Quality of service (QoS) for LTE network based on adaptive neuro fuzzy inference system

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Abstract
The main objective of this paper is to design an Adaptive Neuro Fuzzy Inference System model to calculate the quality of service for LTE HetNet applications. The quality of service parameters considered are delay, loss rate, throughput, and jitter. The adaptive neuro fuzzy inference system is an integration of fuzzy logic and neural network. The advantage of neural network in adaptive neuro fuzzy inference system is to train the neural network algorithm on the parameter values of membership function for fuzzy logic to construct fuzzy decision. So, adaptive neuro fuzzy inference system gives better performance than fuzzy logic alone for LTE network applications (e.g. VOIP, HTTP, VIDEO, and EMAIL). The results based on adaptive neuro fuzzy inference system model produce high quality of service for LTE network applications as compared with fuzzy logic alone. It is also found that adaptive neuro fuzzy inference system results in EMAIL and quality of service outperform fuzzy logic alone by about 28.7% at medium delay, low loss rate, jitter, and high throughput.

1 | INTRODUCTION

Adaptive Neuro Fuzzy Inference System (ANFIS) is a combination of fuzzy logic system and neural network. This model is used to improve a fuzzy system performance using neural network methods. The ANFIS model uses learning algorithm to optimize the fuzzy system parameters. ANFIS model may perform better than the fuzzy logic model as it requires less processing time. Since the fuzzy logic by itself requires long processing time. ANFIS supports the Takagi–Sugeno based systems [1].

In [2–4], the authors designed ANFIS to achieve high quality of service (QoS) during handover process using three input parameters—Signal to Interference Ratio (SIR), speed of mobile, and traffic distance. In [5], fuzzy logic was designed to calculate the handover decision containing multiple QoS parameters. In [6, 7], the authors considered different QoS parameters such as jitter, delay, bandwidth, and bit error rate in their analysis. Moreover, the QoS for several applications in LTE are considered [8]. In [9], the authors designed ANFIS to minimize the time delay and improve the QoS.

In 2020, Chen et al. proposed a federated learning (FL) model over wireless network, in which cellular-connected wireless users transmit their locally trained FL models to a base station (BS) that generates a global FL model and transmits it back to the users. The BS requires to select appropriate users to execute the FL algorithm so as to minimize the FL loss function. Moreover, the impact of the wireless packet transmission errors on the parameter update process of the FL model is explicitly considered [10, 11].

Paper Objectives
- In this work, the services taken into consideration are VOIP, HTTP, Video, and EMAIL, the ANFIS designed to calculate the QoS of four LTE Applications
- A comparison study will be carried out between fuzzy logic and ANFIS for the different applications of LTE network
- Moreover, there are four parameters that will be taken into consideration (delay, loss rate, throughput and jitter) to estimate the QoS for each application

This paper is organized as follows: Section 2 introduces fuzzy logic and ANFIS system, Section 3 introduces the structure of ANFIS system, Section 4 presents steps of fuzzy logic and ANFIS design, Section 5 presents QoS of LTE network applications using ANFIS model, and Section 6 presents
comparison between fuzzy logic and ANFIS for LTE network applications.

2 | FUZZY LOGIC AND ANFIS CONTROLLER SYSTEM

Figure 1 shows the block diagram of fuzzy logic controller. It consists of four stages defined as input parameters, fuzzification, Sugeno fuzzy inference system (FIS), rule base, and defuzzification. The ANFIS controller consists of five blocks defined as training data, fuzzification, knowledge base (rule base), artificial neural network, and defuzzification, as shown in Figure 2.

In Figure 1, the first stage calculates the input parameters based on the authors’ work in [12] whereas, in Figure 2, the first stage performs the training data as given in [12]. In both figures, there are three stages called the fuzzification stage which converts the input parameter values into sets (low, medium, and high), rule base stage which calculates the rule between input and output, and defuzzification stage which calculates the weighted values of all output rules. Figure 2 has an extra stage called the artificial neural network to implement the learning algorithm and the loaded data are trained using hybrid algorithms (e.g. gradient descent algorithm and least square method) in [13, 14].

