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Load Balancing and Optimization in LTE Network Using Fuzzy Logic and Q-Learning Techniques

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Abstract*—Long term evolution (LTE) main objectives are to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. LTE network architecture is designed to support packet-switched traffic with seamless mobility and great quality of service. Notwithstanding these gains, its system performance is hampered by load imbalance due to uneven distribution among neighboring cells. As a remedy to the above stated problem, automated inter-cell optimization is required. It is necessary for the network to conduct inter-cell optimization dynamically and adaptively according to its environments. Several techniques have been proposed in the past to solve the problem of load imbalance in an LTE network. This research seeks to use fuzzy logic controller and Q-learning technique to achieve load balancing in such a network. Using as inputs to the fuzzy controller the reference receivesignal quality (RSRQ) and load difference between adjacent cells. While the output of the controller is a crispy power value use to alter the cell transmit power for a better load performance. Using Q-learning techniques, the output power is optimized to obtain the best possible power increment considering the current state of the network in terms of quality and load and also keep the transmit power within acceptable range. The results obtained showed a remarkable improvement in the load fairness index with a mean value of 0.99 all through the simulation period and a 48% reduction in the number of unsatisfied users from its unbalance state.

***Indexed Terms*—Fuzzy logic, Load balancing, Long-term evolution, Q-learning, Self- organizing networks**

I. INTRODUCTION

LTE main objectives were to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. LTE network architecture is designed to support packet-switched traffic with seamless mobility and great quality of service. The high spectrum efficiency achieved by LTE network is due to the use of flat network architecture (Orthogonal frequency division multiple access (OFDMA) and a robust physical layer techniques multiple input multiple output (MIMO) antennas).Orthogonal Frequency Division Multiple Accessis a variant of Orthogonal Frequency Division Multiplexing (OFDM). It performs well in frequency selective fading channels and provides a feasible and affordable solution with its low complexity in the implementation as well as allows high spectral efficiency by means of compatibility with advanced receiver and antenna technologies. Hence, it is chosen for the downlink (DL) of Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) as selected before in wireless technologies, such as Wi-Fi, WiMAX, LTE; and wired technologies [11].

LTE System Architecture Evolution standardized by third generation partnership project (3GPP), increases data efficiency, and minimizes the number of nodes with respect to the second and third generation systems. Intermediate nodes such as the Radio Network Controller (RNC), the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) are removed and replaced by the System Architecture Evolution (SAE) Gateway (GW), for the reduction of inter-node data traffic delays. In SAE, the central control functions of the RNC are distributed between the evolved NodeB (eNodeB) and the Mobility Management Entity

(MME) as eNodeBscan communicate with each other using a new logical inter-eNodeB interface, called X2. Thus, the eNodeB has more control functions than a 3G Node B. The S1 interface is a multiple interface that connects a pool of eNodeBs to a pool of mobility management entities and gateways [11].

“Reference [6]”proposed a load balancing scheme which can select a proper serving NodeB (SeNB) among the multiple tergetNodeB (TeNB) for each user based on the load difference and the Signal to Interference plus Noise Ratio (SINR). Performance evaluation was conducted in the network simulator OPNET. The simulation results demonstrated that the proposed scheme can get a lower end-to-end delay. [8] Proposed a handover off-set based load balancing algorithm using the parameter “cell specific offset” to force users to handover from the overload eNodeB to the target eNodeB. The main goal of the proposed algorithm is to find the optimal hand over offset that allows the maximum number of users to change cell without any admission rejection at the target eNodeB. A directional cell breathing based reactive congestion control algorithm was proposed, where the coverage area of a cell can be dynamically extended towards a nearby loaded cell when it is under-loaded.

“Reference [2]”applied Neuro-Encoded Fuzzy model to achieve load balancing using two Key Performance Indicators (KPIs) to increase system performance, thereby justifying the load balancing process. The load indicators are: Virtual load (VL) of eNodeBs and their Overall Load State (OS). The first model is based on a KPI termed Load Distribution Index (LDI) while the second one is premised on the number of unsatisfied users in the cell and is termed Unsatisfied Users (USU) model. In another related work, [1] proposes the use of soft computing, precisely adaptive neuro- fuzzy inference system for dynamic QoS-aware load balancing in 3GPP LTE. Three key performance indicators (i.e., number of satisfied user, virtual load and fairness distribution index) were used to adjust hysteresis task of load balancing. “Reference [5]”presents an optimization framework for load balancing in LTE HetNets, by means of cell range assignment using cell-specific offset. For any given offset setting, the resulting cell load is effectively approached via the solution of a system of non-linear equations characterizing the load-coupling relation between cells. A computationally efficient bounding scheme was presented to approximate the solution of the non-linear system and provide theoretical insights into the monotonicity and convergence of the scheme. The bounding scheme is embedded into an algorithm based on the principle of design of experiments (DOE) for cell offset optimization. Simulation results demonstrate the effectiveness of the optimization process for LTE load balancing with HetNet elements.

“Reference [10]”presented a unified self-management mechanism based on Fuzzy Logic and Reinforcement Learning. The proposed algorithm modifies handover parameters to optimize the main Key Performance Indicators related to load balancing (LB) and handover optimization (HOO). The results show that the proposed scheme effectively provides better performance than independent entities running simultaneously in the network. [6] Proposed a load balancing scheme which can adapt to the network conditions and achieve a better network performance by appropriately distributing the load among the neighbouring cells. The proposed scheme can select a proper SeNB among the multiple TeNB for each user based on the load difference and the Signal to Interference plus Noise Ratio (SINR). The performance evaluation was conducted in the network simulator OPNET. “Reference [4]”evaluated mobility load balancing (MLB) in terms of efficient Pico cell utilization and macro layer load balancing. The analysis focuses on video streaming traffic due to specific service characteristics (e.g., play-out buffer delay/ jitter protection) that might make any mobility performance degradation transparent to the end user performance. The Results showed that the proposed MLB scheme can significantly improve the overall network resources utilization by eliminating potential load imbalances amongst the deployment layers and consequently enhance user experience. However this occurs at the cost of increased Radio Link Failures (RLF), a fact that might be critical if appliedin real-time conversational services without additional mobility optimization and interference management techniques.

