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Review and future directions of Fault Tolerance schemes and applied techniques in Wireless Sensor Networks

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Abstract **-** Wireless sensor network (WSN) is a group of spatially dispersed and dedicated sensors for monitoring the physical or environmental parameters and communicating the collected data to a central base station through wireless links. Each sensor node consists of a sensor, microcomputer, transceiver and power source. The gathered data is forwarded through multiple nodes to the central base station. This requirement demands deploying number of nodes in the hostile environment, which might lead to the malfunction or failure of nodes due to power depletion, environmental impacts, radio intrusion, asymmetric communication links, and interruption of sensor nodes. Hence, fault tolerance is one of the critical issues in WSN's. The recent developments in WSN have led to considerable improvements in protocols and fault tolerant mechanisms that are proposed to achieve higher data reliability, accuracy, energy saving, enhance network lifetime and minimize failure of components. This paper discusses and analyses the various fault tolerance mechanisms to identify the strength and weakness of these methods with prime focus on centralized and distributed network environments.

Keywords: Wireless sensor network, fault tolerance, energy efficiency, centralized network, distributed network.

I. INTRODUCTION

Wireless sensor network (WSN) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording of certain physical conditions of the environment and communicating the gathered information to a central location [1].These low powered and dedicated sensor station are called nodes in the networks and are connected via wireless communication channels. Each sensor nodes is equipped with the transducer, microcomputers, transceivers and power sources. The transducers generates electrical signal based on sensed physical effects and phenomena, the processing electronics or micro-computer processes and stores the sensor output data, and finally the transceiver sends the collected data to the central computer. The sensor nodes are powered by a battery and hence have limited power source in real time uses. Moreover, these nodes are deployed at harsh and hostile environments which might cause sensor node failures. Faulty nodes may cause inaccurate sensing outcomes, erroneous data processing and incorrect data communication [2].The significance of such networks has vital importance in places of continuous observances of environments where the permanent presence of human is tough or unfeasible.

Fault Tolerance (FT) is the ability to sustain sensor network functionalities without any interruption in the event of sensor node failure [3]. A computer network is a good example of heterogeneous network as it consists of a number of computers, switches, routers, hubs, etc. But a distributed system consists of number of homogeneous nodes such as wireless sensor networks; each WSN is made with number of sensor in a distributed environment [4]. Faults may be occurred in WSN when a node moved to a different region causing a hole or encounter a link failure. Some of the commonly occurred WSN fault sources are: Sensor nodes, communication network, sink node and application [5]. Generally, FT and diagnosis system can be categorized as either centralized or distributed. The emerging uses of sensors in everyday life are increasing with the development of state-of-the-art technologies and recent advances in the field of electronics and telecommunication and hence existence WSN due to their range of practical applications has attracted interests of researchers in the modern era. The main aspect of this survey article is to describe the common failures of sensor nodes and the different methods used to guarantee the proper functioning of the network, and also a theoretical modelling of an energy consumption to improve fault tolerance for WSN.

The paper was categorised in to five different sections. The section II consists review of important work carried out in WSN' in general. Section III comprises of importance of FT in WSN's and common challenges faced in implementing the various FT mechanisms in WSN's. Section IV describes the important works carried out on FT mechanisms in central and distributed network environments. Section V depicts the conclusion and future directions in the area of WSN's.

II. REVIEW OF LITERATURE

Many studies have been reported in literature that focuses on overcoming various problems and failures of WSN that affects the reliability, availability and the performance of sensor nodes. This survey article recapitulates important contributions proposed to circumvent FT in WSNs and present analysis of the recent literature data.

