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Intelligent Fault Detection and Isolation System in Wireless Sensor Networks: A Review

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Abstract: *wireless sensor networks (WSNs) have been the subject of investigation in the previousyears; networks fault diagnosis obtained considerable notice. Fault diagnosis a fundamental element for wireless networks, particularly in WSNs, due to their ad-hoc essence, limited resources and deployment conditions. WSNsusually made of 100s of nodes that are used in comparatively rigid and difficult conditions. In aspects of hardware value, sensor nodes constantly employ moderately inexpensivechips that tenders those nodes become faulty or error-prone during their lifespan. Electromagnetic interference and natural factors can further impact the WSNs performance. To enhance data quality, increase network security, reduce response time, and increase network lifespan, numerous researches have concentrated on WSNs faults diagnosis. This review labels fault diagnosis techniques in the recent years to three classes according to key attributes and decision centers of working algorithms: distributed, centralized, as well as hybrid methods. All those researches have particular aims, this paper attempts to analyze them.*

Keywords: *Wireless sensor networks (WSNs), Fault diagnosis, Centralized method, distributed method, hybrid method, Fault detection*

I. Introduction

Wireless sensor networks made from few nodes to thousands. Which are wirelessly linked to gatherinfo from events in the environment ofdeployment. The detected data is transmitted over a wireless link to a central node, where it is utilized for decision making. In the past decades, WSN has drawn significant recognition due to its increasing prospect and positive influence on every daily life aspect. Real-life situations are molded into data that can be handled, stored and employed for various objectives by sensors in WSN. Every sensor node is adjusted distinctively in harmony with the deployment environment, like; environmental surveillance [1], scientific observation [2, 3], traffic monitoring [4]. a conventional wireless sensor node is composed of these elements: (a)transceiver, (b) microcontroller, (c) power supply, and (d) additional module, e.g., actuators, etc, as shown in

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figure1 Those nodes use radio channels to interact with each other and distribute their data, that transmitted to an BS or SN directly or via multi hop relays [4].

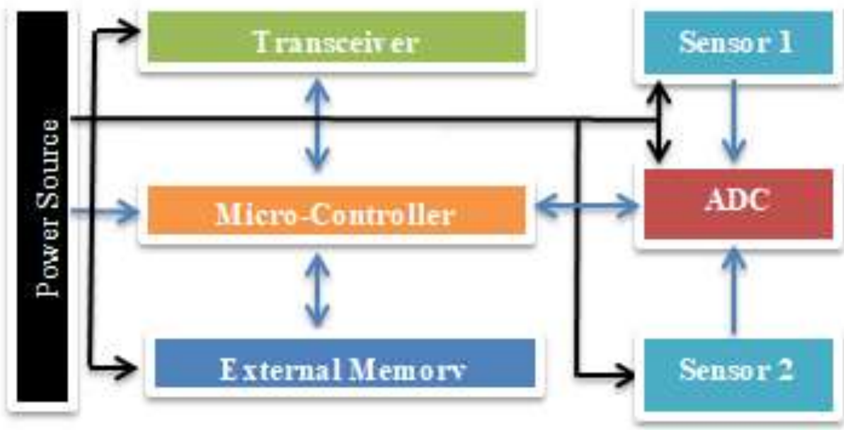

Fig.1 Typical sensor node components.

A WSN has these features that distinguish it from other systems: limited resources, high quantity of various kinds of nodes,dynamic topology, hierarchical deployment systems, self monitoring, and utilization conditions. Sensor networks fault diagnosis is in high need because it can assist to shape the networks to be furtherrobust, energy efficient, stable also scalable. Analyzing the network precisely and in an appropriate time is essential; else the network will not be capable to accomplish the designed purposes faultlessly and efficiently. For example, GreenOrbs is a sensor network which is made of three hundred nodes and used in forests to observe and evaluate events [5, 6]. In the system, sensor nodes collect data at constant periods from the forest to be examined and guarantee that the network nodes functioncorrectly. Therefore, faults diagnosis performs an important function in GreenOrbs network checkingsince a fault could have a huge adverse impact on the system's performance and fidelity [7].

II. WSNS Fault Diagnosis Methods

A. Classification Approach

Fault diagnosis methods have various organization classifications and are of three kinds, based on where the node condition determination is done [8,9] as shown in figure 2.