II. PROPOSED STRUCTURE OF THE LOAD BALANCING AND OPTIMIZATION SCHEME

The proposed fuzzy inference model for LTE load balancing comprises of a fuzzy logic controller block, Q-learning optimization block and a heterogeneous LTE network block as shown in Fig.1. The inputs to the fuzzy logic controller are the load difference and reference signal receive quality difference of any two adjacent cells. Other variables of interest such as alarms, counters, and/or any other key performance indicators (KPIs) acquired from network statistics or call traces can equally be used as inputs. The outputs propose to the cellular network the new reconfigured parameters in this case incremental cell transmit power which could be positive or negative. The output from the fuzzy controller is first optimized with the Q-learning optimizer before being applied to the network.

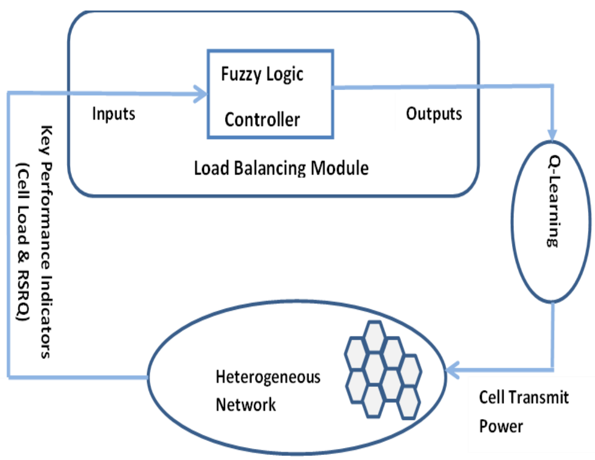

Fig.1. Fuzzy Inference Model for LTE Load Balancing.

The proposed model modifies the service area of the network cells by adjusting its transmit power, PTX(i). A higher/lower transmit power in a base station is directly linked to higher/lower received signal levels in that cell, which has an influence on cell dominance areas. Re-sizing the service areas of a cell can also be achieved by tuning Hand-Over (HO) margins. The HO margin parameter from cell i to cell j, MarginPBGT(i,j), defines by how much the signal level received from a neighbour cell j must exceed that of the serving cell i to trigger a power budget (PBGT) HO from i to j. Thus, a PBGT HO is triggered when,

$$\overline{RSRP}_j - \overline{RSRP}_i \geq Margin_{PBGT(i,j)} \quad (1)$$

Where, $\overline{RSRPi}$ and $\overline{RSRPj}$are the average reference signal received power from the serving cell i and neighbour cellj in dBm, respectively, and $Margin_{PBGT}(i,j)$ is the margin in (dB). As observed in (1), margins are defined on an adjacency basis. Therefore, adjusting this parameter in a single adjacency only has an influence on that adjacency. Thus, cell service areas cannot only be re-sized but also re-shaped. To avoid instabilities in the HO process, a hysteresis region can be maintained by synchronizing changes in both directions of the adjacency (i.e., if the margin from cell i to j is increased by + X dB, the margin from j to i is reduced by −X dB). Unlike margins, transmit power is defined on a cell basis, so that all neighbours are equally affected by changes in the transmit power of a cell. The modification of cell service areas also has an impact on network connection quality. As a result, a user might not be served by the closest base station providing the minimum path-loss which might impair connection quality. Although adaptive modulation and coding in LTE partly alleviates this problem, the link adaptation capability is limited. Therefore, load balancing must be performed carefully to keep Quality-of-Service in a satisfactory level [12].

A.Network Model

The proposed algorithm in this research is applicable to all type of LTE network but for ease of presentation, a hexagonal network topology will be adopted. A hexagonal topology with seven cells numbering 1,2,….7 respectively is shown in Fig. 2, [27].

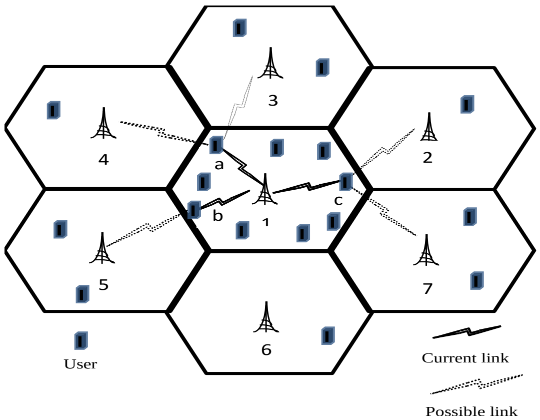

Fig.2.Network Model

Each cell is controlled by a central eNodeB. Cell 1 is assumed to be over-loaded with more users than other cells. Its cell-edge users a, b and c can also be served by cells 3, 4, 5, 2 and 7, respectively. Cell and eNodeB will be used interchangeably throughout this research work and the following assumptions are made:

i. Each user knows the instantaneous signal strength from its serving cell and all the neighboring cells through pilot measurements. All users send them back to their respective serving eNodeBs periodically.
ii. Each eNodeB allocates power equally to all the physical resource blocks (PRB) being used.
iii. Neighboring eNodeBs can exchange their load status information periodically through the X2 interface
iv. Twelve adjacent subcarriers are grouped into a physical resource block (PRB), which is the smallest unit that can be allocated to each user in a subframe (1ms) [22].
v. All time t mentioned in this research represents the time point to conduct load balancing handover, and the span between any t and t + 1 is a load balancing cycle, which is much larger than a subframe.
vi. C, K and K_i are used to denote the sets of cells, users and users served by cell i, respectively. A cell-user connection variable $I_{i;k}(t)$ is defined, which equals 1 when user k which is a member of the set K is served by cell i a member of set C at time t, and 0 otherwise.

B Link Model

The average received SINR at the base station of cell *k* from user *i* at time slot, t is given by:

$$SINR_{i,k}(t) = \frac{P_i(t)/L_{i,k}(t)}{\sum_{j\neq i} P_j(t).\rho_k / L_{j,k}(t) + N} \quad (2)$$

Where, $P_i(t)$ and $P_j(t)$represents the transmit power of the user i at time slot t,$L_{i,k}$represents the path loss from the user i to the base station taking into account the distance between them, and N represents the power of Additive White Gaussian Noise (AWGN). ρ_k Represents the physical resource block (PRB) utilization ratio of cell k. The data rate $S_{i,k}(t)$ at time slot t can be calculated using Shannon Hartley theorem expressed in as:

$$S_{i,k}(t) = x_{i,k}(t)\frac{B}{M}log_2(1 + SINR_{i,k}(t))(3)$$

Where, B represents the total bandwidth for the eNodeB, M is the total number of PRBs for the eNodeB, and $x_{i,k}(t)$ represents the number of PRBs allocated to user i by cell k at time slot t .

