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Adaptive Sampling Fuzzy Controlled Based Fault tolerance in Wireless Sensor Network

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Abstract**—**Wireless sensor network is made of distributed wireless sensor node which sense environment variables and report to base station. Wireless sensor network are increasingly applied in industrial and defense applications. Faults happen in sensor network due to reasons like environmental disturbance and battery energy depletion. Also sensors fail transiently or permanently due to manufacturing defect. In field, due to fault of sensor nodes, the applications built on events from sensors is bound to fail and may cause severe damages. In this work, we propose a efficient fault tolerance method for wireless sensor network. Our mechanism is based on adapting the sampling rate in sensors depending on its data importance and a using spatial temporal correlation to achieve fault tolerance.

I. INTRODUCTION

Wireless sensor networks (WSNs) have received significant attention in recent years due to their potential applications in military sensing, wildlife tracking, traffic Surveillance, health care, environment monitoring, building structures monitoring, etc. WSNs can be treated as a special family of wireless ad hoc networks. A WSN is a self-organized network that consists of a large number of low-cost and low powered sensor devices, called sensor nodes, which can be deployed on the ground, in the air, in vehicles, on bodies, under water, and inside buildings. Each sensor node is equipped with a sensing unit, which is used to capture events of interest, and a wireless transceiver, which is used to transform the captured events back to the base station, called sink node. Sensor nodes collaborate with each other to perform tasks of data sensing, data communication, and data processing. Nodes in WSNs are prone to failure due to energy depletion, hardware failure, communication link errors, malicious attack, and so on.

When a number of sensors fail for whatever may be the reason the resulting network topology may be disconnected which in result is considered as a failure of set of nodes. The nodes that have not failed become disconnected from the rest of the network.

The application built on sensor network will be affected because of sensor node failure and especially if it is safety related applications and because of node failure, critical events are missed and disasters happen the loss is tremendous. Fault tolerance must be provided in the network , so that even in case of node failures, the critical events are not missed. Also certain times faults can be introduced in the path by forged packets by attackers or faults can be introduced due to dissemination. Also with increasing application of mobile agents, faulty agents can be disseminated into network.

The most cause of faults is due to sensor node failing due to battery energy depletion. Battery energy can be minimized by varying the sampling interval and for the case of adjustment in sampling interval, the application demand for data must be satisfied using spatial and temporal correlation. In this work, we propose a adaptive sampling method and spatial temporal correlation for fault tolerance and the method for adapting sampling is decided using Fuzzy logic.

II. SURVEY

In [1] , authors proposed a real time QOS based routing and fault tolerant mechanism for handling real time traffic in wireless sensor network. Congestion , link failure and void problems are handled in this solution. The approach is based on designing redundant path for transmission to handled QOS and faults. But energy is consumed fast and the life time of the network is reduced.

In [2], authors proposed a 1-hop neighbor sensor monitoring to detect faults and the faulty node is isolated from network temporally and if fault persists the node is isolated permanently. Faulty nodes are not isolated in this approach and due to this network partitions happen. This approach can detect faults in the data sensed by sensors but it cannot detect data forward faults.

In [3], authors proposed a approach for placing more nodes in the network but splitting them to active and redundant nodes. Redundant nodes are first kept in sleep position and then woke up to compensate the coverage lost due to fault in active node. But this approach is not scalable for bigger networks as the cost of redundant nodes will increase.

In [4] authors proposed Least-Disruptive topology Repair algorithm to move the nodes to avoid network partition problem. The network partition is measured and nodes are relocated to cover the network partition. It is not always possible to relocate the nodes in un attended environment and also the number of relocation in this approach is high.

In [5] authors proposed a clustering based fault recovery using redundant nodes. Some Nodes within cluster are kept in sleep state and activated to cover for coverage loss. The approach is not optimized for multiple faults.

In [6] authors proposed a fault node recovery algorithm when sensor nodes shutdown due to energy depletion. The idea of fault tolerance is based on reused routing path in this work. The approach can work only for dense sensor network.

