A Survey of Fault Detection and Management Techniques in Wireless Sensor Networks

Mrs. Pranoti Dhairyashil Kale, Dr. R.M.Tugnayat

***Abstract*— In most of the cases deployment of wireless sensor nodes is at remote location, where failure detection & recovery is a crucial task. It's very challenging to observe the effect of failed node on network. Recovery of faulty node as well smooth functioning of network till recovery of faulty node is interesting topics for research. Plug out of faulty node and plug in of recovered node affecting configuration and working of network are demanding areas in fault management.**

The aim of this paper to study state of the art research solutions to detect, recover faulty nodes in wireless sensor nodes. In addition we also identified strengths & weaknesses of these solutions. Further we provide our observations & directions for the 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*— fault diagnosis, fault recovery, fault tolerant, fault Management**

I. Introduction

Wireless sensor networks are mainly designed and deployed for monitoring events and surveillance applications. The application might be alarm indications in disaster areas such as tsunami, earthquake, forest fire detection etc. [4][12]. In most of the above application, network need to be deployed remotely. After deployment, manually monitoring these networks seems to be impossible because of its remote locations. Algorithms working in centralized or distributed manner [9][11], should take care about detection of such faulty nodes. Once detected, these faulty nodes should not affect accuracy of the final result to great extent, as it may hamper the purpose of the deployed network itself. Ideally fault management algorithm should take care of Fault identification, removal, recovery from the fault & try to avoid it in future.

Indian National Center for Ocean Information Services & Earth System Science Organization Under Ministry of Earth Science, Government of India in association with National Disaster Management Authority, Annual Report 2012-13 [4] contributes a lot to motivate research in disaster management area.

Basically fault management [9][11] includes faulty node identification, studying effect of faulty nodes on expected output, identify the cause of fault occurred, corrective actions for recovery of the faulty node. There are two major ways, Centralized or Distributed approach. In distributed approach[1][2][3][6][7][8][13][14][15][16][17] node can independently (without repetitively consulting central authority) self-monitor or self-detect faults. In Centralized approach [5][6] central node frequently monitors node status by injecting requests in wireless sensor networks. Based on available database, administrator may identify any unpredicted observations. The detail analysis may indicate failed or suspicious nodes.

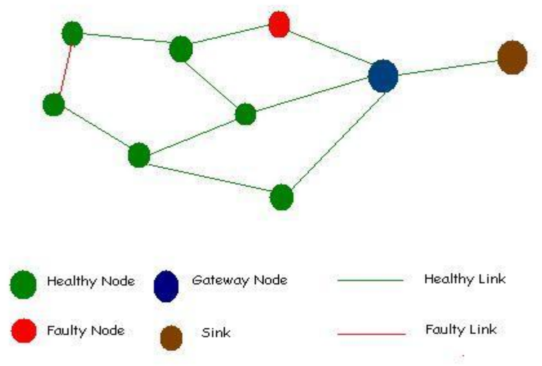

Fig.1 Faulty link, Faulty node in Wireless Sensor Network

Our contribution of the paper is to summarize the state of art extensive survey in the area of fault management. We also analyze the strengths of existing fault management techniques and their weakness. Moreover, we identify further research scope in fault management area.

II. RELATED WORK

Many efforts have been taken by various researchers in different domain like neural network[7][8][15][16][17][18], communication[1][14], node monitoring & data aggregation techniques[5][6][10][13].

We shall categorize the fault management research papers based on domain.

A. Based on Neural Network domain
B. Based on Data Aggregation Techniques
C. Based on Communication domain
D. Based on approach of providing end to end solution

Manuscript received June 16, 2014.

Mrs. Pranoti Dhairyashil Kale, Computer Department, University of Pune, Bharati Vidyapeeth's College of Engineering for Women, Pune, India, 09890164361.

Dr. R.M. Tugnayat, Principal, Shri Shankarprasad Agnihotri College of Engineering Wardha, India, 09763702586.

A. Analysis about papers based on Neural Network domain:

Fuzzy logic data fusion [7], Hierarchical Bayesian Space-Time framework [8], tracing techniques[16], decision fusion[17], Recursive Principal Component Analysis tool[18] are various Artificial Neural Network Techniques used by following research papers. We shall discuss strengths and weaknesses of each paper in detail.

[7][2010] Jethro Shell et al applies fuzzy logic data fusion approach to fault detection within a Wireless Sensor Network. The framework proposed by author is a combination of Control chart, one of the prominent monitoring tools in Statistical Process Control and Clustered Covariance Mean Fusion, Kalman filter for finding the most optimum averaging factor for each consequent state in dynamic, noisy wireless sensor network.