Markus Lanthaker et al. reported self-healing approach to avoid the failures in the WSNs by implementing autonomic computing paradigm, in which the sensor network detects and service failures by itself. It was inferred that autonomic computing approach is one of the possible solutions, because it helps to keep the network independent of human interventions and this solution has proved to be efficient in correcting communication problems and prolonging the network lifetime [6]. Gupta et al. reported an efficient mechanism to recover sensor from failed cluster using 'detect and recover' approach to avoid a full scale re-clustering without shutting down the system. The main objective of this approach is to perform run time recovery of the sensor from the clusters in which the gateway has experienced of some faults. They have followed a consensus model of the gateway to agree on a particular fault in system. This approach enables fault tolerance in the system by the stage of periodic checks on the status of the gateways [7].

Xin-Ming Huang et al. reported grid network fault tolerant routing for wireless sensors. A levelling algorithm was proposed in which each node is assigned with a level value that indicates the distance of the hops to the data sink to find out the node failures. Another method of extending the transmission range is presented to overcome limited performance of the levelling algorithm on partitioned network owing to the dead node. Since the levelling algorithm works effectively for in partitioned network, a combined technique with the extended transmission range is investigated reduce the probability of network partitioning [8]. Iman Saleh et al. proposed a unified approach for FT which can be used to identify the main modules to compare and contrast the different solutions. Some of the schemes are taken for the comparison are: 1. CRAFT 2.GHT 3.Ridesharing 4.Marsulla [9].

Gayathri Venkatraman et al. proposed localized and cluster based methods for fault detection and network connectivity recovery, which are highly energy efficient and responsive. Less energy attainment deals with the fault detection and network connectivity recovery mechanism after the stage of cluster formation. In this model, the nodes in the clusters are ordered in a tree like parent and children. The result revealed the faster response time of the localized cluster based method to ensure uninterrupted operation of the sensor networks and the energy efficiency contributes to a healthy life time for the prolonged operation of the sensor network [10].

Myeong – Hyeon lee et al. proposed distributed fault detection algorithm for detecting and isolating faulty nodes in wireless sensor networks. In this method, nodes with malfunctioning sensors are endorsed to act as a communication node for routing but they are logically inaccessible from the networks as far as fault detection is concerned. By using time redundancy methods and providing sliding window analysis with storage data for previous comparisons the faulty nodes that do not take part in the network was identified. The results revealed that the algorithm detects faulty sensor nodes with high accuracy for a wide range of fault probabilities, while maintaining low false alarm rate[11].Themistoklis Bourdenas et al. reported the impact of sensor faults in activity and gesture classification accuracy and developed a mechanism that will consent to detect the faults during system operations and they identify three layers like: The sensing layer ,analysis layer ,dissemination layer in typical WSN application. In this case, the sensing layer data are collected from the devices, the analysis layer extracts from data and finally the dissemination layer, provides the information to application to built the network. The demonstrated result revealed the self healing approach toward WSNs in initial steps used for building mechanisms which automatically detects faults in two applications areas successfully with low false positives [12]. Peng Jiang et al. introduced improved Distributed Fault Detection (DFD) method for node fault detection. The improved DFD scheme checks the failed node by exchanging the data and mutually testing is performed among neighbour nodes in the network. This scheme changed the detection criteria of DFD in node fault detection and it greatly increases the node fault detection accuracy and helps to obtain the high fault detection accuracy even with the high node failure ratios when node failure ratio is high and average number of neighbourhood is less [13].

Mohammad Zahid khan et al., introduced a zone based fault tolerance architecture (ZFTMA).The ZFTMA architecture is organized by self organization scheme and a fault management scheme, which carried out localized fault detection and recovery with CH rotation and load balancing through hierarchy of nodes [14].

