International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-10 Issue-1, November 2020

Fuzzy Logic Based Hardware Faulty Node Detection And Redundancy Mechanism For Wireless Sensor Networks

N. Priya, P.B. Pankajavalli

***Abstract:** In recent years, applications of wireless sensor network (WSN) is emerged as the revolutionary phase in many functional areas such as industrial, environmental, business, military and many need based self-intelligent real time systems. Some of the applications require data communication from harsh physical environment which poses great challenges to wireless sensor networks. The deployment of these sensor nodes in the hostile environment cause sensor nodes failure. This demands fast, redundant fault tolerant, energy saving approaches which meet the requirements of most recurring failures and path disruption scenarios in wireless sensor networks. Hence there is need for fuzzy knowledge based fault detection because traditional fault detection methods are endured by low detection accuracy. The proposed fuzzy knowledge based faulty node detection and redundancy approach (FNDRA) is presented to identify the faulty nodes and provide the management method for nodes reusability. The effectiveness of the proposed approach was implemented using Matlab and the results shows that the proposed approach meets the constraints and requirements of most common and predicated critical failure scenarios.*

***Keywords:** Wireless sensor network (WSNs), Hardware faults, Fault Detection, Redundancy.*

I. INTRODUCTION

Wireless sensor network (WSN) is a collection of spatially distributed, low cost, low power and autonomous sensing devices, deployed in the monitoring area to measure varying physical conditions [1]. Each sensing devices, called node, has processing and wireless communication capabilities, which enable it to gather information about the environment and to generate, deliver report messages to the remote Base Station (BS). The base station aggregates and analyses the report messages received and decide whether there is an unusual or concerned event occurrence in the monitored area. The concept of wireless sensor network is in the focus of intense research due to wide-range of potential applications enabled by sensor networks,

Revised Manuscript Received on November 30, 2020.
***** Correspondence Author

N. Priya*, Department of Computer Science ,Bharathiar University, Coimbatore, India. Emai:npriyaresearch@gmail.com

P.B.Pankajavalli, Department of Computer Science, Bharathiar University,Coimbatore,India. Email:pankajavalli@buc.edu.in

such as battlefield surveillance, machine failure diagnosis, biological detection, home security, smart spaces, inventory tracking and so on [2–5]. For all the stated applications, a wide range of nodes are deployed in the environment to progress the Quality of Service (QoS) of the network. Since these sensors are deployed in the unfavourable or harsh environment, they are susceptible to failures. The probability of failure of the sensor nodes increases with increase in number of sensor nodes deployed [6, 7]. Faulty nodes may transmit incorrect data to the BS, thereby degrading the overall functionality of the network. Hence, it is desirable to detect these faulty nodes in the network with high accuracy to improve the QoS. To increase the mis-prediction of faulty sensor nodes and enhancing the overall performance of WSN's, many fault tolerant methods have been proposed in recent years.

Software fault and hardware fault are the two broad areas in WSNs for fault identification. The system software of the node execute erroneously which cause the malfunction of the data analysis in the BS due to the software fault [8,9]. However, in the case of hardware fault the different hardware components of the node become defective so that the data packet could not be reached to the intended destination node or BS [10]. The major hardware faults are transmitter circuit fault, receiver circuit fault, microcontroller circuit fault, sensor circuit fault and power/battery fault. The available conventional fault tolerance approaches have limitations in accurately detecting and managing the hardware faults. Fuzzy logic methods provide better performance in diagnosis and detect with the doubtful information particularly in hardware failures. Fuzzy logic has several advantages over traditional methods like instant, design time, computational complexity, low development cost and more specifically flexibility in operation [11, 12]. In the existing literature various approaches have been proposed by researchers to deal with the fault detection problem in WSNs [13-20] and it can be achieved by different techniques such as mean, median, majority voting based, probabilistic neural network policy, cluster based approach, cellular approach , cellular automata technique, and Bayesian algorithm. Therefore it is an essential and important task to ensure the network reliability. Hence, it is seen from the literature that most of the conventional fault detection methods adapted in WSN's have either one of the drawbacks such as poor detection accuracy, lack of energy efficiency, difficulty in reusability of the node etc.

Most of these drawbacks can be circumvented by fuzzy based fault detection schemes, where fuzzy logics are used to overcome the uncertain characteristics of the WSN environment, which in turn helps to enhance the fault detection accuracy. The principle of fault detection evaluation using fuzzy logic consists of a three-step process, the input performance parameter conditions have to be fuzzified, then they have to be evaluated by an inference mechanism using fuzzy rules, and finally they have to be defuzzified.

