Automatic Fault Identification in WSN Based Smart Grid Environment

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Automatic Fault Identification in WSN Based Smart Grid Environment

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Abstract: Wireless Sensor Network (WSNs) plays a vital role in smart grid (SG) environment. Due to the fault tolerance characteristics, cost reduction and large scale convergence. SG introduce many unique challenges caused by system and functional devices. To solve this problem, a WSN based SG network is used for identifying faults. During the process of data transmission, faulty nodes are occurred in the transmission line. Due to the nodes failures, calibration, network failures, low battery, dried sensors, environmental changes and software failures etc., which leads to the interruption in data delivery and spoil the entire WSN based SG network. In order to tackle these problems, the new WSN model is designed to detect the faults in the transmission line based on the SG environment. In this paper, Adaptive Zigbee-Aquila communication protocol (AZACP) is used to find the optimal shortest path for transferring data. AZACP finds the shortest optimal path for transmitting the sensed data to base station with low cost and less time consumption. Fault detection is the process of automatically identifying the fault in the transmission line and isolate the faulty nodes to ensure the efficient data transmission in WSN. Here, Enhanced Recurrent Equilibrium Neural Network (ERENN) is introduced to identify the fault in data transmission. It recognize the strength of the signal to transmit the sensed data and checks the quality of the data in transmission line between the nodes. The proposed approach is implemented in MATLAB software and compared with existing approaches like Adaptive Error Control (AEC), Gallager Humble Spira (GHS), Genetic Algorithm-Ticket Based Routing (GA-TBR), Improved Grid based Routing and Charging (IGRC) and Emperor Penguin Optimized Self-healing Strategy (EPOSH). The proposed approach provides better performance in terms of evaluating performance metrics like throughput, delay, reliability, average residual energy, number of total transmission, network lifetime, efficiency and Bit Error Rate (BER).

Keywords: Wireless Sensor Network, Smart Grid, Fault detection, Sensor Nodes, shortest path, adaptive Zigbee-Aquila communication protocol, Enhanced Recurrent Equilibrium Neural Network.

1. Introduction
Nowadays electricity is an important thing in everyone life. It is very essential to people who use the electrical power for lighting, heating, computers, electronics, machinery, public, transportation systems, cooling and refrigeration etc. [1]. Traditional power grid is used in electric network to transfer the power from the source to destination, which contains the distributed line, generating station and transmission line to transmit the electric power. In the electric power grid, sensor devices are used to gathers real time information and transfers the data to power grid [2], which will diagnose the faults in the system and improve the performance of the power grid. Sensor device are deployed in the power grid equipment to sense the power quality disturbance, current, voltage, system frequency and temperature [3, 4]. Even sensor devices in the power grid, which are also affected by some sarcastic surroundings, radio frequency interference, highly caustic, external vibrations, dust and dirt etc. However
Traditional power grid diagnose the fault and failures, it also provides a poor communication, power failure, and power shutdown in existing electric system [5]. To addresses this problems smart grid is introduced in electric power system.

Smart grid is an advanced distribution and power transmission network. Smart grids are also called as electrical grids, which are used to upgrade the electric power system [6]. Integrating smart grids with power grid to enhance the energy efficiency, safety, reliability, power supply and performance of electric power system [7, 8]. In electric system, the smart grid enables the two-way communication, low-cost network and power delivery network. Some of the important application of using smart grids are remote monitoring for power system, fraud detection in data transmission, automatic metering, controlling load, demand response, distribution automation and diagnosis of faults in transmission line [9]. The performance of electric power system is ensured by smart grids instead of smart meters, communication technology, renewable energy generation and modern sensing devices. Due to the failures of equipment, natural accidents, disasters and capacity limitations in electric system, it is important to maintain the efficiency, safety and reliability of sensed data transmission [10, 11].

The wireless sensor network has played a crucial role in the recent era of the smart grid to improve data transmission performance [12]. In electrical power system communication plays a vital role even smart grid also behave as a data communication network. In this work, sensors devices are connected to the smart grid in order to transmit the information wirelessly [13, 14]. Hence, choosing WSN is an appropriate technology for transmitting the sensed data in smart grid environment [15]. WSN is also used for bidirectional delivery, faultless monitoring, power generation and utilization, which also upgrade the reliability, low-cost solution and energy efficiency for data transmission [16]. Integrating WSN with a smart grid application to communicate all nodes to base station to provide reliable communication.

Faults occurred due to the internal and external influences they are nodes failures, calibration, network failures, low battery, dried sensors and software failures [17]. In WSN fault occurs due to the diverse deployment fields and limited resources of SN. Based on the location and structure faults exist, faults may be temporary or permanent. Several approaches are proposed for detecting faults and faults locations [18, 19]. However existing approaches detect the faults still obtaining a secure data transmission is a challenging one. So it’s necessary to identify the faults location in transmission line and upgrade the efficiency, reliability and secure data transmission in WSN [20]. To addresses this issue in data transmission, the Adaptive Zigbee Aquila Communication protocol is introduced to find the shortest optimal path. Also, Enhanced Recurrent Equilibrium Neural Network (ERENN) algorithm is introduced for automatic fault identification in transmission line.

Motivation: A WSN is a collection of nodes and sensors, which are deployed in unattended or protective area to sense the environment and physical conditions. Nowadays faults are raised during the transmission of sensed data from SN to base station. However, deep learning and machine learning processing algorithm have been proposed in recent years to reduce the faults during transmission, which is not efficient in WSN. Hence, the focus of this proposed method is finding optimal shortest path and identifying faults during data transmission. It’s a challenging role to find the shortest optimal path to transfer sensed data with minimum time consumption. To tackle these issues AZACP is introduced in a WSN based SG environment to reduce the delay for choosing the optimal shortest path for data transmission. ERENN is introduced to diagnose the faulty nodes in transmission line by satisfying network parameters, which improves the detection efficiency. These approaches provide high quality data and high data delivery with least cost of communication system. Using ERENN, faults are identified and diagnosed to make WSN based smart grid environment as more effective and efficient data transmission technology.

The contribution of this paper is mentioned below
• To design an effective WSN based on a smart grid environment to detect the fault in transmission line to provide a high quality data and high data delivery with minimum cost of communication in system
• To propose an AZACP for choosing the shortest optimal path for data transmission with less time consumption to increase the network lifetime.
• To design ERENN to identify the faults and to reduce the delay, maintenance cost and energy.

The work of this paper is arranged as following format: section 2 explain related work similar to this paper. Section 3 explains the proposed methodology for Data transmission using AZACP and automatic fault detection by ERENN. Section 4 explains the result and analysis of proposed and existing approaches. Section 5 concludes this work.

