CHAPTER 4

FUZZY BASED LINK ASSESSMENT TECHNIQUE

4.1 INTRODUCTION

Link in a sensor network is defined as a selectable connection existing between two sensor nodes. It shows the relationship between those nodes while transferring data over the entire network. In mobile sensor networks, the nodes move from one point to another, links between these nodes being affected by its dynamic nature. In a highly dynamic network, (frequent and drastic changes in topology) the cost involved in finding a new route repeatedly from the source to the sink is high, thereby reducing the performance of the network. Here a proper trade-off between topology management and network performance has been achieved using the Kinetic PR Quad tree to store the network structure and updating periodically depending on the mobility of nodes. Failures in wireless sensor networks can occur due to various reasons (Lilia Paradis & Qi Han 2007).

First, sensor nodes are fragile, and may fail due to depletion of batteries or destruction by an external event. In addition, nodes may capture and communicate incorrect readings because of environmental impact on their sensing components.

Secondly, as in any adhoc wireless networks, links are failure-prone, causing network partitions and dynamic changes in network topology (Yick Jennifer et al 2008). Links may fail when blocked by an external object
or environmental condition. Link failure can be identified using a number of parameters like packet delivery, asymmetry, channel quality, stability, delay, packet loss, residual energy and a number of evaluation techniques including PRR, RSSI, and SNR. The presence of faulty links in wireless sensor network reduces the network performance tremendously. It is essential to identify the faulty links in the shortest possible time in order to adapt to the rapid changes in topology due to the mobility of the nodes.

The major contributions of this research are the results of experimental measurement of link quality estimation using a fuzzy logic algorithm. Fuzzy logic formulates a mathematical model to give areas of reasoning, inference, control and decision making under uncertainty.

The Fuzzy Link Quality Assessment Algorithm (F-LQA) identifies the faulty links using an aggregation of various parameters with a fuzzy approach. Special emphasis is made to find out how the link quality behaves during the movement of sensor nodes. Transmission link failures are common in both static and dynamic wireless sensor networks due to factors such as sensor node failure, mobility of the nodes, network congestion and interference. These faulty links in a network need localization and repairs to sustain the health of the network. It is necessary to maintain the dynamic topology of the network to monitor the link quality. Hence, a modified Kinetic PR Quad tree is adopted to maintain the network topology and a Fuzzy-Link Quality Assessment (F-LQA) algorithm has been proposed to estimate the link quality by considering parameters like asymmetry, energy level of nodes and delay.

The proposed algorithm zeroes down the link responsible for the faultiness of the bad topology. The F-LQA algorithm computes the Malfunction Index (MI) value which is found to possess an increased reliability due to the inclusion of a variety of parameters for ascertaining the
link quality. Therefore the conclusion obtained regarding the link reliability is accurate. The proposed algorithm is found to be more energy efficient than other existing approaches thus extending the network lifetime.

4.2 NEED OF LINK QUALITY ESTIMATION

Link quality of sensor nodes shows the strength of communication taken over them. Assessing the link quality plays a vital role in routing which decides that the data packet can select the corresponding path or not. Due to the dynamic nature of the network, node may move from one point to another which may lead to rapid link break over network. The quality of link gets affected due to the motion of the node and it is unpredictable over distance and time. Due to this reason link quality has to be measured and analyzed to make clear decision to forward the packet in the proper route. In a wireless sensor network, a substantial quantum of power is consumed due to improper routing of packets especially in case of dynamic topology. For proper routing with minimum delay, loss and with minimum energy, the links related to that path are checked and the status is maintained at sink level. For that a fuzzy based approach is used to check the quality of the link.

The time varying nature of the link quality induces the Bit Error Rate (BER) of the received packet. If a packet is received with many bit errors, it is discarded leading to packet retransmissions which reduce the lifetime of the network. In case of mobile sensor networks the node data is lost, once the node moves out of the coverage region and hence it is tedious to collect data from the region where the node was primarily designated. The objective of the proposed work is to formulate an approach that contains an effective localization mechanism which is dynamic in nature. This enables constant monitoring of network topology irrespective of the changes that it undergoes due to the mobility of the network. This approach also maintains the data about the link. It guarantees a considerable decrease in the data loss
rate due to node mobility and reduces the power wasted during improper routing thus extending the lifetime of the network.

Energy level is required to sense the event, process it as per the requirement and communicate it to others if necessary. Most of the energy is consumed during unnecessary communication and retransmission over the channel. It plays a main role for considering the lifetime of the network. Hence the average energy level is taken as one of the parameter to test the quality of the link.