The framework observes subgroups, cluster heads, lower & upper threshold limits, find covariance in the network. This will help in reducing uncertainty & false positives within fault detection process. The author verified all results on simulated environment, implementing the same on real deployed sensor network may help for realistic verification.

Hierarchical Bayesian Space-Time theory can be used to predict about the likelihood of something happening in uncertain situations. Kevin et al [8] suggested Hierarchical Bayesian Space-Time modeling (HBST) two-phase modular fault detection framework.

Blind modeling is the first module in the fault detection pipeline. Data from all sensors within the audit time window is modeled assuming all nodes are healthy. The output of blind modeling is given to trusted sensor selection where accurate model of expected behavior is found out. The second phase is reevaluation module which takes the sensors that are marked as trusted and the output is used further for fault decision. Huge set up is required for establishing HBST model before deployment and lot of computational power required to estimate the parameters of the model.

Same kind of Distributed Practical framework of the Bayesian approach is used for specific chemical product stores by Sourour et al [15]. It is used to identify failed nodes with certain level of performance and fault tolerance. Two principle concepts, first sensory threshold (relative to the sensor) or "likelihood ratio threshold" and second decision by minimizing the probability of detection error.

Tracing technique is used for structural health monitoring by author. Vinaitheerthan et al [16] suggest novel efficient tracing technique that encodes and records the inter procedural control flow of all interleaving concurrent events. The traces means Replay debugging tool includes ordering sequence of events, control flow path taken, input values etc. Authors have verified runtime overhead, energy consumed etc on test bed as well actual Golden Gate Bridge monitoring. Major limitation is energy overhead due to tracing. The authors approach is suitable for Event-driven operating system such as TinyOS.

Considering the same application of structural health monitoring another artificial neural network concept, decision making can be used. Decision-making is recognizing and choosing alternatives based on the values and preferences of the decision maker. Concept of decision fusion believes, if a sensor node gives different decision about the occurrence of events from others, it is assumed as faulty. Value decision is, if expected output is n bit & actual output varies from the said no of n bits then declares it as faulty. X. Liu et al [17] focused on "faulty sensor reading" type of fault which is commonly occurring but difficult to detect. Structural characteristics, namely natural frequencies and mode shapes are used for decision making.

But in case of structural health monitoring where expected output might be in analog form so value decision may not be applicable. The model has limited scope in structural health monitoring only.

Another Neural Network concept is Recursive Principal Component Analysis tool. Recursive Principal Component analysis is a statistical procedure that uses an orthogonal transformation to convert and reduce a set of observations of possibly correlated variables to a few principal components. Xie et al [18] proposed Recursive Principal Component Analysis tool stores & updates standard normal behavior of nodes. Algorithm executes & compares behavior of network at that instance with stored one. If after comparison detected result is normal data about behavior is updated with recent one. If detected result is not normal it will release fault alarm.

Author evaluates the performance of RPCA using dataset from a real-world deployment in the Intel Berkeley Research Lab & not implemented algorithm on actual test bed.

B. Analysis about papers based on Data Aggregation Techniques:

Data aggregation algorithms in wireless sensor network will help to collect and aggregate data so that less energy is consumed and network lifetime can be extended. Fatima et al [5] proposed Adaptive Neighborhood Failure Detection mechanism framework. The NFD mechanism has adaptive timers to detect nodes crash due to failure of radio links. Sink send Query packet and wait till Failure Detection Timeout (FDT) for getting a response. Each node keeps a counter, which is incremented at every round. Two possibilities about node status are "Suspected" means suspected of being faulty, and "Mistake" means correction of earlier false suspect status. It is value addition of fault detection logic in Directed Diffusion routing protocol. Frequently broadcasting Query packet & its response may increase network traffic leading to reduction of network lifetime.

In data aggregation techniques deployment of nodes also carries lot of significance. If nodes are deployed with large distance in between it may create many small networks without connectivity [6] in between these networks. If nodes are densely deployed it may cause lot of redundant result resulting in higher cost. So it is quite challenging to optimize no of nodes/cluster (node density)[6]

Habib et al [6] proposed distributed protocol for heterogeneous, static as well as dynamic nodes to k-cover a Region of Interest RoI. The algorithm reduces the energy consumption due to communication and mobility of sensor. Static sink sends monitors all mobile proxy sinks by sending Query packets, mobile proxy sinks compare with their own density of nodes & based on the results decides to merge or lead.