From the above it can be seen that the data rate depends on the channel condition between the users and the eNodeB. Which means that to send the same amount of the traffic, the user with a better channel condition will consume a smaller number of the resource blocks than the user with a worse channel condition. The different load distribution of each eNodeB in an LTE network can be represented by:

$$\rho_k(t) = \frac{\sum_{i\in L} x_{i,k}(t)}{M} \quad (4)$$

Where $\rho_k(t)$ is the physical resource block utilization ratio denoting the ratio between the number of the allocated PRBs and the total number of the PRBs in cell k at time slot t. A larger $\rho_k(t)$ indicates a higher percentage of PRB utilization in cell k, and thus a higher level of load in cell k. Assuming all cells have the same number of PRBs, denoted by M, L represents the set of users in the whole network. $x_{i,k}(t)$ is the number of PRBs that cell k allocates to user i at time slot t which is same as the load of user i. One assumes that the length of the time slot is much larger than the subframe duration (e.g., 1ms). Hence the load or the average PRB utilization ratio of the entire network at time slot t is given by:

$$\rho(t) = \frac{1}{|K|}\sum_{k\in K} \rho_k(t) \quad (5)$$

Where, K is the set of the cell in the network and $|K|$

is the number of cells in K.
However, at any given point in time the total load must not exceed the total capacity of the eNodeB. The load balancing index is given by fairness index of (6)[11].

$$\alpha(t) = \frac{[\sum_{k\in K}\rho_k(t)]^2}{|K|[\sum_{k\in K}\rho_k(t)^2]} \quad (6)$$

Note that the range of $\alpha(t)$is $1/_M \leq \alpha \leq 1$

A larger $\alpha(t)$ is an indication that the load is balance among cells and a small $\alpha(t)$ indicate a greater load imbalance among cells. At the point where $\alpha(t)$=1 means all cell in the network have equal load distribution at time slot *t.*

C System Model

The HO is the procedure that preserves the connection when the user moves around the network. As LTE is being deployed with a frequency reuse of one (i.e. the same frequency is shared by all cells), the intra-frequency HO is very common in these networks. More specifically, the most widely extended algorithm for the HO-triggering decision is the 3GPP A3 event [22]. This algorithm triggers the execution of an HO if the neighbouring cell becomes off set better than the serving cell during a specific period determined by the time to trigger (TTT) parameter. Formally, it is expressed as:

$$RSRPj > RSRPi\ + HOMi\_j \quad (7)$$

Where $RSRP_i$ and $RSRP_j$ are the averaged values of the Reference Signal Received Power (RSRP) measured for serving $cell_i$ and target $cell_j$ respectively, and $HOM_{i\text{-}j}$ is the handover margin (HOM). From $cell_i$ to $cell_j$. Note that the symmetric $HOM_{j\text{-}I}$ is also defined in the opposite direction of the adjacency (i.e., a Pair of cells that are neighbours). In contrast with HO-triggering decisions based on absolute comparisons (e.g. The serving/neighbouring cells below/above a threshold), the A3 event consists of a relative comparison that simplifies the configuration of its parameters since they are independent of the absolute received power levels, which may depend on diverse factors. However, the HOM in [7] is broken down into several terms by the 3GPP, so that:

$$HOMi\_j\ = Hys + Ofi - Ofj + Oci - Ocj + Off (8)$$

Where Hys and Off are the hysteresis and off set parameters respectively for this event. Ofi and Oci are the frequency and cell specific offsets respectively for serving celli. And Ofj and Ocj are the frequency and cell specific offsets respectively for neighbouringcellj. While only one value of Hys and Off corresponding to the A3 event can be used for all the cells and deployed frequencies in the network.Oci and Ocj can be defined per cell and Ofi and Ofj can be defined per frequency layer. In addition to this, the definition of Hys implies the existence of another inequality in which this term has opposite sign:

$$RSRPj < RSRPi - Hys\ + Ofi - Ofj + Oci - Ocj + Off. (9)$$

This inequality is called the leaving condition for this event. If the entering condition given by (7) was previously satisfied, the leaving condition must be satisfied to reset the TTT parameter. By optimizing Hys, the impact of signal fluctuations on the handover process can be effectively reduced. In general, the HOO function is directly related to the parameter Hys, so that its optimization could only be performed at the event level. Conversely, load balancing function is more related to HO parameters that are defined at the cell level(e.g., Oci and Ocj). In practice, different parameters are optimized for different cell pairs. The main network level functionalities are admission control and handover. The admission control is responsible for checking the availability of free Physical Resource Blocks (PRBs) in the candidate cell before accepting a call. A worst-case criterion has been taken to accept calls, i.e., the user is finally accepted if the highest number of PRBs needed to maintain a connection (worst-case PRB requirement) is less than or equal to the number of PRBs available in the candidate cell. If the condition is not satisfied by any candidate cell, then the user connection is blocked. On the other hand, the handover allows user mobility across the network. The call dropping model plays an important role because the optimization algorithm attempts to control the occurrence of this event. A call is dropped when a percentage of data packets are dropped during a specific time interval. Packet dropping may occur not only because there is a poor connection quality, but also because there are not any available resources to be scheduled.

III. SYSTEM MEASUREMENT

The most important outcome derived from sharing traffic between cells is that the call blocking is reduced, especially in those cells highly loaded. To quantify the call blocking, network operators usually use the call blocking ratio (CBR) for such measurements. However, load balancing based on CBR algorithm is not a suitable optimum load balancing algorithm for the following reasons: the proposed CBR indicator provides valuable information once the network already presents an accessibility issue. A prediction of this inconvenient situation would be desirable to avoid or reduce users' dissatisfaction as soon as possible [3]. Load difference between adjacent cells instead of CBR is best used as one of the input indicators instead of call blocking ratio. Load difference is related to bandwidth, by measuring the current cell capacity in radio resource terms, the load balance is performed based on the occupied physical resource block (PRB); The PRB is a basic unit of LTE radio resources that provides instantaneous information about cell load. Accordingly, the key network indicator for this system is represented as the following function, which is calculated for each cell as shown in (10) [12]:

$$Load_{Diff} = Load(cell) - \frac{1}{|K|}\sum_{i=1}^{K} Load(i) \quad (10)$$

Usually LTE cells are designed to support specific number of users in connection mode either voice or data traffic. Considering the load difference which is related to bandwidth alone is insufficient.