3 | ANFIS STRUCTURE

The ANFIS system has five layer architectures:

**First Layer:** Each node $i_n$ defines the input parameter’s membership function (loss rate, delay, jitter, and throughput). Each node is an adaptive node, where membership function is given by

\[
\begin{align*}
O_{i_n}^1 &= \mu_{A_{i_n}} \text{ (delay) for } i_n = 1, 2, 3; \\
O_{i_n}^1 &= \mu_{B_{i_n-3}} \text{ (loss rate) for } i_n = 4, 5, 6; \\
O_{i_n}^1 &= \mu_{C_{i_n-6}} \text{ (throughput) for } i_n = 7, 8, 9; \\
O_{i_n}^1 &= \mu_{D_{i_n-9}} \text{ (jitter) for } i_n = 10, 11, 12.
\end{align*}
\]

where $O_{i_n}^1$ is the output of the first layer, $\mu$ is the membership function of inputs and $A_{i_n}, B_{i_n}, C_{i_n}, D_{i_n}$ are the sets of input parameters (low, medium, and high).

**Second Layer:** The output of each node is defined as the firing strength of the rules in the fuzzy inference engine. Each node in this layer is a fixed node, where firing strength is defined as

\[
O_{i_n}^2 = \alpha_{i_n} = \mu_{A_{i_n}} \text{ (delay)} \times \mu_{B_{i_n-3}} \text{ (loss rate)} \\
\times \mu_{C_{i_n-6}} \text{ (throughput)} \times \mu_{D_{i_n-9}} \text{ (jitter)}
\]

where $O_{i_n}^2$ is the output of second layer, $\alpha_{i_n}$ is the firing strength, and $i_n$ is the number of nodes and rules in layer 2.

**Third Layer:** Each node calculates the normalized firing strength. Each node in this layer is considered a fixed node. Normalized firing strength for each node is calculated by ratio of firing strength of this rule to sum of all firing strength rules.

\[
O_{i_n}^3 = \bar{\alpha}_{i_n} = \frac{\alpha_{i_n}}{\sum_{i=1}^{Q} \alpha_{i_n}}
\]

where $O_{i_n}^3$ is the output of third layer, $\bar{\alpha}_{i_n}$ is the normalized firing strength, and $Q$ is the total number of nodes and rules.

**Fourth Layer:** Each node in this layer is an adaptive node. The output of each node is given by

\[
O_{i_n}^4 = \bar{\alpha}_{i_n} z_{i_n} = \bar{\alpha}_{i_n} \left( p_{i_n} \text{ delay } + q_{i_n} \text{ loss rate} \\
+ t_{i_n} \text{ throughput } + k_{i_n} \text{ jitter } + r_{i_n} \right)
\]

where $O_{i_n}^4$ is the output of fourth layer, and $z_{i_n}$ is the output membership functions, and $p_{i_n}$, $q_{i_n}$, $t_{i_n}$, $k_{i_n}$, and $r_{i_n}$ are the consequent parameters set.

**Fifth Layer:** The node in this layer is a fixed node. The summation of all incoming signals is performed using this node as

\[
O_{i_n}^5 = \sum_{i=1}^{Q} \bar{\alpha}_{i_n} z_{i_n}
\]

where $O_{i_n}^5$ is the output of the fifth layer.

In the first layer, there are 12 nodes that provide the membership function of input parameters. There are 81 nodes in the second layer, where the output of each of them calculates the firing strength in each rule. The normalized firing strength is calculated in the third layer. The output of each node in the fourth layer is the multiplication of the normalized firing strength by the zero-order Sugeno model $z_{i_n}$. The fifth layer represents the output of ANFIS. The structure of ANFIS is as shown in Figure 3.
4 | STEPS OF FUZZY LOGIC AND ANFIS SYSTEM DESIGN

4.1 | Fuzzy logic system design

In fuzzy logic design, there are four steps to calculate the QoS of LTE network application, as discussed in [12, 15].

**Step one:** Define the input parameters of LTE network applications loss rate, delay, jitter, and throughput.

**Step two:** The inputs must be converted into sets. The membership function was used to fuzzify the inputs. So, this step is defined as fuzzification step.

**Step three:** Calculate the rule base between input and output. The form of the rule base is IF...AND...OR, THEN with the operations AND, OR etc. The number of rules can be expressed by \( Q = M^N \) where the set numbers is \( M \) (low, medium, high) and the input numbers is \( N \).

**Step four:** This step is defined as defuzzification step which calculates the weighted value of all the output rules and is expressed by

\[
W^* = \frac{\sum_{i=1}^{Q} \alpha_i z_i}{\sum_{i=1}^{Q} \alpha_i} \tag{6}
\]

4.2 | ANFIS design

There are four steps to design ANFIS to calculate the QoS of LTE network application.

