# Heterogeneous Hardware Fault-Detection Scheme for Large Scale Wireless Sensor Networks

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***Abstract*—Recently, Wireless Sensor Networks (WSNs) have become a key technology in various applications. Sensor nodes are prone to many types of failures such as hardware and software failure. The fault probability increases in large scale WSNs which decreases the quality of service (QoS). To achieve a good QoS it is required to develop efficient fault detection technique. This paper propose a hardware fault diagnosis scheme that detect the heterogeneous hardware fault such as sensor unit fault, trans-receiver unit fault , micro- controller unit fault and battery failure. Self detection takes place for detecting faulty receiver unit, faulty battery unit and faulty sensor unit by using vague set based similarity measurement technique whereas, faulty microcontroller and transmitter unit fault is detected by neighbor nodes. Proposed algorithm performance is evaluated using Simulator and verified the experiment result with other existing algorithms in terms of different performance metrics.**

***Index Terms*—Wireless Sensor Network (WSNs), Heterogeneous hardware fault, Fault detection, Vague set.**

## I. Introduction

The ubiquitous sensing property of Wireless Sensor Network (WSNs) plays a very crucial role in Internet of Things (IoT). To achieve more accurate fault status of sensor nodes is indispensable part of IoT. WSNs is a collection of large number of tiny, low cost, low power and independent multi-functional device [1]. WSNs used in several areas such as environmental monitoring, battlefield surveillance, weather monitoring and health monitoring [2]. In such applications sensor nodes are deployed in hazardous and inaccessible environment that cause a frequent unexpected failures in sensor nodes. The erroneous data in specific operation leads to loss of human life, economic and environmental loss. The failures of sensor nodes effect on the performance of the WSNs [3]. So that fault detection scheme plays a very crucial role to increase the Quality of Service (QoS) in WSNs.

In WSNs, sensor node faults are classified into two categories, viz. software fault and hardware fault [4]. Software faults occur in application and middle-ware, such as fault occur in sensor nodes program [5]. Software faulty nodes respond but produced altered result [6]. However, hardware faults occur due to malfunctions of hardware component presents in the sensor node. According to existing fault detection scheme, hardware faulty nodes do not reused for farther network topology construction and it act as a dead or permanent faulty node in WSNs [6]. Hardware faults can be further classified into five types, viz. transmitter unit fault, receiver unit fault, sensor unit fault, micro-controller unit fault and battery failure [4]. Existing fault detection schemes can be categorized as centralized and distributed. In centralized approach BSs having sufficient amount of energy to monitor and detect the fault status of sensor nodes. Centralized approach increases the message overhead and energy consumption. In the distributed approach, each node is responsible for monitoring and detecting fault status without any central control [7].

Previous methods for fault detection are not appropriate for large area WSNs due to large message overheads and low detection accuracy [6]. Panda and Khilar, proposed a Distributed Fault Detection (DFD) algorithm based on three sigma test [8]. DFD algorithm based on three sigma test to calculate the node failure probability of its own and neighbor. The demerit of DFD is low detection accuracy, high false alarm rate with respect to increase the fault probability. It require two times message exchange to diagnosis the fault status of deployed sensor nodes [8]. To overcome the limitation of DFD algorithm, Panda et al. proposed a Distribute Self-Fault Diagnosis (DSFD) algorithm based on modified three sigma tests, which diagnose both the soft and hard fault [6]. DSFD used time out mechanism to detect the hard fault [6]. In paper [9], Swain et al. proposed a Heterogeneous Fault Diagnosis (HFD) protocol to identify and classify the type of fault occur in the sensor node such as permanent, transient and intermittent fault. They used Analysis of Variance Method (ANOVA) and time-out mechanism to diagnosis the fault status of deployed sensor nodes. The major drawback of this technique is that ones head node fails then fault diagnosis of other nodes are stop [9]. Most of the existing fault diagnosis scheme for WSNs describe in literature does not contemplate hardware fault detection. Previous research on hardware fault detection [4] is not able to provide high detection accuracy with the increasing of faulty nodes within the network. Therefore performance of the network continuously decreases throughout the network lifetime with the increase of faulty node/dead nodes within the network. The present state-of-art moving towards the analysis of heterogeneous hardware faults detection with high detection accuracy to improve network lifetime as well as performance of the network.