A. Mojoodi et al. investigation on redundancy on the number of correct responses that WSN have the received for queries estimated the level of redundancy needed in different network conditions. By estimating the affect of redundancy on the number of correct responses that an on- demand network can have during its lifetime and before losing its total energy, the effect of redundancy on different scenarios of the network is worked out. When the number of clusters needed to response to the request is low or modest, the possibility of error exists in the network is low. But, in the case of clusters the number of nodes are high and hence there is a big chance of error as more paths are needed to maximize the reactions[15]. Abhishek kashyap et al. introduced a relay placement for fault tolerance in wireless network, which consider the problem of adding the smallest number of nodes to a network of static nodes with limited communication range, so that the induced communication graph is connected with both edges and vertex. A fault tolerant topology among static nodes distribution in a Euclidean space of fixed dimension using additional relay nodes is considered. The proposed approximation algorithms for 2-edges and 2- vertex connectivity were specified in terms of the number of relay nodes required. The algorithms also work for achieving k- connectivity for the generalization where the relay nodes cannot be placed in certain polygonal region of the network [16].

Ataulbari et al. proposed a novel integrated Integer Linear Program (ILP) which is different from other techniques.ILP not only finds a suitable placement strategy for the relay nodes, but also assigns the sensor nodes to the clusters and determines a load-balanced routing scheme. Therefore, in addition to the desired levels of fault tolerance for both the sensor nodes and the relay nodes, the proposed approach also meets specified performance guarantees with respect to network lifetime by limiting the maximum energy consumption of the relay nodes. This method used grid approach and an intersection based approach for determining the potential positions of the relay nodes. The simulation results demonstrate that this approach can significantly increase the network lifetime as well if desired levels of fault tolerance in both tiers of the network were provided at the cost of a few additional relay nodes [17]. Arunanshu Mahapatroa et al. developed a distributed detection algorithm to provide a method for detecting permanent, intermittent and transient faults. This algorithm detects faults with high accuracy for a wide range of fault rate. The algorithm could be integrated to fault tolerant wireless sensor networks due to high detection accuracy, low false detection rate and reduced complexity [18].

Sushruta Mishra et al. carried out theoretical and application oriented research on fault detection and recovery mechanisms in wireless sensor networks. Though the simplest way to perform fault detection was by human intervention, there was a high potential of committing errors and less efficient. Hence, feasibility of automatic fault detection techniques for WSN was investigated. Various techniques like self diagnosis, group detection, and hierarchical detection were employed for the purpose. The authors proposed new fault recovery techniques for WSN using Active Replication and Passive Replication [19].

Prasenjit chanak et al. proposed an energy efficient node fault diagnosis and recovery for wireless sensor networks, referred as fault tolerant multipath routing scheme for energy efficient wireless sensor network(FTMRS). The FTMRS is based on multipath data routing scheme. In this method, shortest path data routing ensures energy efficient data routing where the performance analysis of FTMRs shows the better results compared to other popular fault tolerant techniques in wireless sensor networks [20]. Ayasha Siddiqua et al. reported distance based fault detection (DBFD) method for WSN which used the average confidence level and sensed data of sensor nodes. The main objective of the proposed DBFD was to overcome the restriction in the sensor nodes like processing power, memory capability, power supply and communication throughput. DBFD detects the sensor fault using spatial and time information simultaneously. This method sows that sensor nodes with permanent faults and without fault which was judged as faulty are identified with high accuracy for a wide range of fault rate, and keep false alarm rate for different levels of sensor fault model and also the nodes are identified by accuracy [21].

Yunxia Feng et al. focused on reducing both the message and time-cost compared to rebuilding the aggregation and rescheduling the entire network using the amendment strategies assuming that the network adopts a connected dominating set(CDS) based on aggregation scheduling. Thus the fault tolerant data aggregation protocol consists of two parts basic aggregation scheduling strategy and corresponding amendment strategy [22].

Anshika Bhalla et al. illustrated various topology management techniques for handling node failure in WSNs like Partition Detection Recovery Topology Repair Algorithm (PADR), Recovery By Inward Motion (RIM) ,volunteer-in sighted connectivity Restoration ,LeDir (VCR), Least-Disruptive Topology Repair Algorithm , Least-Movement Topology Repair (Le-MoToR) ,K- connectivity. Commonly available fault detection scheme for single node failure are incorporated by the authors. Envisage failures of sensor nodes are energy depletion, link availability, packet loss, network congestion and node failure. They have concluded fault detection is designed to find out the feasible faults depending on various parameters, and fault recovery algorithms aims at treating fault facilely with less energy depletion [23].