**Step one:** Load data from workspace.

**Step two:** Generate FIS. There are two methods to generate the FIS—the grid partition and sub clustering method in [16].

**Step three:** Train the FIS. There are two learning algorithms—back propagation algorithm and hybrid learning algorithm in [17]. Hybrid learning algorithm is a combination of back propagation algorithm and least squares method. It consists of two passes, forward and backward passes. The least square method is forward pass and the gradient descent method is backward pass. To optimize the consequence parameters, the least square method is used and premise parameters are fixed. When the optimal parameters of forward pass are obtained, the backward pass starts immediately.

The gradient descent method is used to modify the premise parameters corresponding to the fuzzy sets. Each combination of forward and backward passes is called an epoch. Table 1 shows the operation of the two passes, forward and backward passes. In training FIS, a number of epochs must be chosen...
TABLE 1 Passes of hybrid algorithm

|                      | Forward pass | Backward pass |
|----------------------|--------------|---------------|
| Premise parameters   | Fixed        | Gradient descent |
| Consequence parameters | Least square method | Fixed |
| Signals              | Node outputs | Error signals |

**FIGURE 4** Flow chart of the ANFIS design steps

to calculate the error. By increasing the number of epochs, the error will be reduced. In forward pass, the least square method is used to calculate the consequence parameters. The squared error is minimized and is called least square method in Equation (7) [18-20]:

\[
E(\theta) = \sum_{i=1}^{m} (z_i - a_i^T \theta)^2 = e^T e = (z - A\theta)^T (z - A\theta)
\]

(7)

where \(e = z - A\theta\) is the error vector produced by a specific choice of \(\theta\), \(A = P \times M\) \(P\) is the number of training data pairs, \(M\) is the number of linear parameters, \(\theta = M \times 1\), \(a_i^T\) is defined as any row in matrix \(A\), \(Z\) is the desired output vector, and \(i\) is the number of row in matrix \(A\).

In the backward pass, the error signal propagates backwards through the network till the dependence of this error for each of the premise parameters is estimated [19]:

\[
a_{ij}(k+1) = a_{ij}(k) - k_j \frac{\nabla E}{\|\nabla E\|}
\]

(8)

where \(k\) is the number of iteration, \(a_{ij}(k+1)\) denotes the updated parameters via \(k\) iteration, \(k_j\) is the parameter that controls stability and rate of convergence (learning rate), \(\nabla\) is the gradient, and \(E\) is the error.

**Step four:** Test FIS. The training data loaded in the first step is tested. The steps of design are shown in Figure 4.

5 QoS OF LTE NETWORK APPLICATIONS USING ANFIS

There are four applications for LTE network, HTTP, VOIP, EMAIL and VIDEO. Four parameters have their effect on the LTE QoS applications. These parameters are the loss rate, delay, jitter, and throughput.

The QoS of the LTE network applications, VOIP, HTTP, VIDEO, and EMAIL, is carried out using ANFIS model. In step1, the data is loaded from the workspace which is generated from FIS. The data is a matrix with five columns where the first four are the input values and the last is the output value. Step2 generates FIS. The grid partition is used in this design. Step3 trains FIS by choosing the algorithm and number of epochs. The hyprid algorithm and 20 epochs are chosen in this design, as shown in Figures 5 and 6. In step4, the data loaded in step1 are tested, as shown in Figures 7 and 8. The ANFIS information for
Each application (VOIP, HTTP, VIDEO, and EMAIL) is tabulated in Tables 2–5, respectively.

The data set is loaded from the workspace, which is generated from fuzzy logic design for LTE Application in [12]. Tables 6–9 are showing samples of loaded data for VOIP, HTTP, VIDEO, and EMAIL applications. The number of data set index loaded is 132. The output of LTE QoS for VOIP, HTTP, VIDEO, and EMAIL applications ranged from 0 to 100%.

Figure 5 shows the training error for VOIP and HTTP applications. The training error depends on the loaded data, algorithm, and number of Epochs. In Figure 5(a), the training error for VOIP application is equal to 0.00025152, where in
TABLE 2  ANFIS information for VOIP application

| Algorithm                  | Hyprid algorithm |
|----------------------------|------------------|
| Error tolerance            | 0                |
| Epochs number              | 20               |
| Linear parameter number    | 81               |
| Non-linear parameter number| 44               |
| Total number of parameter  | 125              |
| Training data number       | 132              |
| Rules number               | 81               |

FIGURE 5(b), the training error of HTTP application is equal to 0.0004406.