2. Related Work
Recent works related to fault detection in WSN based smart grid environments are mentioned below
Arifa et al. [21] proposed a wireless sensor based smart grid by using cognitively driven load management technique for efficient decision making and effective communication among sensor nodes. Minimum delay in data transmission is achieved by using Fuzzy Long Short Term Memory based Crow Search Optimization Algorithm (FLSTM-CSOA). Hence, using cognitively driven load management approach to enhance the throughput, latency of WSN based smart grid. Hence this method is fails to identify the malicious attacks and faults in network, which affects the entire SG communication network
Yang et al. [22] introduced a Grid based Routing and charging (IGRC) Algorithm for effective data transmission. The energy consumption is measured by multiple ring division of WSN in IGRC. Design complexity is eliminated by using IGRC approach, which enhance the performance of WSN based smart grid network. IGRC in WSN based smart grid provide optimal transmission path with optimal transmission time and minimize the dead nodes that leads to fault. But it’s not an efficient method to provide a Proper Smart grid network to detect a fault in the transmission line during data transmission.
Melike et al. [23] suggested a new efficient algorithm for controlling errors and faults for wireless sensor network based smart grid environment. This approach first examines and compares the Reed Solomon Code (RS) and grid Bose Chaudhuri-Hochquenghem code (BCH) with several modulation methods in SG network. The result of the comparison introduces a new adaptive error control (AEC) algorithm. AEC recognizes the behaviour of data transmission line, communication channel in terms of error rate of packet. By using AEC algorithm in WSN, it enhance the throughput, latency and error or fault rate in transmission line, but the reliability among sensor nodes are vulnerable during the transmission of sensed data.
A new method for distributed error detection for wireless sensor network is introduced by Mahdi mojed gharamaleki and shahram babaie [24]. In this work sensor nodes are ranked according to their identification and local importance. Identification of High local importance nodes are considered as HOT nodes. Detecting the status of nodes on the transmission line determines the faulty node. The approach introduced is compared with Jiang’s method, Lee’s method to increase the network density and minimize the nodes failure. Hence the impact of faults during transmission affect the performance of the entire SG network.
Faheem et al. [25] proposed a WSN based smart grid application for efficient data transmission. This work introduce a combination of bio-inspired computing and butterfly-mating optimization called new bio-inspired self-optimized butterfly mating optimization. The proposed approach is used for providing an effective transmission path in a WSN based smart grid application, which enhances the multihop communication network for collecting QoS
information in a WSN based smart grid application. But it also increases the data redundancy for collecting QoS in WSN, which affects the transmission process. **Problem statement:** In WSN, detecting fault in transmission line is a very challenging one. Nowadays, several approaches were proposed for detecting faults in WSN. But these existing methods are not provide an optimal solution for the data transmission process. Thus, the shortest path and the fault identification in WSN based on an SG environment is designed to reduce the maintenance cost and energy consumption in system by using AZACP and ERENN. The proposed approach provides an optimal path and automatically identifying fault in transmission line to make WSN as more effective and efficient.

3. Proposed methodology

3.1 Design of WSN based Smart Grid Environment

In this work, a WSN based on smart grid environment is designed to measure and detect the occurrence of faults in the transmission line. In smart grid environment accelerometer is attached with transmission lines to encounter the behaviour of faulty nodes. In transmission lines numerous sensor devices are deployed such as temperature sensor, humidity sensor, direction sensor, tilt sensor, vibration sensor, and strain sensor. By using these Sensor device the atmospheric conditions, temperature, mechanical strength, dynamic heat capacity, and condition sag are sensed in transmission line. In the structure of smart grid various magnetic field sensors like power, current and heat measuring units are deployed in the transmission line. In smart grid network supporters are deployed among all nodes to measure the behaviour of transmission lines. In network topology, the supporters are arranged in linear manner, because of distributed performance of transmission lines. Transferring the sensed data in transmission line is quite challenging one in a WSN based SG environment. Thus cellular technology is introduced in WSN. The WSN transmission process enables direct communication from the SN to the base station using cellular technology, as shown in Figure 1.

![Figure 1: WSN based Smart Grid Environment](image-url)
In WSN based smart grid environment, all SN transfers the collected data in specified time interval called periodic data. By using the alarm system in the network the data is transmitted to base station and the control of network are divided into rest and busy period in duty cycle. CH transfers the collected data from the SN to base station in busy period. The duration of time is very short because heavy traffic that is considered as busy period. Thus, transferring the sensed data in rest period, the duty cycle is long and less traffic. In SG environment, data transmission is carried out by choosing CH, which makes the data transmission as more effective and efficient. Each group of nodes choose the leader from the neighbour nodes to send the collected information.

3.3 Clustering process
Clustering plays a vital role in energy consumption through the appropriate selection of CH nodes. Cluster Head (CH) selection is carried out by grouping number of nodes and picking the high energy efficient node as CH. In the SG network, CH selection is enhanced by two stage they are set-up stage and steady state stage. In WSN, during the data transmission, SN lose certain amount of energy. The process of selecting the CH node is based on the calculation of the residual energy. A node with higher residual energy is considered as CH and the remaining energy is calculated using principal request of radio model. Remaining energy of \( i^{th} \) node is calculated at time \( t \) is represented by given equation.

\[
RE_i = E_{\text{initial}}^i - E_{\text{consumed}}^i
\]

Here \( E_{\text{initial}}^i \) is an initial energy and \( E_{\text{consumed}}^i \) is a consumed energy of \( i^{th} \) node. After the selection of CH node in current iteration, the notification about selecting new CH is delivered to all neighbour nodes, then the neighbour nodes receive the notification to validate the strength of signal to make decision for clustering. Each neighboring node is allocated time to send the collected data to CH, which ensures high-speed data aggregation. CH has direct communication with the base station, thus the gathered data in CH is directly send to base station. A proposed approach is mainly focused on identifying the faults automatically via SG environment.

3.4 Data Transmission using Adaptive Zigbee-Aquila communication protocol
In this work Adaptive Zigbee-Aquila communication protocol (AZACP) is proposed to find the shortest path to transmit the retrieved data from the SN to base station with less consumption of time. ZigBee is a wireless communication technology, which is widely used in WSN. ZigBee based WSN are proven to be more reliable in packet delivery and provide low rate, network lifetime, minimum energy consumption, and provide large quantities of network nodes in wireless communication technology [26]. ZigBee tree routing algorithm without having any route discovery procedure it transmit the data by choosing multihop. To design zigbee tree routing algorithm, first considered the number of nodes, number of routers and the depth of the network. Where nodes are recognized by the children; parent nodes are recognized by the router; and depth are recognized by tree level in zigbee tree routing algorithm. The address space at \( x \) tree level is delivered by parent node it represented as

\[
S_{\text{max}=1} = \begin{cases} 
1 + W_{\text{max}} \cdot (R_{\text{max}} - x - 1) \\
1 + W_{\text{max}} - S_{\text{max}} - (W_{\text{max}} \cdot S_{\text{max}}^{R_{\text{max}}-1}) \\
1 - S_{\text{max}} 
\end{cases}
\]

\[
S_{\text{max} \neq 1}
\]

Where \( W_{\text{max}} \) is maximum children node, \( S_{\text{max}} \) is maximum parent node, \( R_{\text{max}} \) is depth of tree level. The parent node does not assign the address space to the children nodes, when
Z(X)=0 children node not able to join the network connectivity. The parent node having the capability of allocating the space to the children node \( Q^{th} \) as \( a^n \) end node is given by,

\[
Z^n = Z_{parent} + Z(x)(n-1) + 1 \quad (1 \leq n \leq S_{max})
\]

\[
Z^x = Z_{parent} + Z(x).S_{max} + n \quad (1 \leq x \leq W_{max} - R_{max})
\]

Space to the children node \( Z(x) \) is allocated by the parent node and the children node distribute \( A(e+1) \) address space. The range of descendant node between \( Z < E < Z + Z(X-1) \). The next hop device address given by,

\[
F_v = \begin{cases} 
Z & \text{end device} \\
1 + E \left| \frac{Z - (1 + E)}{Z(x)} \right| & \text{other device}
\end{cases}
\]

However Zigbee tree routing provide high data transmission, but it is not optimal for choosing the shortest path for data transmission. For example, reaching 1-6 destination, Zigbee flows through the nodes 1-2-3-4-5-6 instead of 1-3-6 path. To reach the destination, Zigbee transfer the data without checking the shortest path. Thus, Adaptive Aquila optimization (AAO) is introduced to find shortest path with minimum time consumption. Aquila optimization (AO) [27] is inspired by the behaviour of Aquila for catching the prey. AO is a population-based technique, which is used to optimize the path for transmitting the sensed data. In each iteration, the best path is considered as an optimal path. However AO provide an optimal path for data transmission, due to the immature convergence and poor population diversity affects the entire model.