In [7] authors proposed a heterogeneous relay node based approach for fault tolerance. Nodes have different transmission radius. Each nodes have two paths and in case of faults, redundant paths are used. But this approach is complex at sensor nodes with different routing paths.

In [8] authors proposed a energy aware fault tolerant method called Informer homed routing. The network is clustered and fault is handled in two modes within cluster and inter cluster. Due to this energy is conserved. The approach does not deal with cluster head becoming faulty.

In [9] authors proposed a distributed hierarchical Wireless sensor network architecture for fault management. To locate and analyze fault Gateway devices are added into the network. Agent move around to detect faults. This approach is of high overload because of additional network components.

In [10] authors propose an Active node based Fault Tolerance using Battery power and Interference model (AFTBI) in WSN to identify the faulty nodes using battery power model and interference model. Fault tolerance against low battery power is designed through hand-off mechanism where in the faulty node selects the neighboring node having highest power and transfers all the services that are to be performed by the faulty node to the selected neighboring node. Fault tolerance against interference is provided by dynamic power level adjustment mechanism by allocating the time slot to all the neighboring nodes. If a particular node wishes to transmit the sensed data, it enters active status and transmits the packet with maximum power; otherwise it enters into sleep status having minimum power that is sufficient to receive hello messages and to maintain the connectivity. In this approach , the initiation for fault tolerance is done by the faulty node and if the faulty node suffers sudden failure and shutdown, this approach does not work well.

In [11], authors proposed two algorithms named Full 2-Connectivity Restoration Algorithm (F2CRA) and Partial 3-Connectivity Restoration Algorithm (P3CRA), which restore a faulty WSN in different aspects. F2CRA constructs the fan-shaped topology structure to reduce the number of deployed nodes, while P3CRA constructs the dual-ring topology structure to improve the fault tolerance of the network. F2CRA is suitable when the restoration cost is given the priority, and P3CRA is suitable when the network quality is considered first. The network is deployed in a way to handle fault tolerance in both of these solution and the solution assumes the number of fault nodes that be in the structure. When the number of fault node assumption fails , the entire fault tolerance mechanism built into network fails.

In [12] , authors proposed a redundant nodes based fault tolerant mechanism. The approach used k-connectivity based steiner approach to decide the optimal number of redundant nodes to be placed in the network. By optimizing the number of redundant nodes, the author tried to reduce the cost of sensor network. The approach lacked coverage ratio but increased the connectivity problem.
In [13], authors applied multi agent architecture for fault management. The multi agent system proposed by author had resource manager, a fault tolerance manager and a load balancing manager. Fault tolerance manger applied the idea of agent broadcast to move around and avoid faulty paths. The approach is scalable but suffers from energy depletion problem.

In [14], authors proposed Reuleaux Triangle approach , to characterize k-coverage with the help of Helly's Theorem and the analysis of the intersection of sensing disks of k sensors. Using a deterministic approach, authors showed that the sensor spatial density to guarantee k-coverage of a convex field is proportional to k and inversely proportional to the sensing range of the sensors. This is a deployment time approach which provides the number of sensors to be deployed in area based on continuous coverage. But this kind of approaches fails when the particular area is destroyed also not suitable for random deployments.

In [15] , authors presented a distributed fault detection and node management using cellular automata. Linear cellular automata runs in every node and every sensor node learns it own state using cellular automata. The faulty nodes are detected by temporal and spatial correlation of its data by neighboring nodes. The models for fault detection is learnt at many places and this redundancy results in energy depletion in sensor nodes.

III. PROBLEM DEFINITION

In a wireless sensor network of size N nodes, some nodes can fail with random probability due to many reasons like manufacturing faults. Due to this fault the data from a sensing area can be faulty or not be captured. In some cases like battery energy depletion, depleting accuracy of sensors etc, the fault can be predicted.

