Saudi Journal of Engineering and Technology (SJEAT)
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

An Adaptive Beamforming Antenna Array System for Minimizing Outage Probability in Mobile Cellular Networks

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Original Research Article

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Article History
Received: 12.09.2018
Accepted: 26.09.2018
Published: 30.10.2018

DOI:
10.21276/sjeat.2018.3.10.2

Abstract: The Communication industry in Nigeria was thrown into the Quality of Service challenges as a result of rapid growth of mobile users with their increases in the demand for mobile communication application services. Most often in this country, the outages are high which leads to total network failures, block calls, drop calls. All these are as a result of poor signal strength at the receiving end. This research was aimed at minimizing outage probability in mobile network using beamforming adaptive antenna array system. To achieve this goal, the number of outages was measured at a specified period. A beamforming antenna was designed so as to enhance signal reception. An LMS algorithm was developed for the antenna for signal tracking and acquisition. A model for minimizing the outage probability in the network using adaptive beamforming antenna was then developed and simulated in MATLAB Environment. Results obtained showed that the outage probability is lower with adaptive beamforming antenna and also the BER curve was better with beamforming technique.
Keywords: Adaptive Antenna, LMS Algorithm, Outage Probability, Bit Error Rate.

INTRODUCTION

There is an increasing demand for higher transmission rates and improved quality of service in mobile communication systems due to the global demand for voice, data and video related services. The evolvement of 2G, 3G and 4G networks were various technologies implemented towards improving the performance of mobile communication systems.Cellular radio systems attempt to provide a telephone service to the mobile public with a quality better than that afforded by conventional landline services.

Despite huge amount of money that had been spent in attempts to meet the need of the world market, the vast majority of people particularly in Nigeria still do not have access to good quality communication services. Good quality service, efficient spectrum utilization and cost effectiveness are the fundamental aims of modern mobile radio system design. The motivation of this research was based on the frustrating services such as blocked calls and dropped calls experienced by users while making calls. They are usually very annoying and demoralizing. In Mobile telephony, the quality of service is often expressed in terms of the probability of outage experienced by subscribers. Thus outage probability is statistically a measure that describes the probability of failing to achieve adequate reception of a signal at a paticular location. To achieve adequate reception, outage probability must be minimized so that the desired signal will be greater than the minimum signal level and interference signal power level. Generally, there is always an acceptable threshold value of a signal -to- noise ratio (SNR) for the communication systems. The signal will experience outage value below the SNR threshold level [1]. This paper discusses a technique of reducing outage probability using adaptive beamforming antenna

OUTAGE PROBABILITY

Outage probability is the probability that the instantaneous magnitude of the desired signal envelope is below that required for adequate reception. It is related to the strength of the desired signal. If the desired signal is weaker than the minimum signal level required for adequate reception or the interfering signals are too strong, then an outage is said to occur.

It has been shown in [2] that:

- The most significant call quality impairment is the interruption of conversion when the receiver captures on noise or interference

- Significant improvements in call quality can be obtained by reducing signal fading with adaptive antenna. The improvement is proportional to the reduction in outage

This implies that reception quality is strongly related to the failure to meet both noise and interference protection requirements and thus justify the use of outage probability as a measure of quality. Hence it is a mathematical tool that provides an objective basis for assessing the quality of service provided by a mobile radio system.

ADAPTIVE ANTENNA

Adaptive antenna is an array of multiple antenna elements with the received signals weighted and combined to maximize the desired signal to interference and noise (SINR) ratio [3]. A block diagram of it is shown in fig-1. Here the main beam is put in the direction of the desired signal while nulls are in the direction of the interference. An adaptive antenna can adapt their radiation pattern to changes in their environment by a set of complex weights using beamforming algorithm. To achieve this, each element of the array is associated with a weight that is adaptively updated so that its gain in a particular look-direction is maximized while that in a direction corresponding to interfering signals is minimized. In other words, they change their antenna radiation or reception pattern dynamically to adjust to variations in channel noise and interference in order to improve the SNR (signal to noise ratio) of a desired signal. It identifies spatial signal signature and computes beamforming vectors so as to direct the antenna beam on receiver in order to enhance system performance, channel capacity, coverage and spectrum efficiency.