For that reason, PRB activity may not be always an appropriate indicator for balancing traffic in LTE network where most of the time there could be free resources to allocate user data but cannot be processed due to the limit in the number of accepted users. Hence considering a second input as the number of connected users in the network is required as one of the main parametersto offload temporary congested cells [3].

The input indicator of the fuzzy logic controller(FLC) is defined as the ratio of users in connected mode, i.e., the number of simultaneous users in connected mode N_{active_users} to the cell user limitation $N_{cell\_user\_limitation}$ of the studied cell User(c), in relation to the same ratio averaged in its neighbouring cells User(i):

$$User_{Diff} = User(c) - \frac{1}{|K|}\sum_{i=1}^{K} User(i) \quad (11)$$

Where K is the number of neighbouring cells and User(c) is defined for a cell c as:

$$User(c) = \frac{N_{Active\_user}(c)}{N_{Max\_allowable\_users}(c)} \quad (12)$$

Power load and user sharing as proposed by [3] used as input cell load and active users to achieve load balancing, but the work didn't consider network quality as a priority. Hence active user was a priority regardless of the network quality. This researchput into consideration the quality of the network connection in achieving load balancing. The two inputs used for the FLCare cell load and reference signal receive quality (RSRQ). In LTE network, a UE measures two parameters on reference signal: RSRQ and reference signal received power (RSRP).

A. Received Signal Strength Indicator (RSSI)

The carrier receive strength signal indicator (RSSI) measures the average total received power observed only in OFDM symbols containing reference symbols for antenna port 0 (i.e., OFDM symbol 0 & 4 in a slot) in the measurement bandwidth over M resource blocks. The total received power of the carrier RSSI includes the power from co-channel serving and non-serving cells, adjacent channel interference, thermal noise, etc. RSSI is the total power measured over 12-subcarriers including reference signal (RS) from serving cell and traffic in the serving cell.

B. Reference Signal Received Power (RSRP)

Is the power of the LTE reference signals spread over the full bandwidth and narrowband. A minimum of -20dB SINR (of the S-Synch channel) is needed to detect the ratio of RSRP to RSRQ. In other words,RSRP is the average power of resource elements (RE) that carry cell specific reference signals over the entire bandwidth, so RSRP is only measured in the symbols carrying RS. UE measures the power of multiple resource elements used to transfer the reference signal but then takes an average of them rather than summing them.

RSRP does a better job of measuring signal power from a specific sector while potentially excluding noise and interference from other sectors. RSRP levels for usable signal typically range from about -75dBm close to an LTE cell site to -120dBm at the edge of LTE coverage. The reporting range of RSRP is defined from -140dBm to - 44dBm with 1 dB resolution. The mapping of measured quantities is defined in Table I[14].

Table I: Mapping of Measured Quantities for RSRP

Reported value	Measured value(dBm)
RSRP_00	RSRP<-140
RSRP_01	-140<=RSRP<-139
RSRP_02	-139<=RSRP<-138
……….	……...
……….	……..
RSRP_95	-46<=RSRP<-45
RSRP_96	-45<=RSRP<-44
RSRP_97	-44<=RSRP

C. Reference Signal Received Quality (RSRQ)

RSRQ is a channel indicator type of measurement, and it indicates the quality of the received reference signal. The RSRQ measurement provides additional information when RSRP is not sufficient to make a reliable handover or cell reselection decision. In the procedure of handover, the LTE specification provides the flexibility of using RSRP, RSRQ, or both measured over the same bandwidth:

$$RSRQ = \frac{M \times RSRP}{RSSI} \quad . \qquad (13)$$

Where, M is the number of physical resource blocks (PRBs) over which the RSSI is measured and its typically equal to system bandwidth. RSSI is pure wide band power measurement, including intra-cell power, interference, and noise. The reporting range of RSRQ is defined from -3dB to -19.5dB as shown in Table II [14].

Table II: Mapping of Measured Quantities of RSRQ

Reported value	Measured value(dBm)
RSRQ_00	RSRQ<-19.5
RSRQ_01	-19.5<=RSRQ<-19.0
RSRQ_02	-19.0<=RSRQ<-18.5
……….	……...
……….	……..
RSRQ_32	-4.0<=RSRQ<-3.5
RSRQ_33	-3.5<=RSRQ<-3.0
RSRP_34	-3.0<=RSRQ

The radio frequency (RF) condition for a wireless network is categorized as shown in Table III.

Table III: RF Conditions Categorization for Wireless Network

RF Conditions	RSRP (dBm)	RSRQ (dB)	SINR (dB)
Excellent	>= -80	>= -10	>= -20
Good	-80 to -90	-10 to -15	13 to 20
Mid Cell	-90 to -100	-15 to -20	0 to 13
Cell Edge	<= -100	< -20	<= 0

Using (14), Table IV is generated which is used to create the membership function for the $RSRQ_{Diff}$ input to the fuzzy logic.

$$RSRQ_{Diff} = |RSRQ|_i - |RSRQ|_j \quad (14)$$

Table IV: $RSRQ_{Diff}$

|RSRQi| (dB)	|RSRQj|(dB)	|RSRQi|(dB) - |RSRQj|(dB)
20	10	10
15	10	5
20	15	5
10	10	0
15	15	0
20	20	0
10	15	-5
15	20	-5
10	20	-10

Based on expert knowledge, and in order to get a moderate level of details and a simple fuzzy control rules, an acceptable number of membership function have been selected for each input and output variables as shown in Fig. 3, 4, and 5. The labels and values are as follows: 'Very Negative' and −6 dB, 'Negative' and −3 dB, 'Zero' and 0 dB, 'Positive' and +3 dB, and 'Very Positive' and +6 dB. The summarized label and values for the input variables $RSRQ_{diff}$ and $Load_{diff}$ as well as the output δPTx(cell) is as shown in Table V.

For simplicity and computational efficiency, the employed membership functions are triangular and trapezoidal. The fuzzy rules are defined based on these two indicators and the expert knowledge.

Table VI presents the set of control rules implemented in this system. These rules prioritize the KPIRSRQ$_{diff}$ over the Load$_{diff}$.