Chaotic strategy (CS) is proposed to overcome the immature convergence and poor population diversity. In this paper, chaotic sequences are used to improve the population diversity of Aquila population (AP). CS is used in the generation of the initial population. Chaotic sequences mapped the models based on different chaotic models, they are Logistic map, Tent map, Cubic map and Kent map. Cubic map (CM) provide better performance and uniformity than other maps. CM chaos sequence are used, for evaluating the generation of AP. Due to the population environment and the initial sensitivity of the chaotic maps, diversity in AP is improved.

\[
A_i = \frac{A_{ub} + (A_{ub} - A_{lb}) \times (A_i + 1)}{2}
\]

\[
Z_i + 1 = 4Z_i^3 - 3Z_i \\
1 < Z_i < 1, Z_i \neq 0, i = 0, 1, ..., N
\]

Where \( A_i \) denote the nodes as individual value, \( A_{ub} \) and \( A_{lb} \) represent the upper bounds and lower bounds, \( N \) denotes the AP size. Here dimension represented as \( D \) and \([-1, 1]\) is a vector.
of $\mathcal{D}$ dimensional. Using CS, the first operator and remaining $(N - 1)$ operators are generated by the iteration of each dimension. At last, equation (8) is used to generate the mapped values by the CM onto individual of Aquila. Our goal is to find shortest path with less time consumption thus, the fitness function is calculated for every path to transfer the data.

$$\text{Fitness Function} = \min (\text{energy} + \text{cost})$$ (9)

The node should satisfy the minimum energy consumption and minimum cost requirement is considered as best path for data transmission. By calculating the fitness function, the optimum shortest path for data transmission is selected.

3.4.1 Selection of Transmission line
In AAO, Aquila identify the prey area by high soar with the vertical stoop to decide the optimal area to attack the prey. Likewise, AAO selects the transmission line to send the sensed data. Where the SNs are deployed in unattended or protective areas of transmission line.

$$X_i(t+1)=X_{\text{best}}(t)\times\left(1-\frac{t}{T}\right)+(X_M(t)-X_{\text{best}}(t)\ast \text{rand})$$ (10)

Where the solution $X_i(t+1)$ of next iteration of $t$, $X_{\text{best}}(t)$ represents the optimal path for data transmission from SN to substation, for controlling the exploration $\left(1-\frac{t}{T}\right)$ use the number of iterations. Where current iteration is $t$ and highest number of iterations is denoted by $T$, the population size of nodes in smart grid system is represented by $N$ and $r_1$ is a random number between 0 and 1, and the mean value $X_M(t)$ of current solutions connected by $t^{th}$ iteration are evaluated equation (11).

$$X_M(t) = \frac{1}{N} \sum_{i=1}^{N} X_i(t), \forall j = 1, 2, \ldots, \text{Dim}$$ (11)

Where $N$ denotes the number of population and $\text{Dim}$ is the dimension size of the problem. Contour flight with short glide attack is an important hunting method for Aquila, because Aquila circles the target prey and prepares the land to attack the prey. This strategy called contour flight with short glide attack. Similar to that SN prepares the path for data transmission using below equation.

$$X_2(t+1)=x_{\text{best}}(t)\times\text{Levy}(D) + X_{R}(t) + (y-x)\ast \text{rand}$$ (12)

Where the solution of the next iteration of $t$ is $X_2(t+1)$, $X_R(t)$ is a random solution at the $t^{th}$ iteration taken in the range of $[N]$. $D$ is the dimension space, $\text{Levy}(D)$ is the levy flight distribution function which is calculated using below Equation.

$$\text{Levy}(D)=S\times\frac{u\times\sigma}{|\nu|^\beta}$$ (13)

Where $\nu$ and $\nu$ are random numbers between 0 and 1 and $S$ is a constant values fixed to 0.01, $\sigma$ is calculated using below equation.

$$\sigma=\frac{\Gamma(1+\beta)\times\sin\left(\frac{\Pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right)\times\beta\times2^{\frac{\beta-1}{2}}}$$ (14)
The spiral shape in search represented by \( x \) and \( y \) are calculated by below equations, where \( \beta \) is a constant value fixed to 1.5

\[
\begin{align*}
  y &= r \times \cos (\theta) \\
  x &= r \times \sin (\theta) \\
  r &= r_i + U \times D_i \\
  \theta &= -\omega \times D_i + \theta_i \\
  \theta_i &= \frac{3\times \Pi}{2}
\end{align*}
\]

(15) \hspace{1cm} (16) \hspace{1cm} (17) \hspace{1cm} (18) \hspace{1cm} (19)

Where \( D_i \) is integer numbers from 1 to the length of the search space (\( Dim \)), \( U \) is a small value fixed to 0.00565, \( r_i \) takes a value between 1 and 20 for fixed the number of search cycles and \( \omega \) is a small value fixed to 0.005.

3.4.2 Searching Available paths

Aquila roughly determined the area of prey and it descends vertically to do an initial attack. AAO exploits the selected area to get close and attack the prey. Likewise SN selects the available path and get ready to send the sensed data.

\[
\delta \times \alpha \times \gamma - \delta \times \beta = + \delta
\]

(20)

Where \( X_{i+1} \) represents the solution of the next iteration of \( t \) is used to find optimum Available path, \( X_{best} \) refers to the approximate location of the node until \( i^{th} \) iteration to transfer data, \( rand \) represent the random value between 0 and 1, \( \alpha \) and \( \delta \) are the exploitation adjustment parameters, \( LB \) represents the lower bound and \( UB \) represents the upper bound, and \( X_M \) denotes to the mean value of the current solution at \( t^{th} \) iteration of the given problem.

3.4.3 Selecting Optimal Path

In Walking and grabbing prey method, the Aquila chases the prey in the light of its escape trajectory and then attacks the prey on the ground. Similarly SN to find the shortest path using fitness function to transmit the data to substation

\[
X_1(t+1) = QF \times X_{best} - G_1 \times X(t) \times rand - G_2 \times \text{Levy}(D) + rand \times G_1
\]

(21)

Where \( X_1(t+1) \) is the solution of the next iteration of \( t \), \( G_1 \) refers to various motions of the AAO that are used to keep track of the nodes during transmission, \( QF \) denotes to a quality function and \( G_2 \) denote the flight slope of the AAO that is used to follow the nodes during the transmission from the first location (1) to the last location (t), \( X(t) \) is the current solution at the \( t^{th} \) iteration.

\[
QF(t) = t^{2 \times \text{rand}(t)} - 1
\]

(22)

\[
G_1 = 2 \times \text{rand}(t) - 1
\]

(23)

\[
G_2 = 2 \times \left( 1 - \frac{t}{T} \right)
\]

(24)

Where \( \text{rand} \) is a random value between 0 and 1, \( t \) and \( T \) represent the current iteration and the maximum number of iteration, \( \text{Levy}(D) \) is the levy flight distribution function, \( QF(t) \) is the
quality function value at the $t^{th}$ iteration. By using AZACP, the shortest path with less time consumption is discovered to reduce the congestion and the traffic of the network.