Chanak et al. [21] proposed a fault detection scheme in which each sensor node transmits its fault status to the BS and then BS manages faulty sensor nodes through the fuzzy rule. Since it is a centralized fault technique where each sensor node transmits their fault status to the central node, more exchange of status/data packets took place between the central node and sensor node, which results in the fast deterioration of stored energy at these nodes. Khan et al. [22] proposed fuzzy based fault identification strategy where sensor circuit faulty nodes are detected through neighbour's data analysis in run time. In this approach, BS collects all sensor nodes data and analyzes the data by the Fuzzy Interface System (FIS) to detect sensor circuit faulty nodes within the network. But, due to the non-availability of node information details, this method suffers poor detection accuracy and hence non-faulty nodes are detected as faulty nodes during the diagnosis process. Fuzzy rule based approach for fault node identification using transmitter and battery condition parameters are proposed by Pooja et al. [23]. Though this approach has given good performance results in fault node identification and improved lower alarm rate, the approach has to be tested for large scale sensor networks. Fuzzy logic based fault tolerance method in distributed wireless sensor networks proposed by Bhajantri et al. [24] showed considerable improvements in the energy consumption, throughput and latent period of the network. But these methods have not considered the hardware fault detection as a performance parameter.

Since fuzzy logic allows the inclusion of vague human assessment in computing problems, it can be effectively used in intelligent real time systems[25] and WSN's for decision making, optimization and control. For example, Lopez et al. [26] proposed a new approach for the stability and design of non-linear fuzzy inference systems based on Takagi-Sugeno (T-S) fuzzy models. A convex optimisation technique involving Linear Matrix Inequalities (LMI) has been proposed to self-select the local linear models which guarantee the global stability of the fuzzy models. The developed scheme has been successfully applied to real time scenarios like fault-tolerant control of an induction motor of a rail traction system. Farzin et al [27] designed a T–S fuzzy robust feedback linearization observer applied to a fuzzy ARX-Laguerre to improve the accuracy of fault estimation, reliability, and robustness for the surgical robot used for Sinus surgery. The effectiveness of the proposed algorithm is tested with simulations for better performance. Masdar et al [28] presented a fuzzy logic based faulty node detection algorithm for heterogeneous WSNs , unlike the other fault detection approaches they have used the distance of the neighbours node, coverage and difference of the sensed values to measure the weight of the neighbouring nodes. Identifying the fault and managing the faulty nodes in WSN are important for ensure the uninterrupted communication in WSN. To improve the quality of the network redundancy approaches are considered which allows m sensor nodes within a source cluster. Redundancy is desired not only for the purpose of availability improvement but also for providing robust and fault tolerant when individual sensor nodes are faulty or malfunctioning. Redundancy is required in different network condition with different fault probabilities and it requires cluster to response to the received queries. In an ideal scenario temporal redundancy is used to improve the reliability of the entire system [29].

It ensures that the proposed algorithm can correctly recognize each sensor nodes status at the event of transient faults. In the proposed fuzzy knowledge based faulty node detection and redundancy approach (FNDRA), the aspect redundancy approach is used for the faulty node management. The FNDRA uses hardware redundancies where more sensor nodes applied to recognise the faults and to ensure the reliability.

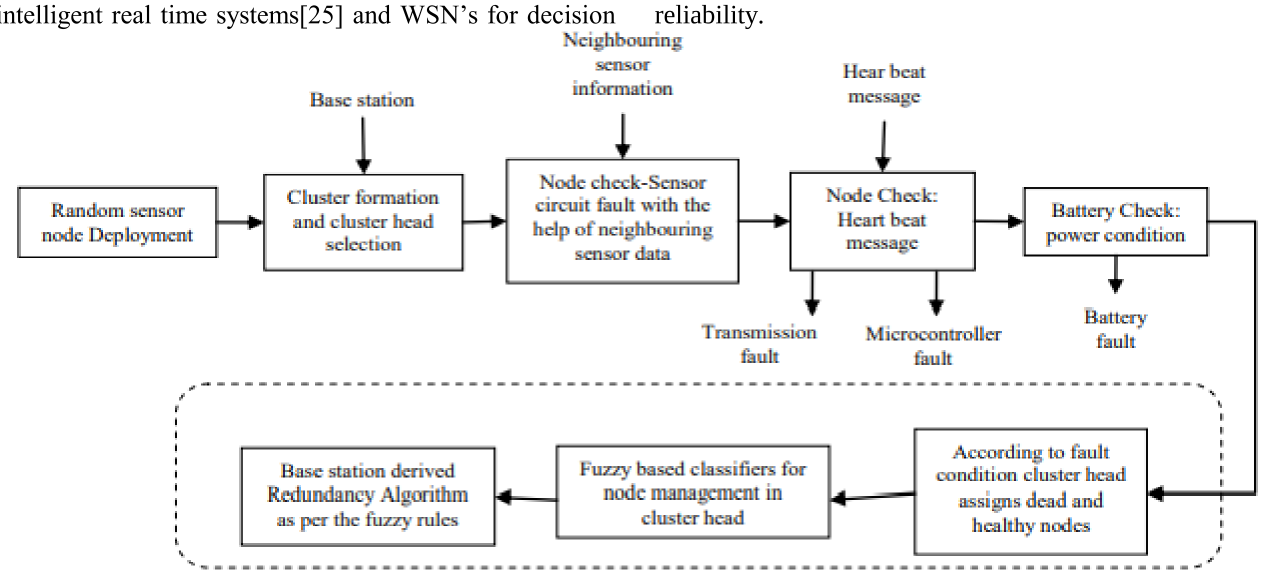

Fig. 1. Flow diagram for fault detection and fault tolerance.