The strength of this paper is that author tried to give end to end solution. End to end means from architecture, on demand k coverage protocol to data-gathering algorithm. Step one is author suggested four-tier architecture containing one static sink which is central co-coordinator, mobile proxy sinks, mobile sensors, and static sensors. In next step author proposed on demand k-coverage protocol that exploits sensor mobility to achieve k-coverage of any region of interest. On top of k-covered network configurations, author proposed two data-gathering protocols that use mobile proxy sinks to deliver the collected sensed data to the static sink.

The limitation of the paper is that author considers only one event at a time & only one static sink whereas practically this is almost impossible. In direct data gathering method, distance to a leader mobile proxy sink may not be shortest distance so end to end delay may be increased. In chain based data gathering approach failure of leader mobile proxy sink may cause data loss as there is no redundant way to connect with static sink.

Peng Yu et al [13] Node Self Detection by History data and Neighbors (NDHN) collects the characteristics of the nodes. The historical data is used to compute & take decision. Author simulated but implementing it in real world scenario will be challenging.

Both Md Zakirul et al [10][2013] & Peng Yu et al [13][2011] insist on node monitoring concept. [13] suggest every node to get neighboring nodes' measurement, concatenate, analyze it & forward faulty/healthy decision till sink. [10] suggest individual node to self-monitor, associated link monitoring & through co-coordinator node send status report till sink.

C. Analysis about papers based on Communication Domain:

In communication domain we have considered papers in which in addition to existing frame format some addition tags are added for fault detection and management.

Abu et al [1] suggest to add In-network Packet Tagging(IPT) in every node. Every node add its own path checksum tag with each data packets going to the sink node. While traversing through path till sink, each node in the path update the tag with its own node ID by means of the Fletcher checksum algorithm. Once packet arrived at sink path checksum is cross verified with stored path checksum in Network Data Base. Initially sink performs Network Path Analysis (NPA) & stores all network paths & their respective path checksums in Network Data Base (NDB). If there is variation in NDB & arrived checksum, Fault Detection and Identification module (FDI) will send control message to affected node.

Above Sequence Based Failure Detection framework detects faults in networks with periodic data transmission to the sink. Author injected failures in real test bed network. Then they try to calculate out accuracy by ratio of total number of faults detected by algorithm to actual injected failures. Author claims that Sequence Based Failure Detection is lightweight, accurate, and scalable. But sink has to store huge path checksum database, computation & verification of path checksum, initialization & execution of all failure detection & identification procedures too much of overheads are there.

Analogous to Election algorithms in distributed operating system concept of voting is used by Shahram et al [14]. The network is divided into two groups of clusters namely downstream group and upper group. Each group consist of several clusters. Each cluster have one voter node. In each cluster the voter nodes do voting operation about sensed data. The voter nodes in upper group forward the data received from downstream group.

Many points like how clusters are formed, who will decide voters, voter node forwards data so what will happen with that etc are not clear. Author claims that their algorithm can detect fault and recover fault in decentralized way.

D. Analysis about papers based on providing end to end solution :

Few authors have proposed end to end solution i. e. from architecture till application. Algorithms included in these papers provide solution for all probable problems in network. Dima Hamdan [2] proposed an integrated fault tolerance framework (IFTF). The framework first diagnose network faults which are likely to happen in WSN deployments; second quickly assess the impact of faults on the whole system behavior; third improve the fault detection rate by detecting some hidden causes of faults (silent or predefined faults); and fourth validate the application after code upgrades or any changes in the operating conditions. IFTF Manager initiates the two services, Application Testing Service & Network Diagnosis Service. Application Testing Service is like black box testing. Services are tested by feeding the nodes with test inputs and examining the outputs to compare them to the expected ones. Network Diagnosis Service consists of location detection phase & consensus phase means monitoring node sharing its findings with other neighbors. The algorithm proposed by author is restricted to mining operation.

Dima et al [3] proposed layer independent adaptive and efficient approach for fault diagnosis in WSN. “SMART” layer works in between operating system & application classified into 4 major components. It executes first failure detection phase consisting of location detection phase &

