Wide Area Network Fault Detection and Routing Model for Wireless Sensor Networks

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Abstract: In a wireless sensor network (WSN), random occurrences of faulty nodes degrade the quality of service of the network. In this paper, we propose efficient fault detection and routing (EFDR) scheme to manage a large size WSN. The faulty nodes are detected by neighbor node’s temporal and spatial correlation of sensing information and heartbeat message passed by the cluster head. In EFDR scheme, three linear cellular automata (CA) are used to manage transmitter circuit/battery condition/microcontroller fault, receiver circuit fault and sensor circuit fault representation. On the other hand, L-system rules based data routing scheme is proposed to determine optimal routing path between cluster head and base station. The proposed EFDR technique is capable of detecting and managing the faulty nodes in an efficient manner.

INTRODUCTION

Wireless sensor networks (WSNs) are ad hoc networks that encompass small inexpensive low power devices, distributed in large number at a remote geographical region, in office buildings or in industrial plants. A WSN is used widely in such environments for monitoring the environment, which includes air, soil and water, habitat monitoring, military surveillance, inventory tracking, condition base maintenance and in many more cases. The main components of a sensor node are a microcontroller, transceiver circuits, memory, power source and one or more sensors. The microcontroller is mainly responsible for data processing and managements of other components of sensor nodes. Transmitter and receiver are combined in a single device known as transceiver. Transceiver is responsible for data receiving and data transmission. The most relevant kind of memory is on-chip memory of a microcontroller. Low capacity memory chip is used for data buffering. The power is stored in batteries, both rechargeable and non-rechargeable and these are the main sources of power supply for sensor nodes. The sensor of a node is a hardware device that is responsible for measuring physical data of the parapet which is to be monitored.

As the sensor nodes are powered by battery and in turn they have limited power source and at the same time these nodes are deployed at harsh and hostile environment, the sensors are prone to failure. Faulty sensor nodes may cause wrong data sensing, erroneous data processing and incorrect data communications. The faults in WSN nodes occur due to failure of any one of its hardware components as discussed above. Based on various faults node status in WSN can be divided into two types; healthy and faulty. A node is defined as faulty if its battery power reaches the threshold limit or if its microcontroller does not work or if transmitter circuit of transceiver is not working properly.

In a node, if the transmitter circuit is not healthy, even though all other hardware components are in good shape, the node is declared as faulty node. The faulty node must be replaced by new node. Otherwise, its responsibility has to be shared by other available healthy nodes.

Fig 1 Classification of sensor nodes with respect to fault

The healthy node may again be categorized into three groups: traffic node, normal node and end node. In a healthy node, where transceiver is operational but the sensor device is malfunctioning, and then we may use this node as traffic node. A traffic node can act as a router in multi hop wireless data communication. The normal healthy node, where all components of sensor nodes are in good shape, may be used for any types of job in WSN. In the end node, the receiver circuit of transceiver is malfunctioning; hence it can sense the parameter of the monitoring field and able to transmit data to the base station via other node. However, the end node cannot receive the data from any other node. Therefore, it cannot be used as router in WSN. Next, an energy efficient data routing technique is proposed for data transfer using normal and traffic node with the help of L-system rule. The rule can be applied for all the member nodes which derive the optimal routing path between cluster head and base station.

II. PROBLEM STATEMENT

The existing techniques declare a node as faulty node for any kind of hardware failure. However, all the components of the hardware circuits of those nodes may not be faulty; they can be reused to improve the performance of WSN. Since, the existing fault tolerant techniques do not reuse any faulty node; hence the number of dead node increases with network life time that reduces the network coverage as well as overall network performance.
Efficient Fault Detection and Routing (EFDR) scheme:

The fault detection technique which detects the different hardware fault distinctly and then categorizes them as normal, traffic or end node. It can be classified into following techniques

- Vector fault detection model
- Fault detection scheme
- CA based routing management
- Data routing scheme

Vector fault detection model

In sensor network, sensor nodes are distributed in a particular area. The neighboring nodes are closely deployed in the sensing region. Therefore, the sensed information of the neighboring node differs in small amount. If the neighbor nodes’ sensing information is \( x(t) \) and current node sensing information is \( y(t) \), then difference between two sensed information is very small because they are closely deployed. If information sensed by a sensor node is \( y(t) \) and neighbor node sensing information is \( x(t) \), and two vectors for a given time interval \( t1 \rightarrow t2 \) and the component of \( x(t) \) along \( y(t) \) is \( cy(t) \), then information difference vector \( e(t) \), is represented by:

\[
e(t) = \begin{cases} 
  x(t) - cy(t), & t1 \leq t \leq t2 \\
  0, & \text{otherwise}
\end{cases}
\]

If the neighbor node information are orthogonal, then the difference vector \( e(t) \) is more than threshold value, and node’s sensor circuit is faulty.

