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Adaptive Equalization Technique for Mitigating Effect of Multi Terrain Multipath Signal Quality

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ABSTRACT

This research presents mitigating the effect of multi terrain on quality of multipath signal using adaptive equalization technique. This was achieved using neural network to improve the performance of an equalizer and then integrated on a wireless network system to improve quality of service at the receiver end during downlink. The system was implemented with simulation and the result when tested showed that the adaptive equalizer was able to improve received signal from -93.5125dBm in the characterized to -73.3875dBm. The percentage improvement achieved is 21.52%. The results achieved were analyzed by the Nigerian Communications Commission (NCC) standard for quality of service and the result showed that the new system achieve good signal indicator which showed that the impact of fading from the environment was not able to affect quality of receiver service. The result achieved as the average signal strength is good, but future work can improve it to very good by training the neural network with more data which has only optimal signal strength.

Keywords – **Adaptive equalization, Multipath, Multi terrain, Neural network, Signal quality.**

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I. INTRODUCTION

The multipath propagation approach employed by Information and Communication Technology Industries (ICTI) often experiences many problems at the receiver end due to obstacles along the line of sight (LOS) such as buildings, mountains, ionosphere, ceiling, water, etc and as a result induces characteristics such as scattering, reflection, refraction, among other which changes the behaviour of the signal such as amplitude, time of arrival, etc and results in technical problems like fading, latency, losses among other indicators for poor QOS. Many ways of combating the effect multipath effect have been presented including the use of multiple antennas in wireless communication systems, which have resulted in multiple channels that enable the rate of data transfer and improved channel capacity [1]. Nevertheless most of the approaches implemented do not provide impressive performance. There is need to develop a solution which is sensitive to these multipath effects on signal quality, mitigating their implications and ensuring quality of service at the receiver end.

One approach to addressing the effective of multipath is the implementation of equalization technique. According to Akaneme and Onoh [2], the equalization techniques perform better than their counterparts, as it has the ability to compensate for losses and variation in signal irrespective of the user position. The equalization technique was formulated from the equalizer, which is an adaptive filter with the ability to compensate for varying frequency of other signal processing units [3]. This was employed in signal processing for the compensation and cancellation of destructive interference signal due to multipath propagation, while simultaneously rejecting addictive interfering signal which are not correlated with the source. However despite the success achieved, the inability of equalizers to dynamically adjust to changing properties of the multipath channels presented the need for adaptive equalizers [4].

Adaptive equalizers are filters which automatically adjust its properties to blend with the channel properties at all boundary conditions and have recorded better performance at the user ends, when compared with the conventional equalizers [5-7]. However despite the success achieved, there is need for a solution which is reliable especially in a case where the receiver behavior is time variant.

To this end, Machine Learning (ML) solution is proposed to optimize the equalization process. The use of ML has the potential to perform better other adaptive algorithms such as Root Mean Square (RMS), Least Square Error (LSE), etc [2]. This is because the ML is an artificial intelligence technique which has the ability to learn and make correct decisions and have excelled in other areas, even here in the field of communication engineering. This approach will therefore adopt the techniques while considering dynamic position of receivers alongside the multipath channel characteristics to improve quality of service in wireless communication.

II. METHODS OF MITIGATING DESTRUCTIVE EFFECTS OF MULTIPATH ON SIGNAL QUALITY

Equalization, diversity, and channel coding are three techniques which can be used independently or hybrid to improve received signal quality.

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2.1 Equalization

Equalization compensates for Inter Symbol Interference (ISI) created by multipath within time dispersive channels. If the modulation bandwidth exceeds the coherence bandwidth of the radio channel, ISI occurs and modulation pulses are spread in time. An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics. Equalizers must be adaptive since the channel is generally unknown and time varying [5]. There are different types of equalizer.

2.1.1 Linear Equalizer

Linear equalizer is usually a tapped-delay-line filter with coefficients that are adapted to the channel state. A linear equalizer can be implemented as an FIR filter. In such an equalizer, the current and past values of the received signal are linearly weighted by the filter coefficient and summed to produce the output [5].

2.1.2 Nonlinear Equalization

Nonlinear equalizers are used in applications where the channel distortion is too severe for a linear equalizer to handle. Three very effective nonlinear methods offer improvements over linear equalization techniques are [8];

- Decision Feedback Equalization (DFE)
- Maximum Likelihood Sequence Estimation (MLSE)

a. Decision Feedback Equalizers

In decision feedback equalization, once a bit is correctly detected, the effect this bit on subsequent bit is determined. The ISI caused by each bit is then subtracted from these later samples. The basic idea behind decision feedback equalization is that once an information symbol has been detected and decided upon, the ISI that it induces on future symbols can be estimated and subtracted out before detection of subsequent symbols [8].

Another form of DFE proposed by Belfiore and Park is called a predictive DFE. It consists of a feed forward filter (FFF) as in the conventional DFE. However, the feedback filter (FBF) is driven by an input sequence formed by the difference of the output of the detector and the output of the feed forward filter. Hence, the FBF here is called a noise predictor because it predicts the noise and the residual ISI contained in the signal at the FFF output and subtracts from it the detector output after some feedback delay. The predictive DFE performs as well as the conventional DFE as the limit in the number of taps in the FFF and the FBF approach infinity. The FEF in the predictive DFE can also be realized as a lattice structure. The Root Least Square (RLS) lattice algorithm can be used in this case to yield fast convergence [6].

b. Maximum Likelihood Sequence Estimation (MLSE) Equalizer

The use of MLSE as an equalizer was first proposed by Forney in which he set up a basic MLSE estimator structure and implemented it with the Viterbi algorithm. This algorithm was recognized to be a maximum likelihood sequence estimator (MLSE) of the state sequences of a finite state Markov process observed in memory less noise. It has recently been implemented successfully for equalizers in mobile radio channels [9]. The MLSE is optimal in the sense that it minimizes the probability of a sequence error. It requires knowledge of the channel characteristics in order to compute the metrics for making decisions and also need the knowledge of statistical distribution of noise corrupting the signal for equalization. Thus, the probability distribution of the noise determines the form of the metric for optimum demodulation of the received signal [10].