Packet reception ratio shows how effectively packets are received by the receiver. It defines the quality of the link through that path. Based on this parameter, asymmetry is taken which defines the difference in connectivity between uplink and downlink. Link latency is another important factor that determines the link quality. The average link latency is the summation of transmission delay and sampling time and increases with the number of hops. To evaluate link quality using fuzzy logic, the above mentioned parameters such as asymmetry, average energy level and delay is taken for analysis.

4.3 FUZZY BASED FAULTY LINK ISOLATION TECHNIQUE

A two dimensional dynamic network topology is used to model a more general sensing area where the mobile stations placed on a plane or the surface can move in any direction is considered. There is a sink or the gateway node for the whole sensor network whose function is to listen to other sensor nodes and transmit the event to the external control centre. It is also meant for maintenance and repair operations in the network. The sink is assumed to be immobile or static in nature.
The network is initially considered in the shape of a 2D grid. The grid is constructed by the geometric projection of a circle, drawn with sink at the centre and the range of the sink as the radius, into a square.

Then the topology is maintained only in terms of the grid structure provided. There is a record called the topology table, maintained in the sink consisting of entities to track the movement of nodes. Additionally, failure of sensor nodes and links contributes to a change in the topology of the network. Node failure may occur due to malicious attacks on the nodes, draining of battery power or technical fault in the nodes which in turn has a direct impact on the link quality between the nodes (Peng Jiang 2009).

4.3.1 Localization of Mobile Nodes

The sensor topology may change due to movement of nodes or deplaned energy. Therefore, redeployment and the relocation process of sensors are essential for all sensors to fall under the coverage area (Pedro Wightman & Miguel Labrador 2009). Sensor nodes in a dense region need to move to a sparse region to improve coverage and connectivity of a sensor network.

4.3.1.1 Kinetic Point Region Tree (KPR Tree) construction

The Kinetic PR Quad tree stores data points, i.e. sensor nodes in a 4-ary tree structure. The quad tree divides the data points such that each cell, a square division of finite space also called quadrant, contains $n$ points (sensor nodes) at the most as shown in figure 4.1. The value of ‘n’ is defined by the user and is usually from 1 to 5.

The position of the node can be scanned by parameters like velocity, time and position. The Kinetic PR tree changes its state whenever there is a change in scanned value. Assuming the node is aware of its location
coordinates and the cluster is a two dimensional grid, the tree is used to monitor the location of nodes. Nodes with non-zero velocity are prone to change their position over time, eventually intersecting the boundary of the cells.

A priority queue is used to store these intersections that a mobile node makes with the quadrant axes, thereby detecting the mobility of the node.

![Figure 4.1 Topology configuration represented by a Kinetic PR tree](image1)

The use of a priority queue to store these intersections is that, it orders them such that the intersection that happens the earliest is accessed first. The KPR Tree changes its structure based on the order of these intersections as in Figure 4.2.

![Figure 4.2 Topology configuration after movement of node 2](image2)
Thus, as the node moves from its original location, the KPR tree reconstructs itself with reference to the new location of the mobile node and hence has the node in range. This improves the sensing capability as the region is still monitored in spite of node mobility.

The grid mapping of a sample cluster and the formation of the KPR Tree from the grid mapped cluster is shown in figure 4.3. Considering the parameters like time, initial position and the velocity of the nodes, the topology of the sensor network is defined in terms of a Dynamic Quad Tree (Ransom Kershaw Winder 2002).

The movement of the nodes over time would change the structure of the PR quad tree’s sub trees. This Dynamic Quad Tree is a top-down tree which is hierarchically structured and height imbalanced. The Quad tree takes into account the static as well as the mobile sensor nodes.

![Sensor Network](image)

**Figure 4.3 Construction of KPR Tree from sensor cluster**

If a particular cell or quadrant contains more than one sensor node, then it should be further subdivided into four equal sized quadrants based on the principle of recursive decomposition. Every quadrant is assumed to be a node of the quad tree and the sub-quadrants, its children.
Any division in the quadrants leads to an increase in the depth of the quad tree. In any event, when the node moves from one quadrant to the other, the quad tree reconstructs itself. At regular time intervals, the Dynamic Quad tree algorithm is iterated so that the mobile nodes in dynamic network are tracked precisely by the parent child relationship of the tree.