Amirzare et al. proposed a new method to increase fault tolerance in WSNs. The aim of the study is to develop an optimized method to reduce energy consumption using Dijikstra’s algorithm. In this algorithm each node creates an interval time between the transmissions of two different packets of data at the same route. When a sensor node receives a new data from other nodes and analyses the shortest route condition for data transmission. The authors also identified that the sensors are under routing for the node extensions, transmission media, connection, coverage, fault tolerance, scalability, data collection, and quality of services reasons [24]. Walaa Elsayed et al. presented a distributed self healing approach (DSHA) in both node level and cluster level for fault tolerance. The proposed DSHA is designed to handle hardware failure of WSN nodes based on the concept of self healing. This was achieved by performing the operations of the proposed fault detection, fault diagnosis, and fault recovery methods. A number of scenarios where considered to evaluate the proposed approach. DSHA was able to detect and recover 2 malfunction nodes out of 5 nodes, thus providing the better network performance [25]. Gholarezakakamanashadi et al. discussed a critical analysis of various fault tolerance mechanism in wireless sensor networks such as redundancy based mechanisms, clustering based mechanism and deployment based mechanism to identify the strength and weakness of each one of these mechanism. After critical analysis it has been observed that the different strategies such as deployment, redundancy, and clustering can be used in different applications with respect to the level of FT requirement. Adding few redundant components can increase level of FT and enhance the accuracy of the data. Efficient clustering can improve energy consumption and increase the life time of the system [26].

Zhewang et al. introduces a fault tolerance mechanism for handling coordination failures for heterogeneous distributed systems. Common Fault tolerance techniques at application level requires code-injection which is not achievable for open systems .Since there was lack of control over the code of the component coordination mechanism called law governed interaction (LGI) to control the flow of messages between system components was proposed. This mechanism for fault tolerance can be used for distributed systems in general [27].

III. FAULT TOLERANCE IN WSN

This section deals with the important approaches available in the literature for FT and suggested alternative paths as corrective actions in response for availing a better knowledge about the algorithms to deal with the FT techniques. A failure is the observation of an error, which occurs when the system deviates from its specification and cannot deliver to its intended functionality. Due to the implementation in harsh environment, WSNs are subjected to faults in several layers of the system Fault may causes in any layer of the system architecture and has the possibility to propagate to above layers from node to sink. FT technique prevents lower level errors from propagating into system failures[28].In real time system two approaches are used to achieve the fault free environment. The first phase is to diagnosis the fault and second is to repair the diagnosed fault. FT is a design that enables a system to prolong operation, possibly at a concentrated level rather than failing completely when some system parts fails. The system as a whole is blocked due to failure of either in hardware or software. Considering FT, in general, faults are focussed at : Node level, network level, sink level and application level. The failures in real time systems are classified into: Crash failure, Time failure, incorrect value failure [29].

III.I Classification of fault tolerance

Recent researchers have developed several techniques that deal with different types of faults at different layers of the network stack. To assist in understanding the assumptions, focus, and intuitions behind the design and development of these techniques, the taxonomy of different FT techniques were used in WSNs was given in [5]:

- Fault prevention: This is to avoid faults before it introduced or affects the hardware or software component of the system.
- Fault detection: This is the task used to collect symptoms of possible faults and different metrics to defining where a repairable fault has occurred and what is the nature of fault.
- Fault isolation: This is to determine the cause of the problem and correlate different types of fault indications received from the network, and propose various fault hypotheses; also known as diagnosis of fault.
- Fault identification: This is to test each of the proposed hypotheses in order to precisely localize and identify faults.
- Fault recovery: This is the process to treat and recovery the faults involved and restoring an error i.e. reverse their adverse effects (error-free state).