A. *Contribution*

The work is focused on using fuzzy logic for fault detection and redundancy approach to achieve the fault tolerance. The proposed approach is the attempt for fault detection with the temporal redundancy technique which helps to continue the satisfactory operation in the event of failure of its sensor nodes.

The approach has the two phases: firstly, hardware fault detection (Fig.1) is carried out in both cluster head (CH) level, node level and the specified hardware components like transmitter, receiver and battery are considered for fault diagnosis. All the hardware component conditions of are measured by fuzzy logic rules which help to detect failures in advance. Secondly, efficient redundancy approach was introduced to reuse the faulty nodes effectively. Algorithm describes about the faulty nodes detection and redundancy approach for the proposed scheme. During the node redundancy process receiver circuit faults are considered to reuse at earliest to avoid the communication interrupt. Receiver circuit conditions were preferred based on the fuzzy rule based decision making in FNDRA scheme. Therefore the proposed approach can ensure the reliability and resiliency of the WSN.

Algorithm: Faulty nodes detection and Redundancy.

N input Node set
N_γ : Receiver Fault Node set
N_δ : Non-fault Receiver Node set
N_ε : Battery fault Node set
N_η : Non-fault Battery Node set
N_λ Transmitter fault Node set
N_ω : Non-fault Transmitter Node set
$N_{\omega 2}=N$;
Fault node detection
while $N_{\omega 2} = \phi$ **do**
    Fuzzy analysis of hardware condition of each node;
    Select each fault node;
     Working set $N_{\omega 2} = N_\alpha \; N_\gamma \; N_\omega$;
    Dead nodes set $N_d = N_\varepsilon \; N_\lambda$;
End while
Redundancy
for each active N
    if end node N Є N_γ **then**
        Node N broadcasts CRM advt,.msg. in the range X;
     end if
     if node N is a CH **then**
        Node N broadcasts NR advt. msg. in the range 2X;
     end if
     if (N Є N_γ receives NR advt. msg) **then**
        set level (N) = level (N) + 1;
     end if;
end for
If N_γ == end node
    Replace the node with the Node R
    Redefine N_γ as R at the result
End if

II. Formal Definition of the Problem

The proposed WSN consists of N number of sensor nodes which have been localized randomly into clusters and each of the sensors is a member of one cluster. The deployed sensor nodes are powered by battery energy. Let e_b be the number of battery fault, e_r be the number of receiver fault and e_t number of transmitter fault which are situated within the deployed sensor nodes. The main objective of the proposed approach is to detect and diagnose the $e_b \, e_r$ *and* e_t to sustain the network operation.

The modified energy consumption by the *i*th sensor model was represented by the following linear equation [26] for the single message transmission.

$$e_i(s) = \begin{cases} (\tau_s + \tau_{c1}\sigma^2)Z_i & if\ \sigma < c_0 \\ (\tau_s + \tau_{c2}\sigma^4)Z_i & if\ \sigma \geq c_0 \end{cases} \tag{1}$$

Where $\tau_s\,[\mathrm{J/bit}]$ is the energy loss per bit by the transmitter electronics circuit, $\tau_{c1}(J/bit/m^2)$ and $\tau_{c2}(J/bit/m^4)$ denote the factor where $c_0 = \sqrt{\tau_{c1}/\tau_{c1}}$. Transmission range is σ. Z_i is the message size which is transmitted by each sensor node.

Where, $\tau_r[J/bit]$ represent the energy dissipation by the receiver circuit.

A. Overview of the Node Definitions

Based on their hardware conditions FNDRA approach categorized the deployed sensor nodes as normal node, end node, and dead node. Regarding to their hardware condition the defined sensors can do different jobs. If the sensor node can sense the environmental event periodically and if all the hardware circuit is working perfectly then that can be defined as a normal node. The end nodes are defined as the sensor node that does not able to receive any signal from the other sensor nodes but it can sense the information in the monitoring field. The dead node denotes the faulty condition of the battery, transmitter and receiver in the connected network.

B. Fuzzy rule based fault detection scheme

The sensor nodes hardware conditions were performed and evaluated by fuzzy logic rules. (i) Fuzzifier (ii) Fuzzy interface system (FIS) (iii) fuzzy rule based and (iv) defuzzifier are the four important phases of fuzzy logic system. Fig.2 shows the fuzzy logic system for fault node detection. For analysing the hardware circuit condition three linguistic variables are given as input for the Fuzzifier phase which was done by the membership function. The fuzzifier outcome was defuzzied by the FIS and fuzzy rule was developed based on the linguistic rules given by FIS. Finally the defuzzifier collects all the outcome value from the FIS and generates the condition for each individual sensor nodes and the output has the possibility like normal node, end node and dead node. The linguistic input variable for the fuzzy system are: battery condition, transmitter condition, receiver condition and the fuzzy system output categories the sensor nodes into three. Depending on the hardware status of the sensor nodes output labels are as follows:

Battery Condition = {Less, Moderate, High}
Transmitter Condition ={Less, Moderate, High}
Receiver Condition ={Less, Moderate, High}

- *Battery energy fault:* Every battery faults are detected by the node itself, battery condition is represented by the fuzzy logic variables based on the remaining energy. High value of the battery denoted the condition good, if the condition of the battery is moderate there is chance of fault occurrence and if the battery condition is less, then the node is about to die and possible fault occurs.