IV. REALIZATION OF FUZZY LOGIC CONTROLLER FOR LTE LOAD BALANCING

The inputs to the fuzzy logic controller as shown in Fig. 3 and 4 are Load$_{diff}$ and RSRQ$_{diff.}$ The output of the FLC is the power increment δPTx(cell) as shown in (15).

$$\Delta PTx(cell) = PTxmax(cell) - [PTx(cell) + \delta PTx(cell)] \quad (15)$$

Where, ΔPTx(cell) is the current power deviation, PTxmax(cell) is the default (maximum) transmit power of the cell,PTx(cell) is the current transmit power of the cell and δPTx output control power increment.

A. *Universe of Discourse for Load$_{diff}$, RSRQ$_{diff}$ and Output Control*

The universe of discourse for Load$_{diff}$, RSRQ$_{diff}$ and δPTxassociated with the fuzzy rule in Table V are as given in(10), (14), and (15). Fig. 3, 4 and 5 gives detailed descriptions of the membership functions. The ranges for each of the variables are expressed by(16), (17), and (18).

$$Load_{diff} = -1 \leq PRB \leq +1 \quad (16)$$

$$RSRQ_{diff} = -10dB \leq RSRQ < +10dB \quad (17)$$

$$\delta P_{\text{TX}} = -6dBm < \delta P_{\text{TX}} < +6dBm \quad (18)$$

Table V:Label and Values for Input and Output Variables

Parameter	μy(RSRQdiff) (dB)	μx(Load diff) (RB)	$\mu_x(\delta$PTx (dBm)
Very Negative	-2.5 to -10	-0.25 to -.00	-6
Negative	0.0 to -5.0	0.00 to -0.50	-3
Zero	2.5 to -2.5	0.25 to -0.25	0
Positive	0.0 to 5.0	0.00 to 0.50	3
Very Positive	2.5 to 10	0.25 to 1.00	6

Table VI: Fuzzy Rules for QLUS Load Balancing

Rules No.	Input1: μy(RSRQdiff) (dB)	Input2: μx(Loaddiff) (RB)	*Output:* $\mu_x(\delta$PTx (dBm)
1	Negative	Negative	Very Positive
2	Negative	Positive	Zero
3	Negative	Very Negative	Very Positive
4	Negative	Very Positive	Zero
5	Negative	Zero	Positive
6	Positive	Negative	Negative
7	Positive	Positive	Very Negative
8	Positive	Very Negative	Negative
9	Positive	Very Positive	Very Negative
10	Positive	Zero	Very Negative
11	Very Negative	Negative	Very Positive
12	Very Negative	Positive	Zero
13	Very Negative	Very Negative	Very Positive
14	Very Negative	Very Positive	Zero
15	Very Negative	Zero	Positive
16	Very Positive	Negative	Negative
17	Very Positive	Positive	Very Negative
18	Very Positive	Very Negative	Negative
19	Very Positive	Very Positive	Very Negative
20	Very Positive	Zero	Very Negative
21	Zero	Negative	Positive
22	Zero	Positive	Negative
23	Zero	Very Negative	Very Positive
24	Zero	Very Positive	Very Negative
25	Zero	Zero	Zero

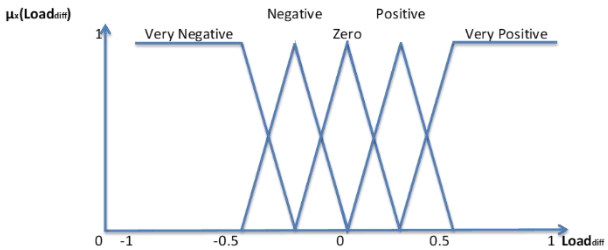

Fig. 3: Membership Function of Load Difference Between Cell A and Cell B

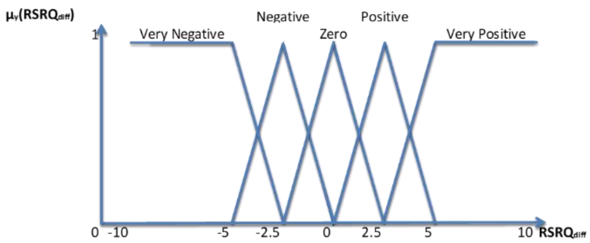

Fig.4:Membership Function of RSRQ Difference Between Cell A and Cell B

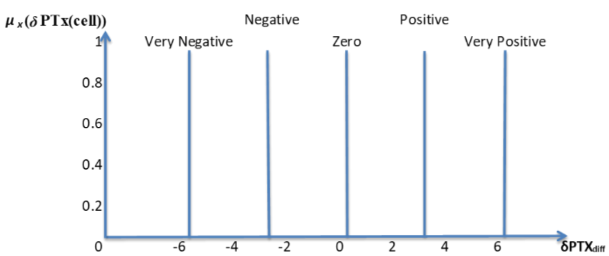

Fig. 5:Membership Function of Incremental Power Output From Fuzzy Logic

V. Network Model Implementation

The following assumptions were made in the computation:

i. For the purpose of explanation and clarity, two hexagonally shaped adjacent cells were used as the service area.

ii. The bandwidth of the cells is the same, but the maximum allowable load can be varied. In this case 20MHz is used with a maximum number of resource block of 100.

iii. A normal cyclic prefix, FDD mode is used giving the OFDM symbols to be 7 per slot, subcarrier spacing of 15kHz and 12 subcarrier per resource block.

iv. All loses along the path of transmission from the eNodeB to the end user was assumed negligible.

A. LTE Cell Block

For an LTE eNodeB with normal cyclic prefix and frequency division duplexing (FDD) mode with a bandwidth (BW) of 20MHz. Each resource block (RB) consists of 12 subcarriers (Nrb_sc) each with subcarrier spacing (deltaF) of 15kHz with 7 OFDM per slot [7]. Hence:

$$RB = deltaF \times Nrb\_sc = 15\, kHz \times 12 = 180\, kHz. \quad (19)$$

For bandwidth between 3MHz to 20MHz, the resource block occupies 90% of the bandwidth. Total number of resource block for a bandwidth of 20MHz is therefore given by (20).

$$Nrb = (0.9 \times BW)/RB = (0.9 \times 20MHz)/180\, kHz = 100 \quad (20)$$

B. Mobile Users Block

Five mobile user groups are specified with same data usage in terms of resource block requirement. The minimum usable resource block per user (Ue) is two. Resource blocks are allocated to each user (Ue) uniformly in a random pattern. The users arrive at different rates as shown in Table VII.

Table VII: End Users Arrival Rate

User group	Arrival rate	No of users
1	Rate1	28
2	Rate2	9
3	Rate3	12
4	Rate4	7
5	Guaranteed user with fixed RB	5

The maximum number of resource block that can be allocated to a user group is:

$$Ue = Ratio \times Nrb \times Rate \quad (21)$$

The arrival rate of users in each group is generated uniformly at random at a sample rate of 100s.