III.II Common challenges of Fault Tolerance in Wireless Sensor Networks:

Sensor networks share common failure issues such as link failures and congestion with traditional distributed wired and wireless networks, as well as introduce new fault sources such as node failures. The faults in WSNs cannot be approached and resolved in the same way as in tradition wired due to the following reasons [40]:

- Traditional network protocols are generally not concerned with energy depletion, since wired networks are constantly driven and wireless ad hoc devices can get recharged regularly;
- Traditional network protocols aim to achieve point-to-point reliability, whereas wireless sensor networks are concerned with reliable event detection; in sensor networks, node failures occur

much more frequently than in wired, where servers, routers and client machines are assumed to operate normally most of the time; this implies that closer monitoring of node health without incurring significant overhead is needed;

- Traditional wireless network protocols rely on functional MAC layer protocols that avoid packet collisions, hidden terminal problem and channel errors by using physical carrier sense (RTS/CTS) and virtual carrier sense (monitoring the channel). Many of the recent fault detection algorithms have either vaguely defined fault models or an overly general fault definition. Looking beyond fault detection and correction techniques, there has been relevant work that frames our thrust to provide fault taxonomy.

III.III Design principles of Fault tolerance in Wireless sensor networks

WSN can be used for real time applications, in which sensor nodes are acting different tasks like neighbour node discovery, smart sensing, data storage and processing, data aggregation, target tracking, control and monitoring, node localization, synchronization and efficient routing between nodes and base station. Fault tolerance in a WSN system can be incorporated at all the five layer of the network architecture viz., Hardware layer, Software layer, Middleware layer, Network communication layer, and Application layer [5][47].

1. Hardware Layer

Faults at hardware layer can be affected by crash of any hardware component of a sensor node, such as memory, battery, microprocessor, sensing unit, and network interface.

2. Software layer

Software of a sensor node comprises into modules: such as system software, operating system, and middleware, communication, routing, and aggregation. Software breakdowns are a common cause of errors in WSNs.

3. Network communication layer

Faults at network communication layer are the faults on wireless communication links. Link faults can be caused by contiguous environments or by radio interference of sensor nodes.

4. Application layer

Fault tolerance also can be identified at the application layer. For example, finding multiple node disjoint paths affords fault tolerance in routing. The system can switch from an unattainable path with broken links to an available candidate path.

IV. FAULT TOLERANT SYSTEMS IN CENTRAL AND DISTRIBUTED NETWORKS

In order to have easy understanding, the various fault tolerance protocols are compared and evaluated under two categories (1) Centralized and (2) Distributed. Centralized systems are easy to maintain as the leader node are liable for identifying the faulty sensor nodes in WSN. The leader node doesn’t generate its own schedule, rather simply collect and forward the communication information to the cluster scheduler. In a centralized network the central leader controller generates routing paths and distribute them to every node, therefore malfunction of the leader node will set the whole system into chaos. Distributed systems are self sufficient in design and enable nodes to organize as well as allow their resources to be used among the connected systems or devices that make users to be integrated with geographically distributed computing facilities. In distributed network every nodes builds its own routing records by using distributed structure that communicate between each other. Distributed methods are trades off to the resources of centralized detection for faster and greater localized detection and restoration. This make distributed systems are very stable and a single failure doesn’t do much harm to the entire system. A summary of comparison of centralized and distributed fault detection approaches with prime focus on Network coverage, Energy efficiency and Fault tolerance are discussed.