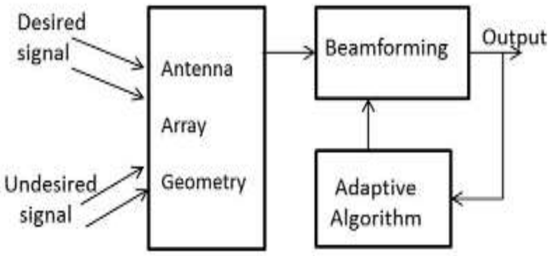

Fig-1: Block diagram of adaptive antenna

BEAMFORMING ALGORITHM

Beamforming algorithm is a technique in which the array of an antenna is exploited to achieve maximum reception in a specified direction by estimating the signal direction [4]. It separates the desired signal from interfering signal by using the technique of adapting the weights with respect to time while maximizing the signal to noise ratio and array output [5]. Fig-2 shows an adaptive beamforming.

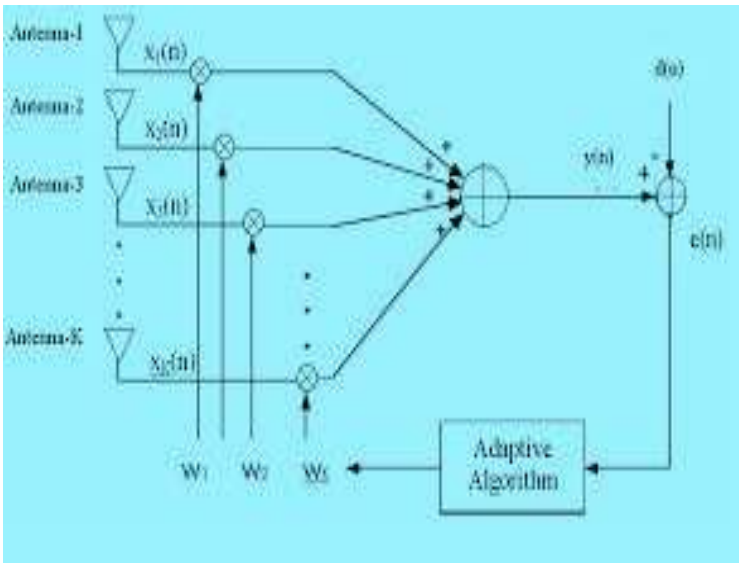

Fig-2: Block Diagram of Adaptive Beam forming [6]

The signal x(n) received by multiple antenna elements is multiplied with the coefficients in a weight vector "w'" which adjusts the phase and amplitude of the incoming signal. This weighted signal is summed up and gives an array output, y(n). An adaptive algorithm is then used to minimize the error e(n) between a desired signal d(n) and the array output y(n).

Without the adaptive algorithm two original signals cannot be extracted. The adaptive beam forming algorithm depends on its performance and convergence rate which are being implemented by a set of iterative equations using Least Mean Square (LMS). LMS is an adaptive algorithm which uses gradient based method of steepest descent. It incorporates an iterative procedure that makes successive corrections to the weight vector so as to obtain minimum mean square error [6].

METHODOLOGY

As stated earlier, the main aim of this work was to develop an adaptive beam forming antenna array for minimizing outage probability in a wireless cellular mobile network. To achieve this goal, some specific research designs were carried out. Details of these designs are shown in the following sections. As shown are the experimental and simulation works carried out.

Determination of outage probabilities

Drive test were conducted at the cell site located at ESUT Agbani with the RF drive test tool to determine the number of outages occurring in the chosen mobile cellular network. Tools used were

- Laptop with required ports and interface.
- TEMS hardware &software.
- USB/Hand GPS and cable interfacing with Laptop.
- Externel mobile antenna.
- Mobile charger
- Inverter.
- USB Hub.

The data collected during the drive test were assessed to evaluate the blocked calls and dropped call. The result obtained as shown in fig-3 indicates that the outageswerevery high.