When \( x(t) \) and \( y(t) \) are perpendicular, or orthogonal, then \( x(t) \) has zero component along \( y(t) \); consequently, \( c = 0 \). Therefore defined \( x(t) \) and \( y(t) \) to be orthogonal if the dot product of the two vectors is zero, that is, if \( x(t)y(t) = 0 \). Therefore, if two sensed information are orthogonal to each other, then the information difference \( e(t) \) is less than threshold.

Fault detection scheme

The EFDR technique detects five types of node’s hardware failures such as battery failure, microcontroller failure, sensor failure, transmitter circuit failure and receiver circuit failure. According to the type of failure, the nodes are used in different purpose such as normal node, traffic node and end node. A node itself can detect the battery/power failure by periodical checkup of its energy level. If the battery energy level of a sensor node is less than the threshold value, then battery fault occurs. Therefore, it will announce itself as faulty node by sending message to its neighbor.

In EFDR technique, each node periodically sends a heartbeat message to cluster head. However, if this heartbeat message is not received for certain period of time then the cluster head can declare the corresponding node as faulty node because of its microcontroller or transmitter circuit failure. In EFDR, each node is responsible for detecting its sensor fault. The sensor failure is detected by each node with the help of vector fault detection model. The node collects data from their nearest neighbor nodes and compares it with own sensing data. If any node finds its sensor fault, it will declare itself as a traffic node. In EFDR, each node can detect its receiver circuit failure by simply diagnosing its received data. A node can declare itself as end node if its receiver circuit is faulty. After receiving the source node will set this route to invalid to do parallel transmitting by using the remaining available routes. When there is no legitimate routing information to the destination node in the source node’s routing table, the source node will re-launch the process of searching for routes.

CA based node management

In the EFDR, the CA is running in every sensor node, cluster heads and base station which stores the neighbor node failure information. The node failure information is represented by three bits stored in three different CA in each node of WSN. The ‘i’th bit of first CA represents sensor circuit condition, the ‘i’th bit of middle CA represent the battery, microcontroller and transmitter circuit condition and ‘i’th bit of last CA represents the receiver circuit condition. Therefore responsibility of the nodes is determined depending on the bit status of the CA. The three neighbours CA change their states according to their state change dependency. They are, Partially dependent CA rules and Fully dependent CA rules.
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The cluster head collects different failure information of its member nodes which is then fed into its three CA. The cluster head is now determining the condition of its member nodes by analyzing the CA.

### Table 1: Node fault information

<table>
<thead>
<tr>
<th>Bit representation</th>
<th>Sensor circuit</th>
<th>Battery/microcontroller</th>
<th>Receiver circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>Healthy</td>
<td>Healthy</td>
<td>Healthy</td>
</tr>
<tr>
<td>110</td>
<td>Healthy</td>
<td>Healthy</td>
<td>Faulty</td>
</tr>
<tr>
<td>101</td>
<td>Healthy</td>
<td>Faulty</td>
<td>Healthy</td>
</tr>
<tr>
<td>100</td>
<td>Healthy</td>
<td>Faulty</td>
<td>Faulty</td>
</tr>
<tr>
<td>011</td>
<td>Faulty</td>
<td>Healthy</td>
<td>Healthy</td>
</tr>
<tr>
<td>010</td>
<td>Faulty</td>
<td>Healthy</td>
<td>Faulty</td>
</tr>
<tr>
<td>001</td>
<td>Faulty</td>
<td>Faulty</td>
<td>Healthy</td>
</tr>
<tr>
<td>000</td>
<td>Faulty</td>
<td>Faulty</td>
<td>Faulty</td>
</tr>
</tbody>
</table>

### Table 2: Classification of node depending on CA State

<table>
<thead>
<tr>
<th>Normal node</th>
<th>End Node</th>
<th>Faulty node</th>
<th>Faulty node</th>
<th>Traffic node</th>
<th>Faulty node</th>
<th>Faulty node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Data routing scheme

After completion of faulty detection using CA rule vectors, next phase of work concentrates on the shortest path based efficient data routing. The L-system based routing scheme for data routing from cluster head to Base station via normal/traffic nodes. The L-system based data routing scheme handles frequent change in node hardware condition and makes an efficient data routing path within a faulty network environment.