To addressed the above problems this paper propose an vague set based distributed self-diagnosing fault detection algorithm, which is able to detect heterogeneous hardware fault such as sensor unit fault, transmitter unit fault, receiver unit fault, micro-controller unit fault and battery failure. Vague sets provide a better environment to deal with vagueness and uncertainty present in information during fault detection [10]. It also increases the reliability of the network.

The paper is organized as follows. Scheme detail of proposed algorithm is described in Section 2. Section 3 provides performance evaluation of the proposed scheme followed by comparative study of simulation results. Section 4 concludes the paper with future work.

## II. Scheme details

### A. *Preliminaries*

To detect the fault in sensor circuit we use vague set similarity measurement technique. Vague sets able to deal with uncertainty and vagueness present in sensor data during fault diagnosis [10].

Let $N$ number of sensor nodes $S = [s_1, s_2, s_3.....s_N]$ are deployed in $A \times Am^2$ monitoring area. Then Vague sets $Z$ of a sensor node data can be defined by following expression. $Z = \{s_i, [t_z(s_i), 1 - f_z(s_i)] \mid s_i \in \text{S}\}$ ie. $Z(s_i) = [t_z(s_i), 1 - f_z(s_i)]$ and condition $0 \leq t_z(s_i) \leq 1 - f_z(s_i)$ should be satisfied for each $s_i \in S$ where $t_z(s_i)$ is characterized by degree of true membership and $f_z(s_i)$ is characterized by degree of false membership of the element to the set $Z$.

• To convert sensor single value sense data into a vague sets of sense data. Let sensor node index set $S = [s_1, s_2, s_3.....s_N]$ and $s_{ij}$is non-negative sensor single value sense data $s_j\{j = 1, 2, 3....n\}$ and $Z_i\{i = 1, 2, 3....m\}$ then single value sense data convert into a vague set of sense data by using below formula.

$$t_z(s_i) = \left(\frac{s_{ij}}{s_j max}\right)^2, \quad f_z(s_i) = \left(\frac{s_{ij}}{s_j max}\right) \tag{1}$$

• Let $a$ and $b$ be vague value sets of two sensor nodes which is define as $a = [t_a, 1 - f_a]$ and $b = [t_b, 1 - f_b]$ then sensor node Similarity measure of vague sets define as.

$$SM(a, b) = \frac{I(a, b) + I(b, a)}{2} \tag{2}$$

where,

$$I(a, b) = min\left( \begin{cases} 1, & t_a \leq t_b \\ 1 - t_a + t_a t_b, & t_a > t_b \end{cases}, \begin{cases} 1, & f_a \geq f_b \\ f_a + (1 - f_a)(1 - f_b), & f_a < f_b \end{cases} \right)$$

$$I(b, a) = min\left( \begin{cases} 1, & t_b \leq t_a \\ 1 - t_b + t_a t_b, & t_b > t_a \end{cases}, \begin{cases} 1, & f_b \geq f_a \\ f_b + (1 - f_a)(1 - f_b), & f_b < f_a \end{cases} \right)$$

### B. *Proposed algorithm*

**Fault detection:** The proposed Algorithm 1 is able to identify the unit wise fault within a sensor node. Micro-controller unit and transmitter unit fault is detected by the neighbor node and sensor unit, receiver unit and battery unit fault is diagnosis by node itself. For unit wise fault detection each sensor node uses single hop communication to transmit and receive neighbor node sense data. All sensor nodes assume to be non-faulty at the time of deployment and their fault status is stored in sensor memory. The proposed algorithm diagnosis the fault status of transmitter, receiver, sensor and battery unit if and only if micro-controller circuit of sensor node is non-faulty otherwise it is simply declare as a dead node. Detection strategy for unit wise fault is stated as follows.