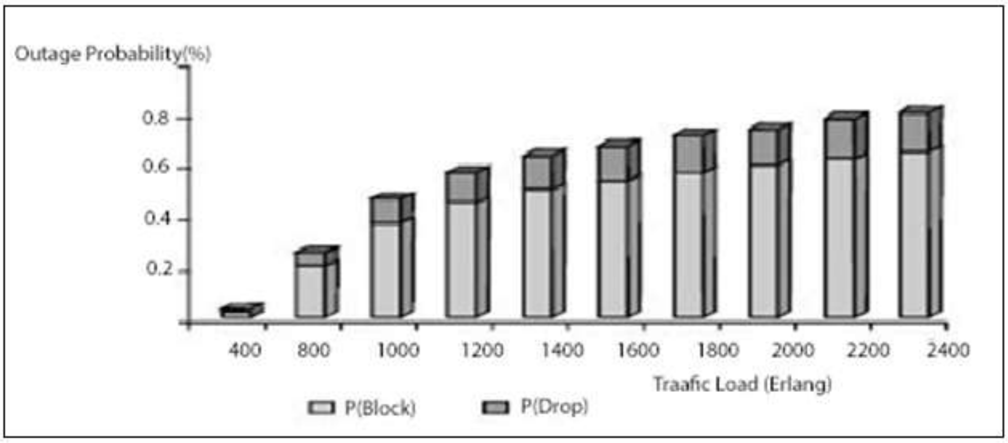

Fig-3: The signal outages without adaptive beamforming antenna

Development of beamforming antenna

A beamforming antenna was developed for proper harnessing of the desired signal. The antenna was configured to radiate, receive the modulated signal and control the direction of transmission. It consists of a central active element that can work as reflectors of radiated power when grounded or as directors of radiated power when isolated. The array elements were spaced apart by half-wavelength to reduce the effect of inter-element mutual coupling. The antenna gain of the array elements were designed to vary as an offset circle. It was situated horizontally in order to receive the incoming signal and perform down conversion. Two LC filters were used to prevent noise from entering the RF section.

Data Acquistion Board (DAQ) which uses 8-bit analog-to-digital converters (ADCs) was designed and used to capture the information signal. The developed beamforming antenna is shown in fig-4.

Fig-4: Developed Beamforming Antenna

LMS Algorithm for the adaptive antenna

The weight vector equation was developed using the method of steepest descent andis given by,

$$w(n+1)= w(n) + \mu\, x(n)[d^*(n)- x^h(n)w(n)] \quad (1)$$

Where μ is the step-size parameter and controls the convergence characteristics of the LMS algorithm;

$e^2(n)$ is mean square error between the beam former output y(n) and the reference signal which is given by,

$$e^*(n)= d^*(n)-x^h(n)w(n) \quad (2)$$

Therefore,

$$w(n+1)= w(n) + \mu\, x(n)\, e^*(n) \quad (3)$$

LMS algorithm was initiated with an arbitrary value w(n) for weight vector at n=0.Successive corrections of weight vector gives minimum mean square error. It can be summarized as follows,

Output $y(n)= w(n)x^h (n)$

Error $e(n)= d^*(n)-y(n)$

Weight, $w(n+1)=w(n) +u\, x(n)\, e^*(n)$

The weight vector is seen to converge and remains stable at,

$$0 < \mu < 1/\lambda max$$

Where λmax is the largest eigenvalue of the correlation matrix

Convergence of algorithm is inversely proportional to the eigenvalue spread of correlation matrix R. A small value ofμ leads to slow convergence but a large value of μ leads to faster convergence though it may be less stable around the minimal level.

Signal model for the reduction of outage probability

The incoming signals undergo a phase shift as they travel across the array. The phase shift between a signal received at the reference element and the same signal received at element m is given by $\Delta\psi_m=\psi_m(t)-\psi_1(t)=-rx_m \cos\phi \sin\theta - ry_m \sin\phi \sin\theta - rz_m \cos\theta$ (4)

Where $r =\frac{2\pi}{\lambda}$

is the propagation constant in free space for linear array of equispaced elements with element spacing aligned along the x-axis such that the first element is situated at the origin, Thusx_m=(m-1)d and $y_m=z_m=0$. As the signals are coming in horizontally we also have $\theta = \pi$ / 2 and then

$\square\square_m \square\square\square\, rd\,(m\,\square 1)\cos\square$	(5)

$s(t)\square\, m_l(t)e^{j2\square f t}$	(6)

Where $s(t)$ *is the incoming signal vector*, $m_l(t)$ is the modulating function of the *lth* source and f^t is he frequency of the carrier signal.