The energy of sensor deplete in proportion to the sampling interval. The sampling interval must be varied over a period of time in operation of sensor to prolong its life time till it is replaced. Due to adaptive of sampling interval the application demand is affected. So a effective method must be devised to c compensate for the data loss. By adaptive sampling rate and compensating for the data loss effective fault tolerance can be done on network, till the sensor is replaced.

IV. PROPOSED SOLUTION

The applications running in base station can demand data from sensors according to its requirements. In this work, we model the application requirements based on two parameters

1. Time between data arrival

2. Tolerant degree of error.

These two parameters can be different for different zones in the network.

The network is split into mesh grids and the application requirement for each grid is known priori.

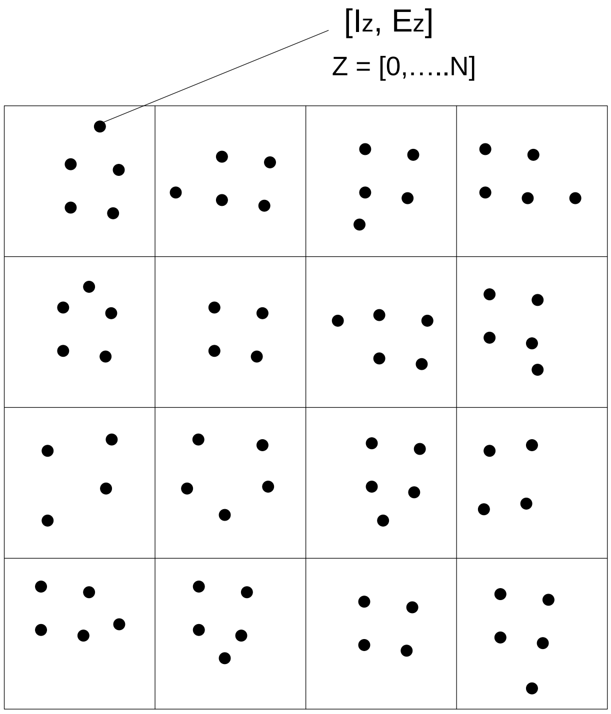

Figure 1

Where Iz is the interval of data arrival and the Ez is maximum error tolerance.

Every time node sends the data to the Sink, the residual energy is also sent from the node.

Based on the residual energy of node, data interval and Error tolerance required, Reconstruction Degree(RD) in the zone, a Fuzzy logic system calculates the sampling rate to be set for the node and the sampling rate decided is sent to the node. Based on the sampling rate , the node adjusts its sampling duration for sensing and sends the values to the sink.

Out of these input parameters, the residual energy, data interval, Error tolerance are all direct parameters and the Reconstruction Degree is a indirect parameter. Reconstruction degree is dependent on the correlation value of sensor with its neighbor nodes in the same zone.

The correlation is based on time and spatial. To calculate the correlation the historic values of sensors are kept at sink. For each sensor, to its neighboring sensor in the same zone, the correlation is calculated using the formula

$$\rho_{X,Y} = \mathrm{corr}(X,Y) = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y}$$

Where E is the expected value operator, cov means covariance, and corr is correlation coefiicient in values between 0 and 1. All the neighbor nodes are sorted based on correlation coefficient from higher to lower and the expected error between the sensor values based on coefficient is calculated and the number of sensors (nse) whose error value is less the error threshold set for application in that zone is found.

Based on the time correlation between the sensor values, ARIMA model is constructed and the maximum error ratio (ME) is measured.

The Reconstruction Degree (RD) is measured as

RD = α (nse) + (1- α)(1/ME)

RD is an indication of how far the data from sensor can be reconstructed using spatial and temporal correlation for the case of missing values in between sampling interval by the application.

Fuzzy function for sampling rate decision is depended on following input parameters.

1. RE (Residual Energy) normalized in between 0 to 1.
2. DI (Data Interval) normalized in 0 to 1 based on min and max values of it.
3. (ET) Error Tolerance is in form of percentage from 0 to 100.
4. RD(Reconstruction degree) values from 0 to 1.