Figure 6 shows the training error for VIDEO and EMAIL applications. In Figure 6(a), the training error for VIDEO application is equal to 0.00026117, where in Figure 6(b), the training error of EMAIL application is equal to 0.0013525.

Figure 7 shows the average testing error for VOIP and HTTP applications. In Figure 7(a), the average testing error for VOIP application is equal to 0.00025152, where in Figure 7(b), the average testing error of HTTP application is equal to 0.00044406.

Figure 8 shows the average testing error for VIDEO and EMAIL applications. In Figure 8(a), the average testing error for VIDEO application is equal to 0.00026117, where in Figure 8(b), the average testing error of EMAIL application is equal to 0.0013525.

6. COMPARISON BETWEEN QoS OF FUZZY LOGIC AND ANFIS FOR LTE NETWORK APPLICATIONS

The comparison between fuzzy logic and ANFIS of LTE QoS for HTTP, VOIP, EMAIL, and VIDEO applications is discussed in this section. The effect of throughput, delay, jitter, and loss rate on LTE QoS application is considered.

TABLE 5  ANFIS information for EMAIL application

| Algorithm                  | Hyprid algorithm |
|----------------------------|------------------|
| Error tolerance            | 0                |
| Epochs number              | 20               |
| Linear parameter number    | 81               |
| Non-linear parameter number| 44               |
| Total number of parameter  | 125              |
| Training data number       | 132              |
| Rules number               | 81               |

TABLE 6  Data set for VOIP application

| Data set index | Delay | Loss rate | Throughput | Jitter | LTEVOIP QoS(%) |
|----------------|-------|-----------|------------|--------|---------------|
| 1              | 12    | 0.159     | 7          | 15.5   | 0             |
| 2              | 10.8  | 0.07      | 17         | 15.5   | 10.3          |
| 3              | 10.8  | 0.06      | 16         | 15     | 11.1          |
| 63             | 11.4  | 0.067     | 17         | 6.51   | 50            |
| 64             | 9.4   | 0.078     | 13.4       | 6.83   | 52.3          |
| 65             | 9.4   | 0.077     | 13.4       | 6.83   | 53.7          |
| 130            | 8.7   | 0.05      | 16         | 6      | 98.9          |
| 131            | 8.65  | 0.05      | 17         | 6      | 99.8          |
| 132            | 8     | 0.05      | 17         | 5      | 100           |

TABLE 7  Data set for HTTP application

| Data set index | Delay | Loss rate | Throughput | Jitter | LTE HTTP QoS(%) |
|----------------|-------|-----------|------------|--------|---------------|
| 1              | 9     | 0.371     | 8          | 12.5   | 0             |
| 2              | 7.52  | 0.204     | 17.3       | 12.5   | 9.32          |
| 3              | 7.51  | 0.2       | 17.3       | 12.5   | 10.4          |
| 63             | 6.8   | 0.185     | 17.7       | 9      | 47.4          |
| 64             | 6.8   | 0.185     | 17.7       | 8.9    | 48.4          |
| 65             | 6.8   | 0.185     | 17.8       | 8.9    | 48.9          |
| 130            | 6.5   | 0.164     | 19         | 4.5    | 99.2          |
| 131            | 6.4   | 0.163     | 19         | 4.5    | 99.8          |
| 132            | 6     | 0.123     | 20         | 4      | 1             |
### TABLE 8  Data set for VIDEO application

| Data set index | Delay | Loss rate | Throughput | Jitter | LTE VIDEO QoS(%) |
|----------------|-------|-----------|------------|--------|-----------------|
| 1              | 5     | 0.2       | 13.5       | 11.7   | 0               |
| 2              | 4.3   | 0.11      | 26.9       | 7.4    | 9.45            |
| 3              | 4.25  | 0.11      | 26.9       | 7.4    | 10.3            |
| 63             | 3.85  | 0.096     | 28.8       | 6.1    | 47.1            |
| 64             | 3.85  | 0.096     | 28.9       | 6.1    | 47.5            |
| 65             | 3.85  | 0.096     | 28.9       | 6      | 48.5            |
| 130            | 3.35  | 0.07      | 32.5       | 4      | 98.9            |
| 131            | 3.33  | 0.065     | 32.5       | 4      | 99.6            |
| 132            | 3     | 0.06      | 34         | 4      | 100             |

