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A Survey of Fault Management System in Wireless Sensor Network

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Abstract — In most of the cases deployment of wireless sensor nodes is at remote location, where fault detection & recovery is crucial task. Fault Management Framework is the set of functions that detect, isolate, identify and correct malfunctions. Fault Management System include algorithms for testing, diagnosing or repairing the network failures. Fault detection module will have collection of all possible symptoms of probable faults. Fault isolation module will observe alarm indication and possibilities of cause and design hypothesis. Based on alarm available fault identification module will test proposed hypothesis suggested by fault detection module and identify fault. Post identification, detected fault should not affect network performance. Fault recovery module will reduce the effect of fault as well repair and reconfigure the fault. The aim of this paper is to study state of the art research solutions to detect faulty nodes in wireless sensor network. Further it provide observations, directions and scope of research work for future improvements. This paper may be a good starting point for those who want to pursue research in fault management area of wireless sensor network.

Index Terms : Management framework, fault tolerance, fault identification, fault isolation, fault recovery, topology

1. INTRODUCTION

A Wireless sensor networks are mainly designed and deployed for monitoring events in environmental applications, precision agriculture, health care applications, industrial applications etc. The application might be generating alarm indications [1] in disaster areas such as tsunami or earthquake, forest fire detection or alert message for farmer to decide watering schedule, crop management in precision agriculture etc. In most of the above applications, network need to be deployed remotely. Post deployment, manually monitoring these networks seems to be impossible because of its remote locations. Detecting health of deployed network is one of the challenging domain in Wireless Sensor Network.

While designing any system main objective is to construct the system in such a way that it can automatically recover from failures without seriously affecting the overall performance. In particular, whenever a failure occurs, the system should continue to operate in an acceptable way while repairing process is going on. It should be able to tolerate faults and continue to operate and deliver optimized output.

Tanenbaum et al [2], Lila Paradis et al [3] defines Fault Management related different terminologies such as Fault Prevention, Fault Correction, Fault Tolerance, Fault Identification. Author describes different symptoms of possible faults such as packet loss, interruption, delay, lack of regular network traffic etc. Reason for the above symptoms may be buffer occupancy level, channel loading conditions, congestion etc.

Topology is the way nodes are deployed on field or site. Movement of the nodes due to environmental factors, intentional or unintentional human interference may affect performance of the network. Paolo et al, Mo Li et al [4][5] discussed techniques for controlling the topology of the graph representing the communication links between network nodes with the purpose of maintaining some global graph property (e.g. connectivity). Reduction of energy [6] consumed and interference through multiple hops is the main goal of designing. Fault occurrence, detection and maintenance may cause changes in topology. Fan Bai et al, Tracy et al [7][8] proposed mobility model designed to describe the movement pattern of mobile users, and how their location, velocity and acceleration change over time. Nafaa et al [9] used terminology "hole" instead of "fault" caused by network traffic congestion, energy dissipation, discuss causes and effects of holes on network performance.

Section 2 mentions role of Fault Management System (FMS), parameters need to be monitored by FMS. Section 3 mentions details about Multi tier Architecture of Fault Management System. Section 4 describes Characteristic of Fault Management System. Section 5 includes all possible symptoms, respective hypothesis and resolving methodology

2. ROLE OF FAULT MANAGEMENT SYSTEM

Fault Management System is suppose to scan or poll the network after a certain duration. Network monitoring algorithms in Fault Management System should monitor residual energy level of individual node, link quality between nodes, congestion level in network traffic, topology changes due to mobility of nodes etc. Logically single node may be sink should not decide failure in the network. There should be multiple confirmation about node failure so that false positive cases can be reduced.

Fault management frameworks address faults as part of a larger network management structure. Such solutions approach fault management at a higher level, e.g. by designing the management infrastructure and information model. These frameworks can be complemented by the specific fault detection and recovery techniques discussed next. A number of such frameworks have been introduced for either ad hoc networks or wireless sensor networks.

3. Multitier Architecture of Fault Management System

Akyildiz et al [10] specifies protocol stack of wireless sensor network. Within network all sensor nodes and sink follow the protocol. WSN Node includes all layers such as physical layer, data link layer, network layer, transport layer, application layer The functions of all above layers is same as TCP/IP protocol only issues in WSN is energy conservation so additional layer considering power related issues “power management plane” need to be addaed. WSN is an adhoc network. Nodes may be static or may be mobile. Node movement causes topology changes so related issues are handled by “mobility management plane”. Major role of sensors node is to sense, compute and communication. Normally to conserve energy of nodes above task is divided among the deployed nodes. This fuction is handled by “task management plane”. Considering traditional issues of energy, mobility etc. it is proposed to add one more layer of Fault management plane. The framework is expected to detect, identify, correct, recover, reconfigure the fault.