The input values are categorized to three ranges L,M,H according to fuzzy membership function below.

The membership function of RE in figure 2.

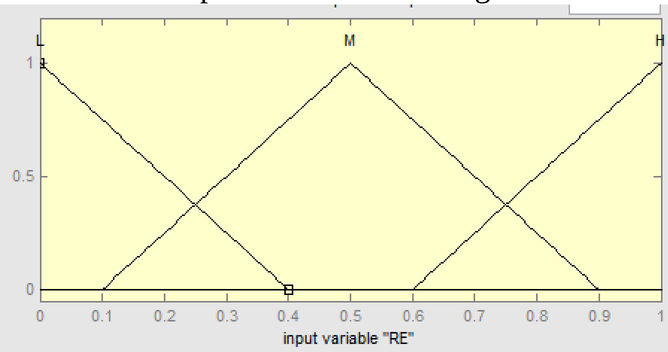

Figure 2

The membership function of DI in figure 3.

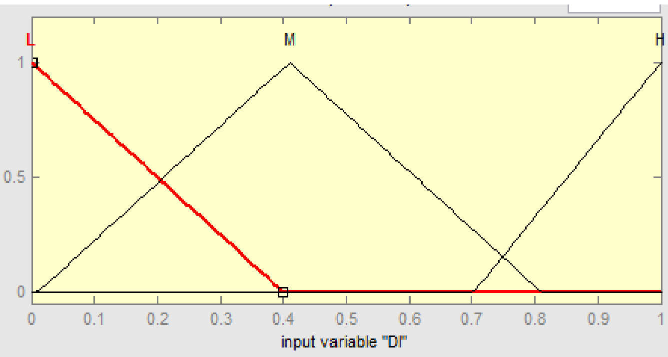

Figure 3

The membership function of RE in figure 4.

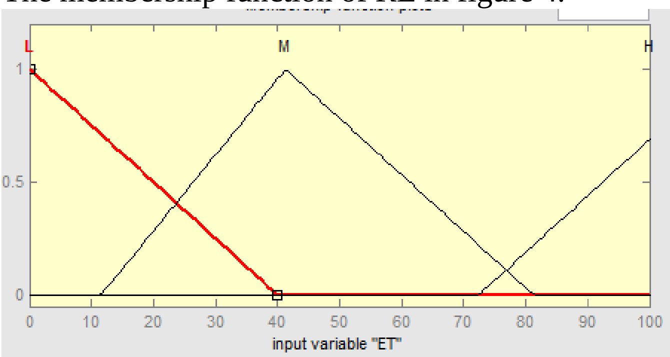

Figure 4

The membership function of RE in figure 5.

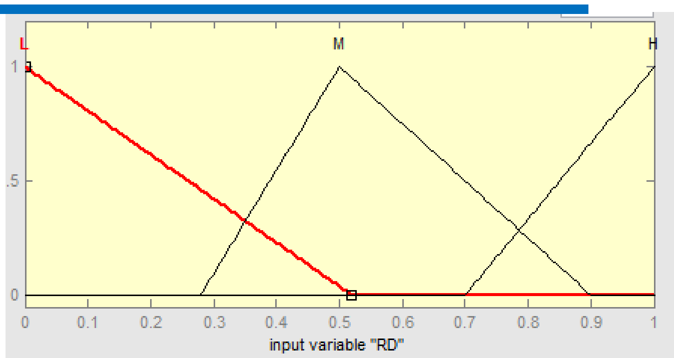

Figure 5

The membership function of output variable sampling rate is Figure 6.