### TABLE 9  Data set for EMAIL application

| Data set index | Delay | Loss rate | Throughput | Jitter | LTE EMAIL QoS(%) |
|----------------|-------|-----------|------------|--------|-----------------|
| 1              | 7     | 0.21      | 11.3       | 12.7   | 0               |
| 2              | 5.9   | 0.125     | 22.2       | 7.6    | 10.1            |
| 3              | 5.6   | 0.125     | 22.2       | 7.6    | 11              |
| 63             | 5.3   | 0.1155    | 23.8       | 6.8    | 43              |
| 64             | 5.3   | 0.1155    | 23.9       | 6.8    | 43.4            |
| 65             | 5.3   | 0.1155    | 23.9       | 6.8    | 43.9            |
| 130            | 4.5   | 0.0935    | 26.2       | 4.5    | 98.9            |
| 131            | 4.5   | 0.093     | 28         | 4.2    | 99.4            |
| 132            | 4.5   | 0.07      | 28         | 4.2    | 100             |

### 6.1 | VOIP application

Figure 9 shows the effect of delay on the LTE VOIP QoS at low values of loss rate, jitter, and high throughput where loss rate, throughput, and jitter are equal to 0.05%, 17 Mbps, and 5 ms, respectively. Note that the LTE VOIP QoS has the same values for ANFIS and Fuzzy Logic.

![Figure 9](image)

**FIGURE 9**  LTE VOIP QoS as a function of delay for ANFIS and fuzzy logic

Figure 10 shows the effect of loss rate on the LTE VOIP QoS at medium values of delay, jitter, and high throughput where delay, throughput, and jitter are equal to 10 ms, 17 Mbps, and 10.25 ms, respectively. It is seen that the LTE VOIP QoS for ANFIS is higher than Fuzzy Logic when loss rate has range of 0.05% to 0.08%.

Figure 11 shows the effect of throughput on the LTE VOIP QoS at medium values of delay, jitter, and low loss rate where delay, loss rate, and jitter are equal to 10 ms, 0.05%, and 10 ms, respectively. Note that the LTE VOIP QoS for ANFIS is higher than Fuzzy Logic when throughput is higher than 13 Mbps.

Figure 12 shows the effect of jitter on the LTE VOIP QoS at low values of loss rate, medium delay, and high throughput where delay, loss rate, and throughput are equal to 10 ms, 0.05%, and 17 Mbps, respectively. It is noticed that the LTE VOIP QoS for ANFIS is higher than Fuzzy Logic when jitter has range of 7–13 ms.

### 6.2 | HTTP application

Figure 13 shows the effect of delay on the LTE HTTP QoS at medium values of throughput, loss rate, and low jitter where loss rate, throughput and jitter are equal to 0.247%, 14 Mbps and 4 ms, respectively. It is seen that the LTE HTTP QoS
for ANFIS is higher than Fuzzy Logic when delay has range 6.7–8.4 ms whereas; there are the same values when delay is larger than 8.4 ms.

Figure 14 shows the effect of loss rate on the LTE HTTP QoS at medium values of delay, throughput and low jitter where delay, throughput and jitter are equal to 7.5 ms, 14 Mbps and 4 ms, respectively. Note that the LTE HTTP QoS for ANFIS is higher than Fuzzy Logic for loss rate range 0.18%–0.3%.

Figure 15 shows the effect of throughput on the LTE HTTP QoS at medium values of loss rate, delay, and low jitter where delay, loss rate and jitter are equal to 7.5 ms, 0.247%, and 4 ms, respectively. It is seen that the LTE HTTP QoS for ANFIS is higher than Fuzzy Logic when throughput has range of 10.5–18 Mbps.

Figure 16 shows the effect of jitter on the LTE HTTP QoS at medium values of loss rate, delay, and throughput where delay, loss rate and throughput are equal to 7.5 ms, 0.247%, and 14 Mbps, respectively. Note that the LTE HTTP QoS for ANFIS is higher than Fuzzy Logic.

6.3 VIDEO application

Figure 17 shows the effect of delay on the LTE VIDEO QoS at low values of loss rate, jitter and high throughput where loss rate, throughput and jitter are equal to 0.06%, 34 Mbps, and 4 ms, respectively. It is seen that the LTE VIDEO QoS for Fuzzy Logic is higher than ANFIS when delay is larger than 4.2 ms, whereas there are the same values for delay less than 4.2 ms.

