COMPUTER MODELING OF SMART ANTENNA SYSTEM

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ABSTRACT

This research studied the adaptive smart antenna system using in cellular phone applications using MATLAB simulation.

In this work, the proposed novel least mean square algorithm (No-LMS) build and studied the results as comparative work with results of two another algorithms called Standard LMS algorithm (S-LMS), and normalized LMS algorithm (N-LMS). The computer simulation work results based No-LMS algorithm have better performance refer to obtain the optimum convergence factor (CF) and shows that robustness smart system, good tracking capability, and high adaptation accuracy than the other algorithms.

The smart antenna system that is based on LMS-algorithms for all types (S-LMS),(N-LMS),and (No-LMS) show that this system is affected by the convergence factor, the computer simulation results shows the minimum mean square error (MSE = 0.007) is obtained for the value of convergence factor equal to (0.2). also the smart system is affected by the number of the antennas are used in smart array and number of samples interval, at least three antennas gives the poor steering of array with large MSE value (0.15).

The test of the three algorithms for different values of signal to noise ratio (SNR) show that the (No-LMS) algorithm gives the minimum MSE values compared with the two those obtain from other algorithms.

KEYWORDS: smart antenna system, computer modeling, noise ratio.

التصميم البرمجي لنظام الهوائي الذكي

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الخلاصة

في هذا البحث تم دراسة نظام الهوائيات التكيفية الذكية المستخدمة في تطبيقات الهاتف الخلوي باستخدام برنامج المحاكاة الماتلاب. وقد تم افتراح خوارزمية المسماة (No-LMS) ومقارنة اداءها مع الخوارزميات (S-LMS) و(N-LMS) وبينت نتائج الحاسوب ان خوارزمية (No-LMS) اعطت افضل اداء وافضل معامل تغطية (CF) عن الخوارزميات الاخرى وفي اسوء الظروف و بينت بان نظام الهوائيات الذكية المستندة إلى الخوارزمية (No-LMS) له فابلية تتبع جيدة ودقة تكييف عالية واستقراريه مقارنه مع الانظمه المستندة إلى الخوارزميات الاخرى. وبشكل عام كل خوارزميات (LMS) تعاني من التاتر بالاداء بعامل التقارب وان النتائج اظهرت بان احسن فيمه لعامل التقارب هي (CF=0.2) سجلت عند اقل معدل مربع خطا (MSE = 0.007) بالإضافه إلى ذلك فان انظمه الهوائيات التكيفيه تتاثر ايضا بعدد الهوائيات في المصفوفه . و اوضحت النتائج بان كلما زاد عدد الهوائيات فان نسبه مربع الخطا المحسوبه تكون افل ويصبح النظام اكثر استقرارا ، وعلى الاقل ثلاث هوائيات تعطي توجيه غير جيد للمصفوفه ونسبه خطا عاليه تصل الى (0.015).

من خلال اختبار الخوارزميات الثلاث لمختلف القيم من نسبه الاشارة الى الضوضاء يتضح بان خوارزميه (No-LMS) تعطي اقل قيم من معدل مربع الخطا مقارنة بالخوارزميتين الاخريين.

1. INTRODUCTION

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 (Trees2002). Over the last few years the demand for wireless services has risen dramatically. This fact introduces a major technological challenge to the design engineer: that is to increase the overall performance and efficiency of the wireless system with an increased number of users under the constraints of spectrum efficiency, power usage and cost. Most of the research on this topic, until very recently, has been largely focused on the development of modulation and coding techniques as well as communication protocols, very little attention has been paid to the overall transceiver structure and antenna technology. Recently developed smart antenna technology may be the solution to satisfying the requirements of next generation wireless networks (**Chris, et.al, 2003**).

Smart antenna for mobile communication has received enormous interests worldwide in recent years. In the last decade, wireless cellular communication has experienced rapid growth in the demand for provision of new wireless multimedia services such as internet access, multimedia data transfer and video conferencing. Smart antennas involve processing of signal induced on an array of antennas. They have application in the areas of radar, sonar, medical imaging location based application and cellular phone applications (**Shaukat 2009**).

