Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 5, Issue 2, 2021, Page 87-94
ISSN: 2616-1192

(www.ujesr.org)

Bit Error Rate Reduction Using the Modified Least Mean Square Algorithm

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Abstract
The cellular network has been evolving in its technology and it has increased in complexity due to the increasing demand and dependence on its services in recent years. Consequently, it has suffered in performance reduction due to high level of error occurrences in the network signal transmission and reception because of the wireless nature of the transmission medium. Since the performance of the Carrier Division Multiplexing Access - based cellular network depends inversely on the Bit Error Rate, therefore minimization of Bit Error Rate for improved network performance becomes the major objective of this paper. The performance evaluation is done by using Least Mean Square adaptive algorithm. From the results, the existing system investigation measurement recorded lowest Bit Error Rate result of 0.125 which is very high and can cause poor performance of the network and spectrum utilization. The developed Modified Least Mean Square algorithm method produced better Bit Error Rate of 0.004 which is very low compared to the measured Bit Error Rate result of 0.125. The developed Modified Least Mean Square algorithm offers the least error level results of 0.004 showing a performance improvement of 98.95% over existing Least Means Square algorithm.

Keywords: *Adaptive antenna array, Adaptive algorithm, Bit error rate*

Received: 9th March, 2021 *Accepted: 19th April, 2021*

1. Introduction

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate is the number of bit errors per unit time. Bit Error Rate, (BER) is used as an important parameter in characterizing the performance of data channels. When data is transmitted over a data link, there is a possibility of errors being introduced into the system. If errors are introduced into the data, then the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, and bit error rate (BER) provides an ideal way in which this can be achieved.

Bit Error Rate (BER) is considered as one of the most important network metrics that reflects on performance of network applications and services. The increasing demand for mobile communication services without a corresponding increase in Radio Frequency (RF) spectrum allocation motivates the need for new techniques to improve spectrum utilization (Abu, 2007). The existing frequency spectrum or radio frequency band (resource) allocated for mobile wireless communication is very scarce, costly and hence must be managed efficiently (Shubair et al., 2007).

Since the available broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality. These challenges necessitate the need for cellular operators to find new ways of increasing the capacity of their networks. Kretly et al., 2002 proposed the use of adaptive antenna system as key solution for increasing the spectral efficiency and improving the system performance in 3G and 4G cellular network. Adaptive or smart antennas are comprised of a number of individual antennas and associated signal processors which provide the "smart" portion. Smart antennas can be used for both signal transmission and reception (Rameshwar, 2008). Smart antennas are being regarded by many as the key solution to increasing the spectral efficiency and improving the system performance in mobile communication (Frank, 2005). In principle, an antenna is "smart" only when it can recognize and track the signal of a particular mobile telephone while suppressing interfering signals. A smart antenna system combines multiple antenna elements with a signal-processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment (Murali, 2004). This can be achieved by forming a beam towards the mobile telephone; hence, the term beamforming is widely used in the literature.

Smart antenna system is an antenna system that responds in some way to electromagnetic wave in order to improve a specified performance metric and in so doing provide increased immunity to interference (nulling the signal level to a vulnerable receiver). Smart antenna systems continually monitor their coverage areas and adapts to the user's direction providing an antenna pattern that tracks the user and provides maximum gain in the direction of the user (Santhi et al., 2008). Smart antennas are arrays with smart signal processing algorithms, used to identify signal signature such as the Direction of Arrival (DOA) of the signal and use it to calculate beamforming vectors. This is then used to track and locate the antenna beam on the mobile target. To minimize interference from different directions, smart antennas can be used at the receiver to form the beam (beamforming) in the direction of the multipath and reject signals from interferers. The direction of users and interferers is obtained using a direction of arrival estimation algorithm. This is done using algorithms such as MUSIC (Multiple Signal Classification), ESPIRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), Matrix Pencil method or one of their derivatives (Godara, 1997). They involve finding a spatial spectrum of the antenna array and calculating the DOA (Direction of Arrival) from the peaks of the spectrum (Ali et al., 2002). Beamforming is the combination of radio signals from a set of small non directional antennas to simulate a large directional antenna. In beamforming, each user signal is multiplied with complex weights that adjust the magnitude and phase of each signal to and from each antenna. This results in formation of radiation pattern by adding the phases of the signal in the desired direction and nulling the pattern in the unwanted direction (Kumar and Rajouria, 2013).