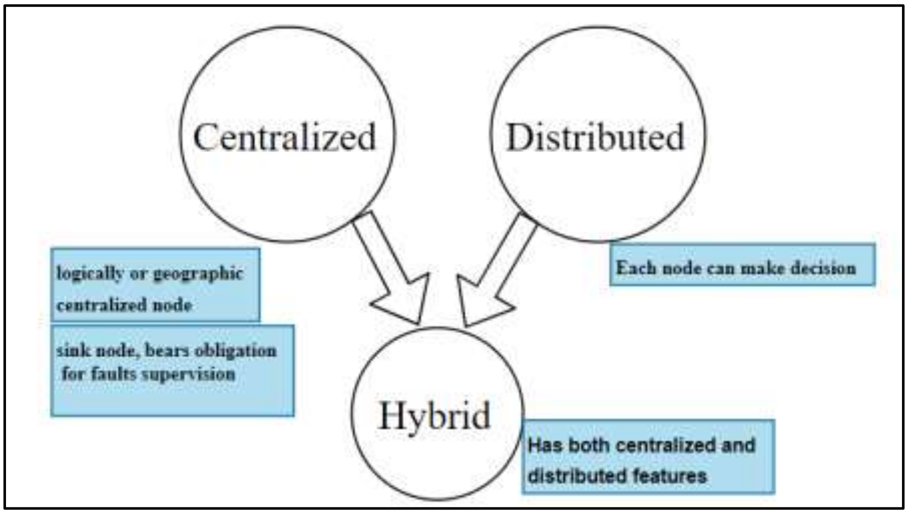

Figure 2 fault detection methods.

B.Fault Types

A valuable process of building a precise description concerning faults diagnosis are to characterize faulty nodes based on faults types, nodes presumed to present. Faults can be categorized according to underlying cause, duration, or on failed component behavior [10, 11]. Based on the response of failed node, faults could be categorized as behavior faults or time faults as shown in figure 3. A sensor node exhibits the behavior fault is incapable to interact with the entire network. A node exhibits soft faults remainsoperational with modify response. According to the duration, faults can be categorized as intermittent, transient, orpermanent. Permanent faults are hard faults that constantly display errors while they are tested [12, 13]. Temporary faults could be divided to internal faults (intermittent)and external (transient). The soft faultmostly caused by circumstances that originate from node deployment surroundings and do not mean the node is faulty. Those faults are difficult to follow on, as usually their adverse impacts quickly vanish [14, 15].

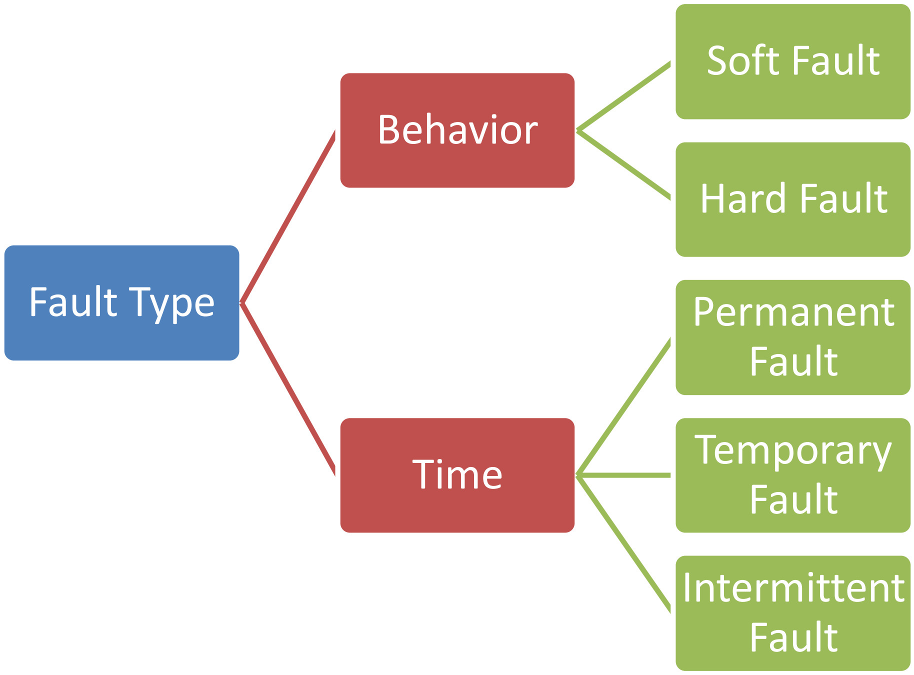

Fig 3 general fault types

Hard faults are as well named permanent faults. They are the outcome of hardware unit failure [16]. Soft faults are constantly intermittent ortemporary, that implies nodes with soft faults appear arbitrarily and hard to foreseeas well as identify [17]. Causes of hard faults are; Battery depletion Communication module faults, etc., while soft faults can occur due to; timing failure and a node behave maliciously or arbitrarily, etc.