2.2 Diversity Technique

Diversity is another technique used to compensate for fading channel impairments, and is usually implemented by using two or more receiving antennas. As with an equalizer, the quality of a mobile communications link is improved without increasing the transmitted power or bandwidth. However, while equalization is used to counter the effects of time dispersion (ISI), diversity is usually employed to reduce the depth and duration of the fades experienced by a receiver in a flat fading (narrowband) channel [7].

Diversity techniques can be employed at both base station and mobile receivers. The most common diversity technique is called spatial diversity, whereby multiple antennas are strategically spaced and connected to a common receiving system. While one antenna sees a signal null, one of the other antennas may see a signal peak, and the receiver is able to select the antenna with the best signal at any time. Other diversity techniques include antenna polarization diversity, frequency diversity, and time diversity. CDMA systems often use a RAKE receiver, which provides link improvement through time diversity [9].

2.2.1 The Space/ Spatial Diversity Techniques

Space diversity also known as antenna diversity, is one of the most popular forms of diversity used in wireless systems. Conventional wireless systems consist of an elevated base station antenna and a mobile antenna close to the ground. This method was used in [11] to evaluate the capacity of multiple antenna wireless system under different arrangement and channel configuration. The existence of a direct path between the transmitter and the receiver is not guaranteed and the possibility of a number of scatters in the vicinity of the mobile suggests a Rayleigh fading signal [7].

The concept of antenna space diversity is also used in base station design. At each cell site, multiple base station receiving antennas are used to provide diversity reception. However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation. Separations on the order of several tens of wavelengths are required at the base station. Space diversity can thus be used at either the mobile or base station, or both. Space diversity reception method can be classified into four categories [7].

- Selection diversity
- Feedback Diversity
- Maximal Ratio Combining
- Equal Gain Diversity

a. Selection diversity

Selection diversity is the simplest diversity techniques which the receiver branch have the highest instantaneous SNR connected to the demodulator. The antenna signals themselves could be sampled and the best one sends to a signal demodulator. For instance, maximal ratio combining (MRC), selective combining (SC), and equal gain combining were used as space receive diversity techniques to examine the performance of massive multiple input multiple output (MIMO) system in wireless communication [12].

b. Feedback Diversity or scanning diversity

Scanning diversity is very similar to selection diversity except that instead of always using the best of M signals, the M signals are scanned in a fixed sequence until one is found to be a above predetermined threshold. This signal is then received until it falls below threshold and the scanning process is again initiated. The resulting fading statistics are somewhat inferior to those obtained by the other methods, but the advantage with this method is that it is very simple to implement only one receiver is required [7].

c. Maximal Ratio Combining

In this method first proposed by Kahn, the signals from all of the branches are weighted according to their individual signal voltage to noise power ratios and summed. Here, the individual signals must be co phased before being summed which generally requires a receiver and phasing circuit for each antenna element. Maximal Ratio Combining produces an output SNR equal to the sum of the individual SNRs. Thus, it has the advantage of producing an output with an acceptable SNR even when none of the individual signals are themselves acceptable. This technique gives the best statistical reduction of fading of any known linear diversity combiner. Modern DSP techniques and digital receiver are now making this optimal form of diversity practical [7].

d. Equal Gain combining

In certain cases it is not convenient to provide for the variable weighting capability required for true maximal ratio combining. In such cases, the branch weights are all set to unity, but the signals from each branch are co phased to provide the equal gain combining diversity. This allows the receiver to exploit signals that are simultaneously received on each branch. The possibility of producing an acceptable signal from a number of unacceptable inputs is still retained, and performance is only marginally inferior to maximal ratio combining and superior to selection diversity [7].

2.2.2 Polarization Diversity

At the base station, space diversity is considerably less practical than at the mobile because the narrow angle of incident fields requires large antenna spacing. The comparatively high cost of using space diversity at the base station prompts the consideration of the using orthogonal polarization to exploit polarization diversity. While this only provides two diversity branches, it does allow the antenna elements to the co-located [7].

In the early days of cellular radio, all subscriber units were mounted in vehicles and used vertical whip antennas. Today, however, over half the subscriber units are portable. This means that most of subscribers are no longer using vertical polarization due to hand-tilting when the portable cellular phone is used. This recent phenomenon has sparked interest in polarization diversity at the base station. Measured horizontal and vertical polarization paths between a mobile and a base station are reported to be uncorrelated by [6]. The decorrelation for the signals in each polarization is caused by multiple reflections in the channel between the base station and antennas. The reflection coefficient for each polarization is different, which results in different amplitudes and phases for each, or at least some, of the reflections. After sufficient random reflections, the polarization state of the signal will be independent of the transmitted polarization [13].

Circular and linear polarization antennas have been used to characterize multipath inside buildings. When the path was obstructed, polarization diversity was found to dramatically reduce the multipath delay spread without significantly decreasing the received power. While polarization diversity has been studied in the past, it has primarily been used for fixed radio links which vary slowly in time. Line-of-sight microwave links, for example, typically use polarization diversity to support two simultaneous users on the same radio channel. Since the channel does not change much in such a link, there is little likelihood of cross polarization interference. As portable users proliferate, polarization diversity is likely to become more important for improving link margin and capacity [6].