**[i] Micro-controller unit fault:** The faulty Micro-Controller (MC) circuit is detected by a neighbor node in which each sensor node ($s_i$) broadcast the line control message at predefined time interval or round to neighbor node ($s_j$). If $s_j$ receive a line control message then $s_j$ declare $s_i$ having non-faulty micro-controller unit and also declare $s_j$ having non-faulty micro-controller unit by checking the previous transmitter and receiver fault status respectively otherwise $s_j$ declare the $s_i$ having faulty micro-controller unit by checking the transmitter unit fault status of $s_i$. If $s_i$ and $s_j$ having non-faulty micro-controller units, previous value of number of transmitted message ($prev.Tx(msg)$) of $s_i$ is incremented by one and become a new transmitted message ($new.Tx(msg)$) of $s_i$.

**[ii] Transmitter unit fault:** The transmitter circuit fault diagnose by neighbor node ($s_j$). $s_j$ send a line control message to $s_i$ by checking the previous fault status of $s_j$ receiver circuit. If $s_j$ receives the OK acknowledgement message from $s_i$ then transmitter circuit is declared as a non-faulty if not then declare as a faulty transmitter circuit.

**[iii] Receiver unit fault:** The receiver circuit fault checked by self-diagnosis. Each sensor node $s_i$ checks the number of line control message received, If the number of received message at round ($n$) is greater than the number of received message at round ($n - 1$) then receiver unit is declare as a non-faulty otherwise it is declare as a faulty receiver circuit.

**[iv] Sensor unit fault:** By using Algorithm 2 each sensor node $s_i$ self-diagnosis the sensor unit fault by calculating the vague similarity measure between sensor node $s_i$ sense data ($D_i$) and neighbor node $s_j$ senses data ($D_j$). For sensor unit fault detection each $s_i$ receives data from $s_j$ then convert the $s_i$ sense data ($D_i$) into a vague set $[t_v(D_i), 1 - f_v(D_i)]$ which consist of true membership function ($t_v(D_i)$) and false membership function ($f_v(D_i)$) and also convert the $s_j$ senses data ($D_j$) into a vague set $[t_v(D_j), 1 - f_v(D_j)]$ where, $t_v(D_j)$ is true membership function and $f_v(D_j)$ is false membership function by using a eq(5) and eq(6). After converting all sense data into a vague set, node $s_i$ calculate the similarity measure by using a eq(7), if the similarity measure of node $s_i$ with node $s_j$ is greater than 95 percent then it is declare as a non-faulty sensor unit otherwise $s_i$ declare having a faulty sensor unit.

**[v] Battery unit fault:** battery unit fault detection is also based on self-diagnosis approach. For battery fault detection each sensor node checks the residual battery level at each round if the battery level is less than threshold ($\theta$) then it is declare as a faulty battery otherwise declare as non-faulty battery unit.

**Algorithm 1** Fault detection

**Input:** Initially $N$ number of non faulty sensor nodes are deployed.
**Output:** The partially faulty sensor node set ($F_s$, $F_t$, $F_b$, $F_{mc}$, $F_r$) node sets.