4.3.1.2 Topology management

In dynamic wireless sensor networks, the nodes tend to move with a well-defined velocity in a particular direction. The topology table consists of node ID ($N_{id}$) and quadrant ID ($Q_{id}$). The node ID is the unique number the node is assigned during deployment.

Every node also has the corresponding $Q_{id}$ denoting the quadrant to which it belongs to the length of the quadrant id purely depends on the number of levels into which the quadrant division happens.

If there is only one level of division the length of the $Q_{id}$ is one. Supposing there are $n$ levels of quadrant division there are $n$ digits in the $Q_{id}$, with each digit representing the quadrant in its corresponding level of division. The initial and the updated topology table for Figure 4.1 and 4.2 are shown below.

**Table 4.1 Topology table for Figure 4.1**

<table>
<thead>
<tr>
<th>Node ID ($N_{id}$)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrant ID ($Q_{id}$)</td>
<td>$Q_{11}$</td>
<td>$Q_{12}$</td>
<td>$Q_4$</td>
<td>$Q_{31}$</td>
<td>$Q_{33}$</td>
</tr>
</tbody>
</table>
### Table 4.2 Topology table for Figure 4.2

<table>
<thead>
<tr>
<th>Node ID (N&lt;sub&gt;id&lt;/sub&gt;)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrant ID (Q&lt;sub&gt;id&lt;/sub&gt;)</td>
<td>Q&lt;sub&gt;111&lt;/sub&gt;</td>
<td>Q&lt;sub&gt;113&lt;/sub&gt;</td>
<td>Q&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Q&lt;sub&gt;31&lt;/sub&gt;</td>
<td>Q&lt;sub&gt;33&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

#### 4.3.1.3 Reconfiguration of nodes

During the topology update phase, the topology table is updated. This phase gets repeated in the periodic intervals. Apart from periodic updating, certain events like depletion of energy in nodes, node failure, link failure, querying the nodes or nodes moving out of range triggers the topology update phase.

#### 4.3.1.4 Construction and reconstruction of topology tree

The KPR tree is a dynamic tree whose structure changes dynamically with the changes in network topology. The topology of the network depends mainly on the node position, and as the node velocity increases and the node changes its position, the topology of the network changes.

The change in the topology of the network is detected when a node moves and hits the boundary of a sub-quadrant. The intersection of a node at a boundary is stored in a priority queue. These intersections are prioritized and based on the priority, reconstruction queries are kindled. Hence, when a node moves, it intersects with the boundary, and the entries in the intersection queue are serviced based on priority thereby instantaneously reconstructing the tree.
With dynamic occurrence of reconstruction, node mobility is addressed and hence data loss due to node movement is reduced or even trivialized thereby improving network reliability.

### 4.3.2 Fuzzy Link Quality Assessment Algorithm (F-LQA)

Fuzzy logic imitates the logic of human thought, which is less rigid than the calculations performed by computer. It is a decision making logic that maps the input variables requiring analysis to the corresponding optimized output based on the rules set for fuzzy. It offers several unique features that make it a good alternative for many control problems. It deals
with the analysis of information by using fuzzy sets, each of which may represent a linguistic term like “Warm”, “High” etc.

Fuzzy sets are described by the range of real values over which the set is mapped called domain and the membership function. The membership function assigns a truth value between 0 and 1 to each point in the domain of fuzzy sets. A fuzzy system has three processes, namely fuzzifier, inference engine and defuzzifier (Pedro Albertos & Antonio Sala 1998). The fuzzifier maps each input value to the corresponding fuzzy sets and thus assigns a degree of membership for each fuzzy set. These fuzzy values are processed by the inference engine, which consist of a rule base.

The rule base is simply a series of IF – THEN rules that relate the fuzzy variables with the output fuzzy variables. The defuzzifier performs defuzzification on the fuzzy solution phase (Lin et al 2008). That is, it finds a single crisp output value from the solution fuzzy set using techniques like centroid, composite maximum, composite mass, etc.

4.3.2.1 Fuzzy variables

The three parameters drawn from the list of parameters affecting the link quality, that greatly impact the performance of the link are Asymmetry, Delay and Residual Energy of the nodes.