Further, if a failure is detected locally, the failure information can be propagated to all other clusters.

However, the authors did not address energy efficient data routing in their work. The above survey enlightens the necessity of fault detection and efficient routing procedure for a distributed sensor network.

![Figure 4 Data routing path between sources to BS](image)

The base station (BS) derives data routing path for cluster heads with the help of L-system rules. For data routing in EFDR, mainly normal and traffic nodes are used. The derived path information is then conveyed to the cluster heads. Cluster heads transmit their data to the base station with the help of data routing path.

### III. IMPLEMENTATION

**Module description**

A fault detection and routing scheme to manage the self-detection mechanism. In self-detection, faulty node diagnoses the malfunction of the physical components of a node via both hardware components and software interface. The hardware interface consists of a flexible circuitry using accelerometers. The circuitry acts as a sensing layer around a node to detect the orientation and impact on the node. Self-detection technique of sensor node failure in is somehow simple as the sensor node presently observes the binary outputs of its sensors node. The binary output is compared with the pre-defined fault models. In the neighbour coordination techniques, faulty node identification is based on neighbouring sensor nodes coordination. In this technique, the reading of every node is compared with its neighbouring nodes’ reading. Advantages: Clustering scheme has become an emerging technique for building scalable and energy balanced applications for WSNs. Cluster-based communication hierarchy to achieve scalability, completeness, and accuracy simultaneously. Fault detection responsibility subsequently distributes among each individual cluster. In this system implemented for three Modules:

- Topology Formation
- Fault Node detection
- L-system basic routing path

**MODULE 1: Topology Formation**

Constructing the Project design in NS2 should take place in the corresponding nodes and sending the broadcast message to the entire nodes. Each node should send hello packets to its neighbor node which are in its communication range to update their topology.
MODULE 2: Fault Node detection

The main components of a sensor node are a microcontroller, transceiver circuits, memory, power source and one or more sensors. The microcontroller is mainly responsible for data processing and managements of other components of sensor nodes. Transmitter and receiver are combined in a single device known as transceiver. The healthy node may again be categorized into three groups: traffic node, normal node and end node. A traffic node can act as a router in multi hop wireless data communication. The normal healthy node, where all components of sensor nodes are in good shape, may be used for any types of job in WSN. In the end node, the receiver circuit of transceiver is malfunctioning; hence it can sense the parameter of the monitoring field and able to transmit data to the base station via other node. The cluster head takes decision after gathering the fault information about its member nodes’ responsibilities and sends them instructions by passing the appropriate CA. An energy efficient data routing technique is proposed for data transfer using normal and traffic node.

MODULE 3: L-system basic routing path

The base station (BS) derives data routing path for cluster heads with the help of L-system rules. For data routing in EFDR, mainly normal and traffic nodes are used. The derived path information is then conveyed to the cluster heads. Cluster heads transmit their data to the base station with the help of data routing path. When base station (BS) derives data routing path, BS station considers itself as axiom and other derived level nodes are selected from normal node or traffic nodes, which are responsible for data transmission from cluster heads to the BS.

The efficient data routing in a faulty environment is very challenging issues in WSN. In WSN, a large number of nodes are deployed in harsh, hostile environment that transfer collected data to the base station via multi hop wireless communication. Furthermore, the stationary and position aware sensor nodes are deployed in ad hoc manner. The efficient route discovery in WSN is problematic due to energy constraint nodes. Sudden change in node status also causes recurrent random topological changes. After the detection of faulty nodes, we try to identify the shortest route through normal and traffic node.

Performance metrics

In order to evaluate the performance of our proposed scheme, described in three traditional metrics have been considered:

Time elapsed:

This is the average time taken to determine the fault in the network.

Energy loss rate:

The energy lost by the network with respect to time.

Number of healthy nodes:

The number of healthy nodes signifies the total number of nodes that are in working condition. The normal node, end node and traffic node are considered to be as healthy node.

IV. CONCLUSION

In this effective fault detection and data routing scheme called EFDR for wireless sensor networks. Faulty sensor nodes are reused to work according to their hardware conditions. Reuse of faulty nodes is determined by the proposed CA rule. To reduce the computational complexity, we proposed the three neighbor linear CA rules for faulty node management scheme. An L-system rule is used for data routing path construction. We proposed L-system rules for efficient data routing. EFDR has good scalability to support sensor network with high density and high number of faulty nodes environment.
REFERENCES