**Table 1**: Algorithm for Data transmission

<table>
<thead>
<tr>
<th>Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong>: Initialize the population</td>
</tr>
<tr>
<td><strong>Step 2</strong>: Initialize the number of parameters, iterations, set of nodes and transmission lines</td>
</tr>
<tr>
<td><strong>Step 3</strong>: while (condition is not satisfied) do</td>
</tr>
<tr>
<td><strong>Step 4</strong>: Calculate the fitness function using equation (9)</td>
</tr>
<tr>
<td><strong>Step 5</strong>: Find the best shortest path $X_{best}(t)$ using fitness function</td>
</tr>
<tr>
<td><strong>Step 6</strong>: for (number of points in population) do</td>
</tr>
<tr>
<td><strong>Step 7</strong>: Mean value updating in equation (11)</td>
</tr>
<tr>
<td><strong>Step 8</strong>: Update the parameters</td>
</tr>
<tr>
<td><strong>Step 9</strong>: if $t \leq \left( \frac{2}{3} \right)$ then</td>
</tr>
<tr>
<td><strong>Step 10</strong>: if $rand \leq 0.5$ then</td>
</tr>
<tr>
<td>// Transmission line selection</td>
</tr>
<tr>
<td><strong>Step 11</strong>: Update the current path using (10) and (12) equations</td>
</tr>
<tr>
<td><strong>Step 12</strong>: Compare it with fitness function using equation (9)</td>
</tr>
<tr>
<td><strong>Step 13</strong>: Store the best fitness value for path</td>
</tr>
<tr>
<td><strong>Step 14</strong>: else</td>
</tr>
<tr>
<td><strong>Step 15</strong>: if $rand \leq 0.5$ then</td>
</tr>
<tr>
<td>// Searching Available paths</td>
</tr>
<tr>
<td><strong>Step 16</strong>: Update the current path using (20) equation</td>
</tr>
<tr>
<td><strong>Step 17</strong>: Compare it with fitness function using equation (9)</td>
</tr>
<tr>
<td><strong>Step 18</strong>: Store the best fitness value for path</td>
</tr>
<tr>
<td><strong>Step 19</strong>: end if</td>
</tr>
<tr>
<td>// Selecting Optimal Path</td>
</tr>
<tr>
<td><strong>Step 20</strong>: Update the current path using (21) equation</td>
</tr>
<tr>
<td><strong>Step 21</strong>: Compare it with fitness function using equation (9)</td>
</tr>
<tr>
<td><strong>Step 22</strong>: Store the best fitness value for path</td>
</tr>
<tr>
<td><strong>Step 23</strong>: end if</td>
</tr>
<tr>
<td><strong>Step 24</strong>: end if</td>
</tr>
<tr>
<td><strong>Step 25</strong>: end for</td>
</tr>
<tr>
<td><strong>Step 26</strong>: end while</td>
</tr>
<tr>
<td><strong>Step 27</strong>: return the best shortest path $X_{best}(t)$</td>
</tr>
</tbody>
</table>

Table 1 illustrates the step by step procedure for finding the optimal path. First Initialize the population and construct the parameters to calculate the fitness function. The best path is selected for data transmission by satisfying fitness function and finally update the current path. Stores the best fitness value path for selecting optimal path.

### 3.5 Automatic Faults Identifications during data transmission by Enhanced Recurrent Equilibrium Neural Network (ERENN)

Faults classified into two range they are soft fault and hard fault. Soft faults are occurred in transmission line to send the data incorrectly and hard faults does not transfer the sensed data.
Faults exist in transmission line as temporary or permanent. Failures in data transfer and impossible to replace the node are considered as permanent fault and the fault in temporary devices are easily replaced considered as temporary fault. In WSN, faults are occurred in transmission line due to the failure of sensing unit, failures of node, complete energy deviation, environmental changes and expired nodes, etc.

During data transmission all SN are used to sense the data to the CH and transmit data to base station in linear manner. By using SG application in data transmission leads to high quality power supply. To tackle this problems Enhanced Recurrent Equilibrium Neural Network is introduced to detect the faults in transmission line, which minimize the risks, cost and enhance the reliability. ERENN is a combination of Recurrent Neural Network and Enhanced Equilibrium Optimization. RNN [28] is a type of artificial neural network have an ability to design a dynamic system.

RNN is used to provide a feedback connection between nodes. Elman neural network is an initial neural network which is classified into four layers they are input layer, hidden layer, context layer and output layer. RNN is used in WSN for identifying nodes and detecting faults. In RNN, the hidden neurons stores the external input neurons and output of the context neurons. Context neurons are also called as memory unit because it stores the output of previous hidden neurons. A single-order dynamic system is identified by original Elman neural network and modified Elman-type RNN have a fixed coefficient for the self-feedback connection in context neuron.

Thus, a modified Elman-type RNN approach is adopted to increase the convergence precision, memorization ability and decrease the learning period. Designing a reliable RNN is essential to optimize the network parameter and network structure thus, Enhanced Equilibrium Optimization (EEO) is proposed to optimize the structure and parameters in the RNN to provide a better solution for identifying faults.

**EEO for Design of Reliable RNN:** EEO is used to optimize the structure and parameters in the RNN. Integration of EEO with RNN to ensure the optimal structure and parameters. EEO algorithm is used to find the numbers of hidden node (i.e. context node). Initially EEO algorithm optimize the RNN parameters, they are initial input of the context node, self-feedback coefficient and weights and then the structure particles are executed by the EEO algorithm to provide optimal set of RNN parameters.

**Encoding design in EEO:** EEO provides the best set of parameter and structure for RNN. Two types of particles are defined in RNN they are structure particle and parameter particle. By using EEO, the structure particle is encoded for creating binary strings, hence the value of structural particle is either 1, which means hidden node exists, or 0. If the hidden node is not in particle, the custom upper limit is used to determine the string length.

EEO encodes the parameter particle for the real number coded vector to optimize the network parameters. Parameter particle represent the initial inputs of all context nodes, the weight of all node from hidden nodes of the structural particle and self-feedback coefficient. EEO algorithm is integrated with RNN to search the context nodes (hidden node) and optimize the parameters like initial input of context nodes, weights and self-feedback coefficient. EEO use the search agents to optimize the parameters. Let us consider the iteration $iter = 1$ for search agents.

\[ E_i(\text{iter}=1) = LB + rand_i(1,d) \times (UB - LB), i = 1, 2, ..., N \]  \hspace{1cm} (25)

Here $d$ is the dimension of the problem, $rand$ is an dimensional vector of random numbers in the range of $[0, 1]$, $LB$ and $UB$ are the lower and the upper bound of the search space.

**Fitness Calculation:** In EEO, the fitness value for all particle is assigned and validated based on the desired optimization. For calculating $i^{th}$ position of search agent for a control volume $v$ is expressed below..
\[
\tilde{E}_i(\text{new}) = \tilde{E}_{eq}(\text{iter}) + (\tilde{E}_i(\text{iter}) - \tilde{E}_{eq}(\text{iter})) \ast \tilde{F}_i(\text{iter}) + \frac{\tilde{R}_i(\text{iter})}{\tilde{\lambda}_i(\text{iter})} \ast v_i
\]  

(26)

Consider \( \tilde{E}_{eq} \) is an equilibrium candidate which is randomly chosen from an equilibrium pool \( \tilde{E}_{eq,\text{pool}} \), \( \tilde{E}_{eq(\text{avg})} \) is the average for the four search agent \( \tilde{E}_{eq(1)}, \tilde{E}_{eq(2)}, \tilde{E}_{eq(3)}, \tilde{E}_{eq(4)} \) are decided using their fitness values they are \( \text{fit}(\tilde{E}_{eq(1)}), \text{fit}(\tilde{E}_{eq(2)}), \text{fit}(\tilde{E}_{eq(3)}), \text{fit}(\tilde{E}_{eq(4)}) \). Using sorted list, the equilibrium candidates and their fitness values for a minimization problem are decided. Fitness value is determined based on the size of network and convergence accuracy of the network. Fitness function is represented in below equation.

\[
\text{fit} = (\text{fit}_1, \text{fit}_2, \ldots, \text{fit}_N)
\]  

(27)