1) Centralized Method

Bill C.P. Lau et al., [18] proposedCentralized Naïve Bayes Detector (CNBD) process, examines end to end communication time gathered at sink node. Therefore all the processing will not be done in the individual sensor nodes that pose no extra power strain on every sensor nodes battery. While Jyrki Kullaaal., [19]modelled a sensor network as a Gaussian technique and every network sensor is evaluated in turn utilizing minimum mean square error (MMSE), which evaluation sensor fault, that is recognized and quantified employing multiple theoretical test, generalized likelihood ratio (GLR).

Cheng-bo Yuet al., [20]collected different sorts of fault indications and combine them after that analyze fault nodes via support vector machine (SVM)and rough set scheme (RS). At the beginning, RS theory is utilized to decrease sampling data attributes to choice decision-making attributes for developing a new simplistic dataset. After thatfresh simple dataset used to prepare SVM. And eventually analyze WSN failure nodes via the trained model of SVM. The Gaussianproceduremodelisentirelydeterminedbyitscovariancematrix (Σ) andmeanvector (μ):

$$p(y) = |2\pi\Sigma|^{-1/2}\exp[-\frac{1}{2(y-\mu)})^{T}\Sigma^{-1}(y-\mu)] \quad (1)$$

Where y is measured variable.The sensor network model is derivative of approximating Σ and μ of sensor network.

R. Dhal et al., [21]whether local structural variations in a complicated network can be characterized from passive remote period course measurements of network dynamics. Especially link failures discovery in network synchronization method from noisy measurements atdistinct network element is acknowledged. By expressing the detection dutyas MaximumA Posteriori Probability (MAP) hypothesis testing issue. In case when the detector is aware of the network state, accurate detection is feasible incommon connectivity states despite the locationof measurement. If the detector does not have awareness, remote signature allows enhanced but not accurate detection, under similar connectivity states.

Wei Gonget al., [22]proposedDID, a directional diagnosis method, in which diagnosis data acquisition is managed via fault inference method. Via many sequences of incremental data probing as well as fault argumentation, root conditions of network anomalies with high reliability are deduced. Used node tracing system to replace the faulty areas topical topology and create an inference model respectively. The DID method achieved in the system offorest monitoring sensor network, GreenOrbs. Experiential outcomes verify design effectiveness and scalability.

XiaohangJin et al., [23] Proposed WSN abnormality detection principle according to autoregressive (AR) model and Kuiper test according topassive diagnosis. At first, AR model with best order is stated according to standardoperational condition of using the Akaike data model. AR then serves like a filter to handleexpected received beacon from various strange situations. Health indicator according to the Kuiper test, that is employed to examine the association amidtraining error of standardsituation and remaining of test situations, is determined for designating WSN health states.

Christopher Oßneret al., [24]introduced SEDEL, for Sensor nEtworkDEfect Localization. SEDEL assist WSN operator to locate faulty nodes in WSN routing topology. Especially, the operator store graph descriptions of routing topology, along with report if WSN has created errors. According to this data, SEDEL designates every node a suspicion rate that is associated with the defect possibility. Therefore, this method can be utilized with any sort of faults, and the fault kind does not have to be known, as long as the operator can determine if a particular process is correct or not. The SEDEL has been examined with a real node deployment. The evaluation reveals that the faulty node is designated as a high possibility in the majority of the tests.

2) Distributed Method

Sujie Shao et al., [25]presented a novel WSNs decentralized fault discovery mechanism based on cooperation and credibility. Initially, a feasible reliability form of a sensor is organized to recognize any unusual sensor status based on to its temporary data association. Derived from the reliable pattern, the unusual sensor is then determined to start fault diagnosis inquiries. Next, the fault request sending diagnosis time is considered to evade the communication overhead caused by random diagnosis inquiriesand enhance fault detection performance based on neighbor assistance. The neighbor sensor diagnosis response is examined based on its status. Ultimately, to additionally enhance the fault detectionefficiency, the diagnosis outcomes of neighbors are split to different categories to estimate sensors fault status which begin fault diagnosis inquiries.