This paper represents the study of performance and design of adaptive smart antenna algorithm used in cellular phone applications. This algorithm is studied for different levels of intelligence. The performance of novel least mean square (No-LMS) algorithm with standard-LMS algorithm and normalized LMS (N-LMS) algorithm has been compared.

Smart antennas shown in **Figure (1)** refer to a group of antenna technologies that increase the system capacity by reducing the co-channel interference and increase the quality by reducing the fading effects (**Trees, 2002**).

A smart antenna array containing M identical elements can steer a directional beam to maximize the signal from desired users, signals of interest (SOI), while nullifying the signals from other directions, signals not of interest (SNOI) (**Chris2003**).

There are many adaptive algorithms that can be used to adjust the weight vector, the beam former must be implemented subject to a number of contradictory demands, regarding to the best choice of the algorithm.

The analog-to-digital converters (ADCs) in such systems will be located as close to the antennas as possible in order to achieve almost complete digital processing. In order to realize this, ADCs capable of digitizing a high-frequency wideband signal at very high sampling rates will be required along with wideband or multi-band antennas and RF analog devices. However, direct analog-to-digital conversion at over sampling rates of very high RF or IF signals, typically ranging between hundreds of MHz to several GHz, may not yet be practical because the reasonably price ADCs and sufficiently high-speed digital devices, such as current signal processors and buffer memories, cannot be used. The under sampling technique is always useful by performing frequency down conversions and quantization at the same time (**Minseok, 2004**).

The most appropriate criterions include:-

(1) Computational complexity, defined as the number of snapshots required to converge to the optimum solution,

(2) Robustness, which is an ability of the algorithm to behave satisfactorily under finite word precision numerical operation, and

(3) Implementation issue. One important class of beamforming algorithms are the non blind algorithms in which training signal is used to adjust the array weight vector (**Shaukat, 2009**).

2- TYPES OF SMART ANTENNAS (RAPPAPORT 98)

There are basically two approaches to implement antennas that dynamically change their pattern to mitigate interference and multi path affects while increasing coverage and range. They are:-

• Switched beam

• Adaptive Arrays

The Switched beam approach is simpler compared to the fully adaptive approach. It provides a considerable increase in network capacity when compared to traditional omni directional antenna systems or sector-based systems. In this approach, an antenna array generates overlapping beams that cover the surrounding area as shown in **Figure (2a).**

When an incoming signal is detected, the base station determines the beam that is best aligned in the signal-of-interest direction and then switches to that beam to communicate with the user. The Adaptive array system is the "smarter" of the two approaches. This system tracks the mobile user continuously by steering the main beam towards the user and at the same time forming nulls in the directions of the interfering signal as shown in **Figure (2b)**. Like switched beam systems, they also incorporate arrays. Typically, the received signal from each of the spatially distributed antenna elements is multiplied by a weight. The weights are complex in nature and adjust the amplitude and phase. These signals are combined to yield the array output. These complex weights are computed by a complicated adaptive algorithm, which is pre-programmed into the digital signal-processing unit that manages the signal radiated by the base station.

3. BENEFITS OF SMART ANTENNA TECHNOLOGY (AHMED2005):-

Smart antennas have several advantages over other antenna systems. For example, smart antennas are able to increase the data transfer rate of a wireless signal as well as reduce the number of errors or obstructed pieces of data. Smart antennas are also able to calculate the direction of arrival of a wireless signal and effectively alert the user to where the signal is the strongest. Smart antennas are easy to use and depend on plug-and-play technology. Many advantages that realize by smart system are:-

3.1 REDUCTION IN CO-CHANNEL INTERFERENCE

Smart antennas have a property of spatial filtering to focus radiated energy in the form of narrow beams only in the direction of the desired mobile user and no other direction.