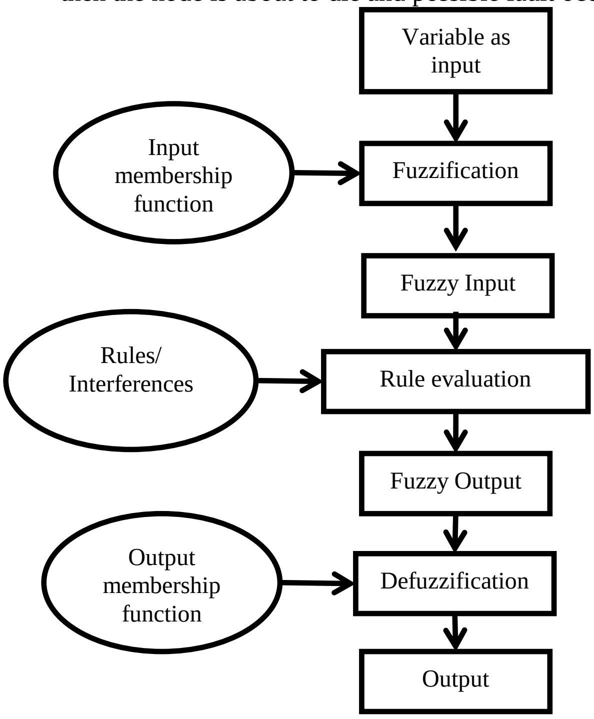

Fig. 2. Operation of fuzzy rule based system

- *Transmitter circuit fault:* CH takes responsibility to verify that every node condition by the lifeline messages. Each sensor node send a lifeline message to the CH with certain time interval on the other hand while receiving the lifeline message CH sends an acknowledgement to the cluster nodes with a lifeline-ok message. The transmitter circuit efficiency is represented by

$$t\emptyset = \vartheta / Z_{time} \quad (2)$$

$Z_{time}$is the total time spent by the network When ϑ is the number of lifeline messages sent by the CH.

- *Receiver circuit fault:* Condition of the receiver sensor node was analysed by the node itself. The efficiency of the receiver circuit was evaluated based on the total number of lifeline – ok message received by the sensor node.

The memberships function for battery conditions are defined as follows:

$$\Delta_{BH}(x) = \begin{cases} 0, & x \le 0.45 \\ \frac{x-0.45}{0.45-0.6} & 0.45 < x < 0.6 \\ 1, & x \ge 0.6 \end{cases} \quad (3)$$

$$\Delta_{BM}(x) = \begin{cases} 0, & x \le 0.2 \\ \frac{x-0.2}{0.3-0.2} & 0.2 < x \le 0.3 \\ 1, & 0.3 \le x \le 0.4 \\ \frac{0.6-x}{0.6-0.4} & 0.4 \le x < 0.6 \\ 0, & x \ge 0.6 \end{cases} \quad (4)$$

$$\Delta_{BL}(x) = \begin{cases} 1, & x \le 0.2 \\ 1 + \frac{x-0.2}{0.35-0.2} & 0.2 < x < 0.35 \\ 0, & x \ge 0.35 \end{cases} \quad (5)$$

Corresponding membership plot is displayed in Fig.3 with x and y axis for battery conditions compared with degree of membership (Low, Medium, High).

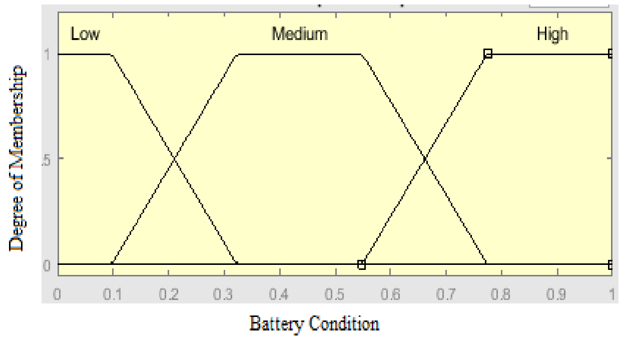

Fig. 3. **Membership function for battery condition**

The membership function developed for Transmitter conditions with (High, medium, low) are given by the following

$$\Delta_{TH}(x) = \begin{cases} 0, & x \le 0.5 \\ \frac{x-0.5}{0.7-0.5} & 0.5 < x < 0.7 \\ 1, & x \ge 0.7 \end{cases} \quad (6)$$

$$\Delta_{TM}(x) = \begin{cases} 0, & x \le 0.3 \\ \frac{x-0.3}{0.4-0.3} & 0.3 \le x \le 0.4 \\ \frac{0.4-x}{0.4-0.7}, & 0.4 \le x \le 0.5 \\ 0, & 0.5 \le x \end{cases} \quad (7)$$

$$\Delta_{TL}(x) = \begin{cases} 1, & x < 0.3 \\ 1 + \frac{x-0.3}{0.4-0.3} & 0.3 \le x \le 0.4 \\ 0, & x > 0.4 \end{cases} \quad (8)$$

The corresponding membership plot for the Transmitter circuit is displayed in Fig.4.