The incoming signal at element m will be in that case

$$x_m(t)\square m_l(t)e^{j(2\square f t\square\square_m)} \quad \square c_{lm}(t)\square s_l(t)\, b_m(\square)\square c_m(t)$$

(7)

and

$$b_m(\square_l)\square e^{j\square_m} \square e^{\square j kd(m\square 1)\cos\square_l}$$

(8)

Where $c_{lm}(t)$ is a random noise component on the *mth* ele-ment, which includes background noise and electronic noise generated in the *mth* channel.Considering all sources simultaneously, the signal at the mth element will be

$$x_m \square \sum_{l\square 1}^{L} m_l(t)e^{j(2\square f_0 t\square\square_m)}\square c_m(t)\square \sum_{l\square 1}^{L} s_l(t)\, b_m(\square_l)\square c_m(t) \quad (9)$$

The array signal vector becomes

$$X(t)\square(x_1(t)\, x_2(t)\, x_3(t)........x_m(t)........x_M(t))^T \quad (10)$$

while the incoming signal vector is

$$S(t)\square(s_1(t)\, s_2(t)\, s_3(t)........s_l(t)........s_L(t))^T \quad (11)$$

And the noise vector is

$$C(t)\square(C_1(t)\, C_2(t)\, C_3(t)........C_m(t)........C_M(t))^T \quad (12)$$

The steering matrix (dimensions M by L) is

$$B\square(b(\square_1)\, b(\square_2)\, b(\square_3)........b(\square_l)........b(\square_L)) \quad (13)$$

In matrix notation

$$X(t)\square Bs(t)\square c(t) \quad (14)$$

Let's denote the weights of the beam former as

$$W\square(w_1\, w_2\, w_3........w_m........w_M)^T \quad (15)$$

Where w is called the array weight vector. The total array output will be

$$y(t) = \sum_{m=1}^{M} w_m^{*} x_m = W^{H} X(t) \quad (16)$$

Where superscripts T and H respectively, denotes the transpose and complex conjugate transpose of a vector or matrix.

Simulation of developed adaptive antenna

Simulation for an adaptive beamforming antenna was done in MATLAB environment shown in fig-5. In the simulation, the adaptive antenna of 6elements in LMS was used. The signal arrived at 10^o. Three interfering signals were at -30^o, -60^o and 45^o.