FIG 1: PROPOSED FAULT MANAGEMENT FRAMEWORK

4. Characteristic of Fault Management System

Tanenbaum et al [2] Fault Tolerant System should be reliable i.e. it should run continuously without failure for longer duration. It should be cost effective, maintenance free and ready topain use immediately so that these services can reach till mass level. User Interface of the designed system should be easily understandable by a non technical person also. Fault Tolerant System should be safe, robust, intelligent enough to be able to find ideally all categories of fault. If fault is detected Fault Management System should be able to analyze the actual component or entity failed in the network. Tamoghna et al [11] explains need of intelligent decision making specifically in modern agricultural fields. Intelligent decision making may switch on/off a pump/valve when the water level applied to the field reaches some predefined threshold value. Users carrying mobile phone can also remotely monitor and control the on-field sensors.

While designing the Fault Management System in query driven or event driven or continuous updating sensed readings from nodes to sink within the network the probable symptoms are mentioned in the next section.

5. Possible Symptoms. Hypothesis and Resolving Methodologies

This section mentions possible symptoms, hypothesis of respective symptoms, probable resolving methodologies adopted by earlier research papers.

Symptom No	Output Availability	Within defined Duration	Output Within boundary	Event Occurred	Other parameters
1	✓	✓	✓	✓	NA
2	X	✓	NA	✓	NA
3	✓	X	✓	✓	NA
4	✓	✓	X	X	NA
5	X Or ✓	✓	X Or ✓	✓	Connectivity problem
6	X Or ✓	✓	X Or ✓	✓	Background noise high

TABLE 1: POSSIBLE SYMPTOMS

Fault Symptom 1

Output is available at sink within define time may be in query driven, event driven, periodic reporting from sensor to sink method.

Fault Hypothesis 1: Continuous network health monitoring algorithms are working fine. All components in the network are working at least with minimum expectation.

Resolving Methodology 1: Algorithms should monitor/check status of all components in the network regularly.

Related work: Many algorithms are proposed for monitoring network health by different researchers. Different approaches are suggested for non occurrence of fault or if occurred it should be detected immediately such as polling, game theory techniques, collaborative techniques, self monitoring techniques, artificial intelligence approach etc. It is presented in summarized way in next few paragraphs.

Most basic way of detecting faults is polling of each node by others, this approach is simple but flooding will cause lot of energy dissipation. To improve this technique, solution of polling few sample nodes is suggested by Kleninberg et al [12]

ε-net Model was proposed detecting network failure. Basic idea is to divide network into subsets. Each subset will have "monitoring agent" Agent will periodically communicate with all other nodes in the network. If two nodes in the subnet are not able to communicate it is recorded as fault. To construct subset, random sampling method is effective. Author's model proposed basic and pioneer concept in fault detection which can be further extended for detection of node and edge failure.

Extension of detecting network failure model is Network Failure Detection and Graph Connectivity by Kleinberg et al [13]. Author proposed selection of "detectors" that is sentinel nodes at a subset of network by random sampling scheme using ε-net theory. Base station learns dead or alive bit of each sentinel. Author suggested detection set for edge failure as well detection set for node failure.

Main disadvantage of Kleinberg's algorithm is it uses ε-net theory for random sampling of nodes applicable for wired network. This scheme has a large rate of false positives that is many of the cuts detected by algorithm may be minor and can be neglected. Specially when sensor network is remotely deployed, these false positives creating false alarms will be very costly matter.

Another approach for monitoring is ε-approximation Technique inspired by kleinberg's sentinel model Shrivastava et al [14] uses ε-approximation theory instead of ε-net theory. To minimize false positives, sensors are imagined as points in the plane and linear cut is a line that partitions the point set. Basic idea is to use zigzag path called separator convert linear cut into dual points which will inform base station about healthy or faulty status. Author uses Point-Line Duality concept, transformation that exchanges points and lines. According to Duality theorem a point P(a,b) is equivalent to line L(y) where y=ax-b. Shrivastava et al uses radial sampling and sentinel method. Random sampling method chooses k nodes randomly, whereas in radial sampling k directions.

Self Monitoring Technique For fault detection, Jin et al [15] Efficient neighbor collaboration uses Self-monitoring of wireless sensor network (SMWSN) neighbor coordination. Thomas et al [16] Collaborative Technique Proposed solution based on Byzantine failures i e logical faults. Set of non faulty nodes having same sensed data perform an agreement. Largest and smallest data values are dropped from set and average is computed over the remaining data. Compare average to threshold for final decision.

Zhanshan et al [17] Author proposed dynamic hybrid fault modeling architecture using evolutionary game theory. More applicable for biological and ecological systems to develop the modeling architecture.