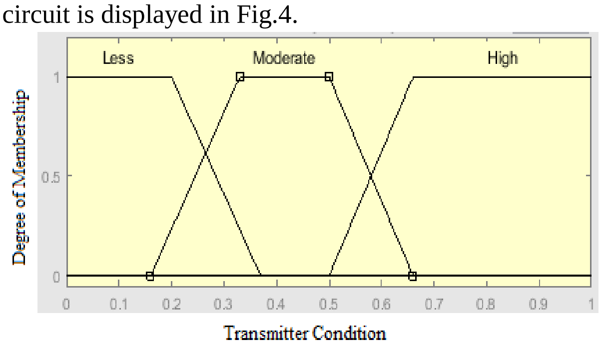

Fig. 4. **Membership function for Transmitter condition**

The membership functions for receiver circuits are defined as

$$\Delta_{RH}(x) = \begin{cases} 0, & x < 0.45 \\ \frac{x-0.45}{0.6-0.45} & 0.45 \le x \le 0.6 \\ 1, & x > 0.6 \end{cases} \quad (9)$$

$$\Delta_{RM}(x) = \begin{cases} 0, & x < 0.2 \\ \frac{x-0.2}{0.3-0.2} & 0.21 \leq x \leq 0.3 \\ 1, & 0.3 \leq x \leq 0.45 \\ \frac{0.6-0.2}{0.6-0.45}, & 0.45 \leq x \leq 0.6 \\ 0, & x > 0.6 \end{cases} \quad (10)$$

$$\Delta_{RL}(x) = \begin{cases} 1, & x < 0.2 \\ \frac{x-0.2}{0.35-0.2} & 0.2 \leq x \leq 0.35 \\ 0, & x > 0.35 \end{cases} \quad (11)$$

Corresponding membership plot was depicted in Fig.5 with receiver condition compared with (Low, Medium, High) degree of membership.

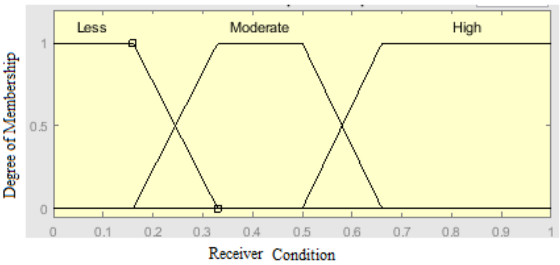

Fig 5. **Receiver circuit membership function**

Output membership function is depicted in Fig.6 here degree of membership helps to resolve various bounds for the nodes type. The membership function for node decision is defined as follows:

$$\Delta_{Dead}(x) = \begin{cases} 0, & x = a \\ \frac{x-a}{b-a} a \leq x \leq b \\ 1, & x > b \end{cases} \quad (12)$$

$$\Delta_{End}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a} a \leq x \leq b \\ 1, & x = b \\ \frac{c-x}{c-b}, & b < x \leq c \\ 0, & x > c \end{cases} \quad (13)$$

$$\Delta_{Normal}(x) = \begin{cases} 1, & x < a \\ \frac{x-a}{b-a} a \leq x \leq b \\ 0, & x > b \end{cases} \quad (14)$$

Table. 1 Node Decision Based on the Hardware condition using Fuzzy logic

Rule no	Battery condition	Transmitter condition	Receiver Condition	Node Decision
0	Less	Less	Less	Dead node
1	Less	Less	Moderate	Dead node
2	Less	Less	High	Dead node
3	Moderate	Less	Less	Dead node
4	Moderate	Less	Moderate	Dead node
5	Moderate	Less	High	Dead node
6	High	Less	Less	Dead node
7	High	Less	Moderate	Dead node
8	High	Less	High	End node
9	Less	Moderate	Less	Dead node
10	Less	Moderate	Moderate	Dead node
11	Less	Moderate	High	Dead node
12	High	Moderate	Less	End node
13	High	Moderate	Moderate	Normal node
14	Moderate	Moderate	Moderate	Normal node
15	High	Moderate	Less	End node
16	High	Moderate	Moderate	Normal node
17	High	Moderate	High	Normal node
18	Less	High	Less	Dead node
19	Less	High	Moderate	Dead node
20	Less	High	High	Dead node
21	Moderate	High	Less	End node
22	Moderate	High	Medium	Normal node
23	Moderate	High	High	Normal node
24	High	High	Less	End node
25	High	High	Medium	Normal node
26	High	High	High	Normal node

Based on the membership functions 27 fuzzy rules were developed for a node decisions shown in Table.1.

