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A Survey on Fault Detection Techniques for Wireless Sensor Networks

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Abstract: Wireless sensor networks (WSN) has emerged as one of the most promising technologies for the future. Due to the advances in the field of sensor design, information technologies and wireless networks, there is a increase in the usage of wireless sensor networks. Wireless sensor networks are tend to fail, which leads to loss of data delivery from source to destination, hence degrades the quality of service. Therefore, there is a need to detect faults in the network. This paper presents analysis of various fault detection techniques in wireless sensor network such as centralized and distributed approach.
Keywords: Fault detection, Sensor node, Wireless sensor network.

Introduction

Wireless sensor network have recently emerged as a significant research topic due to advances in MEMS(micro-electro-mechanical systems) and wireless networking technologies. Wireless sensor network is a type of network which comprises of wirelessly communicating sensor nodes. The sensors sense, measure, collects information from the monitored field. The sensed data is forwarded to a Sink via Gateway. Sensor nodes communicate with one to another by using radio interface and thus form a network. Fig. 1 illustrates typical Wireless sensor network.

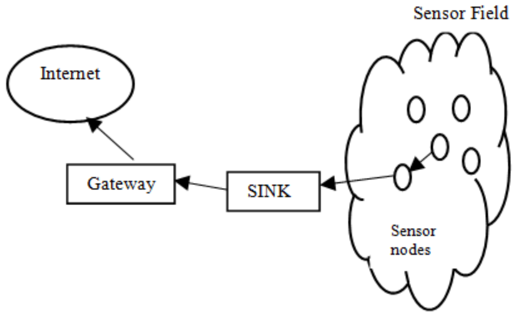

Figure 1. Typical Wireless Sensor Network

The main components of sensor network comprise of a sensing unit, processing unit, power unit, transceiver, mobilizer and location finding system. Basic block diagram of sensor node is given in Fig. 2. *Sensing unit:* There are two subunits in sensing units, sensors and analog to digital converter (ADC). The data generated by sensor which are usually analog in nature will be converted to digital signals by ADC. And further sent to processing unit

Processing unit: There are two subunits in processing unit, processor and storage unit. Processors processes and carry out the assigned tasks and store the sensor unit output. The several processing units such as microcontrollers, microprocessors and field-programmable gate arrays (FPGA) are used based on the specification required. Flash memory is widely used due to the storage capacity and low cost.

Transceiver: Connectivity between node and the network is facilitated by Transceiver. The communication schemes such as optical communication, infrared and radio-frequency (RF) can be used.

Power unit: Sensor nodes are powered by power unit. Either rechargeable or non-rechargeable batteries are used. To facilitate the user to get knowledge of location with high accuracy, location finding system is provided.

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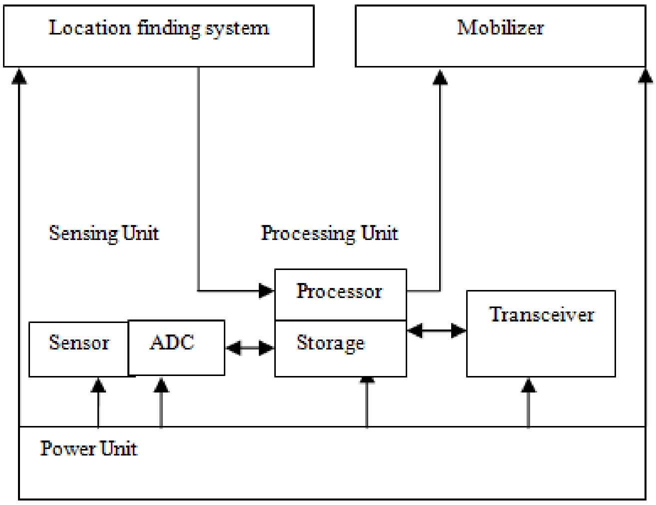

Figure 2. Basic block diagram of sensor node[1]

Compare to conventional networking technologies wireless sensor network have more advantages like lower price, scalability, reliabilty, accuracy, flexibility and low power consumption. Also the properties such as self-organization, mobility, tolerance to failures in nodes, dynamic nature of network topology, heterogeneity of nodes, inherent intelligent pocessing capabality and their ease of deployement made them to apply in huge area's of applications. Wireless sensor network has number of high profile applications such as military applications, area monitoring, environmental monitoring, industrial monitoring, medical field, agriculture, habitat and tracking.
The most challenging task in wireless sensor network is to maintain the network operational as long as possible. Sensor nodes will become faulty when the characteristics or nature of that particular node depart from original specification. The nodes in wireless sensor networks are tend to failure may be due to their low power or may be due to their deployment in unmonitored or hazardous fields which may lead to fault in sensor node.