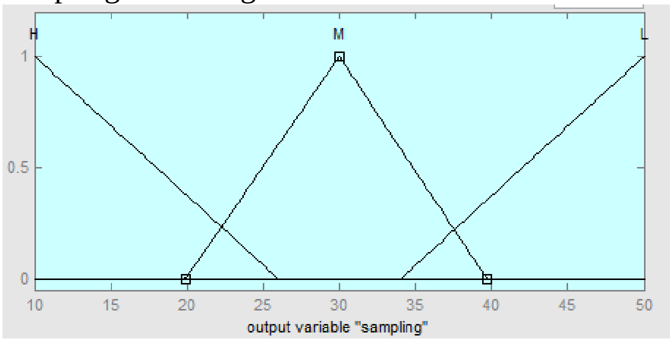

Figure 6

The rule set for decision is given below

RE	DI	ET	RD	Sampling
L	L	L	L	H
L	L	L	M	H
L	L	L	H	H
L	L	M	L	H
L	L	M	M	H
L	L	M	H	H
L	L	H	L	H
L	L	H	M	M
L	L	H	H	M
L	M	L	L	M
L	M	L	M	M
L	M	L	H	M
L	M	M	L	H
L	M	M	M	H
L	M	M	H	H
L	M	H	L	H
L	M	H	M	H
L	M	H	H	H
L	H	L	L	M
L	H	L	M	M
L	H	L	H	M
L	H	M	L	M
L	H	M	M	M
L	H	M	H	M

M	L	L	L	M	H	L	L	L	M
M	L	L	M	M	H	L	L	M	M
M	L	L	H	M	H	L	L	H	M
M	L	M	L	M	H	L	M	L	L
M	L	M	M	M	H	L	M	M	L
M	L	M	H	M	H	L	M	H	L
M	L	H	L	M	H	L	H	L	L
M	L	H	M	M	H	L	H	M	L
M	L	H	H	M	H	L	H	H	L
M	M	L	L	M	H	M	L	L	L
M	M	L	M	M	H	M	L	M	L
M	M	L	H	M	H	M	L	H	L
M	M	M	L	M	H	M	M	L	L
M	M	M	M	M	H	M	M	M	L
M	M	M	H	M	H	M	M	H	L
M	M	H	L	M	H	M	H	L	L
M	M	H	M	M	H	M	H	M	L
M	M	H	H	M	H	M	H	H	L
M	H	L	L	M	H	H	L	L	L
M	H	L	M	M	H	H	L	M	L
M	H	L	H	M	H	H	L	H	L
M	H	M	L	M	H	H	M	L	L
M	H	M	M	M	H	H	M	M	L
M	H	M	H	M	H	H	M	H	L
M	H	H	L	M	H	H	H	L	L
M	H	H	M	M	H	H	H	M	L
M	H	H	H	M	H	H	H	H	L

Table 1

The sampling rate is decided on the fuzzy de-membership and returned to the node. The node adjusts it sampling rate, so as to reduce it energy consumption. But the application requirement of data arrival may be shorter than the sampling interval. So for this case, the constructed spatial and temporal model results are applied to a linear function to get the value for that time.

Say the spatial model is predicting the data as P1 and the temporal model is predicting the data as P2, then the predicted results is given as

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P = W1*P1 + W2*P2.
Where W1 and W2 is a constant satisfying the relation W1+W2=1.

V. RESULT

We have implemented the proposed solution in jprowler simulator and tested with following setup

No of sensors	*100-500*
Area of deployment	*1000 * 1000 m*
Sensor range	*50m*
Deployment model	*Random*
Data rate	*10 packets/ sec*
MAC protocol	*802.11 a*
No of base station	*1*
Propagation model	*One way*
Type of antenna	*Omni*
Simulation Duration	*10 minutes*
Energy at Node	*50joule*

Table 2

Faults were introduced into network at interval of 20 seconds and the top 5 nodes in the replacement list is replaced. Each node failed with random probability and a node which failed in last interval was not failed.

The performance of the system is measured in terms of following metrics

1. Average Error for faulty nodes
2. Fault Detection Accuracy
3. Fault Detection Latency
4. Network Overhead
5. Average Energy Consumption

Average Error for faulty nodes is measured as the sum of error between observed and predicted data for each faulty node divided by total number of faulty nodes.
Fault Detection Accuracy is measured in terms ratio of no of faults detected to the total number of faulty nodes at that period of time.
Fault Detection Latency is measured in terms of average difference of time between fault occurrence time and the fault detected time.
Network overhead is measured in terms of number of packets exchanged in the network.
Energy consumption is measured in terms of total of energy consumed at each node divided by number of nodes.