Retrieval Number: 100.1/ijitee.A80741110120
DOI: 10.35940/ijitee.A8074.1110120
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication

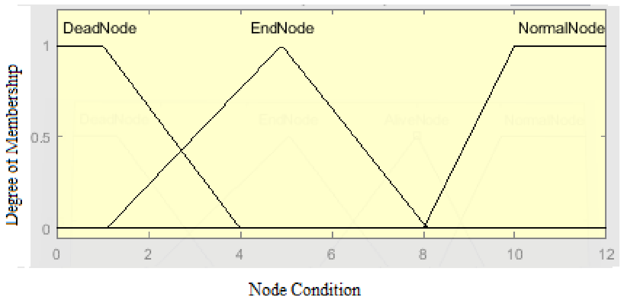

Fig. 6. Membership function for node decision parameter

C. Node redundancy approach for faulty node management

To achieve fault tolerance node redundancy approach is used in this phase because it is a key factor for reliable data transmission in WSN. For increasing the fault tolerant factor and to ensure the uninterrupted communication receiver faulty nodes are considered to be redundant.

If the receiver circuit condition is low and the sensor node does not receive any data from its neighbour nodes for a certain time that sensor node is considered as a faulty node. Energy dissipation by the receiver circuit for receiving Z_i (bits) message is represented by the following equation.

$$e(r) = (\tau_r Z_i) \qquad (15)$$

Where, $\tau_r [J/bit]$ represent the energy dissipation by the receiver circuit. But it can able to sense the CRM (communication request message) and send it to the CH and not to its neighbour nodes. To respond to query *q* with *R* redundant node which is connecting the CH to the base station for node redundancy is given by

$$J_q(R) = CH_{Z_i} + S_{Z_i}) \qquad (16)$$

Then the CH can deliver the NR (node request) to the base station with requested sensor data if any redundant node is alive. This ensures that the base station still get sufficient data to perform if the redundant nodes are deployed in the region even when some nodes fail to perform. Fig.7 illustrate the decision making process for node management Therefore the redundancy approach helps to maximize the application network lifetime and could increase the reliability of the data delivery in the WSN.

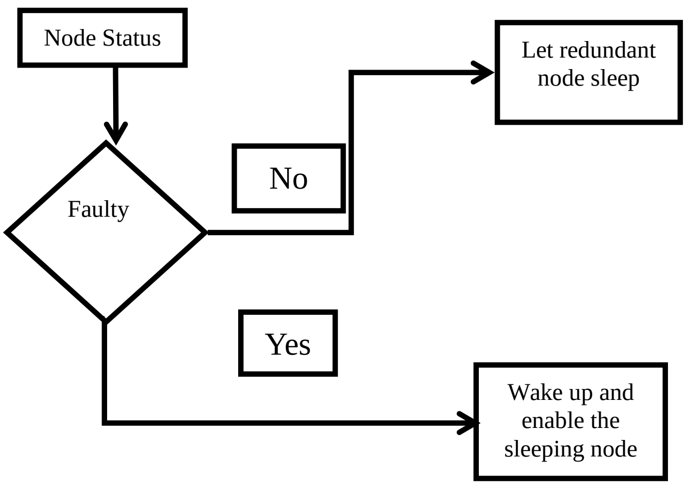

Fig. 7. **Decision making and operating phase of node management scheme**.

IV. PERFORMANCE EVALUATION

Simulation studies were carried out to evaluate the performance of the proposed FNDRA scheme for WSN's using MATLAB. Node deployment was randomly distributed in 1000*1000 m^2.

The proposed FNDRA scheme was compared with FNCM and FDWSN in terms of average delay, packet delivery ratio, detection accuracy, network lifetime, dissipated energy. Experimental parameters are given in Table.2

Table.2 Simulation parameters.

Parameters	Values
Number of nodes	1000
Network range	1000* 1000
Sensing range	10m
Initial energy	0.5J
Data Packet Size	800 bits
Duration of each round time	20s
Data aggregation energy	5nJ/bit

Detection accuracy

The ratio of the number of faulty nodes are proportion of the sum of faulty nodes identified in the network. For comparison 300 faulty sensor nodes were considered. Fig.8 shows the detection accuracy of the sensor node, the analysis depicts that the improvement of detection accuracy of the FNDRA is about 0.96% than the FNCM scheme. The FNCM it is able to detect 0.92%, and the FWDS able to detect 0.90%. Therefore performance of the proposed methodology increases as a result of the fuzzy logic based detection.

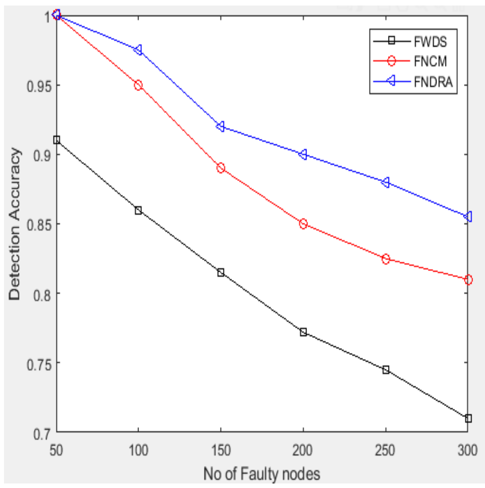

Fig.8 Detection accuracy Vs faulty nodes

Average delay

The average delay was measured by the time required to transmit data from source to destination in the network.