3.2 RANGE IMPROVEMENT

Since smart antennas employs collection of individual elements in the form of an array they give rise to narrow beam with increased gain when compared to conventional antennas using the same power. The increase in gain leads to increase in range and the coverage of the system. Therefore fewer base stations are required to cover a given area.

3.3 INCREASES IN CAPACITY

Smart antennas allow more users to use the same frequency spectrum at the same time bringing about tremendous increase in capacity.

3.4 MITIGATION OF MULTI PATH EFFECTS

Smart antennas can either reject multi path components as interference, thus mitigating its effects in terms of fading or it can use the multi path components and add them constructively to enhance system performance**.**

3.5 COMPATIBILITY

Smart antenna technology can be applied to various multiple access techniques such as TDMA, FDMA, and CDMA. It is compatible with almost any modulation method and bandwidth or frequency band.

3.6 SIGNAL GAIN
Inputs from multiple antennas are combined to optimize available power required to establish given level of coverage.

4. THE LMS AND N-LMS ALGORITHMS:-
4.1 LMS-ALGORITHM (HYKIN 96)
The algorithm uses a gradient descent to estimate a time varying signal. The gradient descent method finds a minimum, if it exists, by taking steps in the direction negative of the gradient. It does so by adjusting the filter coefficients so as to minimize the error.

The gradient is the Del operator (partial derivative) and is applied to find the divergence of a function, which is the error with respect to the nth coefficient in this case. The LMS algorithm approaches the minimum of a function to minimize error by taking the negative gradient of the function. LMS algorithm can be implemented as shown in **Figure (3)**

The desired signal d (n) is tracked by adjusting the filter coefficients c (n). The input reference signal x (n) is a known signal that is fed to the FIR filter. The difference between d (n) and y (n) is the error e (n). The error e (n) is then fed to the LMS algorithm to compute the filter coefficients c (n+1) to iteratively minimize the error.

4.2 N-LMS-ALGORITHM (RALLAPALL2007)
Most parameters of the NLMS algorithm are the same as the LMS algorithm, except that the step size or the coverage factor is now bounded between 0 and 2. The normalization term, makes the convergence rate independent of signal power. The normalized least mean square algorithm (N-LMS) is an extension of the LMS algorithm, which bypasses the step size issue by selecting a different step size value, μ, for each iteration of the algorithm. This step size is proportional to the inverse of the total expected energy of the instantaneous values of the input vector. The N-LMS algorithm shows far greater stability with unknown signals. This combined with good convergence speed and relative computational simplicity makes the NLMS algorithm ideal for the real time adaptive echo cancellation system. As the NLMS is an extension of the standard LMS algorithm, the N-LMS algorithms practical implementation is very similar to that of the LMS algorithm.

5. ADAPTIVE SMART ANTENNA MODEL (ASA-MODEL)
Figure (4) demonstrates the adaptive smart antenna model; the ASA-model is proposed and discussed as comparative work between (No-LMS) algorithm with S-LMS algorithm and (N-LMS) algorithms by use the Matlab simulation program.

 The system model shown can be used to test the different algorithms performance and scope the novel and optimal one in different environments.

Where:-

u (r) : represents the input signal from uniform linear array.

m (r) : the output signal from the unknown channel.

I (r): the interference signal.

y (r): the received signal is obtained by summing the interference signal with m (r).

The signal y (r) is applied to the adaptive equalizer to reduce the noise that is generated by the effect of the channel. The output of the equalizer gives the signal x (r). This signal is compared with the original transmitted signal u (r) to obtain the error signal e (r).