Managerial approach for overall fault management is proposed by Linnyer et al [18][19]. Author proposed MANNA Architecture for fault management having Self Managing capabilities such as Self Configuration, Self Diagnostic, Self Healing. The model requires network topology map, residual energy map, sensing coverage area map, communication coverage area map, cost map (cost required to maintain desired performance level), audit map (security or safety of the sensor from external attack).

Artificial Intelligence approach for fault tolerance is proposed by Shahadat et al [20]. Logic followed by author is to fragment data packets so that it can be confirmed sent through channel to avoid retransmission of the same packet. Prabir et al [21] proposed Sensor Potential Measurement Technique for identifying faulty node. Algorithm is based on the iterative computation of a fictitious "electrical potential" of the nodes by its neighboring nodes.

Fault Symptom 2

Output not available at sink within define time may be in query driven or periodic reporting from sensor to sink method.

One or many components in the network are not be working.

Fault Hypothesis 2: One or many components in the network are not be working.

Resolving Methodology 2: Fault Management System module at sink and sensor node may check its all data aggregation paths. From whichever path data is not available it should reverse trace that route to identify the cause at network layer. Algorithm should verify at data link layer whether node is not in sleep mode as per its duty cycle. Like a relay if any component in the route is failed output may not be available.

Related work: Many algorithms are proposed for detecting this type of fault so that it will be easier to find out which component in the deployed network is failed. Different approaches are suggested such as Bayesian fault recognition algorithm, Comparison technique etc.

Krishnamachari et al [22] proposed algorithm for differentiating between faulty sensor measurements and unusual environmental conditions. Bayesian decision algorithm is a set of nodes agreed on an operation before commitment. The algorithm obtains sensor readings of all neighbors of node i and generate random number based on number of neighbors as well sensor readings of all neighbors. Threshold decision scheme will decide lower and upper boundaries. Checking of generated random number is performed. If it is outside threshold range node is declared as faulty.

Lee et al [23] Comparison Technique propose a distributed algorithm for detecting and isolating faulty sensor nodes in wireless sensor networks. Nodes with malfunctioning sensors are allowed to act as a communication node for routing, but they are logically isolated from the network as far as fault detection is concerned. The proposed fault detection algorithm expects at least one node to pass the threshold test to proceed. Each sensor node first compares its sensed data with its neighbors. Xuanwen et al [24] author uses Bayesian network to differentiate between measurement error and sensor fault. Normally to decide fault, majority voting scheme is suggested by researchers but author achieves better detection and correction by optimizing between variables decided based on sensor fault rates to achieve optimal detection.

Fault Symptom 3

Output is available at sink but not within a define time may be in query driven, periodically sending readings from sensor to sink method.

Fault Hypothesis 3: Congestion in the network.

Resolving Methodology 3: Identification of end to end propagation delay will reduce congestion.

Related work: Bill et al [25] proposed an architecture having devices in clusters controlled by PAN Coordinator, each cluster will have one PAN Coordinator, group of PAN Coordinators are controlled by first PAN Coordinator. The end-to-end transmission time of all packets is used in training and testing phase to identify Node Congestion. Since training is given to individual node, every node is able to test and check fault without any cost. Training and computation cost may be major issue compare to communication cost.

Fault Symptom 4

Output available at sink is out of boundary conditions but actual event does not happen/occur applicable more in event driven.

Fault Hypothesis 4: Logical error in the sensor node or aggregation logic not working**.**

Resolving Methodology 4: Comparison of each node reading with its previous history reading. If present sensor reading differs than the previous reading, two possibilities reading changes because of event occurred, but assumption is event does not occur, so node is sensing and giving wrong output is the only one probability left.

Related work: Shuo Guo et al [26] proposed Ranking Difference Technique. Proposed algorithm provide solution for logical faults or data faults i.e. Byzantine data faults with either biased or random errors. FIND ranks the nodes based on their sensing readings as well as their physical distances from the event. This is called estimated sequence. Basic principal used is distance monotonicity i. e. change in pattern of ordering distance among nodes based on its readings as “signal attenuates with distance”. Detected sequence and estimated sequence difference is ranking difference. Higher the ranking difference “faulty” node probability is higher. The algorithm is implemented in low noise level environment. It can work only in event driven model that is number of events are less and rarely occurring. Mobility of nodes might be challenging case study for "FIND" algorithm.

Fault Symptom 5

Output may or may not be available post event occurrence. Output if available within time, may or may not be within boundries.

Fault Hypothesis 5: Network should always work in healthy condition but if above symptom occures connectivity might be the issue. logical error in the sensor node or aggregation logic not working**.**

Resolving Methodology 5: Faulty element in the network causes partition/s in the network. Connectivity problem may be resolved by sending mobile component which will patch these isolated networks.