Figure 18 shows the effect of loss rate on the LTE VIDEO QoS at medium values of delay, throughput, and low jitter where delay, throughput and jitter are equal to 4 ms, 23.75 Mbps and 4 ms, respectively. It is noticed that the LTE VIDEO QoS of
ANFIS is higher than fuzzy Logic for loss rate range 0.11%—0.16%.

Figure 19 shows the effect of throughput on the LTE VIDEO QoS at medium values of loss rate, delay, and low jitter where delay, loss rate, and jitter are equal to 4 ms, 0.13%, and 4 ms, respectively. It is seen that the LTE VIDEO QoS for ANFIS is higher than Fuzzy Logic when throughput has range 20–27 Mbps.

Figure 20 shows the effect of jitter on the LTE VIDEO QoS at low values of delay, medium loss rate and high throughput where delay, loss rate and throughput are equal to 3 ms, 0.13%, and 34 Mbps, respectively. It can be seen that the ANFIS and fuzzy logic LTE VIDEO QoS have the same values.

6.4 EMAIL application

Figure 21 shows the effect of delay on the LTE EMAIL QoS at low values of loss rate, jitter and high throughput where loss rate, throughput and jitter are equal to 0.07%, 28 Mbps, and 4.2 ms, respectively. It is seen that the LTE EMAIL QoS for ANFIS is higher than Fuzzy Logic when delay has range 4.8–6.2 ms by 2.9%–9.5%, whereas the LTE EMAIL QoS for fuzzy logic is higher than ANFIS when delay is larger than 6.2 ms.

Figure 22 shows the effect of loss rate on the LTE EMAIL QoS at low values of delay, jitter and high throughput where delay, throughput and jitter are equal to 4.5 ms, 28 Mbps and 4.2 ms, respectively. Note that the LTE EMAIL QoS of fuzzy logic is higher than ANFIS for loss rate range of 0.15%–0.21%.

Figure 23 shows the effect of throughput on the LTE EMAIL QoS at medium values of delay, jitter, and low loss rate where delay, loss rate and jitter are equal to 5.75 ms, 0.07%, and 6.5 ms,
Table 10 Summary of comparison between ANFIS QoS and fuzzy logic for LTE VOIP QoS

| Parameter       | ANFIS better than fuzzy logic | Fuzzy logic better than ANFIS |
|-----------------|-------------------------------|-------------------------------|
| Delay (ms)      | 8 ms to 12 ms                 | Have the same value           |
| Loss rate (%)   | 0.05 to 0.067%                | By 5.51%                      |
|                 | 0.068 to 0.089%               | By 5 to 0.1%                  |
|                 | 0.09 to 0.1%                  | By 0.2%                       |
| Throughput (Mbps)| 9 to 10.6 Mbps                | By 2.28 to 0.1%               |
|                 | 11 to 15.3 Mbps               | By 0.5 to 4.9%                |
|                 | 15.4 to 17 Mbps               | By 5.51%                      |
| Jitter (ms)     | 6.8 to 11 ms                  | By 0.1 to 4.6%                |
|                 | 11.1 to 13.5 ms               | By 4.4 to 0.1%                |
|                 | 13.6 to 15.5 ms               | Have the same value           |

Figure 22 QoS of LTE EMAIL as a function of loss rate for fuzzy logic and ANFIS

Figure 23 LTE EMAIL QoS as a function of throughput for fuzzy logic and ANFIS

respectively. It is seen that the LTE EMAIL QoS for ANFIS is higher than Fuzzy Logic at throughput higher than 16.5 Mbps.

Figure 24 shows the effect of jitter on the LTE EMAIL QoS at medium values of loss rate, delay, and throughput where delay, loss rate and throughput are equal to 5.75 ms, 0.14%, and 19.65 Mbps, respectively. Note that the LTE EMAIL QoS for ANFIS is higher than Fuzzy Logic.

Table 10-13 shows the summary of comparison between ANFIS QoS and fuzzy logic QoS for LTE VOIP QoS, LTE HTTP QoS, LTE VIDEO QoS, and LTE EMAIL QoS respectively.