From Fig.9 the observation shows that when the node fault occurrence is low, the probability of dead node occurrence is low. When 60% of node failures occurs, the possibility of dead node occurrence is increased and the average delay is improved.

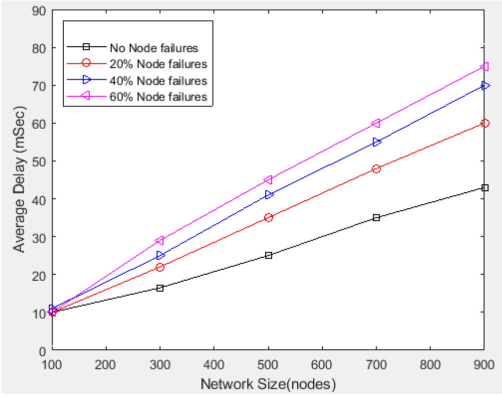

Fig.9 Average delay with different percentage of faulty nodes

Global energy

Global energy is considered by the total amount of remaining energy of all active nodes and it is calculated by the following equation:

$$Average\ remaining = \sum_{i=1}^{n} (\alpha_i + \beta_i + \gamma_i)/Total\ round \quad (17)$$

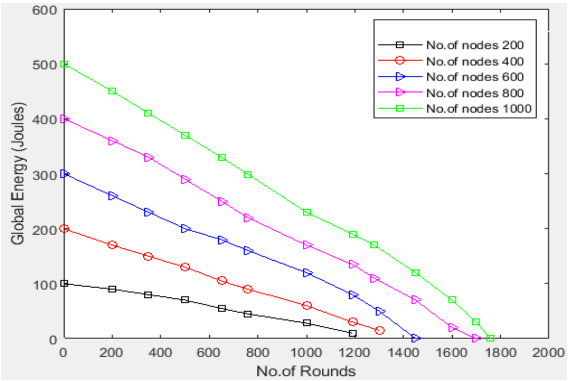

Fig.10. Global Energy Loss in FNDRA

From the observation, energy loss in the network is gradually decreased when number of sensor node increases. The proposed FNDRA scheme tried try to reuse the faulty nodes the energy consumption of the N_γ nodes are increased due to this energy utilization of the deployed nodes ($N_{\gamma)}$ are high .The redundancy approach in FNDRA scheme tried to recover 100 receiver circuit fault nodes and utilized properly as normal node from end node.

V. CONCLUSION

Fault detection and managing the faults are the two important aspects to ensure the network connectivity and it helps to minimize the subsequent failures of the network. The proposed fuzzy rule based fault node detection and redundancy approach (FNDRA) analyses the various hardware conditions through fuzzy logic that can be applied to detect and monitoring the environmental condition .The FNDRA scheme detects the faulty nodes and reduces rapid increment of the faulty nodes by utilizing the redundancy approach which helps to maximize the application network lifetime. Through the simulation it is demonstrated that proposed scheme offers the improved performance than the other schemes As a future study, sink mobility based mechanism can be taken into account to identify the environmental condition in real time.