By ascending order these values are arranged:

\[
[\text{sorted_fit, sort_index}] = \text{sort(fit)}
\]  

(28)

At that time, the equilibrium candidates and their fitness are defined as:

\[
\text{fit}(\tilde{E}_{eq(1)}) = \text{sorted} - \text{fit}(1) \text{ and } \tilde{E}_{eq(1)} = \tilde{E}(\text{sort_index}(1))
\]  

\[
\text{fit}(\tilde{E}_{eq(2)}) = \text{sorted} - \text{fit}(2) \text{ and } \tilde{E}_{eq(2)} = \tilde{E}(\text{sort_index}(2))
\]  

\[
\text{fit}(\tilde{E}_{eq(3)}) = \text{sorted} - \text{fit}(3) \text{ and } \tilde{E}_{eq(3)} = \tilde{E}(\text{sort_index}(3))
\]  

\[
\text{fit}(\tilde{E}_{eq(4)}) = \text{sorted} - \text{fit}(4) \text{ and } \tilde{E}_{eq(4)} = \tilde{E}(\text{sort_index}(4))
\]  

(29)

\[
\tilde{E}_{eq(\text{ave})} = \frac{1}{4}(\tilde{E}_{eq(1)} + \tilde{E}_{eq(2)} + \tilde{E}_{eq(3)} + \tilde{E}_{eq(4)})
\]  

(30)

At last, the equilibrium pool is expressed as

\[
\tilde{E}_{eq,\text{pool}} = \{\tilde{E}_{eq(1)}, \tilde{E}_{eq(2)}, \tilde{E}_{eq(3)}, \tilde{E}_{eq(4)}, \tilde{E}_{eq(\text{ave})}\}
\]  

(31)

For \( i^{th} \) search agent, the exponential term \( \tilde{F}_i \) assist the EEO for the exploitation and the exploration

\[
\tilde{F}_i(\text{iter}) = a_i \text{sign}(r_i - 0.5) e^{-\tilde{\lambda}_i(\text{iter}) \left[ \frac{(1 - \frac{\text{iter}}{\text{max_iter}})}{\frac{\text{iter}}{\text{max_iter}}} \right]^{\text{iter}}}
\]  

(32)

Where \( \tilde{\lambda}_i(\text{iter}) \) is a random vector of \( d \) dimension in the interval \([0, 1]\) for the search agent in \( \text{iter} \) (iteration), \( \text{iter} \) is the current iteration and \( \text{max_iter} \) the maximum number of iterations. Hence \( a_i \) is used to control the exploration and \( a_2 \) is used to control the exploitation. \( \text{sign} \) is used to control the direction of search based on a random number \( r_i \) between \([0, 1]\). The position update will go through in EEO. Exploration of participation probability \( \tilde{E}_{eq} \) and the generation rate \( \tilde{G}_i \) is expressed as

\[
\tilde{G}_i(\text{iter}) = \tilde{G}_{i,0}(\text{iter}) \ast \tilde{F}_i(\text{iter})
\]  

(33)

Where \( \tilde{G}_i(\text{iter}) \) and \( \tilde{GCF}_i(\text{iter}) \) are calculated as

\[
\tilde{G}_{i,0}(\text{iter}) = \text{GCF}_i(\text{iter})(\tilde{E}_{eq}(\text{iter}) - \tilde{\lambda}_i(\text{iter}))
\]  

(34)

\[
\text{GCF}_i(\text{iter}) = \begin{cases} 0.5r_1 & r_2 \geq \text{GP} \\ 0 & r_2 < \text{GP} \end{cases}
\]  

(35)
Where $GP$ is the generation probability, $GCF$ is the generation rate for control factor $r_i$, and $r_j$ are the random numbers in the interval $[0, 1]$. For next iteration, the position of the search agents depends on the equilibrium pool. It contains average among the four best positions. During an exploration in every iteration leads to the search agent falling into a local minimum, to tackle this problem EEO is proposed. An adaptive decision is processed based on the current fitness of the search nodes and the average fitness of all $N$ search nodes

$$
\tilde{E}_i(\text{iter} + 1) = \begin{cases} 
\tilde{E}_i(\text{new}) & \text{fit}_i(\text{iter}) < \text{fit}_{\text{avg}}(\text{iter}) \\
\tilde{E}_i(\text{new}) \otimes (0.5 + \text{rand}(1,d)) & \text{fit}_i(\text{iter}) \geq \text{fit}_{\text{avg}}(\text{iter})
\end{cases}
$$

Where $\text{fit}_i(\text{iter})$ denotes the fitness value of the $i^{th}$ search agent at an $\text{iter}$ (iteration), $\otimes$ denotes the element-wise multiplication and $\text{fit}_{\text{avg}}(\text{iter})$ denotes the average fitness of all search agents at an $\text{iter}$ (iteration), and is evaluated by below equation

$$
\text{fit}_{\text{avg}}(\text{iter}) = \frac{1}{N} \sum_{i=1}^{N} \text{fit}_i(\text{iter})
$$

In EEO, the fitness value for the current iteration and previous iteration is get compared by using following equation.

$$
\tilde{E}_i(\text{iter}) = \begin{cases} 
\tilde{E}_i(\text{iter} - 1) & \text{iter} > 1 \text{and } \text{fit}_i(\text{iter}) < \text{fit}_i(\text{iter} - 1) \\
\tilde{E}_i(\text{iter}) & \text{iter} = 1
\end{cases}
$$

And

$$
\text{fit}_i(\text{iter}) = \begin{cases} 
\text{fit}_i(\text{iter} - 1) & \text{iter} > 1 \text{and } \text{fit}_i(\text{iter}) < \text{fit}_i(\text{iter} - 1) \\
\text{fit}_i(\text{iter}) & \text{iter} = 1
\end{cases}
$$

In WSN based SG environment, the number of nodes are represented as $N$ and $a^{th}$ node. The discrete variable $R_a$ is used to represent the flow of current through $a^{th}$ node, which is represented as $F_a$ and switch state $a^{th}$. Where $\alpha_a, \beta_a, U_a, V_a$ represent the node voltage, resistance, active power and reactive power. By attaining the maximum number of iterations, the fitness value of each network in each iteration delivers the best network. Thus, EEO based RNN is integrated to minimize the complexity of the network and performance of the network. ERENN based SG generate the automatic fault identifying methods in following points they are constructing network parameters, fault node detection, fault node isolation and sub nodes selection.

### 3.5.1 Network Parameters for Smart grid

In a WSN based SG environment, SN are deployed in transmission line to transfer the sensed data, which may vary for each transaction. This makes difference in flow of energy, power, voltage and current. In SG the network parameters for current ($C_i$), voltage ($V_i$), transformer overload ($TO_i$) and control parameters ($CP_i$) are represented in equation (40).

$$
\text{Network Parameters (NP)} = \begin{cases} 
V_{\text{min}} \leq V_i \leq V_{\text{max}} & \text{For node voltage} \\
CP_i \leq CP_{\text{max}} & \text{For control parameters} \\
C_i \leq C_{\text{max}} & \text{For current flow} \\
TO_i \leq TO_{\text{max}} & \text{For transformer overload}
\end{cases}
$$

$$
\text{(40)}
$$
By using these NP in SG easily calculate the variation in sensor nodes during the transmission. Here the Input layer of ERENN represent the SN input and output of structure and parameter particle. The process of optimizing structure particle and parameter particle by ERENN is represented in equation format.

\[ R_i(N) = h(net_i(N)) = net_i(N) = o(N) i=1,2,...,n \]  

Where \( o \) and \( R_i \) are the input layer and output layer, \( N \) denotes the \( N^{th} \) iteration.