Faulty node types in wireless sensor networks:

1) Crash node: In this type, fault will likely to be occur due to problems in battery. Or may be due to problems in hardware such as, circuit shorting and open circuit issues. Because of this, faulty node will fail to perform activities related to network. This kind of failure occurs due to natural calamities.
2) Omission Node: In this type, node fails to transfer message or data in prescribed specified timings. These types of faults are introduced by hacker with the intension of spoiling the working of entire network.
3) Packet dropper Node: In this type, sensor node fails to send all packets in the wireless sensor networks And such node retains few packets in the wireless sensor networks. These types of faults are also introduced by hacker with the intension of spoiling the working of entire network.

Faulty nodes will not send the actual observed data instead they may send arbitrary readings which will lead to faulty diagnosis and degrades the quality of service. Overall task of sensor network should not be affected by the failure of sensor node. This is called reliability or fault-tolerance.
Hence there is a need for recognition, correction or removal or replacement of faulty sensor nodes so that reliable data delivery can be achieved.
There have been several research work carried out in the area of fault detection in WSN in many approaches. In section I, we briefly reviewed some pioneer works carried out to detect fault in Centralized and distributed approaches. Finally section II illuminates brief conclusion.

I RELATED WORK

Many pioneer works is undertaken related to fault detection mechanism. The fault detection mechanism is categorized into Centralized approach and Distributed approach. The following section describes about aforementioned approaches.

Centralized approach:

In centralized approach, monitoring and tracing of faulty nodes will be handled by the geographically or

logically centralized sensor node.
Normally central nodes are with unlimited resource (ex. Battery energy) and wide range of fault management maintenance is executed by those central nodes.
Central node regularly introduces requests or queries into the networks, there by retrieve the details of each sensor node and network performance by adopting an active detection model by analyzing the retrieved information, identification and localization of failed or suspicious nodes is done.

N Ramanathan et.al [2], describes about prototype tool named Sympathy, which aims to detect and debug failures in pre- and post-deployment sensor networks. It gathers a large class of sensor network failure and localize each failure. This approach automatically detects and diagnoses failures by collecting and analyzing a minimal set of current states from centralized sink. Sympathy indicates failure if the sink has not received sufficient data from every node. In this approach, important event are selectively transmitted to sink node via sympathy node. Hence minimizes number of communication messages. The disadvantage of this technique is broadcasting of messages causes data redundancy at sympathy node. Sympathy detects a failure if and only if some sink component does not receive sufficient packets. This approach is not applicable for large-scale networks.

In research work of **Jessica Staddon et.al [3],** every node provides little detail about its neighbors during every measurement in a particular amount of time. Therefore by having adjacency info of the overall network, entire network topology is constructed by base station. After knowing the details about node topology, the failed nodes are effectively discovered. This approach uses simple divide-and-conquer strategy based on adaptive route update messages. Since additional messages have to be sent by node, this technique is expensive.

In **Sergio Marti et. al** [4], authors proposes a method where categorization of nodes is done by measuring their dynamical behavior. In many cases, misbehaving nodes can be a significant problem hence tools called *watchdog* and *pathrate*r are used. Where watchdog detects misbehaving nodes and pathrater helps routing protocols to avoid these nodes. This approach enables diffusion to achieve energy savings by selecting empirically good paths and by caching and processing data in network. But if there is any presence of collisions this method fails to find-out misbehaving node.

The centralized approach is effective and precise in many aspects. And can perform well in wireless sensor network with a less no. of sensors. As the no. of nodes increases, performance degrades. And cannot be used in large-scale networks. Message traffic is high since Central node acts as a single point, where concentration of data traffic is more. Therefore results high traffic of message also quick depletion of energy in several areas of the network, specifically in the regions where the nodes and central nodes are very closer. Response delay is more in multi-hop networks. Therefore, distributed approach can be implemented for large scale networks.

Table 1: Comparative table for Fault detection techniques in Centralized approach

Paper	**Key feature**	**Limitations**
N Ramanathan et.al [2]	Selectively transmit important event to sink node.	Redundancy of data
Jessica Staddon et.al [3]	This approach has knowledge of entire network topology Uses simple divide and conquer strategy based on adaptive route update messages.	Technique is expensive
Sergio Marti et. al [4]	Categorization of nodes is done by measuring their dynamical behavior	In the presence of collisions, the approach fails to detect misbehaving node.
Remarks: Centralized approach cannot be well suited for large scale networks.		