2.2.3 Frequency Diversity

Frequency diversity is implemented by transmitting information on more than one carrier frequencies. The rationale behind this technique is that frequencies separated by more than the coherence bandwidth of the channel will be uncorrelated and will thus not experience the same fades. Theoretically, if the channels are uncorrelated, the probability of simultaneous fading will be the product of the individual fading probabilities. Frequency diversity is often employed in microwave line-of-sight links which carry several channels in a frequency division multiplex mode (FDM). Due to troposphere propagation and resulting refraction, deep fading sometimes occurs [7].

2.2.4 Time Diversity

Time diversity repeatedly transmits information at time spacing that exceed the coherence time of the channel, so that multiple repetitions of the signal will be received with independent fading conditions, thereby providing for diversity. One modern implementation of time diversity involves the use of the rake receiver for spread spectrum CDMA, where the multipath channels provide a redundancy in the transmitted message. By demodulating several replicas of the transmitted CDMA signal, where each replica experience a particular multipath delay, the rake receiver is able to align the replicas so that a better estimate of the original signal may be formed at the receiver. The wireless propagation channel is time variant. So the signals that are received at different times are uncorrelated. For sufficient decorrelation, the temporal distance must be at least $\frac{1}{2vax}$, where v_{max} is the maximum Doppler frequency [7].

2.2.5 Angle Diversity

A fading dip is created when Multipath Components (MPCs) interfere destructively. If some of these waves are attenuated or eliminated, then the location of fading dips changes In other words, two co-located antennas with different patterns see differently weighted MPCs, so that the MPCs interfere differently for the two antennas [13]. This is the principle of angle diversity (also known as pattern diversity). Angular diversity is usually used in conjunction with spatial diversity. Different antenna patterns can be achieved very easily. Different types of antennas have different patterns. But even identical antennas can have different patterns when mounted close to each other [7].

2.3 Channel coding

Channel coding improves mobile communication link performance by adding redundant data bits in the transmitted message. At the baseband portion of the transmitter, a channel coder maps a digital message sequence into another specific code sequence containing a greater number of bits than originally contained in the message. The coded message is then modulated for transmission in the wireless channel. Channel coding is used by the receiver to detect or correct some (or all) of the errors introduced by the channel in a particular sequence of message bits [6]. Because decoding is performed after the demodulation portion of the receiver, coding can be considered to be a post detection technique. The added coding bits lowers the raw data transmission rate through the channel (expands the occupied bandwidth for a particular message data rate). There are two general types of channel codes: block codes and convolutional codes. Channel coding is generally treated independently from the type of modulation used, although this has changed recently with the use of trellis coded modulation schemes that combine coding and modulation to achieve large coding gains without any bandwidth expansion [6].

2.4 Combination of interleaving and coding

Advanced version of repetition coding is forward error correction coding with interleaving. The different symbols of a code word are transmitted at different times. This increases the probability that at least some of them arrive with a good SNR. The transmitted code word can then be reconstructed [7].

2.5 Rake receiver

In Code Division Multiple Access (CDMA) spread spectrum systems, the chip rate is typically much greater than the flat-fading bandwidth of the channel. Whereas conventional modulation techniques require an equalizer to undo the inter symbol interference between adjacent symbols, CDMA spreading codes are designed to provide very low correlation between successive chips. Thus, propagation delay spread in the radio channel merely provides multiple versions of the transmitted signal at the receiver. If these multipath components are delayed in time by more than chip duration, they appear like uncorrelated noise at a CDMA receiver, and equalization is not required. The spread spectrum processing gain makes uncorrelated noise negligible after dispreading. However, since there is useful information in the multipath components, CDMA receivers may combine the time delayed versions of the original signal transmission in order to improve the SNR at the receiver [13].

The rake receiver is essentially a diversity receiver designed specifically for CDMA, where the diversity is provided by the fact that the multipath components are practically uncorrelated from one another when their relative propagation delays exceed a chip period. It utilizes multiple correlators to separately detect the M strongest multipath components. The outputs of each correlators are then weighted to provide a better estimate of the transmitted signal than is provided by a single component. Demodulation and bit decisions are then based on the weighted outputs of the M correlators.

From studied literatures, many works have been presented to solve the problem of fading in multipath propagation, however despite their successes solution has not been achieved in reducing it completely among others, various adaptive algorithms such as Root Mean Square (RMS), Least Mean Square (LMS), Kalman filter and decision feedback algorithms have all been employed to optimize equalizers and update the received signal based on varying properties of signal and receiver impact of fading on quality of service considering the random behavior of the receiver and also varying channel to a rate which guarantees a good QOS; and this has remained a gap waiting to be addressed. In many previous works such as in [2,14,15], despite their success, the error result obtained during the training process, presents the need for artificial intelligence solutions, as the desired reliability has not been achieved to provide optimal user experience. This will be addressed in this research using adaptive equalization techniques.

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III. METHODOLOGY OF RESEARCH

The methodology characterized the case study area and obtained live data of wireless network performance of the environment, considering key performance indicators for quality of service such as path loss and signal strength. The analysis of the data was conducted to read the effect of destructive interference on the quality of receiver data due to multipath constraints characterized in the environment; then adaptive equalization techniques was developed using machine learning to improve the quality of service in the area. The optimization solution developed was implemented using MATLAB and tested with data inspired from the test bed to read the performance for optimal quality of service in the area.