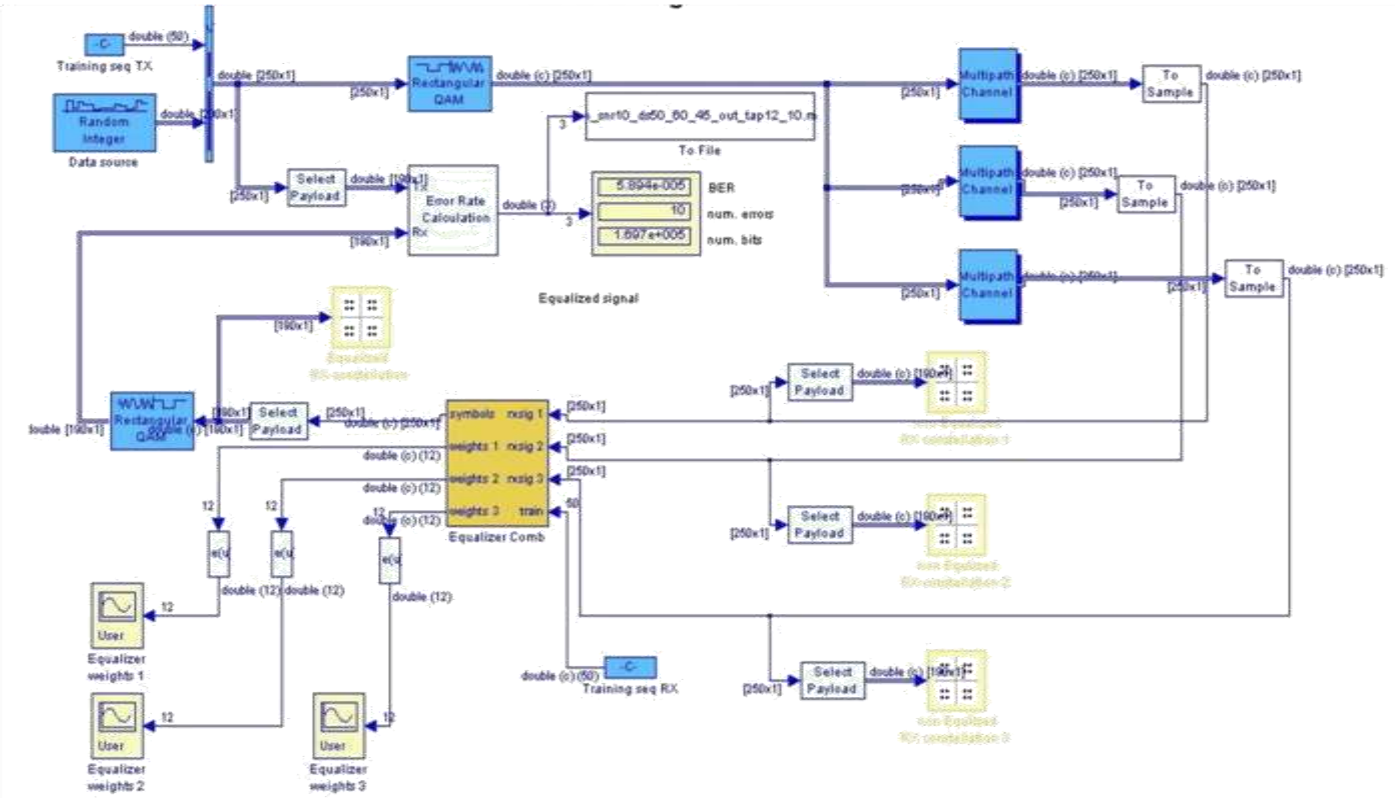

Fig-5: Simulation of the developed adaptive antenna

The smart antenna algorithms compute the antenna weights for all six antenna elements so that thesignal-to-noise-and-interference ratio (SINR) becomes optimum. The parameters used for the simulation are shown in Table-1.

Table-1: Simulation Parameters

Number of antenna elements (N):	6
Element spacing (d):	0.5 λ
Noise variance (σ^2):	0.001
Frequency Reuse Factor	0.7
Perfect Power Control	Perfect
Mobile User Location	0^o at main beam
Total number of data samples (K):	600
Forgetting factor (α) (for LMS):	0.9
DOA of desired signal:	0^o
DOA of interferer signal (I_1)	-30^o
DOA of interferer signal (I_2)	-60^o
DOA of interferer signal (I_3)	45^o

Themobile user traffic parameters such as mean call duration and mean arrival time were generated using Poisson distribution model. Simulation was carried out with different traffic load condition to obtain the outage probability under various traffic load condition. Blocking of a new mobile User occursif its capacity is below the minimum threshold level as required during call connection request while dropping of a mobile user will occur if an active mobile user moving out from current beam coverage wants to enter another beam but fails due power limitation at new antenna beam. Outage probability was obtained by summing the blocking and dropping probabilities Fig 3 shows the simulation environment.Also simulation on outage probability without adaptive beamforming antenna was also carried out and measurement of BER was taken for comparison.

RESULTS

The simulation result in figure 6 shows the composition of blocking probability and dropping probability. It can be seen that the outage probability is lower with adaptive beamforming antenna.