A smart antenna system (also called an adaptive antenna system) can be employed to automatically adjust its directional response to null the interferer thereby enhancing the reception of the desired signal (Rameshwar and Wakde, 2005). Therefore, adaptive beamforming is a powerful technique of enhancing a signal of interest while suppressing the interference signal and the noise at the output of an array of sensors through the adaptive beamforming algorithm. The adaptive algorithm computes the appropriate complex weights to dynamically direct the maximum radiation of the antenna pattern toward the signal of interest and places nulls toward the unwanted signals (Rappaport, 2002). Improving the interference suppression and noise reduction capabilities of any system in the presence of large interferers hence increases the capacity of that system (Nwabueze and Ibegbunam, 2016). The huge amount of data that users expect to access has required an effort to increase the capacity of wireless networks. The main limitation of most communication systems is the increasing interference between channels and multipath fading; smart antennas technology has emerged, solving some of these problems and improving the performance of wireless networks (Varum et al., 2017). Thus, the smart antenna system is limited in addressing some of the problems affecting or reducing the channel capacity and general performance of the network due to its slow convergence problem of the smart antenna Least Mean Square (LMS) algorithm (Al-Sadoon et al., 2016) which governs the function of the adaptive antenna technology. This limitation of the adaptive antenna occurred because the Least Mean Square (LMS) algorithm applied in most works such as (Yasin et al, 2010; Arunkumar et al., 2013; Al-Sadoon et al., 2016; Varum et al., 2017) to improve the performance of the network uses one variable called the adaptive weight. To address this issue of performance degradation, the smart antenna was studied and the algorithmic functions of the adaptive signal processor was modified based on the Bit Error Rate level reduction to achieve improvement in network performance and also increase in channel capacity.

This paper presents the analysis techniques used for evaluating the performance of Carrier Division Multiplexing Access (CDMA) based cellular network using Bit Error Rate (BER) reduction method. This work is limited to using two acclaimed techniques for evaluating Carrier Division Multiplexing Access (CDMA) performance:

i. Analysis and simulation of different adaptive algorithms for adaptive beamforming antenna system and using methodical performance comparison to establish the adaptive algorithm with best interference rejection capability.
ii. A mathematical model using MATLAB to model the cellular network for Bit Error Rate (BER) optimization with tests on live base

stations to ascertain the extent of performance improvement.

2. Technical evaluation and simulation method

2.1 Adaptive antenna array

Figure 1 shows the block diagram of functional Adaptive Antenna Array to achieve network performance improvement. The adaptive antenna is an array of antennas which is capable of changing its antenna pattern dynamically to adjust to noise, interference and multipath. They are used to enhance received signals and may also be used to form beams for transmission. In adaptive array, signals received by each antenna are weighted and combined using complex weights (magnitude and phase) in order to maximize a particular performance criterion e.g. the Bit Error Rate (BER), Signal to Interference and Noise Ratio (SINR). Fully adaptive system uses advanced signal processing algorithms to locate and track the desired and interfering signals to dynamically minimize interference and maximize intended signal reception (Shanti et al., 2008).