### 3.5.2 Fault nodes Detection

After the consideration of the network parameters in SG, ERENN starts to identify the faults in transmission line. ERENN based SG network is used to detect the faults automatically in WSN. ERENN provide a weighting with its own dynamic for each node, alike in WSN each and every nodes have their own dynamics. Let us consider the number of nodes as \( N_{con}(\alpha) \) and \( N_{discon}(\alpha) \) inserted and removed in clustering process at time \( \alpha \). Data transfer \( DT(\alpha) \) for each node at \( \alpha \) time interval, probability matrix for state transition is \( P(\alpha) \) and \( \beta(\gamma) \) represent the way for transferring faulty node at interval of \( \alpha \).

Let the Number of nodes \( N \) starts with initial time 0 which means \( N_{con}(0) = \{ N_0 \} \). Consider \( N \) as number of nodes, \( N - R \) represent the edge (\( R \)) of the node. From the set \( DT(\alpha) \) and \( P(\alpha) \) a node \( N \) choose another node which is \( i (N - R) \). Repeat the process for separating \( i \), else \( DT(\alpha) \) holds the edge (\( R \)) to \( N \), or else update the Nodes of \( N_{discon}(\alpha) \) and move \( N_{discon}(\alpha + 1) = N_{discon}(\alpha) - \{ R \} \) & \( N_{con}(\alpha + 1) = N_{con}(\alpha) + \{ R \} \)

\[ N_{discon}(\alpha + 1) = N_{discon}(\alpha) - \{ R \} \& N_{con}(\alpha + 1) = N_{con}(\alpha) + \{ R \} \]  

Encoding the structural particle for creating binary strings, hence the value of structural particle is either 1, which means hidden node exists, or 0. If the hidden node does not exists in particle then the user-specified upper limit is used to determine the string length. Hidden layer of ERENN is represented in below equation.

\[ net_{H}^j = \sum_i W_{ji}^{H}(N) \times R_i^j (N) + \sum_j W_{ji}^{HC} (N) \times R_j^C (N) \]  

\[ R_j^C (N) = P(net_{H}^j (N)) \]  

Here the input and output SN are represented as \( net_{H}^j \) and \( net_{H}^j (N) \). \( R_j^C \) is an output SN of context layer in ERENN. Faulty nodes are identified by satisfying the conditions of network parameters of SG. Which is represented in below equation.

\[ N_{discon}(\alpha + 1) = \begin{cases} N_{con}(\alpha) & \text{; } NP < DT(\alpha) \\ N_{discon}(\alpha) & \text{; } NP > DT(\alpha) \end{cases} \]  

By using equation (30) the network parameters are calculated for checking the faulty nodes in transmission line. Faulty nodes are detected if the network parameters are greater than \( DT(\alpha) \) data transfer of SN. If the calculated NP is lesser than set \( DT(\alpha) \) is considered as healthy node.

### 3.5.3 Fault node Isolation

Faulty nodes in transmission line is automatically identified by satisfying NP based on ERENN. After the detection of faulty nodes in transmission line, ERENN starts to isolate the faults by calculating the distance of transmission line to transfer data. If healthy nodes sensed the data in current iteration, it means that they will not participate in transmission process for next iteration based on the energy of node status. Hence fault may occur at any time in
transmission line thus, ERENN updates the weights of every node in every iteration. By satisfying NP conditions in equation (25) to tackle the loss in data transmission.

\[
\delta_{pq}(\alpha + N) = \begin{cases} 
\frac{i^t \beta_{pq}}{P_{\text{best}}'}; & i^t \beta_{pq} > \bar{\delta}_{pq}(\alpha), \\
\delta_{pq}(\alpha); & i^t \beta_{pq} \leq \bar{\delta}_{pq}(\alpha)
\end{cases}
\]  

(46)

Current iteration for network routing is \( P_{\text{best}} \) and \( \bar{\delta}_{pq} \) which is obtained with minimum energy loss during data transmission. \( N_{\text{disconn}}(\alpha) \) is an null property obtained from equation 28. All nodes in the network should satisfy the condition of network parameter, else \( i(N - R) \) get rejected from the \( DT(\alpha) \) set to isolate the faulty nodes in transmission lines. Parameter particle represent the initial inputs of all context nodes, the weight of all node from hidden nodes of the structural particle and self- feedback coefficient. Thus the representation of optimizing parameter particle is represented in below equation.

\[
R_i^C(N) = \alpha R_i^C(N - 1) + R_j^H(N - 1)
\]

(47)

Here the self- feedback connecting coefficient is in the range of \( 0 \leq \sigma < 1 \).

3.5.4 Sub-nodes Selection

Faulty nodes are eliminated on the transmission line by updating the status of each node based on ERENN. By the help of sub nodes, the faulty nodes get replaced to obtain the optimal data transmission in WSN. Eliminate the faulty node in the transmission line and then replace the transmission path by selecting optimal sub-nodes for successful data transmission. Replacing the faulty nodes by sub nodes using below equation

\[
Q_{pq}(\alpha) = \begin{cases} 
\frac{\delta_{pq}(\alpha)\bar{\delta}_{pq}(\alpha)}{\sum_{N \in K} \delta_{pq}(\alpha)\bar{\delta}_{pq}(\alpha)}; & (p, q) \in DT(\alpha), \\
0; & (p, q) \notin DT(\alpha)
\end{cases}
\]

(48)

Threshold value is represented by \( K \) it is a reciprocal of the resistance to ensure the heuristic value. Replacing the transmission path by selecting the sub nodes randomly. Optimizing the parameter particle is represented in output layer of ERENN is represented as follows

\[
X_q(N) = LF(\text{net}_q^O(N)) \quad q = 1, 2, ..., n
\]

\[
\text{net}_q^O(N) = \sum_j W_{qj}^{OH}(N) \times R_j^H(N)
\]

(49)

Here \( \text{net}_q^O \) are the input and \( X_q(N) \) output of the RNN layer. \( LF \) is an linear function and using \( W^{OH} \) to calculate the weight among input and output layer of SN to relocate the faulty nodes in WSN.

\[
\bar{Q}_{pq}(X + 1) = \bar{Q}_{pq}(X) - (\bar{s} \times (\alpha(W + xyz(F_1 - F_2))) - \alpha)
\]

(50)

Here \( \alpha \) is used to eliminate the collision to maintain the time interval among data to selects the optimal sub node for transmission. Solution for replacing faulty node is obtained by selecting \( \bar{Q}_{pq}(X + 1) \) sub node.
Table 2 Algorithm for Automatic Fault Identification

<table>
<thead>
<tr>
<th>Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1:</strong> Deploy SN in Transmission line based on RNN</td>
</tr>
<tr>
<td><strong>Step 2:</strong> Monitor the behaviour of SN</td>
</tr>
<tr>
<td><strong>Step 3:</strong> Identifying faults in Transmission line</td>
</tr>
<tr>
<td><strong>Step 4:</strong> Generate the Network Parameter (NP)</td>
</tr>
<tr>
<td><strong>Step 5:</strong> Satisfy the condition of NP in Equation (40)</td>
</tr>
<tr>
<td><strong>Step 6:</strong> Optimize the parameter by using EEO</td>
</tr>
<tr>
<td><strong>Step 7:</strong> while (condition is not satisfied) do</td>
</tr>
<tr>
<td><strong>Step 8:</strong> Detect the fault by using equation (41) and (45)</td>
</tr>
<tr>
<td><strong>Step 9:</strong> if $NP &gt; DT(\alpha)$ then</td>
</tr>
<tr>
<td><strong>Step 10:</strong> Isolate the faulty node by equation (46)</td>
</tr>
<tr>
<td><strong>Step 11:</strong> if $NP &lt; DT(\alpha)$ then</td>
</tr>
<tr>
<td><strong>Step 12:</strong> Consider it as healthy node</td>
</tr>
<tr>
<td><strong>Step 13:</strong> Sub-node Selection using equation (48)</td>
</tr>
<tr>
<td><strong>Step 14:</strong> end if</td>
</tr>
<tr>
<td><strong>Step 15:</strong> end if</td>
</tr>
<tr>
<td><strong>Step 16:</strong> end while</td>
</tr>
</tbody>
</table>

Table 2 explains the work flow of detecting faults in transmission line during data transmission. Initially, generate the network parameter such as node voltage, current flow, network parameters and transformer overload. Network parameter is performed by every node to satisfy the condition to check the behaviour of nodes in each iteration. If $NP > DT(\alpha)$ then the node consider as Faulty node. Then the faulty nodes get isolated by selecting sub nodes. If $NP < DT(\alpha)$ then it is a healthy node to transfer data. Selection of sub nodes replace the transmission path to provide optimal data transmission in a WSN based SG environment.