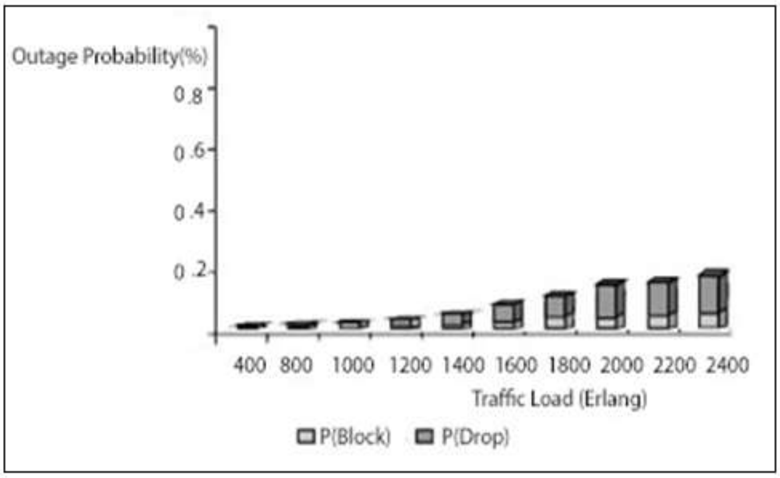

Fig-6: The signal outageswith adaptive beamforming antenna

The percentage improvement of using adaptive beamforming antenna is

$$=\frac{P(without\ adaptive\ beamforming\ antenna - with\ adaptive\ beamforming\ antenna)}{P(without\ adaptive\ antenna)} x\ 100\%$$

$$=\frac{0.8-0.2}{0.8} x\ 100\%$$

$$= 75\%$$

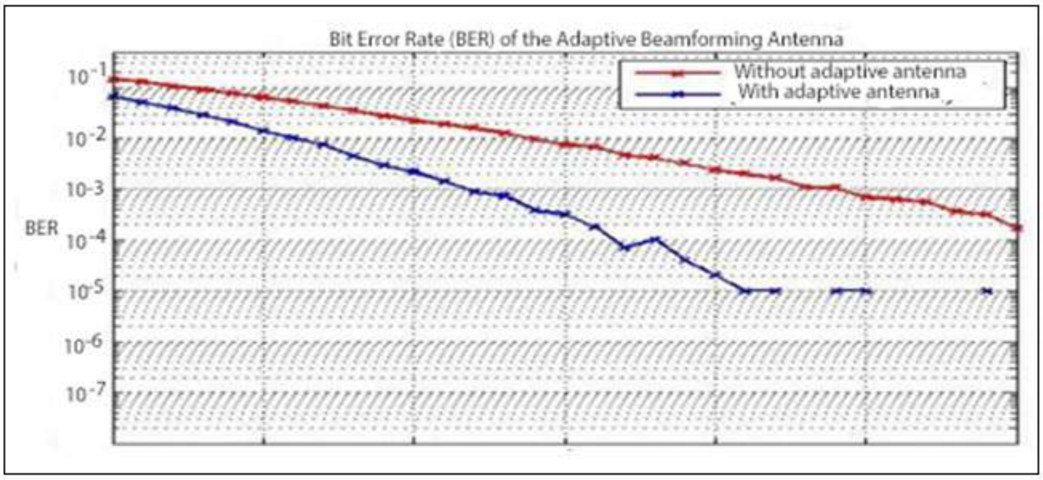

Fig-5: BER vs Eb/N$_0$

Fig-5 shows the Bit Error Rate (BER) vs. Signal noise ratio (Eb/N$_0$) with and without using beam forming technique. The BER curve is better with adaptive beam forming antenna compared to without adaptive beam forming antenna.

CONCLUSION

In adaptive beam forming, the radiation pattern of an adaptive antenna is controlled through LMS algorithm which optimizes according to the environment. The simulation results demonstrated a significant performance improvement using adaptive beam forming antenna. It has better convergence rate, lower outage probability and improved coverage. The performance also increases with the increasing number of the array antenna. The comparison study of Bit Error Rate (BER) vs. Signal noise ratio (Eb/N_0), with and without beam forming in Rayleigh channel was also obtained. The simulation results demonstrated a significant performance improvement using adaptive beam forming array antenna. Adaptive beam forming algorithms also improve the directivity of antenna. In future, it is expected that these beam forming algorithms can be implemented in Cognitive Radio Architecture.

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