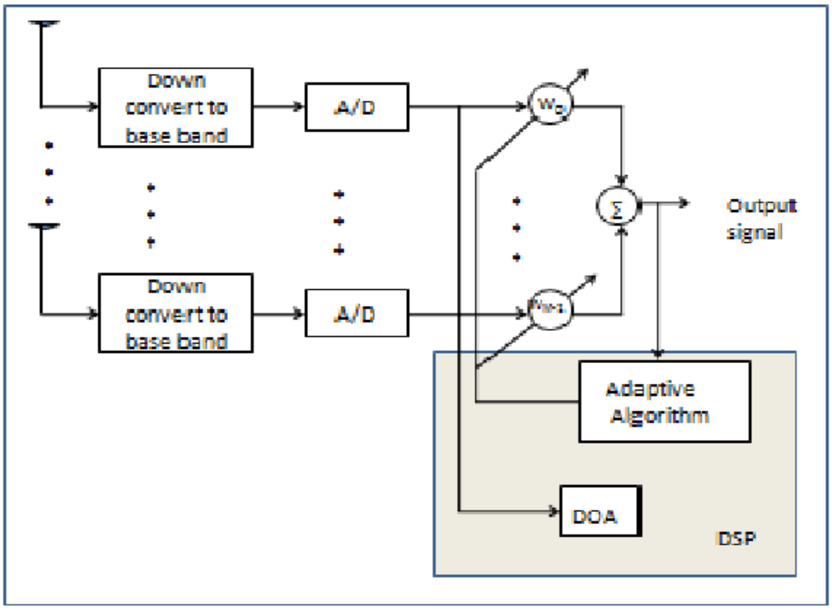

Fig. 1: Block diagram of functional adaptive antenna arrays system, using the Least Mean Square adaptive algorithm (Roy, 2007)

Unlike conventional antennas, the adaptive antenna array confines the broadcast energy to a narrow beam. It optimizes the way the signals are distributed on a real time basis by focusing the signal to the desired user and 'steering' it away from the other users occupying the same channel in the same cell and adjacent or distant cell (Shubair et al., 2007). The adaptive antenna uses the RAKE receiver principle to achieve bit error rate minimization (Fig. 2). RAKE receivers are in widespread use, especially in CDMA systems employing spread spectrum techniques.

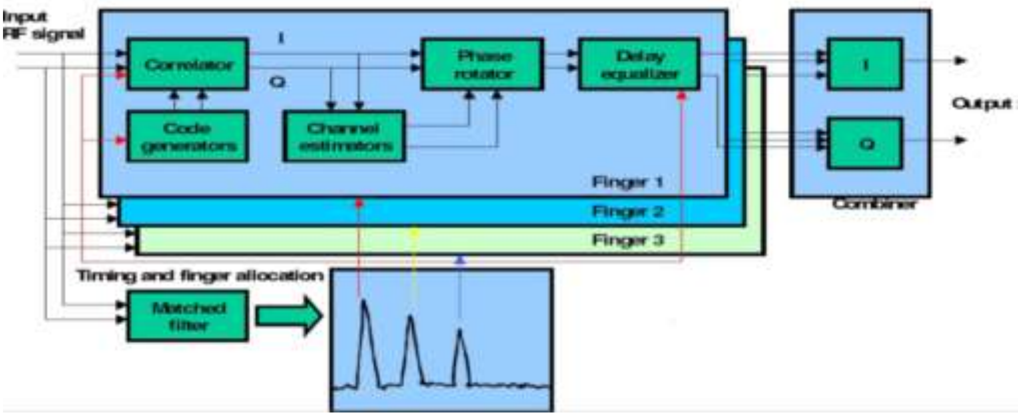

Fig. 2: Block diagram of simplified adaptive beamforming RAKE receiver employed in bit error rate performance simulation

2.2 BER performance simulation using least mean square (LMS) algorithm

The antenna input is considered as a continuous waveform given by x(t). In order to process this waveform digitally, it must first be converted into a discrete time vector. Each value in the vector represents the instantaneous value of this waveform at integer multiples of the sampling periods. The values of the sequence, x(t) corresponding to the value at n times the sampling period T_s, is denoted as x(n).

$$x(n) = x(nT_s) \quad (1)$$

Considering the smart antenna system as a transversal finite impulse response (FIR) filter whose characteristics can be expressed as a vector consisting of values known as tap weights connecting the antenna array input subsystem. These tap weight functions determine the performance of the smart antenna. Each antenna array element connects to weight function. That means that a ten-element array antenna has ten weight functions. The weight function values are expressed in the column vector form as,

$$w(n) = [w_0(n)\ w_1(n)\ w_2(n) \ldots\ w_{N-1}(n)]^T \quad (2)$$

This vector represents the impulse response of the smart antenna. The number of elements in this vector is N which is the order of the filter (Hutson, 1997). The output of the smart antenna at a time sample 'n' is determined by the sum of the products between the tap weight vector, w(n) and N time delayed input values. If these time delayed inputs are expressed in vector form by the column vector:

$$x(n) = [x(n)\ x(n-1)\ w(n-2) \ldots\ x(n-N+1)]^T \quad (3)$$

The output of the smart adaptive antenna at time sample 'n' is expressed in the following equation as:

$$y(n) = \sum_{n}^{N-1} w_i(n)x(n-1) \quad (4)$$

In the adaptive smart antenna system as demonstrated in Fig. 1, the actual output y(n) of the antenna is compared with a desired output or reference input to generate a cost function also known as error. In practice, the input delayed signal contains noise signals with other interfering signals. These interfering signals cause degradation or reduction of the quality of received signal naturally. As a result, this causes the cost function to be very high and reduce the performance of the smart antenna final output. In order to improve the antenna output performance, the error is required to be minimized as much as possible. The adaptive antenna uses algorithms to iteratively alter the values of the weight functions in order to minimize a value known as the cost function. This difference is known as the estimated error of the adaptive antenna, and it is expressed as follows:

$$e(n) = d(n) - y(n) \quad (5)$$

where $y(n)$ is the actual output and $d(n)$ is the desired output or reference input. Applying Least Mean Square (LMS) algorithm, the error generated in Equation (5) is used by the adaptive processor to update the tap weight function in every iteration process of the algorithm for the preparation of another output signal and reduced error generation. The weight functions of the adaptive antenna are updated in every iteration process of algorithm according to the following formula (Farhang-Boroujeny, 1999):

$$w(n+1) = w(n) + 2\mu e(n)x(n) \quad (6)$$

Table 1: Results of bit error rate performance using least mean square algorithm

Number of Elements	Weights, w	BER
1	$w1$	1.45
2	$w2$	1.32
3	$w3$	1.95
4	$w4$	1.85
5	$w5$	1.25
6	$w6$	1.18

2.3 Bit error rate improvement algorithm using modified least means square

The bit error rate computational algorithm presents the summarized BER computation and analysis in a flowchart as demonstrated in (Fig. 2). The Modified Least Means Square (MLMS) is presented as follows:

i. Initialize the dependent variables: weight w and phi
ii. Form the processes for the Bit Error Rate level computation and the following iterations for the nth time.
iii. Form the input signal x(n)
$x(n) = x(nT_s)$
iv. Form the actual output y(n) of the system with the input signal and the adaptive weight

$$y(n) = \sum_{n}^{N-1} w_i(n)x(n-1)$$

v. Form the reference set point

$$d(n) = \sin\left(2\pi N w_0(n) + phi(n)\right)$$

vi. Compute the error estimator to the adaptive processor from the actual output y(n) and the reference set point d(n)

$$e(n) = d(n) - x(n)w(n)$$
$$e(n) = \sin(2\pi N w_0(n) + phi(n)) - x(n)w(n)$$

vii. Update and compute the weight through iteration process for the improvement of the performance of the network.

$$w(n+1) = w(n) + \mu x(n)\sin(2\pi N w_0(n) + phi(n)) - x(n)w(n)$$

where, phi is the real positive constant (0<phi<1) and mu is the rate of adaptation (0<mu<1). The number of sequence and the mu were kept constant throughout the experiment.

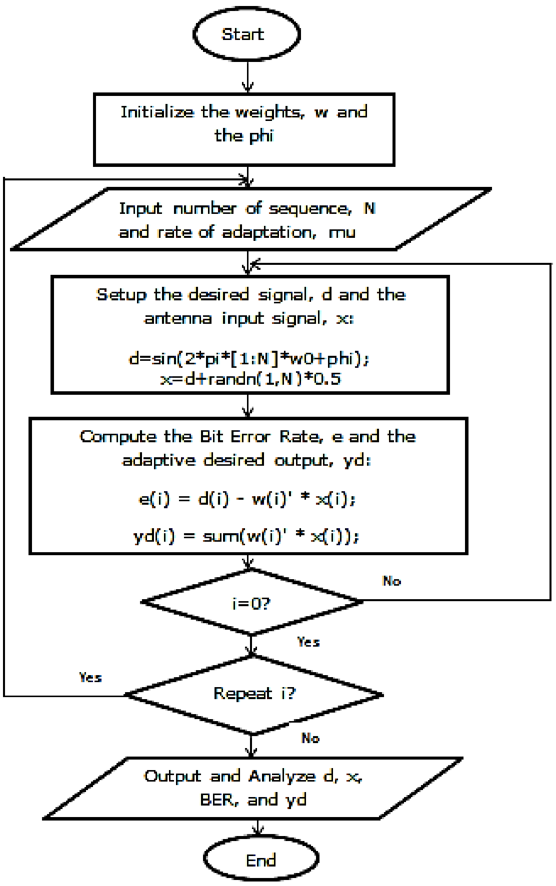

Fig 3: Flowchart for bit error rate improvement computation using the Modified Least Mean Square algorithm.