Asymmetry

Asymmetry is the difference in connectivity between the uplink and the downlink. The communication between the sensor nodes is usually bidirectional. Asymmetry is mainly due to the discrepancy in terms of hardware calibration. In other words, nodes do not have the same effective transmission power, reception sensitivity and noise floor. Therefore, it is not
sufficient to estimate the link quality as the quality of the link in one
direction. \textit{F-LQA} takes into account link asymmetry by measuring the
difference between the uplink \( PRR (PRR_{up}) \) and the downlink \( PRR_{down} \),
where \( PRR \) is the Packet Reception Rate which is the ratio of the number of
data packets received to the total number of packets sent:

\[
AsymmetryLevel(A) = |PRR_{up} - PRR_{down}|
\]  
(4.1)

**Average Energy Level (E)**

Average Energy level (E) of the nodes forming the link is assumed
to be the virtual energy of a link. The energy required to sense events is
usually a constant and cannot be controlled. Hence, the energy expended to
keep the communication system on (for listening to the medium and for
control packets) is the dominant component of energy consumption. The
Energy level is a normalized value between 0 and 1.

**Delay (D)**

It is important to measure packet transmission delays inside the
network so that real-time control strategies can be adjusted (e.g., in plant
automation and control), and abnormal delays can be detected and corrected
in a timely manner. Delay is the difference between the time in which the
packet is sent to the time in which packet is received.

\[
Delay(D) = Time_{received} - Time_{sent}
\]  
(4.2)

\( Time_{received} \): Time in which data packet is received by a receiver node.

\( Time_{sent} \): Time in which the same data packet is sent to the receiver by a
transmitter node.
4.3.2.2 Fuzzification

Consider the sensor network $G(S,L)$ where $S$ represents the sensor nodes $s_1, s_2, s_3, \ldots, s_n$ deployed randomly in the environment and links $l_1, l_2, \ldots, l_m$ are the links connecting the nodes. Let us assume the universal fuzzy set as $S = \{s_1, s_2, s_3, \ldots, s_n\}$. During the formation of quad tree, nodes are aligned under parent node and are considered as elements in subsets.

Let us take the subset $A$ where node $s_1$ is placed. Then its subset is given by $Z(A) = \{\mu_A(S), 0, 0, \ldots, 0\}$. For subset $B$ having elements as $s_2 & s_4$ then $Z(B) = \{0, \mu_B(S), 0, \mu_B(S), 0, 0, \ldots, 0\}$, where $\mu(S)$ is the membership function of sensor node $S_i$ for the respective subset. This value lies between 0 and 1 depending on $D$, $A$ and $E$.

The membership function describes the membership of the elements ‘s’ of the base set ‘S’ in the fuzzy set ‘A’, whereby, for $\mu_A(S)$, a large class of functions can be taken (Ping Huang et al 2007).

Here Hammacher’s function which is one of the Fuzzy Intersection operations is used to convert the input parameters into crisp values.

\[
Malfunction\text{ }Index(MI)_{A,E,D} = \frac{AD}{E + (1-E)(A + D - AD)} \tag{4.3}
\]

where,

$A$ is the asymmetry in a link

$D$ is the delay between the nodes in a link

$E$ is the residual energy.

The Hammacher's function yields a Malfunction index (MI). The lower the value of MI is, the better is the link. The resulting value seen after
fuzzification is computed for each link. The MI value which is the output of
F-LQA acts as a decision maker in Optimal Sequential testing in categorizing
the link to be good or bad. The expected testing cost of this approach is
computed using Equation (4.4).

\[ T = \sum_{i=1}^{n} c_i + (1 - p_i) c_{i+1} + c_M \tag{4.4} \]

where,

- \( c_i \) - cost of testing a link (includes the computational overhead
  like control packets)
- \( p_i \) - probability of the link being faulty
- \( c_M \) - cost of computing the Malfunction Index for each link.

The F-LQA algorithm used for the computation of the MI Value is
found to be more reliable than any of the classical approaches of link quality
assessment as it considers three parameters, namely Delay, Asymmetry,
Residual energy level of nodes for link quality evaluation in the network
rather than a single parameter.

Hence the decision taken whether the link of the node is classified
to good or bad is strong and stable. The fuzzy set and its membership
functions are defined for all the variables delay, Asymmetry and energy are
shown in figure 4.5 and the decision states are framed. For the various levels
based on the conditions observed for fuzzy variables the quality of the link is
observed and decision on its stability or instability is taken.
Figure 4.5 Membership function for fuzzy variables

It is possible for a node to have adequate energy $E_a$ or inadequate energy $E_{ia}$ depending on sensing, processing and communication processes. Symmetry refers to the synchronous communication between two sensor nodes. It may be low ($S_l$) or high ($S_h$) depending on the hardware specifications used for nodes. The parameter delay may be considered as very less ($D_{vl}$), less ($D_l$), normal ($D_n$) or high ($D_h$) depending on environmental factors, traffic, link quality etc.
Based on the fuzzy variables $3 \times 2 \times 4 = 24$ fuzzy rules can be implemented for getting the optimized result. Some of the fuzzy rule set is given in the following Table 4.3.