Parameters >>>>>> / ref paper	Centralized/distributed	Mobility of nodes	Mobility of sink	Link quality	Congestion level	Fault detection / correction/ tolerance
[1][2014] Abu et al	distributed	Static only	Static only	yes	yes	Fault detection
[2][2012] Dima et al	distributed	Not mentioned	Not mentioned	yes	no	Fault tolerant
[3][2012] Dima et al	distributed	Not mentioned	Not mentioned	yes	no	Fault detection
[5][2011] Fatima et al	centralized	Not mentioned	Not mentioned	yes	no	Fault Detection
[6][2013] Habib et al	both	Mobile & static	static	no	no	Fault tolerant
[7][2010] Jethro Shell et al	distributed	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Fault detection
[8][2012] Kevin et al	distributed	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Fault detection
[10][2013] Md Zakirul et al	Semi centralized/semi distributed	Mobile	Mobile	yes	no	Fault detection
[13][2011]Peng Yu et al	distributed	Not mentioned	Not mentioned	No	No	Fault detection
[14][2010] Shahram et al	distributed	static	static	No	No	Claims fault detection & recovery
[15][2013] Sourour et al	distributed	Not mentioned	Not mentioned	No	No	Fault detection
[16][2013] Vinaitheerthan et al	distributed	Not mentioned	Not mentioned	yes	yes	Fault detection
[17][2011] X. Liu et al	distributed	Not applicable	Not applicable	no	no	Fault tolerant model for faulty sensor reading
[18][2012] Xie Yingxin et al	Not applicable	Not applicable	Not applicable	No	No	Fault detection

consensus phase means monitoring node sharing its findings with other neighbors. Second it executes duty cycle management. Third phase is neighboring management where each node maintains neighboring node updates. This helps to update network topology dynamics, nodes redeployment, nodes failures, nodes reconnection and so on.

Based on certain threshold of link quality a node is considered neighbor. Fourth is messages protocol, node sends Heartbeat message (H) to check whether neighbor nodes is alive or not, Query message (Q) to inquire about the status of a suspicious node, Reject message (R) to indicate that a suspicious node is still alive, Acknowledge message (A) to acknowledge the reception of Reject message about a suspicious node. Authors have included almost all logical algorithms to function complete for fault management system. Authors failed to mention overheads in terms of network traffic & how it affect network lifetime.

Similarly Md Zakirul et al [12] suggests an embedded algorithm for self monitoring of each node to check faults in its own behaviors & transmit result to the coordinators. Link Monitoring for 1-hop neighbors is done and transmit a behavior report to the coordinators. Finally these reports are sent to sink & sink in return may take any action for fault tolerance. Report about a link status is prepared by CMC (continuous time Markov chain), link failure probability etc. For observing faults of the node on its own in active mode, author define 3 process states, Preprocessing (P) is the initial state that waits or prepares for new tasks; Working (W) state that mainly processes the tasks; Idle (I) is the idle period of time during processing a task. Algorithm is embedded in node itself no involvement of sink. Each node individually monitors the links to its 1-hop neighbors. Finally all information is gathered at sink & remote monitoring center. It is just simulation in OMNeT++ & verified the results as proof of concepts assuming remote control car as mobile event.

Many efforts have been taken by various researchers in different domain like communication[15], neural network[7][8][16][17][18], node monitoring & data aggregation techniques[5][6][10][13]. Few authors have opted for special fault management layer in between WSN Operating system & application[2][3]. Adding additional checksum field [1] in network packet & verifying decoded tag information at sink may also help in fault management.

Majority of papers are using Neural Network techniques. Both [15][2013] & [17][2011] uses the concept of value fusion & decision fusion from parallel decentralized detection scheme. only the difference is [15] uses Bayesian approach whereas [17] uses natural frequencies & mode to detect faults. All mentioned algorithms in both papers are designed for a particular application [15] for storage of chemical products, [17] for civil structural health monitoring. Fault tolerant system should ideally give same output result, irrespective of faulty node. Proper coverage of network area will help in the same. [6][2013] Habib et al suggests two data gathering approaches in architecture of mobile, static nodes, static sink, mobile proxy sink. Author proved chain based approach perform better than direct data gathering approach. Decision of adding nodes in region of Interest will be based on local density that is number of mobile sensors in the communication range.

Future Research Directions:

Fault Management domain has immense scope to contribute. Fault Management domain consists of identifying abnormal behavior of network. Find out reason for this unaccepted output. Isolate the element responsible for this result. Applying some recovery techniques to help network in resuming normal behavior. Precautionary measures to reduce frequency of the same fault occurrence again.

Fault Management from methodological point of view composed of steps like analysis of system, designing algorithms, testing of algorithms. From technological point of view components involved are nodes, links, and embedded algorithms. Other than this is environmental factor.

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. Cyclically executing these algorithms may help to identify fault prior to any major disastrous effects. Fault prediction is most important step in proactive approach.

In reactive approach, from abnormal behavior we come to know about existence of fault. Our fault detection algorithms will help to identify the root cause of fault & take corrective actions. 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 prediction area. 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 this survey paper. Next to design solution on these gaps & plan the scope of efforts required. Without disturbing basic objective of network deployment, provide various solutions for the betterment of the objective.