3.1 Characterization of the Case Study Area Network

This research characterized the case study area using drive test method. The characterization was done using a test bed which was mounted on the car and drove round the area for data collection considering key performance indicators such as signal strength, distance and attenuation. The test bed was developed mounting the transmitter and receiver on the car. A dipole Omni-direction antenna with 4dBi was installed on a tripod stand and connected with the transmitter and receiver respectively with 30dBm signal strength. The spectrum analyzer was installed inside the laptop and used to monitor the quality of wireless communication as the testing began. It should be noted that this work is part of the study in [16].

3.1.1 Measurement Models

The measurement for the quality of service in the urban area was performed using the empirical formulation inspired from Hata model [17] for evaluation of QOS in wireless communication systems operating at frequency between 150 to 1500MHz. The reason for the adoption of this model for measurement was because it considered obstacles in the propagation path which blends it to the case study. The general path loss formulation is presented in [18];

$$P_l = A + 10_y \log_{10}\left(\frac{d}{d0}\right) + X_f + X_h + s \text{ for } d > d0 \quad (1)$$

where d is the distance between base station and the mounted receiving antenna on the car [m], d0= 100[m]; λ=Wave length[m]; X_f=Correction for frequency 980 [MHz]; X_h=Correction for receiving antenna height[m]; s= Correction for shadowing [dB]; y= Path loss exponent

By statistical method, the random variables are taken as the path loss exponent y and the weak fading standard s is derived. The parameter A is defined as [19,20]:

$$A = 20\log 10\left(\frac{4\pi d_0}{\lambda}\right) \quad (2)$$

The path loss exponent y is given as follows [20]:

$$Y_y = a - bh_b + \left(\frac{c}{h_b}\right) \quad (3)$$

Here, the parameter h_b is the base station antenna height which is between 15m and 90m range. The constants a, b, and c depend upon the types of terrain within the Milliken hills area. The value of parameter γ propagation in an urban area is $6 < \gamma < 9$ [20]. The frequency correction factor X_f and the correction for antenna receiver height X_h is given as $X_f = 6.2\log 10\,(f/2000)$ and $X_h = -10.9\log 10\,(hr/2000)$ [19]. The gain of the antenna or urban area is derived from [21]:

$$Gr = (42.58 + 13.7\log 10\,(f))[\log 10\,(hr) - 0.586] \quad (4)$$

For quite large urban areas [21]:

$$G_r = 0.860h_r - 1.960 \quad (5)$$

where d= Distance transmitter and receiver antenna in [km]; f= frequency range in [GHz]; h_b=Transmitter antenna height in [m]; h_r=Receiver antenna height in [m]

3.1.2 Data Collection

The data collection was done driving with the test bed around the area and taking the measurement. The total area coverage during the drive test is 417,07003m^2, while the total drive test distance covered is 4km. The QOS performance of the transmitter and receiver were measured after ever 100meter driver. The map of the drive test area was presented in Fig. 1, while the data collected and all results were reported in the chapter four of this work.

Fig. 1: Map of the drive test area during the characterization (Source: Google Map)

3.2 System Modeling

The system modeling developed the free space model of radio wave propagation without obstacle, then the multipath propagation models considering multi terrain in the case study urban area and the channels dynamics with time was developed. A problem formulation model which presented the impact of the terrains on the quality of service of the receiver at dynamic conditions due to change in motion was developed. An adaptive equalizer solution was developed to solve this problem using machine learning algorithm.

3.2.1 Free space path propagation model

This model begins with the free space path propagation model which modeled the transmitter power in LOS propagation to an infinite distance. The power flux of the transmitter was presented as equation 6;

$$P_d = \frac{P_t}{4\pi d^2} \quad (6)$$

where P_t the transmitted power (W/m^2) is, P_d is the power at a distance d from antenna. From the model in equation 6, the power received by the antenna can be computed using the relationship between the antennas Aperture (A), received signal wavelength λ and power density P_d. The antenna Aperture model is presented as;

$$A = \frac{\lambda^2}{4\pi} \quad (7)$$

While the receiver power P_r at distance d which is dependent on the Aperture of the antenna and the flux power density is presented as;

$$P_r = P_d A = \frac{P_t \lambda^2}{(4\pi d)^2} \quad (8)$$

3.2.2 Model of the Multipath Propagation

The model of equation 8 presented the ideal receiver power without obstructions of any form in an urban area. This model can also be represented as;

$$R_t = h_o p(t - t_o) \quad (9)$$

where the transmitted power of the transmitter is $p(t)$; wireless link channel is $h_o(t - t_o)$; the receive signal is attenuated by a factor of h_o and delay time is t_o. In the case of multipath propagation, the receiver signal in equation 9 is received from multiple channels at varying time and distance and attenuation as shown in the equation 10;

$$R_t = \sum_{n=0}^{N} h_o p(t - t_n) \quad (10)$$

where n is the number of channels used for the signal transmission. In the case where multipath channels varies with time due to the behavior of the receiver or the dynamic nature of obstacle at the propagation path, the receiver signal is presented as;

$$R_t = \sum_{n=0}^{N} h_n^t p(t - t_n^{(t)}) \quad (11)$$

where the channel characteristics such as attenuated factor (h_n) and delay time is (t_n) can vary with time depending on the obstacles along the path of propagation.

3.2.3 Model of the Multipath problem formulation

One of the multipath problems experienced in the characterized environment is fading which occurred due to the presence of obstacles in the propagation path. This obstacles induces scattering, reflection and diffraction on the signal path which induces poor quality as a result of fading. The problem effect on users is random based on the behavior of users such as motion and position. Recall that in the multipath propagation model, the behavior of channel was considered, in this case, the behavior of users in the environment was considered and formulated using a lognormal distribution with probability density function of slowly varying received signal power as;

$$P_s(P) = \frac{\xi}{\sqrt{2\pi\sigma P}} exp\left(-\frac{\xi In(P) - \mu)^2}{2\sigma^2}\right), P \geq 0 \quad (12)$$

Where ξ = 10/In 10, $\mu = \xi$ in $(\breve{P})$ is the logarithmic mean power in dB, σ is the fading standard deviation in dB.