Let the unknown channel is represented mathematically as a function $(1/J_c)$, and the adaptive equalizer as (E). In the case of absence the interference effect (ideal channel), that mean the output of equalizer x (r) is the same input signal u(r) and we can obtain (**Shannon8**):-

$$J_c = E \qquad\qquad (1)$$

That produces

$$\frac{E}{J_c} = 1 \tag{2}$$

From **figure(4)** the unknown channel is assumed the linear channel with response same as the response of the finite impulse response filter with time (t):- adaptive

$$J_c = [j_{c0}, j_{c1}, j_{c2}, \ldots\ldots\ldots j_{cn-1}] \tag{3}$$

The parameters of the equalizer can written as:-

$$E(r) = [e_0, e_1, e_2, \ldots\ldots\ldots, e_{n-1}] \tag{4}$$

For the nth LMS-filter parameters:- $Ei(0) = 0, \; for \; i = 0,1,2,3,\ldots\ldots\ldots n-1$
The output of unknown channel:-

$$M(r) = [m(r-1), m(r-2), m(r-3),\ldots\ldots\ldots, m(r-n-1)] \tag{5}$$

The output is calculated as:-

$$M(r) = \frac{1}{J_c(1)}(u(r) - J_c(2:n)M^T(r)) \tag{6}$$

By adding the interference signal the received signal become and can show in figure (5):-

$$y(r) = m(r) + I(r) \tag{7}$$

$$Y(r) = [y(r), y(r-1), y(r-2),\ldots\ldots\ldots, y(r-n-1)] \tag{8}$$

The equation (8) represents the received signal in matrix form, and the output of the equalizer is:-

$$x(r) = E(r-1)Y^T(r) \tag{9}$$

The resultant error signal:-

$$e(r) = u(r) - x(r) \tag{10}$$

If the error signal is equal to the interference signal that refer to the adaptive smart antenna system based the LMS-algorithms is estimated the unknown channel successfully and the standard LMS-algorithm can represented:-

$$E(r) = E(r-1) + \mu Y(r).e(r) \tag{11}$$

where (μ) is the convergence factor (**Cowan85**).

6. COMPUTER SIMULATION TEST:-
6.1 CHOICE OF CONVERGENCE FACTOR
The convergence factor (μ) controls how far we move along the error function surface at each update step. Convergence factor certainly has to be chosen $\mu > 0$ (otherwise we would move the coefficient vector in a direction towards larger squared error). Also this parameter must not become too large. Furthermore, too large a convergence factor causes the LMS algorithm to be instable, i.e., the coefficients do not converge to fixed values but oscillate. Closer analysis (Hykin96) reveals, that the upper bound for μ for stable behavior of the LMS algorithm depends on the largest Eigen value

(λ_{max}) of the tap-input auto-correlation matrix and thus on the input signal. For stable adaptation behavior the coverage factor has to be:-

$$0 \langle \mu \langle \frac{2}{\lambda_{max}} \tag{12}$$

The convergence time of the LMS algorithm depends on the convergence factor (μ). If μ is small, then it may take a long convergence time and this may defeat the purpose of using an LMS filter. However if μ is too large, the algorithm may never converge (**Amrita2010**).

6.2 NOVEL ALGORITHM
There is proportion between the stability of the adaptive algorithm and the convergence ratio for the smart system. If the μ-value is large that produces the fast convergence ratio but this fast convergence ratio led to low stability and low accuracy for smart system. In other hand, the low values give good stability the accuracy.
The No-LMS algorithm is suggested to give the suitable convergence factor, this factor is dependent upon the equation:-

$$0 \langle \mu \langle \frac{E[(u(r))^2]}{2.E[(e(r))^2]}.\sigma \tag{13}$$

Where:-
$(u(r))^2$: input signal power.
$(e(r))^2$: error signal power.
E[ ]: the expected value.
σ: the standard deviation. The graph of the standard deviation shown in **Figure (7)**

$$\sigma = \frac{A}{\sqrt{2 \times 10^{0.1SNR}}} \tag{14}$$

Equation (14) graph can be shown in **figure (6)**
Where:-
A: the input signal amplitude.
SNR: the signal to noise ratio.
Now the error signal equation can be written:

$$e(r) = \sigma - w^H(r).u(r) \tag{15}$$

Where w^H(r) the estimated of the tap weight of LMS-filter.