C. Cell Power Allocation Block

As mentioned above, each resource block (RB) consists of 12 subcarriers out of which two are referred to as reference signal receive element (RSRE) because they carry the reference signal for that resource block. The remaining ten subcarriers or elements are called resource block receive element (RBRE) because they carry the actual data for that resource block. [7]. The reference signal receive element power is given by:

$RSRE_{power} = power_{in_{dBm}} - 10 \times Log\,(12 \times Nrb_{Ue}) + Pb$(22)

Where;

$Power_{in_{dBm}}$ = Power from a single antenna port in dBm,

Pb= Power boosting factor, Nrb = Number of resource block per cell.

The resource block receive element power is given by:

$RBRE_{power} = Power_{in_{dBm}} - 10 \times Log(12 \times Nrb_{Ue}) - 0.25 \times Pb + Intf$ (23)

Where;

Intf = Is the interference factor from neighbouring cells [20].

D. Cell Channel Status Indication (CSI)

The total received signal strength indicator (RSSI) for a specified number of resource block assigned to users (Nrb_{Ue})is calculated as shown in (24).

$RSSI = Nrb_{Ue}\left(10 \times RBRE_{power} + 2 \times RSRE_{power}\right)$. (24).

Reference signal received power (RSRP) is equal to the reference signal received element (RSRE) [14].

$RSRP = RSRE_{power}$. (25).

Reference signal receive quality is as shown in(26).

$RSRQ = \frac{RSRP}{RSSI}$ (26).

E. Q-learning Block

In Q-learning, the agent maintains a table of Q[S,A], where S is the set of states and A is the set of actions. The agent can use the temporal difference equation (27) to update its estimate for Q(s,a).

$Q = Qn + \alpha(r + \gamma max(Qn, Qn\_1)$ (27)

WhereQ is the optimized value, Qn is the current value, Qn_1 is the previous value, α is the learning rate, r is the reward, γ is the discount factor [4].

For an FDD with channel bandwidth greater than 10MHz, the maximum antenna output power is specified at 64dBm with a power control range of 20dB. The Q-Learning optimizer is to keep the cell transmit power within a specified range. For this research, the cell transmit power was maintained within 46dBm plus or minus 6dBm.

The Q-learning algorithm was written and implemented with the MATLAB software. This was used to optimize the output from the fuzzy logic controller.

$r = \delta PTx.$ (28)

From (15), cell transmit power is being optimized with the incremental power from the fuzzy controller as shown in (29).

$PTx = PTx(cell) + \delta PTx(cell).$ (29)

Modifying (27) with (28):

$Q = Qn + \alpha(\delta PTx + \gamma\, max(Qn,\ Qn_1))$ (30)

The output from the Q-learning algorithm as expressed in (30), is the optimized incremental power output to be feedback to the LTE network. Hence(29) is modified as:

$PTx = PTx(cell) + Q$ (31)

The cell transmit power is increased or decreased based on the input response from the fuzzy controller to the network load and receive signal reference quality at its inputs. But there is an upper and lower limit bound constraining the amount of power that can be pushed in or taken out from the cell transmitter. Practical RF LTE antennas have 500w (57dBm) as the maximum output power it can produce and a minimum as low as -50dBm in some cases. For this research, a default transmit power of 46dBm has been chosen with a plus or minus 6dBm as its control range to keep the cells from overshoot to neighbouring cells.

From the above stated facts, the equality constraint is given as:

$40dBm \leq PT_{x(cell)} \leq 52dBm$(32)

$0 \leq \gamma \leq 1$ (33)

$0 \leq \alpha \leq 1$ (34)

Solving (30) and (31) with the three constrains in (32), (33), and (34) analytically is practically cumbersome and almost impossible since there are more variables than equation. But with written script in MATLAB, the plotted returned the best values of α as 0.2 while that of γ is 0.2.

F. Satisfied/Unsatisfied Users

This indicator relates to the number of users in the cell that can achieve the desired bit rate in terms of resource block required despite resource limitations.

(35) and (36) show users satisfaction in the network [2].

$$Satisfied_{USERS} = U \times \left(min(1, {}^{1}/_{\rho}\right) \qquad (35)$$

$$UnSatisfied_{USERS} = U \times (max(0, (1 - {}^{1}/_{\rho}))(36)$$

Where, ρ is the virtual load as given by (5) and U is the total number of users in the cell.

If ρ< 1 implies all the users are satisfied.

VI. SIMULATION RESULTS

Load balancingyielded an increase in the overall performance of the network. Some of the measurable indexeshighlighted are number of satisfied and unsatisfied users from the customer's perspective and load distribution index from the service provider perspective.

A. Simulation of the Load Distributions without Fuzzy Logic Controller and Q-learning Optimizer

Fig. 6, 7, and 8shows simulation result of the load distribution from cell A and cellB without the application of the proposed quality and load user system (QLUS). The variation of the load on both cells is obviously unbalance as can be seen from the load differences depicted in the plots of Fig.6.

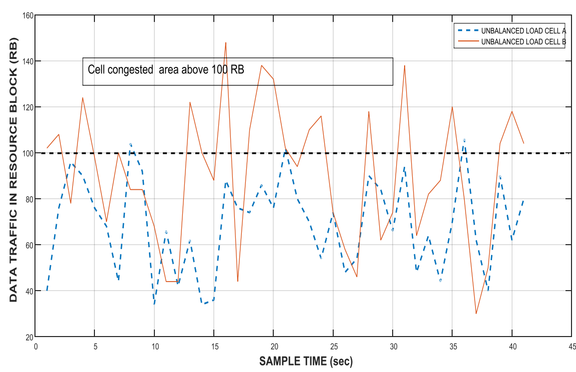

Fig.6: LTE Cell A and Cell B load Distribution without QLUS and Q Learning Optimizer

B. Simulation results of cell A connected usersand users' satisfaction

The number of satisfied and unsatisfied users in the network are measured using (35) and (36).