Figure 3 presents the Modified Least Means Square (MLMS) method for the performance enhancement of the adaptive controller which helps to improve the performance of the adaptive antenna by reducing the bit error rate. The main controlling factors in this approach are the weight w and the real positive constant phi. The initial weight w0 and the positive constant phi were varied as demonstrated in Table 2 to achieve the desired performance improvement through iterations i. The modification of the Least Mean Square algorithm for the network performance which is centered on BER reduction was achieved in this work with the introduction and manipulation of phi in the desired signal model. This scenario was demonstrated in the flow chart in Fig. 2 for the modified Least Mean Square algorithm adaptive antenna system. The initial weight function of adaptive antenna and phi at the desired signal were manipulated to start iteration at the beginning of the computation of the

Least Mean Square program for an experiment. This was repeated until a desired system performance was achieved.

Table 2: Results of bit error rate performance using Modified Least Mean Square algorithm

Initial weight, w0	Real positive constant, phi	BER
0.01	0.1	0.131
0.001	0.1	0.103
0.0001	0.1	0.1001
0.0001	0.01	0.01031
0.0001	0.001	0.001314
0.0001	0.0001	0.0004142

3. Simulation results

The performance will be centered on the result analysis of the adaptive antenna model shown in figure 1 above. The Bit Error Rate (BER) is considered to be one of the most important performance measures for communication systems and hence it has been extensively studied. The exact analytical evaluation of the probability of error in Carrier Division Multiple Access (CDMA) cellular network is still an open subject. The reason for the adaptive beamforming RAKE receiver model is to reduce the field bit error rate values at different number of antenna array as shown in Fig. 2.

3.1 Bit error rate performance analysis of conventional adaptive antenna array

Figure 4 shows a graphical representation of the Bit Error Rate performance of simple adaptive antenna array. Analysis of the graphical representation in Fig. 4 demonstrates the following:

i. The bit error rate was not stable as the number of connections changed. This equally shows that the network performance must be negatively affected and it will will keep on fluntuating as the number of connection changes. Since the performance of the network is determined by the bit error rate, the continues change in bit error rate will have negative effect on the general performance of the network.
ii. The bit error rate increased with increase in the number of connections. This is a usual network occurrence which affecs the network throughput negatively because it affects the network channel utilization.
iii. The least bit error rate measured was 0.1. This value of the bit error rate is still high and with this value the utilization of the network channel will also become very poor. This will have negative effect on the performance of the network which will result to call drops, reduced network speed etc.