3.3 Development of the Adaptive Equalization Algorithm

From the problem formulation model, it was uncovered that fading is a major problem on multipath propagation and in order to recover the transmitted data, there is need for compensation of the channel impulse response. This presented the need for equalization process which employed filters to achieve the aim. The received signal are filtered with inverse response $g_m(t)$ of the dynamic propagation channel m. the soft symbol estimate z of the multipath equalizer is expressed as;

$$z(t) = \sum_{m-1}^{M} g_m(t)^H y_m(t) \quad (13)$$

where $y_m(t) = [y_m(t)(t + L) \ldots \ldots . y_m(t)(t - L + 1)]^T$.

The equation 13 presented the equalized signal from the multipath channel; however the solution was unable to solve the time varying characteristics problem of the channel, problem of varying time receiver behavior due to motion, and also the inverse impulse response is of infinite time. According to Jacob et al. [15], the solution to the later problem using truncation o the impulse inverse filter constraining its duration with the channel length (L), while the solution to the problem of varying time characteristics of the channel and receiver can be solved using adaptive update. In many previous works such as such as [2,14,15] among others, various adaptive algorithms such as Root Mean Square (RMS), Least Mean Square (LMS), Kalman filter and decision feedback algorithms have all been employed to optimize equalizers and update the received signal based on varying properties of signal and receiver with time, however despite their success, the error result obtained during the training process, presents the need for artificial intelligence solutions, as the desired reliability has not been achieved to provide optimal user experience. The machine learning algorithm which was adopted for this optimization of the equalizer is the feed forward neural network. The architectural diagram of the adaptive equalizer for the multipath problem was presented in figure 2.

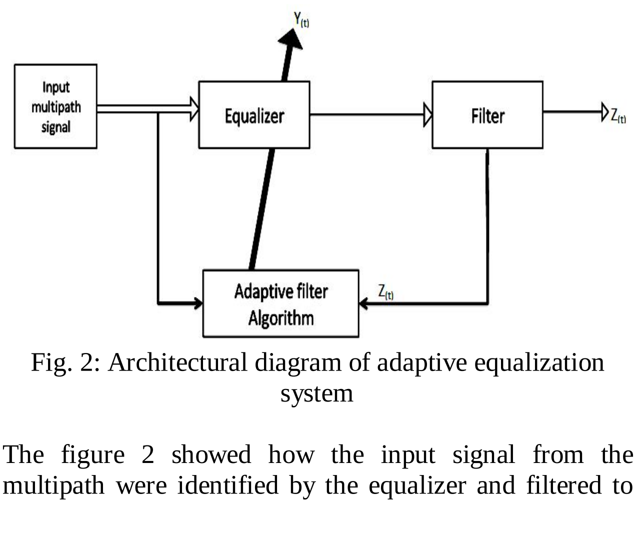

Fig. 2: Architectural diagram of adaptive equalization system

The figure 2 showed how the input signal from the multipath were identified by the equalizer and filtered to

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generate the model in equation (13) which was trained with the adaptive algorithm for to output desired receiver signal. The development of the adaptive algorithm was done developing a Feed Forward Neural Network (FFNN) model. The model of the FFNN was developed from a single neuron as shown in equation 14 [22];

$$v_k = \sum_{i=1}^{N} w_{ki} x_i \quad (14)$$

where x_i is the neuron input from the equalizer output; w_{ki} is the corresponding weight to the input x_i; The neuron's output is obtained by sending the weighted sum v_k as the activation function φinput that resolves the output of the specific neuron. $y_k = \varphi(v_k)$. The activation function used is the tanh function as it does not suffer issues of convergence like the sigmoid function counterpart. The model of the neuron with the activation function was presented in the equation 15;

$$v_k = \sum_{i=1}^{N} w_{ki} x_i + \varphi(v_k) \quad (15)$$

Having established model of the neurons, it was interconnected considering the number of n channels of the multipath to form the neural network as shown in figure 3.

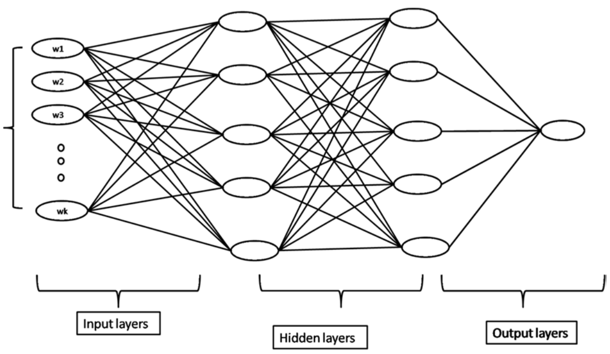

Fig. 3: Model of the feed forward neural network

The figure 3 presented the neural network model formed from the connection of the neurons in equation 14 using the training parameters in Table 1 which was inspired from the attributes of the multipath signal and then used to configure the network.

Table 1: Neural Network Parameters

Maximum number of epoch to train	1333
Epoch between display	200
Maximum time to train in sec	Infinity
Maximum validation failure	5
Scale factor for tolerance	0.001
Scale factor for step size	0.1
Initial step size	0.01
Minimum performance gradient	1e-6
Cost horizon	7
Control horizon	1
Control weighting factor	0.05
Search parameter	0.001

Having developed the model of the neural network, the data collected from the test bed which contained 10000 samples of multipath data was feed to the model as shown in figure 4 for training.