The proposed solution was compared with solution [11] and [13].

The number of nodes was increased from 100 to 500 and average error for faulty node was measured. The result is below in Figure 7

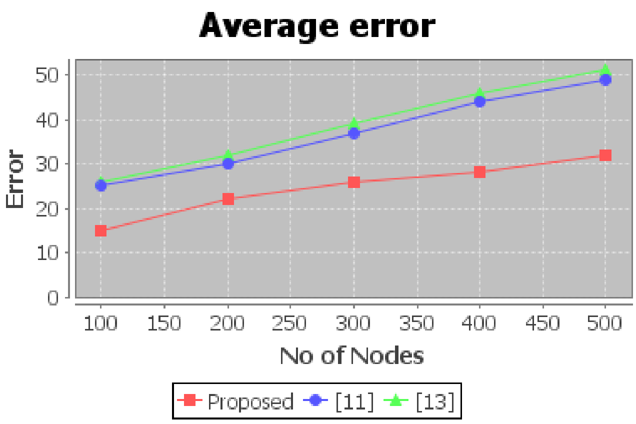

Figure7

From the results, the error in the approach is comparatively less in the proposed solution.

The network overhead is measured by varying the nodes from 100 to 500 and the result is below in Figure 8.

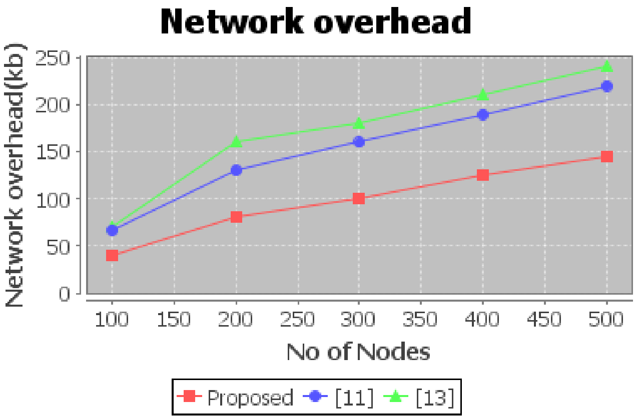

Figure 8

From the results, it can be seen that the network overhead is less in the proposed approach.

We measured the average energy consumption by varying the nodes from 100 to 500 and the result is below in Figure 9.

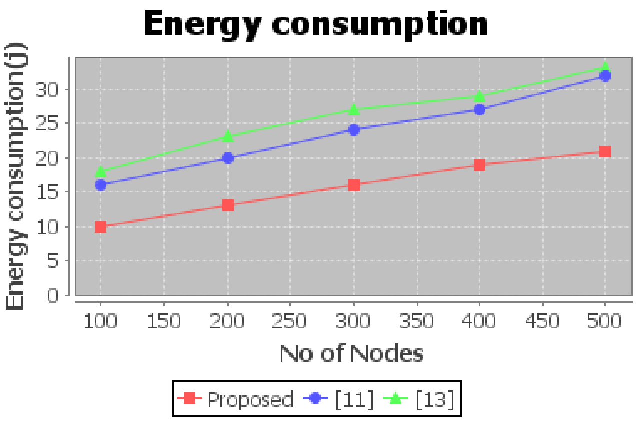

Figure 9

From the result , the energy consumption is less in the proposed solution thereby increases the life time of the sensor network.

VI. CONCLUSION

We have surveyed the current solutions for fault tolerance in this work and proposed a efficient adaptive sampling based fault tolerance to provide short term fault tolerance in wireless sensor network. We have measured the accuracy of data capture in presence of faults and proved that our solution has better accuracy..

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