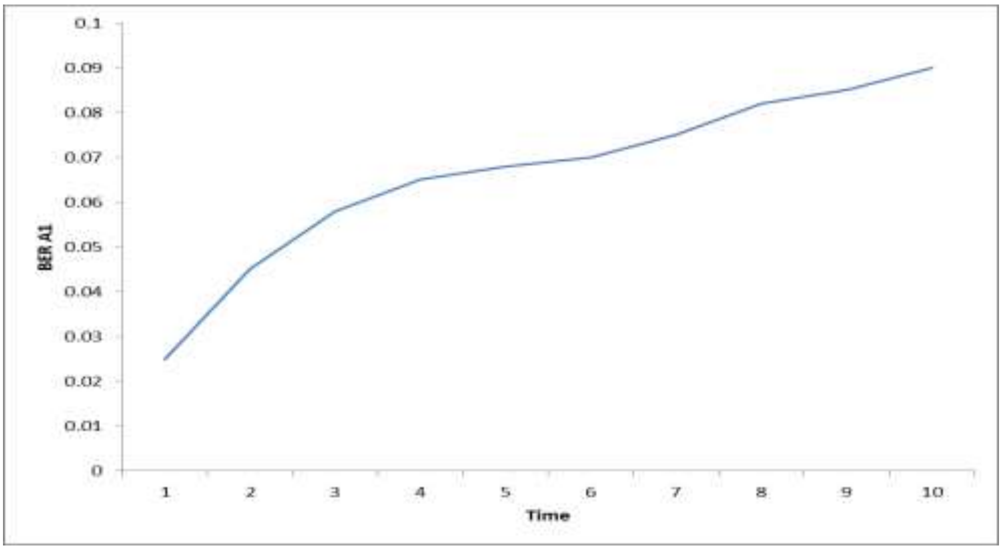

Fig. 4: Bit error rate performance analysis of adaptive antenna array using LMS algorithm

3.2 Bit error rate performance analysis of adaptive antenna array using modified least mean square algorithm

For the BER improvement experiment, the number of sequence N and the rate of adaptation mu, were kept constant and the values of w0 and phi were varied. The number of sequence N, for the iteration was chosen arbitrarily and the rate of adaptation mu, was chosen from the range (0<mu<1). N=11, mu=0.01. The result shown in Fig. 5 demonstrates the behaviour of the output of the adaptive antenna system based on the BER level reduction when initial weight and phi are 0.0001 and 0.0001, respectively. The least Bit Error Rate level achieved is 0.0004142 which means that the system performance improved significantly. This shows that the performance of the network system has improved more significantly with more reduced bit error rate. This indicates that the network speed will also be improved on and the network channel utilization will also improve due to the reduced bit error rate. This will solve the problem of network congestion because the speed of data processing and transfer will be significantly increased to enhance the network throughput. Significant improvement was achieved with more change in the phi while keeping the initial weight of the adaptive antenna constant at 0.0001. This means that the introduction of more variables in the adaptive antenna algorithm achieved more bit error rate reduction and therefore, achieves better network performance and will also improve general network throughput. The change in the phi variable achieved more bit error rate reduction than the change in the weighting factors of the adaptive antenna array system.

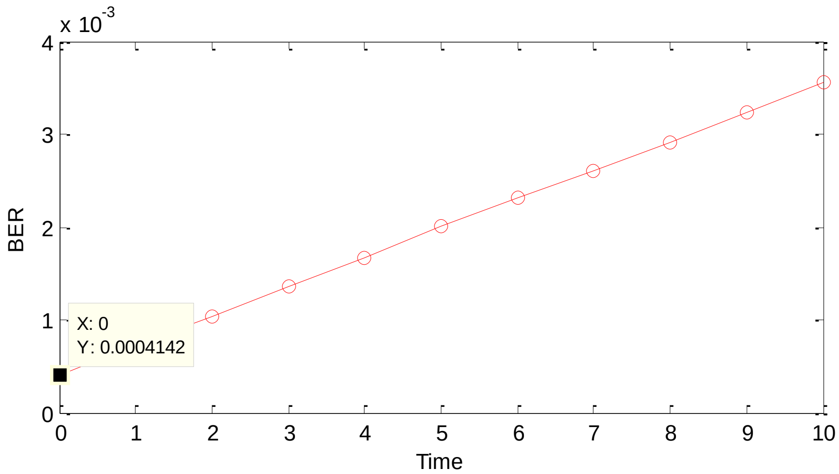

Fig. 5: Bit error rate performance analysis using MLMS algorithm when w0 = 0.0001 and phi = 0.0001

4. Conclusions

The modified Least Mean Square Adaptive Antenna model is a proven method for Bit Error Rate and interference reduction and channel capacity improvement of cellular network system. Simulation results when compared against Least Mean Square based Adaptive Antenna Array and Modified Least Mean Square based adaptive antenna array reveals that the result obtained using the Modified Least Mean Square Adaptive algorithm is significantly reduced when compared to the Least Mean Square adaptive algorithm (ie. field bit error rate). Based on analysis and findings from this work, the Modified Least Mean Square algorithm offers several advantages over Least Mean Square adaptive algorithm, these include performance improvement in terms of Bit Error Rate reduction. The Bit Error Rate results obtained confirmed the effectiveness of the proposed modified Least Mean Square Adaptive antenna model. Finally, from the simulation results, it can therefore be inferred that there is significant cellular network performance improvement using Modified Least Mean Square algorithm.

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