**Table 4.3 Fuzzy rule for fuzzy variables**

<table>
<thead>
<tr>
<th>Energy (E)</th>
<th>Asymmetry (A)</th>
<th>Delay (D)</th>
<th>Link Quality (LQ)</th>
<th>Decision states</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate</td>
<td>High</td>
<td>High</td>
<td>Worst</td>
<td>$X_0$</td>
</tr>
<tr>
<td>Inadequate</td>
<td>High</td>
<td>Normal</td>
<td>Poor</td>
<td>$X_1$</td>
</tr>
<tr>
<td>Inadequate</td>
<td>High</td>
<td>Very less</td>
<td>Poor</td>
<td>$X_2$</td>
</tr>
<tr>
<td>Adequate</td>
<td>High</td>
<td>Normal</td>
<td>Good</td>
<td>$X_3$</td>
</tr>
<tr>
<td>Adequate</td>
<td>Low</td>
<td>Very Less</td>
<td>Excellent</td>
<td>$X_4$</td>
</tr>
<tr>
<td>Marginal</td>
<td>High</td>
<td>Normal</td>
<td>Good</td>
<td>$X_5$</td>
</tr>
<tr>
<td>Marginal</td>
<td>Low</td>
<td>Normal</td>
<td>Good</td>
<td>$X_6$</td>
</tr>
<tr>
<td>Inadequate</td>
<td>Low</td>
<td>Very less</td>
<td>Poor</td>
<td>$X_7$</td>
</tr>
<tr>
<td>Inadequate</td>
<td>High</td>
<td>Very less</td>
<td>Poor</td>
<td>$X_8$</td>
</tr>
</tbody>
</table>

Based on the fuzzy variables, decision is made about the link quality. Then the node decides whether to follow that route or not.

$$P(E_a \cup A_s \cup D_v) = LQ_E$$ (4.5)

where $LQ_E$ refers to Excellent Link quality.

The membership functions for fuzzy variables are

$$\mu (E) = \begin{cases} 
0 & ; E < E_1 \\
\frac{E - E_1}{E_2 - E_1} & ; E_1 \leq E \leq E_2 \\
1 & ; E > E_2 
\end{cases}$$ (4.6)
\[ \mu (A) = \begin{cases} 
1 & ; A < A_1 \\
\frac{A - A_1}{A_2 - A_1} & ; A_1 \leq A \leq A_2 \\
0 & ; A > A_2 
\end{cases} \quad (4.7) \]

\[ \mu (D) = \begin{cases} 
0 & ; D < D_1 \\
\frac{D - D_1}{D_2 - D_1} & ; D_1 \leq D \leq D_2 \\
1 & ; D > D_2 
\end{cases} \quad (4.8) \]

The relationship between the parameters is considered and its membership function is analyzed and is plotted in Figure 4.6, Figure 4.7 and Figure 4.8. By considering \( E_1 = 0.15J \), \( E_2 = 0.4J \), \( A_1 = 0.2 \text{ sec} \), \( A_2 = 0.85 \text{ sec} \) and \( D_1 = 0.2 \text{ sec} \), \( D_2 = 0.85 \text{ sec} \) the following membership functions can be obtained.

![Figure 4.6 Representation for membership function of node energy](image-url)
The optimized Link Quality for a link related to the particular path consisting of \( n_1 \) nodes is given by

\[
LQ = \frac{\mu_L \left( \sum_{i=1}^{n_1} (1 - \mu_D) / n_i \right)}{1 - \mu_s} \tag{4.9}
\]
For a network of ‘n’ nodes, link quality is given by

\[ LQ = \frac{\sum_{i=1}^{n} \mu_E \left( \frac{\sum_{j=1}^{n} (1-\mu_D)}{n} \right)}{n(1-\mu_s)} \]  

(4.10)

Link quality over a wireless sensor network is tested and analyzed for various values and the result shows the achievement of better link quality for optimised values of variables taken. Figure 4.9 shows the result of link quality observed for various states stated in Table 4.3. From Figure 4.9 it is observed that an excellent link quality index when the energy is adequate, asymmetry is low and the delay is very less which is calculated from Equation (4.9).