7 | CONCLUSION

This paper considered ANFIS for different LTE applications. The architecture of adaptive model based on FIS is described. The LTE QoS for four applications considering several parameter delays, throughput, loss rate and jitter was provided. The design presented was compared between fuzzy logic and ANFIS for LTE QoS applications. The ANFIS QoS of LTE applications are developed by using the training data obtained from fuzzy logic system. The ANFIS provided better results as compared with the fuzzy logic at different values of delay, loss rate, throughput, and jitter. It was found that the ANFIS LTE VOIP QoS is higher than fuzzy logic system by 5.5% with delay, jitter medium values, loss rate low values, and throughput high values. Moreover the ANFIS LTE HTTP QoS was found higher than
### TABLE 11  Summary of comparison between ANFIS and fuzzy logic for LTE HTTP QoS

| Range      | ANFIS better than fuzzy logic | Fuzzy logic better than ANFIS |
|------------|-------------------------------|------------------------------|
| **Delay (ms)** |                               |                              |
| 6 to 6.6 ms | Have the same value           |                              |
| 6.7 to 7.6 ms | By 1.6% to 6%                 |                              |
| 7.7 to 8.5 ms | By 7.3 to 0.1%                |                              |
| **Loss rate (%)** |                               |                              |
| 0.123 to 0.17% | Have the same value          |                              |
| 0.18 to 0.25% | By 1.5 to 7.85%              |                              |
| 0.26 to 0.33% | By 7.77 to 0.1%               |                              |
| **Throughput (Mbps)** |                               |                              |
| 8 to 10 Mbps | Have the same value          |                              |
| 10.1 to 14.6 Mbps | By 0.1 to 7.8%             |                              |
| 14.7 to 20 Mbps | By 7.6 to 1.1%                |                              |
| **Jitter (ms)** |                               |                              |
| 4 to 8.6 ms |                              | Have the same value          |
| 8.7 to 12.5 ms | By 9.6 to 1%                 |                              |

### TABLE 12  Summary of comparison between ANFIS and fuzzy logic for LTE QoS VIDEO

| Range      | ANFIS better than fuzzy logic | Fuzzy logic better than ANFIS |
|------------|-------------------------------|------------------------------|
| **Delay (ms)** |                               |                              |
| 3 to 4.1 ms | Have the same value           |                              |
| 4.2 to 4.6 ms |                              | By 1.7 to 7.7%              |
| 4.7 to 5 ms |                              | By 8.7%                      |
| **Loss rate (%)** |                               |                              |
| 0.06 to 0.08% | Have the same value          |                              |
| 0.09 to 0.13% | By 0.4 to 2.9%                |                              |
| 0.14 to 0.17% | By 2.6 to 0.4%               |                              |
| **Throughput (Mbps)** |                               |                              |
| 13.5 to 17 Mbps | Have the same value         |                              |
| 18 to 25 Mbps | By 0.5 to 2.7%              |                              |
| 26 to 28.5 Mbps | By 2 to 0.2%                 |                              |
| 29 to 34 Mbps |                              | By 0.1 to 1.1%               |
| **Jitter (ms)** |                               |                              |
|                      | Have the same value          |                              |

### TABLE 13  Summary of comparison between ANFIS and fuzzy logic for LTE EMAIL QoS

| Range      | ANFIS better than fuzzy logic | Fuzzy logic better than ANFIS |
|------------|-------------------------------|------------------------------|
| **Delay (ms)** |                               |                              |
| 5 to 5.8 ms | By 2.9 to 24%                 |                              |
| 5.9 to 6.08 ms | By 21 to 0.7%                |                              |
| 6.1 to 7 ms |                              | By 1.5 to 50%                |
| **Loss rate (%)** |                               |                              |
| 0.07 to 0.14 % | Have the same value         |                              |
| 0.15 to 0.21% |                              | By 2.1 to 25%               |
| **Throughput (Mbps)** |                               |                              |
| 11.3 to 16 Mbps |                              | By 16.4 to 3.6%             |
| 17 to 25 Mbps | By 3.2 to 28.1%              |                              |
| 26 to 28 Mbps | By 28.7%                     |                              |
| **Jitter (ms)** |                               |                              |
| 4.2 to 11 ms | By 24.4 to 0.5%              |                              |
fuzzy logic by 7.6% with delay, loss rate, throughput medium values, and jitter low values, also the ANFIS LTE VIDEO QoS was found higher than fuzzy logic by 2.9% with delay, loss rate, throughput medium values, and jitter low values.

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