T. Panigrahiet al., [26]proposed fault tolerant decentralized evaluation in WSNs, once faulty nodes exist in the network and it is not aware of them. For this, a robust distribution predicting procedures employing a robust

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function such as error saturation nonlinearity and Huber cost function are introduced to make the network fault tolerant.

Feng Zhen et al., [27] described machinery monitoring scheme based on the wireless sensor network method, that is used at Cold Rolling and Continuous Annealing line (CRCAL) in steel companies. The gateway state communication information examined with statistic approach in cluster managed by the diagnosis node. Merging along with multivariate statistical process control (MSPC) theory, the introduced scheme of gateway irregularity detection based on Principal Component Analysis (PCA), the technique is verified to be efficient and trustworthy according to the real data from field test monitoring network system.

Hongsheng Xu et al., [28]adopted an attribute compression algorithm via combining rough set with neural network pattern to reduce node fail, to accomplish data reduction, enhance precision and fault analysis schemecapability. The researchuse a neural network and rough set to failure event of node by employing knowledge reduction of logic operation and discernibility matrix, reducing the unnecessary attribute node fault. Then, the fault determination complex table is produced via the listed fault, and ultimately, discover fault location consistent to fault event and final decision table reparation. The laboratory outcomes confirm that this approach enhances the fault diagnosis robustness, and improves WSN limited energy practicability.

Peng Tanget al., [29]usedtwo hundred sensor node to illustrate that the suggested NHCRF process can achieve great and practical outcomes for WSN health diagnosis. NHCRF model can enhance diagnosis of WSN fault due to the relaxed independence theory of Hidden Markov model. To magnify the robustness and anti noise capability of NHCRF, the nearest neighborstheory is employed when calculating dependences.Standard HCRF models the conditional likelihood of classlabel assumed a set of consideration by

$$p(y|x,\theta) = \sum_s p(y,s|x,\ \theta) = \frac{\sum_s e^{\varphi(y,s,x:\theta)}}{\sum y^1 \in y, s \in S^{mw^{\varphi}(y^1,s,x:\theta)}} \quad (2)$$

where s $=\{s_1, s_2 \ldots, s_m\}$, each si$\in$ S captures specificfundamental dynamics of every class, and S is HCRF model hidden states set. The possible function

φ(y; s; x; θ) <R, parameterized by θ , measures the compatibilitybetween observationsset label and hidden states configurations.

3) Hybrid Approach

Amna Zafaret al., [30]introduced hybrid faults diagnosis design that; proactively examines for faults detection and starts faults diagnosis on-demand base, gathers and analyzesprocess performance state indicators and achieves inter process communication aware fault diagnosis according to preference examination. The physical entities architecture that would carry out the logical entities in a regular WSN determined as;

- ❖ DA diagnostic agent to regularly observe sensor node procedures.
- ❖ LCH local cluster head which conducts faults analysis in clusters.
- ❖ ESCH error specific cluster head to managespecific kinds of faults via a specific fault diagnosis.

Chun Lo et al., [31] presented an algorithm for identifying general nonlinearity faults without utilizing reference sensors. This paper presents a fault diagnosismodel structure that is achieved in a pair of wireless sensors.

The sensor nonlinearities detection is determined to be similar to answering largest empty rectangle (LER) problem, given characteristics set derived from a sensor outputs analysis. A low difficulty algorithm that provides an estimated answer to LER problem is introduced for embedment in resourceconstrained wireless sensors. Through determining LER problem, sensors damaged via nonlinearity faults could be segregated and recognized.

FarzinPiltanet al.,[32] proposed a strong, smart, model centered on hybrid faults detection and diagnosis (FDD) method for WSN in proximity of uncertainties and noise. WSN modeling is according to adaptive technique that merges fuzzy C-means clustering algorithm along with altered autoregressive external model and used for fault detection in WSN. The suggested adaptive nonlinear ARX fuzzy C-means clustering method acquires both error reduction alsoenhanced convergence comparable to that of conventional fuzzy C-means clustering algorithm.