*// Initialisation* :
**for** each $s_i$ **do**
  Set initially all sensor node units are good;
  Set $prev.T_{x}(msg).(s_i) = 0$;
  Set $prev.R_{x}(msg).(s_i) = 0$;
  Set $Round = 0$;
  Set $SD = \phi$ ;
  Collect monitoring area neighbor node sense data $D_j$ from the neighbor nodes of $s_i$;
**end for**
*// Fault detection* :
**while** $Round = n$ **do**
  $s_i = s_i - S_d$;
  **for** each $s_i$ **do**
    Broadcast line control message to $s_j$ in the range $R$;
    **if** (Node $s_j$ receive message) **then**
      MC of node $s_i$ declare non-faulty;
      MC of node $s_j$ declare non-faulty;
      Set $new.T_{x}(msg).(s_i) = prev.T_{x}(msg).(s_i) + 1$;
      $new.R_x(msg).(s_j) = prev.R_x(msg).(s_j) + 1$;
    **else**
      MC of node $s_i$ declare faulty;
    **end if**
    **if** (MC of $s_i == 1$ && MC of $s_j == 1$) **then**
      $s_j$ send line control message to $s_i$ ;
      **if** ($s_i$ send ACK to $s_j$ **then**
        $T_x$ of node $s_i$ declare non-faulty;
      **else**
        $T_x$ of node $s_i$ declare faulty;
      **end if**
    **end if**
    **if** (MC of $s_i == 1$) **then**
      **if** $(new.R_x(msg).(s_i) > prev.R_x(msg).(s_i))$ **then**
        $R_x$ of node $s_i$ declare non-faulty;
      **else**
        $R_x$ of node $s_i$ declare faulty;
      **end if**
      **if** (Battery level of $s_i < \theta$) **then**
        Battery of node $s_i$ declare non-faulty;
      **else**
        Battery of node $s_i$ declare faulty ($F_b$);
      **end if**
      Calculate the vague set of $D_i$ and $D_j$ using eq(1);
      Calculate the vague similarity measure from eq (2);
      **if** (similarity measure $> 95\%$) **then**
        Sensor unit of node $s_i$ declare non-faulty;
      **else**
        Sensor unit of node $s_i$ declare faulty;
      **end if**
    **end if**
  **end for**
**end while**

## III. Performance evaluation

The performance of proposed scheme has been evaluated using Matlab 2014a software. To configure the network $50-1000$ sensor nodes are deployed in $1000 \times 1000\ m^2$ squared area. The performance of proposed algorithm is compared with existing HFD [9], DSFD [6] and DFD [8] algorithm in terms of various performance metrics such as fault detection accuracy (FDA), false alarm rate (FAR) and energy consumption.

***A) FDA and FAR performance analysis :*** The performance of proposed algorithm is evaluated in terms of FDA and FAR. All the Hardware components of sensor nodes are tested at different fault probabilities range from 0.05 to 0.30 with the step size is 0.05 with 15 average degree. Average fault detection accuracy of micro-controller, Transmitter, Receiver and Battery are evaluated at different fault probability and by increasing a network density from 50 to 300 sensors with step size is 50 as shown in TABLE I. The performance of proposed algorithm for sensor unit fault is compared with existing DSFD, DFD and HFD algorithm in terms of FDA and FAR. FDA and FAR with respect to fault probability are shown in Fig. 1 and 2 respectively. From Fig. 1 we can see that our proposed algorithm shows 1.5 %, 2 % and 3.8 % better result in terms of FDA as compared to HFD, DSFD and DFD algorithm respectively. Similarly from Fig.2 we can see that our proposed algorithm shows 0.5 %, 2.2 % and 4.5 % better result in terms of FAR as compared to HFD, DSFD and DFD algorithm respectively.

TABLE I: Average Fault detection Accuracy of Micro-controller, Transmitter, Receiver and Battery

| Number of node | Micro-controller (%) | Transmitter ( %) | Receiver (% ) | Battery (%) |
|---|---|---|---|---|
| 50 | 91.76 | 100 | 97.5 | 100 |
| 100 | 100 | 100 | 100 | 100 |
| 150 | 100 | 100 | 100 | 100 |
| 200 | 100 | 100 | 100 | 100 |
| 250 | 100 | 100 | 100 | 100 |
| 300 | 100 | 100 | 100 | 100 |

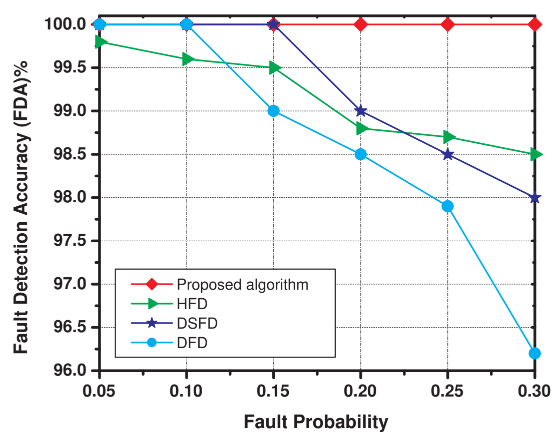


Fig. 1: FDA vs fault probability

***B) Energy consumption analysis :*** To evaluate the impact on energy consumption we consider a 1000 homogeneous sensor