REFERENCES

1. Di Tian , Nicolas D. Georganas, Connectivity maintenance and coverage preservation in wireless sensor networks, Ad Hoc Networks 3 (2005) 744–761
2. D. Estrin, R. Govindan, J. Heidemann, S. Kumar, Next century challenges: Scalable coordination in sensor networks, Proceedings of the ACM International Conference on Mobile Computing and Networking (MOBICOM-99), Washington (1999) 263–270.
3. J. Kahn, R. Katz, K. Pister, Next century challenges: Mobile networking for smart dust, Proceedings of the ACM International Conference on Mobile Computing and Networking (MOBICOM-99), Washington (1999) 271–278.
4. A. Cerpa, J. Elson, D. Estrin, L. Girod, M. Hamilton, J. Zhao, Habitat monitoring: Application driver for wireless communications technology, in: Proceedings of the ACM SIGCOMM, Workshop on Data Communications in Latin America and the Caribbean, Costa Rica (2001) 3–5.
5. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: A survey, Computer Networks 38 (4) (2002) 393–422.
6. Shuang Jia, Lin Ma, Danyang Qin, Fault detection modelling and analysis in a wireless sensor network, Journal of Sensors, 7935802 (2018) 1-9
7. R.Vishnuvarthan, R Sakthivel, V.Bhanumathi, K,Muralitharan , Energy efficient data collection in strip- based wireless sensor network with optimal speed mobile data collectors , Computer Networks 156 (2019) 33-40
8. Mohammad Alam, Analysis of Different Software Fault Tolerance Techniques (2009) 01.
9. J.C. Laprie, J. Arlat, C.Beounes, K.Kanoun, Hardware and software fault tolerance, commission of the european communities directorate-general telecommunications, Information Industries And Innovation, Springer (1990)
10. A. Messaoudi, R. Elkamel, A.Helali, R. Bouallegue, R, Distributed fuzzy logic based routing protocol for wireless sensor networks, Proceedings of 24th IEEE International Conference on Software, Telecommunications and Computer Networks (SoftCOM), (2016) 1-7.
11. S. Arjunan, P. Sujatha, (2017)A survey on unequal clustering protocols in Wireless Sensor Networks, Journal of King Saud University Computer and Information Sciences vol. xx (2017) 1-14.
12. P. Jiang, A new method for node fault detection in wireless sensor networks, Sensors (Basel) 9(2) (2009)1282-1294.
13. NengsongPeng, Weiwei Zhang, Hongfei Ling, Yuzhao Zhang, LixinZheng, Fault-tolerant anomaly detection method in wireless sensor networks, Information Vol. 9(9) (2018) 236.
14. Meenakshi Panda, P.M Khilar, Distributed self-fault diagnosis algorithm for large scale wireless sensor networks using modified three sigma edit test. Ad Hoc Networks 25 (2015) 170-184.
15. Meenakshi Panda, P.M.Khilar, Energy efficient distributed fault identification algorithm in wireles sensor networks 2014, 323754, 1-16
16. SantoshineeMohapatra, P.M. Khilar, Rakesh Swain, Fault diagnosis in wireless sensor network using clonal selection principle and probabilistic neural network approach, International Journal of Communication Systems 3 2 (2019).
17. G. Venkataraman, S. Emmanuel, S. Thambipillai, A cluster-based approach to fault detection and recovery in wireless sensor networks, Proceedings of the 4th international conference on wireless communication system, (2007) 35–39.
18. M. Asim, H. Mokhtar, M. Merabit, A cellular approach to fault detection and recovery in wireless sensor network, Proceedings of the third international conference on sensor technology and applications (SENSORCOMM -09) (2009) 352–357.
19. I. Banerjee, P. Chanak, H. Rahaman, T. Samanta, Effective fault detection and routing scheme for wireless sensor networks. Computers & Electrical Engineering, 40(2) (2014) 291–306
20. H. Yuan, X. Zhao, L. Yu, A distributed bayesian algorithm for data fault detection in wireless sensor networks. In Proceedings of international conference on information networking (ICOIN) (2015) 63–68.

21. P. Chanak, I. Banerjee, T. Samanta, H. Rahaman, Fuzzy based fault management scheme in wireless sensor network, Proceedings of eco-friendly computing and communication systems, communications in computer and information science, (2012) 30–38
22. S. A. Khan, B. Daachi, K. Djouani, Application of fuzzy inference systems to detection of faults in wireless sensor networks. Neuro computing, 94(1) (2012) 111–120.
23. PoojaJadav, K. VinothBabu, Fuzzy logic based faulty node detection in wireless sensor network, Proceedings of International Conference on Communication and Signal Processing (2017)
24. LokeshBhajantri, Fuzzy logic based fault detection in distributed sensor networks, International Journal of Scientific Research in Computer Science and Engineering 6 (2018) 27-32.
25. P.Manikandan, D.Ramyachitra, R.Nandhini, Fuzzy based algorithms to predict Micro RNA regulated protein interaction pathways and ranking estimation in Arabidopsis thaliana, Gene, Volume 692, (2019).
26. C.J. Lopez, R.J. Patton, s. Daley, "Fault-tolerant traction system control using fuzzy inference modelling 31(10) (1998) 137-142
27. FarzinPiltan ,Cheol-Hong Kim, Jong-Myon Kim, Adaptive fuzzy-based fault-tolerant control of a continuum robotic System for Maxillary Sinus Surgery, Applied Sciences 9 (2019) 2490.
28. Mohammad Masdari, SuatOzdemir, Towards coverage- aware fuzzy logic-based faulty node detection in heterogeneous wireless sensor networks, Wireless Personal Communications (2019).
29. Daniel-IoanCuriac, ConstantinVolosencu, Dan Pescaru,LucianJurca, AlexaDoboli,Redundancy and its applications in wireless sensor networks :A survey,wseas transactions on computers Issue 4, Volume 8, April (2009).

AUTHORS PROFILE

N. Priya is a PhD Research Scholar in the Department of Computer Science, School of Computer Science and Engineering, Bharathiar University, Coimbatore, Tamil Nadu. She has received M.Sc Information Technology from Madras University, Chennai and M.Phil Computer Science from Sri Chandrasekharendra Sarawathi Vishwa Mahavidyalaya University. Her main research work focuses on Wireless Sensor Network and Fault Tolerance Mechanisms in Distributed Environments.

P. B. Pankajavalli Phd, is an Assistant Professor in the Department of Computer Science, School of Computer Science and Engineering, Bharathiar University, Coimbatore, Tamil Nadu, India. She has around 16 years of experience in teaching. She is carrying out a funded project in the domain Sensor Networks. She has published around 100 papers in journals, Conferences proceedings both at National and International level, 4 book chapters, one edited book and filed an Indian patent. Her areas of interest include Ad-hoc Networks, Wireless Sensor Networks and Internet of Things.