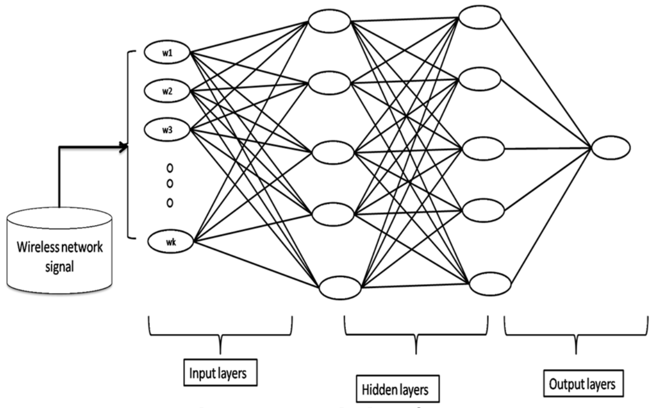

Fig. 4: The FFNN with data for training

The architectural model in figure 3.3 showed how the data was feed to the FFNN model. This was identified as a Nonlinear Auto Regressive Model (NARX) in [22] and then trained with back propagation algorithm in figure 5. Before the during the training process, the input data was divided into training, test and validation sets respectively in the ratio of 70:15:15 and then the back-propagation training algorithm was used to train the FFNN to learn the multipath data and then generate the desired adaptive algorithm.

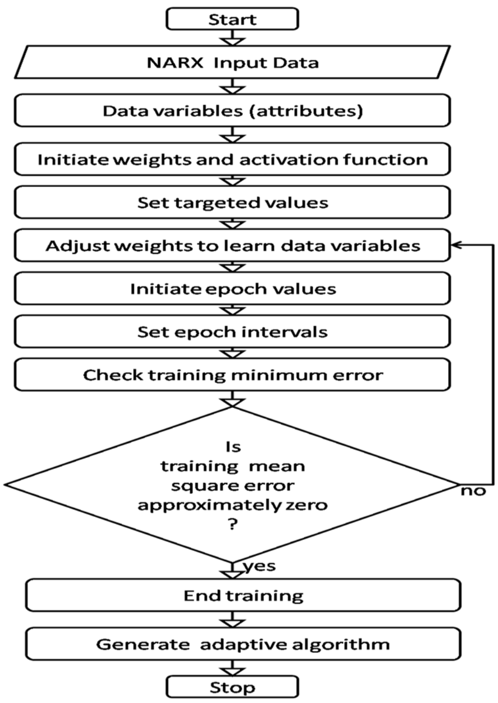

Fig. 5: Back-propagation training algorithm

The FFNN training process with the back-propagation algorithm in figure 5 was done loading the data of the

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multipath collected into the FFNN model for system identification as NARX and then trained with the training algorithm to generate the Neural Network Adaptive Algorithm (NNAA) needed as in the flow chart of figure 6 while the follow chart of the algorithm generated is in Fig. 7.

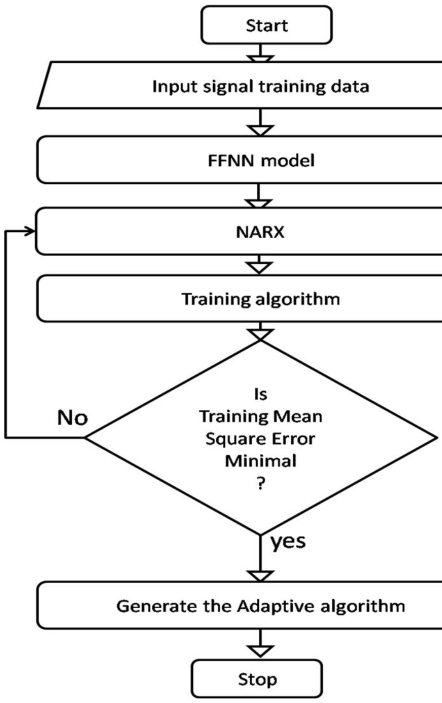

Fig. 6: Flowchart of FFNN training

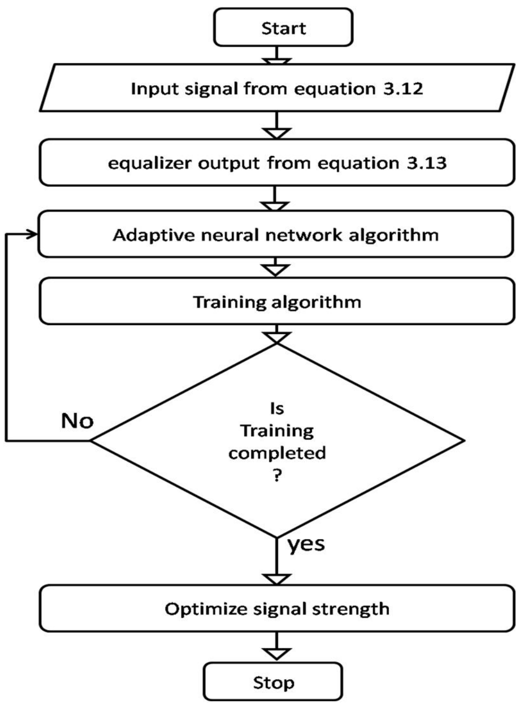

Fig. 7: Flow chart of the adaptive equalization algorithm (AEA)

3.4 System Implementation and Simulation

The implementation of the algorithm developed was achieved using signal processing toolbox, neural network toolbox and MATLAB. The signal processing toolbox was configured with the equalizer model in equation 13, while the neural network toolbox was used to train the data collected and generate the adaptive algorithm used to update the equalizer. The training tool is presented in figure 8.