Distributed approach:
This approach enables the decision-making concept by sensor node at certain level. More the number of decisions a node make lesser will be the no. of messages to be received by the central node. i.e., central node will receive the information only if a real fault occurred in the network. Due to this, this technique helps in more energy conservation in node. Also extends lifetime of network with less data traffic. Examples of such approach are: Self-detection and self correction of node, failure identification via neighbor co-ordination and

clustering approach.

A. Self detection of node:

In **S. Harte et. al** [5], focuses on detection of physical malfunctions (sensor, battery, RF transceiver), caused by impacts or incorrect orientation. Here interference with sensor node is detected by designing a flexible circuit which uses accelerometers. These accelerometers behave as sensing layer around a node. Accelerometer performs software analysis on raw data to detect malfunctions and damage probability is assessed. If unhealthy node is found, the impact of that node on whole network is viewed. But in this approach, if there is presence of complete non-operational node, PC will not get the data and cannot be analyzed.
But the above disadvantage can be overcome, if approach is based on nodes monitoring each others. These approaches are implemented in [6,7].

In **Krishnamachari B et. al** [6] ,occurrence of event is detected by utilizing the data from nearby nodes. It is likely to be event has occurred, if nearby node agrees. If nearby node disagrees, it is likely that there is a fault. This article also proves that, measurement errors are uncorrelated, if errors are due to faulty equipments. And spatially correlated, if errors are due to environmental conditions. Faults are corrected and detected by developing Bayesian algorithm. This work shows better performance in minimizing no. of errors also has the additional advantage of being completely distributed and localized- i.e., each node needs to obtain information only from neighboring sensors in order to make decisions.

In **Ruiz, L. et**. al [7] , proposed fault detection technique using management architecture for wireless sensor networks called MANNA., which defines automatic management services. It facilitates self-configuration of nodes, self-diagnosis and self-healing services. This work also promotes resource productivity with less network cost and applications which have critical requirements could be a lot benefited with the knowledge provided by MANNA fault detection. However, this approach would result in increase in energy consumption.

In **F Koushanfar et.al** [8], introduces techniques that enables efficient multimodal sensor fusion in presence of faults and errors. This approach aims at designing low over-head fault-tolerant sensor networks also it enables usage of one type of sensor to back-up sensors of different types. This technique is applicable to both binary and multilevel sensors system also simultaneously addresses fault detection and correction.

B. Neighbor co-ordination:

In this technique, nodes will detect suspicious nodes by interacting with their neighbors. Node communicates with central node only after getting confirmation regarding failure occurrence. Hence, this design minimizes data traffic and conserves energy.

In **M. Ding et al.** [9], proposed algorithms which are purely localized. This minimizes the disadvantages employed by fault detection techniques which relay on 0/1 decision predicate for event, event region and event boundary computation. In 0/1 decision predicate, there is a possibility of missing spatial information on deployed sensors. But in many cases, there is a requirement of precise measurements and high robustness, which is not possible by 0/1 decision predicate. But this paper aims for detection of faults by taking any type of scalar values as inputs.

In **W. L. Lee et.al** [10], developed a localized algorithm which enables automatic self configuration of nodes also local and global self stabilization of nodes by allowing network to adopt to present network conditions. Here Sensor node acts as self reporting node. Once after the occurrences of externally triggered events, node tries to obtain extra slots from neighboring nodes and facilitates exchange of information. Role of central manager is to periodically analyze the sensor data which is reported by all other nodes. Also carry out the resource transfer function in systematic way. Provides controlling and monitoring in a better way and manages networks, after detecting event triggers.

In **Q. Han et.al** [11], developed a protocol to achieve expected reliability guarantees efficiently. And evaluated the protocol in the presence of varying fault rates under different application reliabilities. In this approach sink will act as decision maker during that particular timings by analyzing the reports retrieved from sensor nodes. This approach reduces communication overhead also minimizes resource consumption by adaptively adjusting the number of retransmissions based on current network fault conditions.

In **Tsang-Yi Wang et.al** [12], proposes fault detection technique which uses collaborative sensor fault detection scheme(CSFD). Here local sensors sequentially send their decisions to a fusion centre. It enables elimination of unreliable local decisions when performing distributed decision fusion.

C. Clustering approach:

Cluster formation is the process of grouping the nodes into several clusters. Where each cluster comprises of cluster head and cluster member. In this technology fault management tasks are distributed into each individual region. In a group, cluster head executes fault detection using centralized approach.