![Figure 4.9 Link quality decision based on fuzzy parameters](image)

The proposed F-LQA algorithm is simulated with and the performance is analysed in the following section.
4.3.3 Performance Analysis

An extensive performance evaluation has been made by comparing various parameters of the aforementioned F-LQA approach with existing approaches packet reception rate (PRR) protocol, the required number of packet transmissions protocol (RNP), window mean with exponentially weighted moving average (WMEWMA), expected transmission count (ETX) protocol, and FOUR-BIT protocols and it was found that the proposed approach improves the performance comparison.

This section presents the performance comparison of the F-LQA approach with the existing protocols with the parameters like the packet delivery ratio (PDR), Bit Error Rate (BER) and reconfiguration time of the proposed tree topology.

The experimental setup includes a sink and sensor nodes varying from hundred to thousand nodes. The nodes are assumed to be dynamically moving with constant velocity and have identical computational power and capability (Homogenous network). The network simulation parameters of F-LQA are tabulated in Table 4.4.

Table 4.4 Simulation setup parameters for F-LQA

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>100</td>
</tr>
<tr>
<td>Network Size</td>
<td>100m x 100m</td>
</tr>
<tr>
<td>Data size</td>
<td>6400 bytes</td>
</tr>
<tr>
<td>Control packet</td>
<td>100 bits</td>
</tr>
<tr>
<td>Topology</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>0.5J</td>
</tr>
<tr>
<td>Simulator</td>
<td>NS-2</td>
</tr>
</tbody>
</table>
4.3.3.1 Impact of node density on network configuration time

Network configuration time is the measure of the time required to update the topology tree, when there is a change in the topology. Figure 4.10, brings out the inference that the time required for the reconfiguration increases with the density of the network. This increase in time is due to the time incurred for quadrant splitting and configuration of nodes. Once the higher level tree structure is formed new nodes are added as leaf nodes with minimal changes in the topology and hence the reconfiguration time is almost constant. The position of the node that is joining or removing the network also influence the time. If a node is joined at the leaf of a tree the time taken for tree modification is less when compared to the node joining near sink or middle of the tree.

![Reconfiguration time graph](image)

Figure 4.10 Reconfiguration time for the topology tree

4.3.3.2 Analysis of Packet Delivery Ratio(PDR) of the F-LQA

Packet Delivery Ratio(PDR) is the ratio of the total number of packets that have reached the destination node to the total number of packets originated at the source node. Figure 4.11 shows the impact of node density
on Packet delivery ratio of F-LQA with FOUR BIT, ETX, WMEWMA, PRR and RNP.

**Figure 4.11 Comparison of Packet Delivery Ratio under various methods**

When the node density increases the traffic in the network which, in turn increases the packet loss and retransmission thereby affecting the number of packets delivered to the sink. From the simulation observations, found that the F-LQA outperforms more than 18% better PDR when compared to FOUR BIT protocol.

4.3.3.3 **Analysis of bit error rate of the F-LQA**

In data transmission, the bit error rate or bit error ratio (BER) is the number of received bits that have been altered due to noise, interference and distortion, divided by the total number of transferred bits during a particular time interval.

Figure 4.12 shows the effect of path distance on bit error rate of F-LQA and other protocols. From the graph it is observed that the bit error rate increases with the path length due to the channel conditions like noise,
interference, distortion, bit synchronization, and fading etc. The F-LQA have comparatively better BER of 38% than FOUR BIT protocol. In F-LQA, the link quality is assessed based on the delay, asymmetry and average energy of the nodes, the links having better quality of these parameters only considered for further routing. so the F-LQA outperforms better than existing protocols.

![Figure 4.12 Comparison of Bit Error Rate under various techniques](image)

**Figure 4.12 Comparison of Bit Error Rate under various techniques**

4.4 SUMMARY

This chapter has proposed Fuzzy based link isolation technique for dynamic wireless sensor network to increase the network life time by isolating the faulty links in the network from transmission and to improve other QoS parameter like packet delivery ratio and to reduce the bit error rate and topology tree configuration time against varying the density of the network. Dynamic Quad tree data structure is proposed to handle the mobility of the network and store the topology changes. The proposed algorithm is used to assess the link quality using energy, symmetry and delay as member functions The F-LQA protocol has shown better performance in improving network life time, packet delivery ratio over the FOUR BIT and other protocols. This proposed protocol also reduces control overhead and end to end delay considerably.