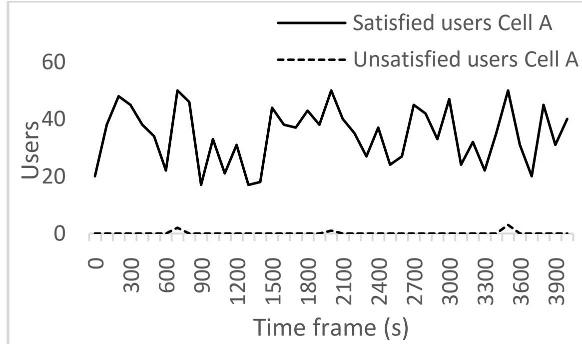

Fig. 7: Simulation Results of Cell A Connected Users Load and Users Satisfaction

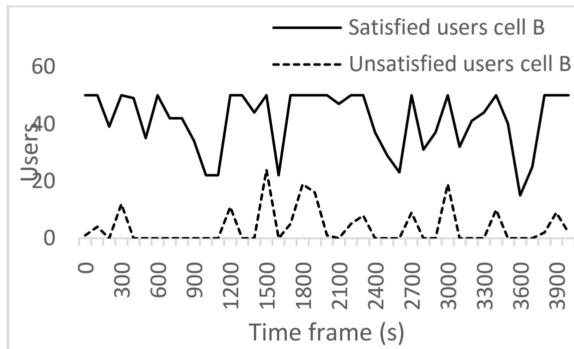

Fig.8: Simulation results of Cell B Connected Users, Load and Users Satisfaction

From Fig. 7 and 8, the total number of unsatisfied users in cell A and cell B before load balancing is applied are 6 and 157 respectively. Cell B is assumed to be in a very busy environment with high demand for network resources hence the high volume of traffic causing congestion in its network during peak periods resulting to very high number of unsatisfied users. While cell B is congested forsome given period, its adjacent cell A has excess and idle resources that can accommodate the demands of some of the users in cell B.

A congested cell has an impact on the quality ofservice the users are experiencing as shown in Fig. 9 and 10. The further the network quality degrades, the more the number of unsatisfied users. The effect is more pronounced on cell B because it is more congested than cell A. If the trend continues unchecked, it will get to a point where the network service provider will start losing its customers to other networks with better quality resulting to revenue losses.

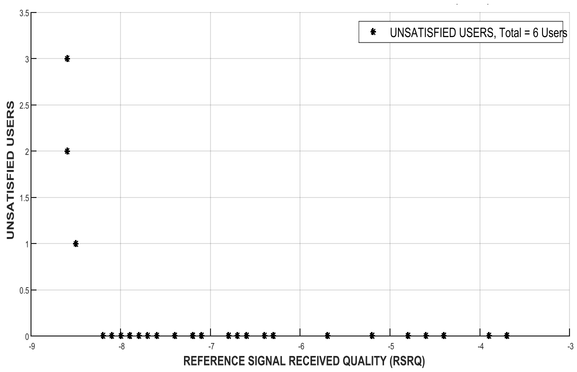

Fig. 9: LTE Cell A Unsatisfied Users and Network Quality

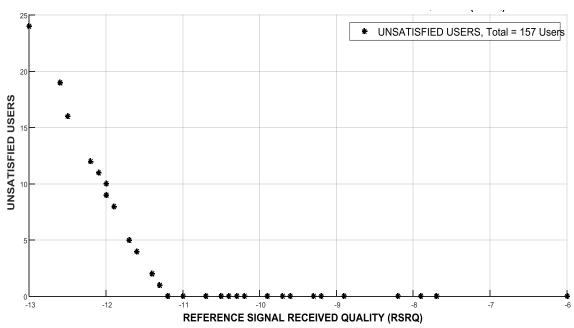

Fig. 10: LTE Cell B Unsatisfied Users and Network Quality

C. *Simulation of the Load Distributions with Fuzzy Logic Controller and Q-learning Optimizer*

Fig. 11, 12 and 13 shows the load distribution for cell A and cell B after the application of the proposed Quality and Load user System (QLUS) and Q learning algorithm to balance and optimized the loads on both cells. It can be seen from Fig. 11 that the load difference between the two cells have been reduced as much as possible compared to the load difference seen in Fig.6. The simulation resultsshow the effective performance of the Quality and Load user System to achieve load balancing in LTE network. The number of unsatisfied users was significantly reduced in both cells. Hence the cells are more balanced load wise. Each cell takes advantage of idle resources of its neighbour when in need of it.

The load balancing cycle is a planned process which first seeks a target cell with free resources to accommodate some or all its unsatisfied users due to constrained resources with the condition not to overload the target cell itself.

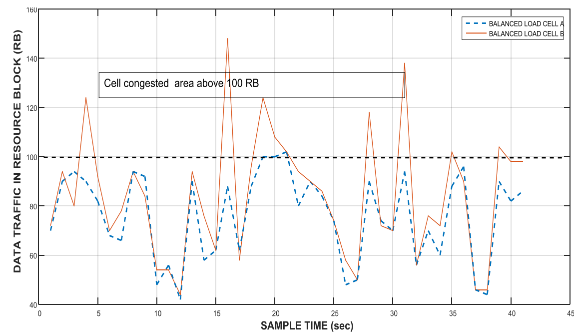

Fig. 11: LTE Cells A and B load Distribution with QLUS

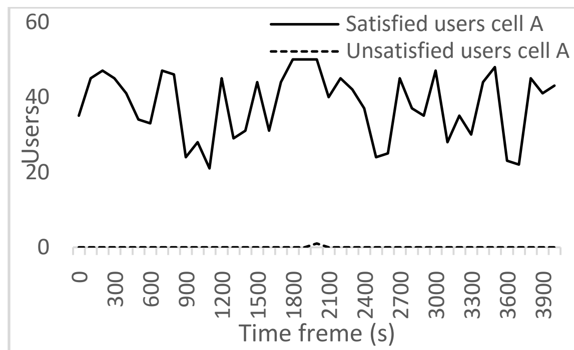

Fig. 12: Simulation results of Cell A Connected Users, Balanced Loads and Users Satisfaction

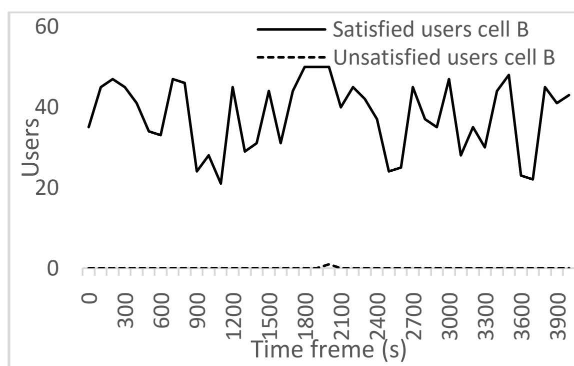

Fig. 13: Simulation results of Cell B Connected Users, Balanced Loads and Users Satisfaction