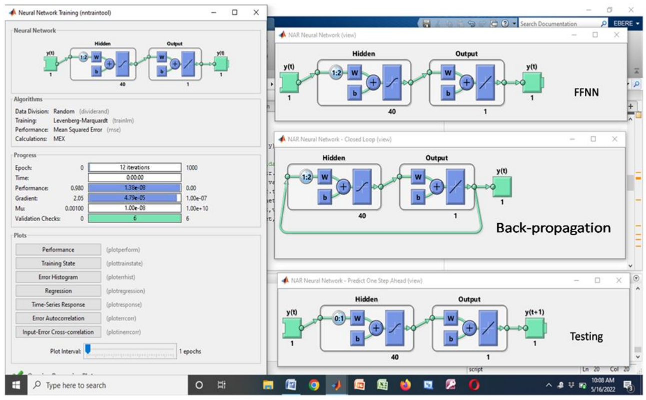

Fig. 8: The neural network training tool

The figure 8 showed the neural network tool which was used to load the wireless data for configuration and training. The data loaded with the input from Table 3.1 was used to configure the neural network and then the training algorithm selected and then train the neurons and test until the desired AEA was generated and then deployed on the user equipment using MATLAB codes for service optimization of user within the environment.

IV. RESULTS AND DISCUSSION

This section presented the performance of the adaptive equalizer developed and trained in this research for the optimization of quality of service in the receiver end. The performance of the equalizer was evaluated considering Mean Square Error (MSE) of performance and also the Receiver Operator Characteristics (ROC) curve. The MSE was used to check the error which occurred during the training of the algorithm, with the aim of achieving error value of zero or approximately. The ROC on the other hand was used to determine the ability of the adaptive neural network equalizer to correctly equalize receiver signal strength range to ≤-75dBm. The MSE performance was presented in the figure 9.

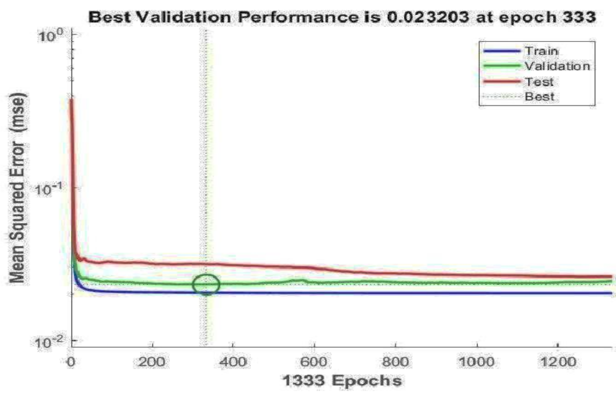

Fig.9 MSE performance of the adaptive equalizer

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The MSE performance showed how the neural network was trained to learn the signal strength which was sued as a reference point for equalization. The result showed that the MSE which was recorded during the training is 0.023203Mu. The implication is that the result achieved is approximately zero which implied that the neurons learn the data in good condition and achieved tolerable error.

The table 2 presented the validation performance of the simulation; the result showed that the average signal strength achieved with the simulation after tenfold validation is -63.64dBm which is good according to the NCC standard for quality of service.

Table 2: Validation result

Iterations	Signal Strength (dBm)	Signal strength Indicator
1	-64.12	Good
2	-58.6	Very good
3	-58.1	Very good
4	-59.4	Very good
5	-65.7	Good
6	-63.2	Good
7	-65.6	Good
8	-66.8	Good
9	-68.4	Good
10	-66.5	Good
Average	-63.64	Good

Having simulated and validated the performance of the neural network based equalizer developed and achieved good signal indicated amid the multipath terrain; the neuro-equalizer was integrated on the case study wireless network for communication process at a frequency of 980MHz and the performance was evaluated along the multi terrain environment where previously the characterization was performed. The results obtained were measured with the spectrum analyzer for two experiments a total respective distance of 4km covered within the environment and presented in the table 3.

Table 3: Result of the system integration with Adaptive equalizer

Distance (meters)	Receiver signal strength (dBm)	Receive r signal strength (dBm)	Average Receiver signal strength (dBm)
100	-72	-74	-73.0
200	-69	-67	-68.0
300	-69	-69	-69.0
400	-75	-73	-74.0
500	-70	-72	-71.0
600	-75	-73	-74.0
700	-75	-72	-73.5
800	-67	-66	-66.5
900	-77	-75	-76.0
1000	-68	-68	-68.0
1100	-78	-77	-77.5
1200	-68	-67	-67.5
1300	-78	-75	-76.5
1400	-69	-67	-68.0
1500	-72	-71	-71.5
1600	-67	-65	-66.0
1700	-69	-66	-67.5
1800	-85	-84	-84.5
1900	-85	-84	-84.5
2000	-83	-84	-83.5
2100	-83	-82	-82.5
2200	-80	-81	-80.5
2300	-74	-75	-74.5
2400	-73	-74	-73.5
2500	-67	-66	-66.5
2600	-77	-78	-77.5
2700	-68	-67	-67.5
2800	-78	-76	-77.0
2900	-79	-78	-78.5
3000	-81	-89	-85.0
3100	-79	-75	-77.0
3200	-72	-75	-73.5
3300	-67	-65	-66.0
3400	-69	-66	-67.5
3500	-75	-78	-76.5
3600	-74	-76	-75.0
3700	-67	-68	-67.5
3800	-77	-74	-75.5
3900	-68	-67	-67.5
4000	-78	-74	-76.5
Average	-73.9	-73.3	-73.4

The table 3 presented the performance of the system integration when tested in two respective experiments conducted at the case study area with multi terrain. The result showed that the average signal strength received with the adaptive equalizer developed with neural network and integrated with the receiver is -73.4dBm. The implication of the result is that the quality of good as it satisfied the NCC standard for quality of service. The graphical analysis of the result is presented in the figure 10. The figure is the analysis of the result obtained when the receiver performance was tested at the multi terrain environment. The result showed that the signal varies as the position of the receiver changes, however the average signal strength achieved is good as the adaptive equalizer continues to process and ensure that the quality of service is maintained at the required standard considered for the neural network training and NCC requirements.