4. Result and Analysis

The proposed approach is implemented in MATLAB software, with the simulation parameters represented in Table 3. Total network size of $100 \times 100m^2$ and the base station is located at $40 \times 100m^2$ with initial energy of 500 kV. In SG totally 43 sensors are placed they are 15 weather sensors, 10 sensors to monitor line galloping, 9 vibration sensor and 9 magnetic field sensor with sensing radius of 10m in proposed approach. Data transmission of every packet is transmitted in every 60ns with the transmission range of 50m. The performance of proposed approach is compared with existing approaches [29] such as Adaptive Error Control (AEC), Gallager Humble Spira (GHS), Genetic Algorithm-Ticket Based Routing (GA-TBR), Improved Grid based Routing and Charging (IGRC) and Emperor Penguin Optimized Self-healing Strategy (EPOSH). The various performance metrics are throughput, delay, reliability, average residual energy, number of total transmission, network lifetime, efficiency and Bit Error Rate (BER).

Table 3: Simulation Parameters

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>43</td>
</tr>
<tr>
<td>Packet Size</td>
<td>1024 bytes</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>500 kV</td>
</tr>
<tr>
<td>Network Size</td>
<td>$100 \times 100m^2$</td>
</tr>
<tr>
<td>Location of Base station</td>
<td>$40 \times 100m^2$</td>
</tr>
<tr>
<td>Sensing Radius</td>
<td>10m</td>
</tr>
<tr>
<td>---------------</td>
<td>-----</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>50m</td>
</tr>
<tr>
<td>Transmission interval</td>
<td>60ns</td>
</tr>
</tbody>
</table>

Figure 2 shows the clustering process of SG network. In clustering process, each clusters are identified by unique colours. CH is selected by calculating the high residual energy, which send the collected data from neighbour nodes to the base station. In SG network nodes are deployed in transmission line that are selected based on the strength of the CH signal cluster.

**Figure 2:** Clustering Process of SG Wireless Network

Data transmission process of proposed approach is explained in Figure 3. Dotted line represents the routing process of CH to base station. In figure 3 the faulty nodes are not represented during data transmission process because the proposed approach choose the
another transmission line instead of choosing a faulty transmission line for the data transmission.

Figure 4: Throughput of Network

Throughput of the network is measured by calculating the transmitted packet in the transmission line is analysed in Figure 4. Throughput of the network is calculated by the number of nodes and measured in terms of Pkts/sec in a WSN based SG network. In SG network deploy 43 nodes in size of 100\(\times\)100 m\(^2\). The proposed approach improves the throughput performance by obtaining 1880.973 packet/sec in 18 nodes. The proposed method is better than the existing approaches are AEC (1566.876 Pkts/sec), GHS (1498.66 Pkts/sec), GA-TBR (1699.696 Pkts/sec), IGRC (1602.769 Pkts/sec) and EPOSH (1800.197 Pkts/sec).

Figure 5: Delay of nodes

Delay is calculated for the data transmission speed in the network. Delay of the packet during data transmission is a key issue in WSN. The delay performance is reduced in the
network to reach the destination by the number of hops and link busy state. Here hops are used to increase the time to route the packet to reach destination. Figure 5 illustrates the comparison of delay performance in proposed approach and existing approach. To complete one bit of data transmission in 18 nodes, the existing approaches consume (1.7245 ns) delay for AEC, (1.3235 ns) delay for GHS, (1.2232 ns) delay for GA-TBR, (0.9574 ns) delay for EPOSH respectively. Hence the proposed approach complete the data transmission for 18 nodes in (0.9155 ns), which is more effective and efficient than other existing approaches.

Figure 5: Comparison of Delay Performance

![Comparison of Delay Performance](image)

Reliability of proposed approach and existing approaches are given in Figure 6. Reliability is calculated by the ratio between healthy nodes and faulty nodes during data transmission. The reliability of proposed approach obtain (94.8213 %) in 30\textsuperscript{th} iteration, which is more reliable than the reliability for 30\textsuperscript{th} iteration in existing approaches like GHS (62.8033%), IGRC (78.8599%), GA-TBR (76.0093%), NACL (89.1206%) and EPOSH (91.3065%).

Figure 6: Reliability of Network

![Reliability of Network](image)

The comparison of average residual energy for proposed and existing approaches is shown in Figure 7. The average residual energy for proposed approach in 30\textsuperscript{th} iteration is (425.33 kV) which provide better performance than existing approaches in 30\textsuperscript{th} iteration they are GHS

Figure 7: Average Residual Energy

![Average Residual Energy](image)
(281.0159 kV), AEC (243.0283 kV), IGRC (378.4912 kV), GA-TBR (290.5153 kV) and EPOSH (411.3998 kV).

In SG network, the number of total transmission for proposed approach and existing approaches are analysed in Figure 8. Total transmission of nodes is measured in terms of bits/ns. Let us consider the SG network deploy 43 SN in size of $100 \times 100 m^2$. The proposed approach obtain (1229566 bits/ns) for 30th iteration, which is better than existing approaches like GHS (73130.7 bits/ns), AEC (39829.12 bits/ns), IGRC (222727 bits/ns), GA-TBR (114745.8 bits/ns) and EPOSH (1004342 bits/ns).

Figure 9 represent the comparison of proposed approaches and existing approaches. Figure clearly shows that the proposed approach achieve (42.619%) for 30th iteration to extend the large network life time compared to existing approaches like GHS (24.1447 %), IGRC (19.0386 %), GA-TBR (34.3563 %), NACL (28.1365 %) and EPOSH (39.184 %) for 30th iteration.
Figure 10: Efficiency of Fault Detection

Figure 10 represents the performance of fault detection in proposed and existing approaches. The efficiency of detecting faults in the proposed approach achieves (98.3%) for the 1st cluster, (96.78%) for the 2nd cluster, and (94.454%) for the 3rd cluster, which is more efficient than existing approaches like AEC, GHS, GA-TBR, IGRC, and EPOSH.

Figure 11: Performance of Bit Error Rate

The performance of Bit Error Rate in the proposed approach and existing approaches analyzed in Figure 11. BER is measured in terms of Errors/ns. The proposed approach obtains (0.1014ns) for the 1st cluster (0.0398ns for the second cluster) and (0.0353ns) for the third cluster, which is more reliable than existing approaches like AEC, GHS, GA-TBR, IGRC, and EPOSH.

Table 4: Comparison value for the proposed approach and existing approaches varying in No. of Nodes.