D. Satisfied/unsatisfied users after load balancing cycle.

The number of unsatisfied users can be seen to have greatly reduced in both cell A and cell B because of load balancing done with QLUS. This action also effectively improved the quality of service of more users. This is a win-win situation for both the end users and the network service provider. In cell A, the number of unsatisfied users dropped from 6 to 1 which indicates 83% improvement. This is shown in Fig. 12. While cell B which had 157 number of unsatisfied users also had some improvement with the figure dropping to 84 as shown in Fig. 13. This value indicates a 47% improvement from its unbalance state. For the entire network there is a 48% improvement as the number of unsatisfied users dropped from 163 to 85. These indicators are necessary for network forecasting and planning. If a cell still experiences congestion after load balancing and the number of unsatisfied users is reasonably high over a considerable period, physical network infrastructural expansion will have to be carried out to take care to expand the network capacity. Also, product promotion can be initiated to encourage usage during off peak periods to decongest the cells.

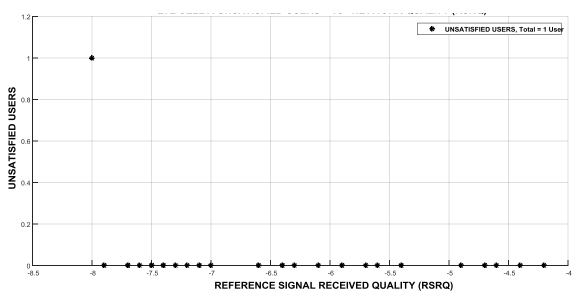

Fig. 14: LTE Cell A Unsatisfied Users and Network Quality with QLUS

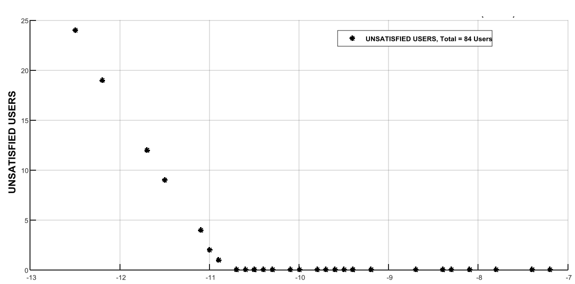

Fig. 15: LTE Cell B Unsatisfied Users and Network Quality with QLUS

E. Simulation of the Network Performance as Indicated by the Load Balancing Indexα(Alpha) with and without Q-learning Optimizer

The load balancing index given by the fairness index in (7)was also simulated to measure the stability and effectiveness of the propose QLUS. A larger α value is an indication that the load is balance among the cells while a small α value indicate a greater load imbalance among cells. At the point whereα is equal to unity, means all cells in the network have equal load distribution [11]. Fig. 16 shows the variation of the fairness index before and after load balancing and the application of Q learning optimizer. The index value ranged from0.8 to 1 with a standard deviation of 0.05 from its unbalanced load. The result indicates the degree of uneven load distribution in the cellwithin the simulated time frame. While great improvement can be seen after load balancing was carried out, the fairness index can be seen approaching unity with a standard deviation of 0.01 which is almost negligible.

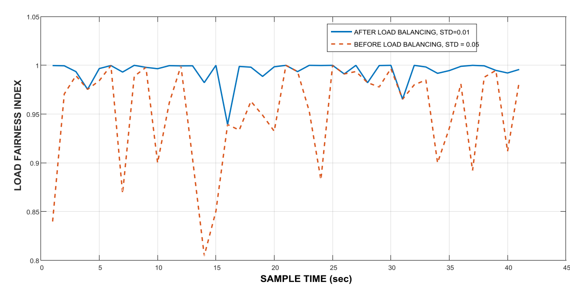

Fig. 16: LTE Cell Load Fairness Index

F. Simulation of the Network Performance as Indicated by Call Blocking Ratio (CBR)

The call blocking ratio indicating how efficiently the available network resources are use can be seen to have improved greatly after the load balancing cycle. As shown in Fig.17. CellA experienced 83% improvement while cell B experienced 48% improvement, this result is in consonant with the user satisfaction. The fewer the calls that are blocked, the more satisfied users will be.

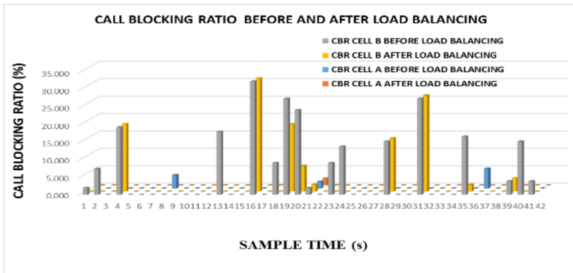

Fig.17: Call Blocking Ratio (CBR)

CONCLUSION

This research presents a successful application of FLC to balance the load on adjacent cells in an LTE network simulated in MATLAB/Simulink environment freeing upresources forusage in the entire network. A hexagonal shaped having specific number of resource block (RB) based on the bandwidth of the eNodeB with varying number of users arriving at a uniform but random rate. The users having various resource requirement whose sum is equal to the load on the cell they are latched on. The load difference of two adjacent cells as shown in Fig.11. can be seen to have reduced after the application of Quality and Load user System (QLUS) and Q learning optimizer.

The main load balancing indicator in any network is determined by the measurement of the fairness index $\alpha(t)$of the network shown in Fig.16.oscillate between 0.8 and 1 for the unbalanced network. This indicates a wide disparity in the load distribution in the various cells of the network. With the application of the fuzzy logic controller and Q learning optimizer, the fairness index approaches a value of unity throughout the simulation period. This indicates the effectiveness of the proposed Quality and Load user System (QLUS) and Q learning optimizer to achieving load balancing in the networks.

The quality and load user system (QLUS) can be seen to have performed better as compared to the work done by [15]. The overload distribution index increases monotonically from about 0.6 to a maximum value of 0.85. The upward trend of the load fairness index in his work indicated that there is a large degree of load imbalance at the early stage of the simulation showing that some cell could have been congested already before load balancing was achieved at the later stage. While this research shows the load distribution index with a mean value of 0.99 which is attributed to the fact that load balancing was carried out right from the onset before the cells starts getting congested. This gives a better all-round customer experience.

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