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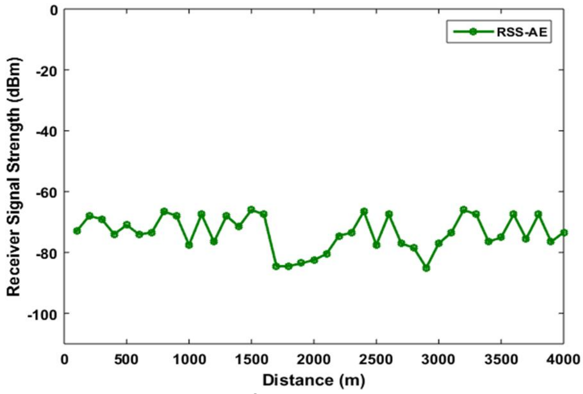

Fig. 10: The analysis of system integration with neural network adaptive equalizer

A comparative analysis was performed to compare the difference between the receiver with neuro-adaptive equalizer and without the equalizer. This was achieved comparing the results of the characterization and the result of the system integration as shown in the table 4.

Table 4. Comparative received signal results

Distance (meters)	Average Receiver signal strength (dBm) with Neuro-adaptive equalizer	Average Receiver signal strength (dBm) without Neuro-adaptive equalizer
100	-63.0	-93.1
200	-68.0	-88.0
300	-69.0	-89.4
400	-74.0	-94.2
500	-71.0	-91.2
600	-74.0	-94.0
700	-73.5	-93.5
800	-66.5	-86.5
900	-76.0	-96.6
1000	-68.0	-88.2
1100	-77.5	-97.5
1200	-67.5	-87.5
1300	-76.5	-96.5
1400	-68.0	-88.0
1500	-71.5	-91.5
1600	-66.0	-86.0
1700	-67.5	-87.5
1800	-84.5	-104.5
1900	-84.5	-104.5
2000	-83.5	-103.5
2100	-82.5	-102.5
2200	-80.5	-100.5
2300	-74.5	-94.5
2400	-73.5	-93.5
2500	-66.5	-86.5
2600	-77.5	-97.5
2700	-67.5	-87.5
2800	-77.0	-97.0
2900	-78.5	-98.5
3000	-85.0	-100
3100	-77.0	-97.0
3200	-73.5	-93.5
3300	-66.0	-86.0
3400	-67.5	-87.5
3500	-76.5	-96.5
3600	-75.0	-95.0
3700	-67.5	-87.5
3800	-75.5	-95.5
3900	-67.5	-87.5
4000	-76.5	-96.5
Average	-73.38	-93.51

The table 4 presented a comparative analysis of the results with the adaptive neural network based equalizer and the characterized. The result showed that the average signal strength at the receiver with neural network equalizer is -73.38dBm, while that of the characterized is -93.51dBm. The results showed that the new receiver achieved good signal indicator, then the characterized which has poor signal indicator. Figure 11 presents a graphical analysis of the comparative results to show how the respective receiver signal strength changes with distance.

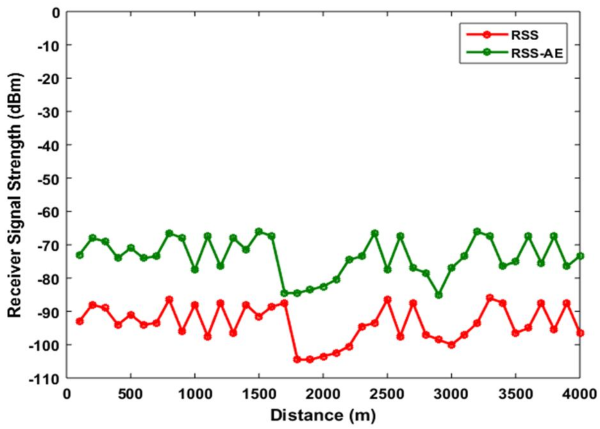

Fig. 11: Comparative received signal performance

The Fig. 11 presented a comparative result of the characterized and new system with adaptive neural network based equalizer. The result showed that the signal strength patterns with the neural network was a lot better and satisfied the requirement by the NCC for quality of service, while that of the characterized has great room for improvement due to the impact o fading in the environment. The percentage improvement achieved on the signal strength is 21.52% with the neuro based adaptive equalizer.

V. CONCLUSION

Milliken-hills is a popular place in Enugu State, Nigerian which house many populations of people from Ninth mile, cola camp, Ngwo, among other neighboring villages. Also the road network in this is one of the most busies pathway outside of Enugu, as it connects the state with other neighboring states. The Milliken-hills is characterized by many beauty of nature such as mountains, hills as the

name implied, valleys, rivers, rain forest among others. However it has remained so sad that these natural offerings have affected quality of communication in the area, due to fading on signal channels and this has remained a very big problem.
This research has address this issues using neural network based adaptive equalizer which was trained with data collected from NCC. The equalizer was used to improve the quality of communication in the area. The result of communication when tested with the new adaptive equalizer showed that the quality of service has greatly improved than when compared with the characterized system without the adaptive equalizer.

ACKNOWLEDGEMENTS

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