<table>
<thead>
<tr>
<th>Performance</th>
<th>No of Nodes</th>
<th>Throughput (Pkt/s)</th>
<th>Delay (ns)</th>
<th>No. of Total Transmission (bits/ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHS</td>
<td>8</td>
<td>1604.202</td>
<td>1.3169</td>
<td>44855.18</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>1498.66</td>
<td>1.3235</td>
<td>73130.7</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>1394.916</td>
<td>1.3347</td>
<td>76323.35</td>
</tr>
</tbody>
</table>
Table 4 represents the comparison of proposed approach and existing approach by varying in number of nodes. The comparison of reliability performance for proposed approach and existing approaches are mentioned in Table 5. The comparison of Average residual energy for proposed approach and the existing approaches are illustrated in Table 6. Table 7 illustrate the comparison of network lifetime for proposed and existing approaches. Table 8 illustrate the performance of the proposed approach and existing approaches in terms of efficiency and Bit error rate.

Table 5: Comparison of Reliability performance for proposed approach and existing approaches varying in No. of Iteration

<table>
<thead>
<tr>
<th>Reliability Performance (%)</th>
<th>10th iteration</th>
<th>20th iteration</th>
<th>30th iteration</th>
<th>40th iteration</th>
<th>50th iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHS</td>
<td>69.9762</td>
<td>64.0612</td>
<td>62.8033</td>
<td>62.0188</td>
<td>60</td>
</tr>
<tr>
<td>IGRC</td>
<td>84.9878</td>
<td>82.1141</td>
<td>78.8599</td>
<td>76.9354</td>
<td>74.822</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>80.333</td>
<td>79.0736</td>
<td>76.0093</td>
<td>74.0854</td>
<td>69.9764</td>
</tr>
</tbody>
</table>

Table 6: Comparison of Average residual energy for proposed approach and existing approaches

<table>
<thead>
<tr>
<th>Reliability Performance (%)</th>
<th>10th iteration</th>
<th>20th iteration</th>
<th>30th iteration</th>
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<th>50th iteration</th>
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<tr>
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<td>78.8599</td>
<td>76.9354</td>
<td>74.822</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>80.333</td>
<td>79.0736</td>
<td>76.0093</td>
<td>74.0854</td>
<td>69.9764</td>
</tr>
</tbody>
</table>

Table 7: Comparison of network lifetime for proposed and existing approaches

<table>
<thead>
<tr>
<th>Reliability Performance (%)</th>
<th>10th iteration</th>
<th>20th iteration</th>
<th>30th iteration</th>
<th>40th iteration</th>
<th>50th iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHS</td>
<td>69.9762</td>
<td>64.0612</td>
<td>62.8033</td>
<td>62.0188</td>
<td>60</td>
</tr>
<tr>
<td>IGRC</td>
<td>84.9878</td>
<td>82.1141</td>
<td>78.8599</td>
<td>76.9354</td>
<td>74.822</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>80.333</td>
<td>79.0736</td>
<td>76.0093</td>
<td>74.0854</td>
<td>69.9764</td>
</tr>
</tbody>
</table>
### Table 6: Comparison of Average Residual Energy for proposed and existing approaches

<table>
<thead>
<tr>
<th>Average Residual Energy (kV)</th>
<th>10(^{th}) iteration</th>
<th>20(^{th}) iteration</th>
<th>30(^{th}) iteration</th>
<th>40(^{th}) iteration</th>
<th>50(^{th}) iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHS</td>
<td>299.364</td>
<td>283.8578</td>
<td>281.0159</td>
<td>272.4672</td>
<td>274.6889</td>
</tr>
<tr>
<td>IGRC</td>
<td>399.3787</td>
<td>389.5692</td>
<td>378.4912</td>
<td>349.6904</td>
<td>342.4203</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>299.3615</td>
<td>289.557</td>
<td>290.5153</td>
<td>288.9291</td>
<td>279.7576</td>
</tr>
<tr>
<td>EPOSH</td>
<td>451.271</td>
<td>430.6961</td>
<td>411.3998</td>
<td>402.2232</td>
<td>391.7883</td>
</tr>
<tr>
<td>PROPOSED</td>
<td>492.271</td>
<td>447.1657</td>
<td>425.33</td>
<td>431.9747</td>
<td>420.2688</td>
</tr>
</tbody>
</table>

### Table 7: Comparison of Network Life time for proposed and existing approaches

<table>
<thead>
<tr>
<th>Network Lifetime</th>
<th>10(^{th}) iteration</th>
<th>20(^{th}) iteration</th>
<th>30(^{th}) iteration</th>
<th>40(^{th}) iteration</th>
<th>50(^{th}) iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHS</td>
<td>25.0267</td>
<td>23.9355</td>
<td>24.1447</td>
<td>24.2601</td>
<td>23.0769</td>
</tr>
<tr>
<td>IGRC</td>
<td>24.8412</td>
<td>20.0367</td>
<td>19.0386</td>
<td>18.0401</td>
<td>17.0424</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>40.2526</td>
<td>35.447</td>
<td>34.3563</td>
<td>32.1521</td>
<td>30.2252</td>
</tr>
<tr>
<td>EPOSH</td>
<td>42.109</td>
<td>40.0889</td>
<td>39.184</td>
<td>36.9794</td>
<td>36.2594</td>
</tr>
<tr>
<td>PROPOSED</td>
<td>45.544</td>
<td>43.3384</td>
<td>42.619</td>
<td>40.3225</td>
<td>40.065</td>
</tr>
</tbody>
</table>

### Table 8: comparison value for proposed approach and existing approach varying in number of Cluster

<table>
<thead>
<tr>
<th>Performance</th>
<th>No. of Cluster</th>
<th>Efficiency (%)</th>
<th>Bit Error Rate (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEC</td>
<td>Cluster 1</td>
<td>59.2304</td>
<td>0.8019</td>
</tr>
<tr>
<td></td>
<td>Cluster 2</td>
<td>60.2154</td>
<td>0.6618</td>
</tr>
<tr>
<td></td>
<td>Cluster 3</td>
<td>56.599</td>
<td>0.7332</td>
</tr>
<tr>
<td>IGRC</td>
<td>Cluster 1</td>
<td>69.8076</td>
<td>0.4053</td>
</tr>
<tr>
<td></td>
<td>Cluster 2</td>
<td>64.7941</td>
<td>0.4008</td>
</tr>
<tr>
<td></td>
<td>Cluster 3</td>
<td>64.3146</td>
<td>0.2689</td>
</tr>
<tr>
<td>GA-TBR</td>
<td>Cluster 1</td>
<td>88.7052</td>
<td>0.5357</td>
</tr>
</tbody>
</table>
5. Conclusion

WSN plays a vital role in smart grid environment to provide numerous application. The introduction of the sensor utilization with SG based WSN ensure the efficiency. The major issue of WSN is identifying faults during data transmission. In WSN all SN are placed in the SG network and selecting CH based on the residual energy of nodes. In recent time, data transmission process is heavily affected by faulty nodes. Thus, the proposed approach is integrated with SG network to tackle the identification of faults and delay in data transmission. The proposed approach enhance the detection of faults and isolate the faulty nodes in transmission line based on ERENN. The performance of proposed approach is compared with existing approaches like AEC, GHS, GA-TBR, IGRC and EPOSH. The result and analysis shows that the proposed approach provides better performance in identifying faults than existing work in terms of comparing throughput, delay, reliability, average residual energy, number of total transmission, network lifetime, efficiency and bit error rate. The proposed approach is implemented in MATLAB software. As a future work, the proposed approach is enhanced by hybrid optimization to provide a reliable and cost effective technique.

Compliance with Ethical Standards

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Conflict of Interest: Authors 1Rekha MN & 2Dr. U B Mahadevaswamy, declares that they have no conflict of interest.
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Consent to Publish: All the authors involved in this manuscript give full consent for publication of this submitted article.
Authors Contributions: All authors have equal contributions in this work
Availability of data and materials: No data Availability

Reference