In **Tai et al.** [13], failure information which are locally detected will be transferred to remaining clusters through gateway. In this case gateway node is taken as the neighbor of the cluster heads.
In addition, the nodes which get data from cluster head's of two or more clusters will virtually acts as gateway. Simultaneously multiple clusters are created. Process of clustering will continue in an iterative way. Except the isolated nodes, (nodes whose range of transmission is out of the network node) remaining nodes will associate with clusters. This technique enables local clusters to have awareness about any changes in the entire network.

In **Yang Yang et.al** [14], defined a two-round detection and decision process in which each node has 2-hop neighbors. Every single node is provided with two views of hop clustering neighbors, so that detection accuracy performance will not be influenced by unbalanced fault distribution.

In **Gayathri Venkataraman et.al** [15], approach involves fault detection based on localized cluster concept. Also facilitates network connectivity recovery. This method consumes less energy, since no additional replacement or movement of sensors is required to recover the fault. This approach is effective and responsive.

In **M.Asim et.al** [16], proposes a grid-based approach where network is portioned into a virtual grid of cells to support scalability. Here fault management tasks are performed by a cell manager and gateway node of each cell. This approach aims to perform fault detection locally and in distributed fashion. Nodes easily back up each other in case of recovery.
Here detection and recovery of faults is done with less energy consumption.

In **G.Gupta et.al** [17], proposes a run-time recovery mechanism, which handles faults in one faulty gateway based on decisions of healthy gateways where full-scale re-clustering and deployment of redundant gateways are not required. In this approach high-energy gateway node acts as a centralized manager to handle the sensors and serves as a hop to relay data from sensors to a distant command node. In this technique, sensors are recovered from faults without shutting down or re-clustering the system. This approach performs periodic checks on the status of gateways. Sensors managed by a faulty gateway are recovered by re-associating them to other clusters based on backup information created during the time of clustering.

In **Mahapatro et.al** [18], developed an online fault diagnosis algorithm. It considers faults in different sections of sensor networks and communication channel. Spatially correlated sensor measurements are taken into account to obtain local view. In this approach additional diagnostic messages to be exchanged is minimum since this algorithm works together with normal network activities. Hence it is energy efficient.

Table 2: Comparative table for Fault detection techniques in Distributed approach

Approach	**Paper**	**Key feature**
Self-detection of node	S. Harte et. al [5]	This approach is mainly a hardware approach. Focuses on the detection of malfunctions, caused by impacts or incorrect orientation. Damage probability is assessed.
	Krishnamachari B et. al [6]	The proposed algorithm has the additional advantage of being completely distributed and localized. Uses concept of spatial co-relation. Shows better performance in minimizing no. of errors.
	Ruiz, L. et. al[7]	This work promotes resource productivity without incurring a high cost to network. Faciliates automatic management services.

	F Koushanfar et.al [8]	This approach facilitates low over-head fault-tolerant sensor networks. Significant cost savings are achieved
Neighbor co-ordination:	M. Ding et al. [9]	Provides a drastic improvement over works that take only 0/1 decision predicates. Decreases false alarm rate in faulty sensor detection.
	W. L. Lee et.al [10]	This approach allows systematic resource transfer that allows time slots (resources) from one part of the network to be transferred to another part. Supports non-uniform and reactive sensing in different parts of network.
	Q. Han et.al [11]	This approach provides expected reliability guarantees.
	Tsang-Yi Wang et.al [12]	Significant improvement in fault-tolerance capabilities over the conventional decision fusion without using CSFD.
Clustering approach	Tai et al. [13]	This approach exploits inherent message redundancy to achieve both robustness and efficiency.
	Yang Yang et.al [14]	This approach has higher clustering accuracy and lower fault detection ratios.
	Gayathri Venkataraman et.al [15]	In this approach, response time is faster, which ensures uninterrupted operation of the sensor networks. Energy efficiency is high.
	M.Asim et.al [16]	This approach provides scalability of the network and increase network life time.
	G.Gupta et.al[17]	This approach shows considerable improvement in the stability of the system and reduces the overhead of re-clustering and system reconfigurations.
	Mahapatro et.al [18]	It not only identifies the fault status in one-hop neighbors, but also from all sensor nodes in WSN.

II CONCLUSION

In the emerging applications of wireless sensor network, fault detection mechanisms become more interest research topics. In this paper various approaches used for fault node detection is discussed and key factors are listed. One can choose the fault detection algorithm based on the required specification. From the reviews on related work it can be concluded that centralized approach is effective and accurate in several ways and well suited for small scale wireless sensor network and not suitable for large-scale networks since quality degrades as number of sensor increases. Also faces more message traffic and quick energy reduction in several areas of the network. Response delay is more in multi-hop communication. Therefore distributed approach can be implemented for large scale networks.

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