IV.I Network coverage

Sensing coverage and network connectivity are two fundamental to ensure effective environmental sensing and robust data communication in a WSN. In centralized approach as a result of unplanned deployment of nodes coverage holes are formed in the network so that target area is not covered properly. They may also occur due to changing topology, which make some sensor nodes to move over time that leads to coverage holes. Thus the Holes affect the network capacity, coverage of the network and make possibility for the packet loss[33]. Single point of failure, less scalability is the drawbacks of the centralized approaches. Zou et al [42] proposed a virtual-force-based mobile sensor deployment algorithm (VFA), for coverage solution to the centralized system, centralized combines the ideas of potential field and disk packing of nodes .Powerful cluster-head found in VFA which will communicate with all the other sensors, to collect sensor position information and calculate forces and desired position for each sensor. In the case of distributed approach, the problem of coverage loss is due to physical damage of the hole. Hole detection is one of the major fundamental issues since it identifies damaged, attacked or out of coverage nodes in the network. Corke et al. [43] proposed an energy efficient self healing mechanism for Wireless Sensor Networks based on Distributed Computational Model. The proposed solution is based on probabilistic sentinel scheme. To reduce energy consumption while maintaining good connectivity between sentinel nodes, the solution was composed on two main concepts: (1) node adaptation and (2) link adaptation.

IV.II Energy conservation

Energy efficiency can be achieved either by using energy more economically or by reducing the amount of service used. Centralized approach is a chain process for communication, if there is a hole in the network then data will be routed along the hole boundary nodes again and again which will lead to premature exhaustion of energy present at these nodes. The impair functionality of the nodes in WSN can introduce the faults due to the energy depletion. To overcome this particular problem Ahila Jerlin et al. [44] provide a Fault tolerant multi path routing scheme FTMRS solution for energy depletion in centralized approach. FTMRS is based on multipath data routing scheme in which one shortest path is identified and used for main data routing. Moreover, this technique identifies two backup paths as alternative path for faulty network and to handle the overloaded traffic on main channel to use energy more economically. But distributed system is a comprehensive solution for effective energy consumption of WSN. In general energy-efficient wireless sensor networks are designed by recovering nodes from transmission faults that utilises self-healing capability to measure faults in WSN. Unlike centralized approach distributed approach doesn't follow any central scheduler for commanding and communicating. Clustering is the most popular topology and control method used in distributed approach to reduce energy consumption and improve scalability of WSNs due to sudden failure of the cluster heads which directly affect the cluster members. Distributed Fault Tolerant Clustering Algorithm DFCA is the solution for energy conservation suggested by Azharuddin, et al. [45] were the algorithm presented a distributed recovery of the faulty cluster members due to sudden failure.[DFCA].

IV.III Fault tolerance

Fault tolerance has an important role because a wireless medium is rather erroneous. The dreadful reliability of message delivery in a wireless medium can have destructive effects on sensing data. Handling message loss can result in significant overheads and performance degradation. As discussed above, in the centralised approach, the central base node is responsible for identifying the faulty sensor node. Utilization of self-healing in centralized approaches was not possible due to the chain process communication. In centralized approaches most of the management and monitoring tasks are preferred by the central manager or base station. The central manager generally adopts an active monitoring model to detect faults, and identified the performance of an individual sensor node. Also, due to centralize mechanism all the traffic is directed from the central point. This creates communication overhead and quick energy depletions. In distributed approach decisions are made locally and management functions are shared throughout the network. There are lots of approaches which consider distributed concept for fault detection and recovery. Solitary advantage of distributed approach is that less number of messages is required to be delivered to the central manager [2, 36].

V. CONCLUSIONS AND FUTURE SCOPE

This review paper summarizes methodologies used for FT for WSNs, with prime focus on packet delay, energy efficiency precision, and network structure. The failures of sensor node are shared in the network, but handling of failure node is a major challenging task. The failure could be node failure or link failure. The failure nodes are causes the degradation of network performance. WSN's for centralized and distributed WSNs showed that the distributed cluster-based protocols have the ability to manage the clusters better than the centralized based approach. This is due to the fact that the distributed system follows the better energy saving approach compared to centralised system. This solution facilitates the optimal number of clusters that are formed in every round, which is almost impossible in traditional centralized approach. Significant frame work comparisons of new and existing fault tolerance protocols which in turn helpful to the researchers to create a new protocol proposals that suits to the sensor networks is also discussed. Future studies may include assessing the performance of other well-known protocols for handle the fault tolerance in wireless sensor networks.

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