inputs are mapped into fuzzy variables with respect to the membership functions developed for conversion and different degrees of membership.
With entering any of the input values to the system, the value is evaluating by membership functions and the membership degree is calculated for each fuzzy variable. Fuzzy variables and the degree of membership of each one of them are used in the inference (conclusion).

2.5. Fault Tolerance

The fault tolerance topic has been widely studied in wireless sensor networks. In these studies, the subjects of routing, topology control, data gathering, etc. have been investigated. Since sensor networks are used in harsh and adverse environments, the nodes in these networks are at risk of attack and error prone. Consequently, the nodes are simply damaged from internal and external factors or their energy would finish. Thus, issues such as the breakdown of active routes, network fragmentation, loss of data, etc. would occur in sensor networks. On the other hand, as the nodes in the network are neither re-charged nor replaced, therefore, some mechanisms and protocols need to be designed that even in the presence of errors can well do their work according to performance measures.

First, we must have a clear vision of the fault tolerance term. Thus, we need to define reliability and fault tolerance and describe the difference between them. Reliability refers to the ability of operating units at a specified time interval without compromising the performance measures. Fault tolerance is the ability or capability of an operating unit to perform the functions set out in the presence of one or more errors. The difference between fault tolerance and reliability is that the former relates to the performance period until the error occurs, while the latter is related to the performance of operating units in the presence of the error.

3. Research Background

Muhammad Lahsani [7] has provided an algorithm that makes the LEACH protocol tolerable against the errors. The FT_LEACH algorithm performs its work in three phases. First, at cluster forming time, two cluster heads
are selected for each cluster. The main cluster head is selected based on the original primary selection of LEACH protocol. The second cluster head is selected based on the obtained weight. The nodes send the Hello packet containing the index of the main cluster head and the obtained weight. Finally, among the exchanged weights, the maximum weight in each cluster is achieved, and the node with this weight will be considered as the alternative cluster head. Then, the nodes send their data for both cluster heads. Whenever the original cluster head does not send the data to the base station, the alternative cluster head will send the data to the base station.

In [8], Rudranath and Anuroopa introduced an error tolerance algorithm in which based on the cluster head behavior, the presence or absence of an error is detected. The process goes as follows. If the cluster head does not send data to the base station, this would be interpreted as the sign of error presence. Two mechanisms have been proposed for error of fault recovery. In the first solution, the most energetic node is selected as the cluster head, which re-gathers the data and sends them to the base station. In the second approach, two cluster heads are selected from the beginning. The first and second cluster heads simultaneously collect data. If the first cluster head does not send the data to the base station, the second cluster head will send the data to the base station.

4. Proposed FFT_LEACH Algorithm

To improve the LEACH protocol in terms of energy consumption and fault tolerance, this protocol is improved in several steps. First, the base station zones the network. In this case, it starts sending Hello packets up to the radius of K (m). The nodes receiving the message will put the number of their own area equal to 1. Again, the base station sends the packet to a radius of 2k m. The nodes that already have received this package will not process it. The new nodes receive the packet and put their own area equal to 2. This process continues until the entire networked is zoned.

In the second phase, the nodes inside the zones are clustered. In this phase, the nodes select the cluster head based on their mechanism of LEACH. After determining the cluster heads, they will send advertisement messages. If the two cluster heads are in a distance less than 3/4K, the cluster head with a smaller ID gives its role to the cluster head with a larger ID and sends its head cluster canceling message. This message is called as CancelCH. In the third phase, the nodes will find the highest score given to each cluster head using fuzzy algorithm and select their desired clusters and join them. After selecting the cluster head, the nodes send the JointRequest for the cluster heads. After collecting the joint request messages, each
cluster head node sends the Scheduling message to its cluster nodes. The nodes begin to send data sensed from the environment one by one and in turn to the cluster head. However, unlike LEACH algorithm, they do not delete the sensed data from the buffer. At the end of each round that the cluster head needs to gather data and send them to the cluster heads, the nodes become active at the moment and listen to channel that whether their cluster-heads send them data or not? If they send data, the nodes will delete the sensed data of the last cycle from the buffer. Otherwise, the nodes will send the data of this cycle and the next cycle together to the cluster head of the next cycle. After receiving the data, the cluster head will gather the data and send them to the base station.

4.1. Simulation Results

The FFT-LEACH and DFT-LEACH were implemented in NS 2 simulator in the following conditions:

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Parameters</th>
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<tbody>
<tr>
<td>Scenario 1</td>
<td>LEACH</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>LEACH</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>LEACH</td>
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<tr>
<td>Scenario 4</td>
<td>LEACH</td>
</tr>
</tbody>
</table>

Routing protocol: Droptail
Queue type: Droptail
Number of Nodes: 25, 50, 100, 200
Node location: Random
Initial energy: 1 J
Transmission range of nodes: 50 m, 50 m, 50 m, 50 m
Sensing intervals: Second, Second, Second, Second
Queue length: 50, 50, 50, 50

4.2 Death of the First Node

In this section, we investigate the death time of the first node. Smaller values indicate that the node's energy has finished faster and the load distribution has not properly done. By our impression, it can occur due to two different possibilities. First, it is likely that a cluster with a high volume of many nodes has been formed. Second, it is likely that the clusters are distributed in such way the node has failed to join the cluster for several times. In the table
below, you can see the death time of the first node for different scenarios.

4.3. Death of the Last Node

This section belongs to the death of the last node that sends its data alone to the well node or the base station. Much later the last node energy is over, the longer lifetime of the sensor network would be. Thus, this parameter can be also named as the lifetime of the network. Certainly, the well node is removed from the statistical issues, because we assumed that this node benefits from features that other nodes are deprived of them. Among these advantages is the higher energy.

4.4. Consumption Energy

In this section, we investigate the energy consumption of nodes. Considering the fact that we succeeded to calculate the death of the last node, it would mean the total energy of all nodes has been consumed. In this case, we can only calculate the time of energy consumption of the nodes. To compare this parameter, we were forced to re-run the simulation. However, in these simulations, the initial energy of nodes was considered equal to 5 J. Then, the following information was extracted from the simulator output files.

5. Conclusion

After simulation and extraction data requirements from the simulated data, the improvement of the proposed algorithm is evidently demonstrated in all studied aspects. The reason for the proposed algorithm success is lack of using the alternative nodes as cluster
heads and also reduced ratio of the number of routing packets to the FT-leach algorithm. Also, we tried to somehow make load distribution in the network. Thus, this leads us to reduce energy consumption.

Reference