Rakesh Ranjan Swain et al., [33]presented an automatic design offault diagnosis that could diagnose various kinds of faults in kind of soft and hard faults. The introduced design implements feedforward neural network prepared with hybrid metaheuristic algorithm that merges the basics of exploitation and exploration of search space. The suggested procedure made of various states like a clustering phase, and classification phase, fault detection, plus decision and diagnosis stage.The WSN residual signal is calculated as:

$$r(k) = [Z]^T - [\hat{Z}]^T = [W_T^T(k)W_B^T(k)W_R^T(k)]^T - [\hat{W}_T^T(k)\hat{W}_B^T(k)\hat{W}_R^T(k)]^T \qquad (3)$$

Where r(k), $W_T^T(k)W_B^T(k)W_R^T(k)$are the WSN residual signal.

The applied methodology can diagnose complex faults like soft permanentfaults, hard permanentfaults, intermittentfaults, as well as transient faults for nodes beside links. The proposed implementation can as well distinguish between various kinds of faulty function for both links and nodes in network.

III. Comparison of Fault Diagnosis Techniques

1) Many methods of neighbor coordination just examine Spatio-temporal relationships between sensors data of nearby nodes and overlookdependencesamidsensor node attributes. This, in return, decreases detection precision of the diagnosis system and raises false alarm level.

2) Limited works have been done on analyzing transient and intermittent errors. No research discusses a mechanism to distinguish between intermittent and transient.

3) Most methodspresume that nodes are stationary and do not takes into account nodes movement.

4) Most of those methods utilize a prefixed threshold to identify faults. Nevertheless, an ideal threshold is not simple to fix. Also, considering fixed thresholds might not be precise for dynamic WSNs.

5) In test based approaches, the sensing components status overlooked,thus in return fails to examine all sensor node functional systems.

6) Existing methods acknowledge only static faults; the node state is not permitted to change through examination routine.

7) Most methods fail if network has malicious nodes in it. Malicious nodes work togethermight separate healthy nodes in a way that mistakenly identify themselves asdefective.

8) Generally most works does not recognize errors in channels of communication.

9) Most fault diagnosis techniques just contemplate uniform wireless networks, which nodes are identical in terms of hardwareandprotocol;therefore, fault determination process cannotbe employed to Heterogeneous Wireless Sensor Networks directly.

IV. Conclusions

Faults diagnosis can be recognized at each side of networks, like at base station centralized, node planes (decentralized), or incorporation of both the (hybrid). The hybrid networks have more comprehensive image of entire A network evaluates it for node-based method, and thus judgments might be completed from comparatively more comprehensive view. The node plane evades interchange in the clouds and delay that improves the network's total lifespan. As a conclusion, the hybrid method obtains the benefits of the other methods while evading their weaknesses. Therefore, by utilizing this method, a more reliable fault analysis protocol or algorithm be capable of introduced. Important have been working on categorization the topics of reliability, robustness, and lifespan in WSN. This review presents a more extensive image of modern promising methods for the detection and diagnosis. It in addition expands on their solid and feeble points. We trust so as to this review determination be crucial in introducing further reliable, scalable, robust, intelligent protocols and get-up-and-go efficient soon.

Table 1 summary of the related studies in fault detection field.

Author	**Year**	**Network diagnosis**	**Fault persistence**	**Approach ofDiagnosis**
Bill C.P. Lau	2014	Centralized	Permanent& Transient	Self-diagnosing
Cheng-bo Yu	2014	Centralized	Permanent, Intermittent and Transient	SVM
R. Dhal	2015	Centralized	Intermittent and Transient	Topology control
Wei Gong	2015	Centralized	Intermittent and Transient	Topology control
XiaohangJin	2015	Centralized	Intermittent and Transient	Model based
Christopher Oßner	2016	Centralized	Intermittent and Transient	Topology control
Sujie	2017	Distribu	Permane	Spatial-

Shao		ted	nt, and Transient	temporal coordination
T. Panigrahi	2016	Distributed	Intermittent and Transient	Spatial coordination
Feng Zhen	2016	Distributed	Intermittent and Transient	Cluster-based
Hongsheng Xu	2016	Distributed	Permanent, Intermittent and Transient	Spatial coordination
Peng Tang	2016	Distributed	Intermittent and Transient	Probabilistic method
Amna Zafar	2015	Hybrid	Intermittent and Transient	Cluster-based
Chun Lo	2015	Hybrid	Intermittent and Transient	spatial coordination
FarzinPiltan	2019	Hybrid	Permanent	Cluster-based
Rakesh Ranjan Swain	2018	Hybrid	Permanent, Intermittent and Transient	Cluster-based

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