Related work: Fault recovery techniques are applied to treat faults for reducing its effect on the network. Majority algorithms work at network layer, adding redundancy in routing paths for fault tolerance. For fault detection and recovery algorithm work at the transport layer or application layer.

Dini et al [27] propose algorithm for reconnecting partitions specifically in tunnel scenario. Partition Detection System (PDS), running on the base station is able detect the presence of network partitions and provide a rough estimation of their positions. If Base station determines network partitioning, one or more mobile nodes are sent inside the tunnel. The mobile node navigates inside the tunnel till it reaches target location. It consist of two partitions safe partition and isolated partition. Mobile node is in contact with both safe and isolated partition if partition gap is within range of single mobile node. When inter-partition gap is too wide single mobile node is not sufficient to reconnect them. In such cases mobile node have to move maximum nearest place to isolated partition maintaining connectivity with mobile node.

ivity problem.

Aggregation logic is affected by topology of the network Connectivity among nodes need to be verified. Almost all algorithms implemented by researchers uses hierarchical approach i.e sensor-actor or sensor-super node. Failure of Actor or Super node is still an unexplored area.

Ameer et al [28] proposed algorithm for Restoring Connectivity among the nodes. If failure occurs node will move itself to establish connectivity again following algorithm suggest minimum movement/relocation of the node as well relocation of least number of nodes so less communication overhead will be there. Ning Li et al [29] proposed K-Approximation Technique for observing topology control scenarios. Author uses the concept of reducing the number of links in the network to decrease the degree of routing redundancy in topology control algorithms. Mihaela et al [30] proposed k-degree Any cast Topology Control (k-ATC), event based co-ordination framework using Linear programming and distributed solution with an adaptive mechanism to trade off energy consumption for delay when event data has to be delivered within specific latency boundary. The author have not considered applications that require a fault-tolerant bidirectional topology that provides communication path both from sensor to super nodes and from super nodes to sensors. Another related problem that author have not addressed Value Of K When Network Topology Is Known. Author have not considered super node to super node communication.

Fault Symptom 6

Output may or may not be available post event occurrence. Output is available within time, may or may not be within boundries.

Fault Hypothesis 6: Node is faulty if background noise increase above a certain reference.

Resolving Methodology 6: Measure the background noise in sensed reading, if it is above certain reference declare that node as faulty.

Related work: In a mobile LEACH [31] architecture, if one of the end node moves away from the head the probability of error increases due to increased background noise.

Algorithms are suppose to detect any failure in network. The failure may be node, link or increase in noise etc. Fault Management framework (FMS) is suppose to be designed to provide solution for all possible symptoms. FMS should be equipped with ideas or explanations that will be tested through various methodologies, properly studying previous experimentation done related to that symptom. Ideally Fault Management Framework should deal with of Fault identification, removal, recovery from the fault & try to avoid it in future. Fault prevention will intercept probable faults; fault detection will investigate different parameters to gather characteristics of possible faults; fault isolation is to segregate, relate categories of fault and propose various fault speculation or hypotheses. Fault identification will check verify every speculation or hypotheses to identify faults. Fault recovery considers techniques to reduce effects of fault.

Our contribution of the paper is to summarize the state of art extensive survey in the area of fault management. It also analyzes strength of existing fault management techniques and its weakness. Moreover we identify further research scope in fault management area.

6. Future Research Directions

Fault Management domain have immense scope to contribute. Fault Management framework will identify abnormal behavior of network. Find out reason for unexpected output. Isolate the element responsible for this result. Applying recovery techniques to help network, resuming normal behavior. Algorithms proposing precautionary measures to reduce frequency of the same fault occurrence again.

We believe that fault management is a part of project design in software engineering life cycle. Lot of scope is there to work in fault management domain. The scope of fault prediction may be extended to understand post occurrence effect of fault on the network. Our future research plan shall be to work on the research gaps mentioned in the references. Next objective will be to design solution on these gaps & plan the scope of efforts required. Without intruding main objective of network deployment, provide various solutions for the betterment of the objective.

7. Conclusion

Fault Management approach may be proactive or reactive. In proactive approach, after initial deployment we may inject some faults. Fault detection algorithms may be tested iteratively to identify injected fault in the network prior to any major disastrous effects. In reactive approach, post occurrence of fault in the deployed network, from abnormal output behavior algorithm may detect existence of fault. Fault detection algorithms will help to identify the root cause of fault & take corrective actions. From methodological point of view Fault Management Framework is composed of steps like designing algorithms, simulation of algorithms, deploying it on actual network, analysis of network output. From technological point of view components involved are nodes, links, connectivity, background noise, embedded algorithms. Algorithm should be designed to consider the effect of environmental factor on deployed network.

It is proposed that if communication is limited to minimum number of hops, power consumption will be less & hence possibility of failure.

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