We shall consider advantages of both proactive and reactive approaches, centralized as well distributed approaches. As shown in the figure1 our first phase will follow centralized approach for deployment and configuration. Whereas for second phase implementation and execution we shall for distributed approach.

III. Conclusion

In Centralized approach due to heavy traffic at sink, there is possibility of communication hole problem & if sink itself fails how system will be stable is not discussed by anyone till date as per our reading. But coordination of all failure management system is easier compared to distributed approach. We are planning for hybrid approach which will result in best of both approaches.

Most of the failure occurs due to remote deployment which leads into connectivity issues so we propose to start implementing failure management with deployment & connectivity issues i. e links among the nodes, coverage in network. Next possibility of occurrence of failure is hardware/ software/battery failure.

Our intuition suggests if communication is limited to minimum number of hops power consumption will be less & hence possibility of failure due to battery consumption can be reduced. So our maximum transactions should be single hop.

Acknowledgment

I would like to sincerely appreciate valuable suggestions provided by Dr.R.M.Tugnayat and Prof G.B..Regulwar for improving the content of this paper.

References

[1] Abu et al “Failure Detection in Wireless Sensor Networks: A Sequence-Based Dynamic Approach” ACM Transactions on Sensor Networks, Vol. 10, No. 2, Article 35, Publication date: January 2014

[2] Dima et al “Integrated Fault Tolerance Framework for Wireless Sensor Networks” 19th International Conference on Telecommunications (ICT 2012)

[3] Dima et al “SMART service for fault diagnosis in wireless sensor networks” Sixth International Conference on Next Generation Mobile Applications, Services and Technologies 2012.

[4] Earth System Sciences Organization, Indian National Center for Ocean Information Services (ESSO) (INCOIS) Annual Report 2012-13

[5] Fatima et al “Efficient Adaptive Failure Detection for Query/Response based Wireless Sensor Networks” Wireless Days (WD), 2011 International Federation for Information Processing (IFIP)

[6] Habib et al “Joint k -Coverage and Data Gathering in Sparsely Deployed Sensor Networks – Impact of Purposeful Mobility and Heterogeneity” ACM Transactions on Sensor Networks, Vol. 10, No. 1, Article 8, Publication date: November 2013.

[7] Jethro Shell et al “Fuzzy Data Fusion for Fault Detection in Wireless Sensor Networks” Workshop on Computational Intelligence (UKCI), 2010 UK

[8] Kevin et al “Sensor Network Data Fault Detection with Maximum A Posteriori Selection and Bayesian Modeling” ACM Transactions on Sensor Networks, Vol. 8, No. 3, Article 23, Publication date: July 2012.

[9] Lilia Paradis et al “A Survey of Fault Management in Wireless Sensor Networks” Journal of Network and Systems Management (c 2007) DOI: 10.1007/s10922-007-9062-0

[10] Md Zakirul et al “Local Monitoring and Maintenance for Operational Wireless Sensor Networks” 12th IEEE International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom), 2013

[11] Mengjie Yu et al “Fault Management In Wireless Sensor Networks” IEEE Wireless Communications • December 2007

[12] National Disaster Management Guidelines, Management of Tsunamis August 2010.

[13] Peng Yu et al “A Self Detection Technique in Fault Management in WSN” IEEE Conference on Instrumentation and Measurement Technology (I2MTC), 2011

[14] Shahram et al “Improving Fault Management using Voting Mechanism in Wireless Sensor Networks” International Conference on Computational Intelligence and Communication Networks 2010

[15] Sourour et al “Application of distributed fault detection in WSN to dangerous chemical products based on Bayesian approach” International Conference on Advanced Logistics and Transport (ICALT), 2013

[16] Vinaitheerthan et al “Diagnostic Tracing for Wireless Sensor Networks” ACM Transactions on Sensor Networks, Vol. 9, No. 4, Article 38, Publication date: July 2013.

[17] X. Liu et al “Fault Tolerant WSN-based Structural Health Monitoring” 41st International Conference on Dependable Systems & Networks (DSN), 2011

[18] Xie Yingxin et al “Adaptive and Online Fault Detection using RPCA Algorithm in Wireless Sensor Network Nodes” Second International Conference on Intelligent Systems Design and Engineering Application 2012.

Mrs. Pranoti Dhairyashil Kale, working as Associate Professor in Computer Department of Bharati Vidyapeeth's College of Engineering for Women, Pune. She has completed her ME(Computer) her area of research is Wireless Sensor Network. She is Life Member of ISTE.

Dr. R.M. Tugnayat, is Principal at Shri Shankarprasad Agnihotri College of Engineering Wardha, India.