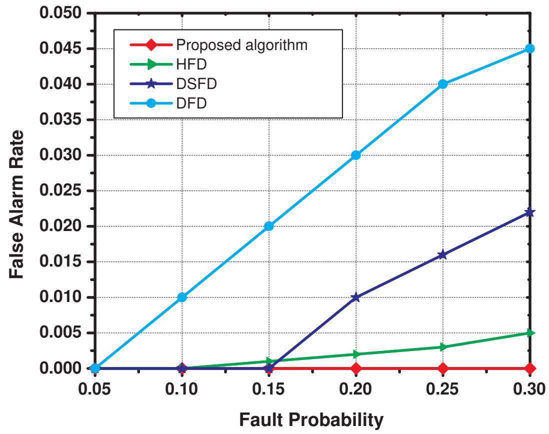


Fig. 2: FAR vs fault probability

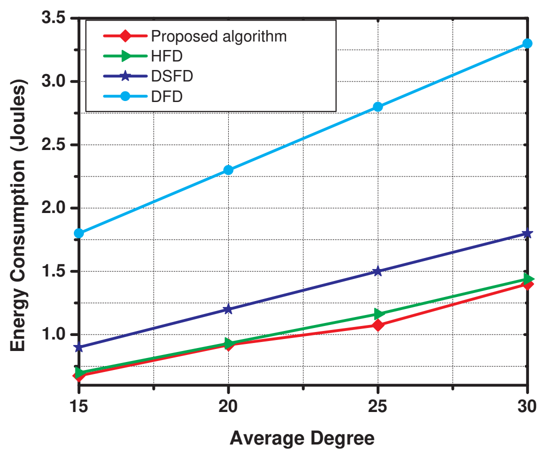


Fig. 3: Energy consumption in sensor circuit fault detection vs average degree

nodes. The initial energy for all the sensor nodes are unique. Fig 3 depicts the total energy consumption of all the scheme for sensor unit fault detection with respect to average degree of a network. As we can see that the energy consumption of proposed algorithm is low as compare to HFD, DSFD and DFD algorithm by varying the average degree of a network. fig 4 shows the total energy consumption in transmitter and microcontroller circuit fault diagnosis. Form Fig 4 we can see that energy consumption increased with increasing the network density.

## IV. Conclusion and Future Work

This paper proposed a heterogeneous hardware fault detection scheme for large scale WSNs. Proposed algorithm is able to detect the faulty hardware component present within a sensor node. In the proposed scheme, microcontroller, transmitter and receiver circuit fault is detected by analyzing the line control message. Battery failure is analyze by using predefined threshold level. For sensor circuit fault detection

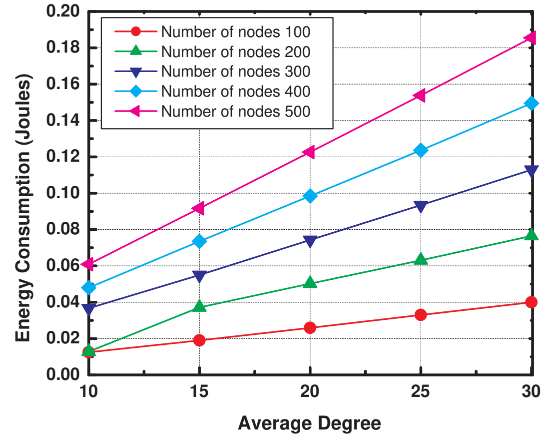


Fig. 4: Transmitter or micro-controller circuit energy consumption in fault detection vs average degree

we use vague set based similarity implication function, which is able to cope-up with uncertainties in WSNs. In sensor unit fault detection, proposed algorithm compared with DSFD and DFD and HFD scheme. Simulation result show that proposed algorithm results are more efficient by providing a low FAR and high FDA. In the proposed scheme efficiency and reliability of wireless sensor network has been increase. Future work can be extended to implement the proposed scheme which reused partially faulty node by using the heterogeneous hardware fault status obtained from proposed scheme.

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