7. RESULTS AND DISCUSSION
The computer simulation test using matlab simulation program for ASA-model based three algorithms called S-LMS, N-LMS, and No-LMS show that:-
From the **Figure (7)** the No-LMS algorithm has the optimum performance compared with the other two algorithms (S-LMS, and N-LMS) for small values of the Mean Square Error (MSE) and the sample interval, whereas the two other algorithms need the large values of mean square error (MSE) and the sample interval at the same value of convergence factor (CF =0.2) to be stable.
By varying the value of the convergence factor from the value 0.04 and below, the MSE values is increased and that produces unstable system as shown In **Figure (8)**, but from this values the No-LMS algorithm gives the good system stability but for the large numbers of sample interval, the N-LMS algorithm produces low stability for large number of sample interval, and the S-LMS algorithm fail.

The relationship between the mean square error and the number of the convergence factor for increase the values of CF from 0.26 and above, the system tends to be unstable that can be shown in **Figure (9).**

Figure (10) represents the inverse proportion between the number of antennas and the MSE values when the number of antennas is increased that led to reduce the value of the MSE and vice versa; that means the ASA system is affected by the number of the antennas in the array.

The other test that appears the good performance of (No-LMS) algorithm over the other two algorithms can be shown in **Figure (11)**, when varying the values of SNR the (No-LMS) algorithm still gives conceivable errors than that obtained from the other algorithms (S-LMS, and N-LMS).

8. CONCLUSIONS

The optimum convergence factor for the minimum mean square error is obtained to No-LMS algorithm whereas S-LMS and N-LMS algorithms gives mean square error values larger than that obtain from No-LMS for same value of convergence factor; that means this algorithm (No-LMS) gives best performance also in bad conditions.

The smart system used in cellular phone applications is affected by the fine varying for convergence factor, and the stability of the whole system depends on these fine variations of different types of algorithms, these variations of same as slow tuning for small steps, also this small value variations of convergence factor appear the considered effect on system performance.

The computer simulation test shows that number of antenna in smart array also has large effect on the stability of the system based to this array.

The S-LMS gives bad performance and fails in worst environments.

9. REFERENCES

1. Ahmed El Zooghby "Smart Antenna Engineering", Artech house, Second edition, p-7, 2005.

2. Amrita Rai, Amit Kumar "Analysis and Simulation of Adaptive Filter with LMS Algorithm", International Journal of Electronic Engineering", Vol (2), pp121-123, 2010.

3. C.F.C Cowan, P.M. Grant "Adaptive Filter", Prentice Hall, 1985.

4. Chris Loadman, Zhizhang Chen, and Dylan Jorgen "An overview of Adaptive Antenna Technologies for Wireless Communications" , Communication Networks and Series Research Conference, Session A3, Moneton, New Brunswick Canada, 2003.

5. Hykin, Simon "Adaptive Filter Theory", Third Edition, Prentice Hall Inc.NJ, 1996.

6. Minseok Kim "Hardware Implementation of Signal Processing in Smart Antenna Systems for High Speed Wireless Communication" ,PhD. Thesis, "Yokohama National University" , 2004.

7. N.P. Rallapall, S. Sharma, and A. Jain "Simulation of Adaptive Filter for Hybrid Echo Cancellation", IEI Journal-ET, Sept, 2007.

8. Rappaportm T. S. " Smart Antennas: Adaptive Array Algorithms and Wireless Position Location", New York, IEEE Press, 1998.

9. S.F.Shaukat, Mukhtar Ul Hassan, and R. Farooq "Sequential Studies of Beam Forming Algorithms for Smart Antenna Systems", World Applied Sciences Journal, Vol-6, pp 754-758, 2009.

10. Shannon Liew "Adaptive Equalizers and Smart Antenna System", PhD.Thesis, 2002,University of Queensland.

11. Trees H.V. "Detection, Estimation, and Modulation Theory", PartIV, Optimum Array Processing, John Wiely&Sons, 2002.
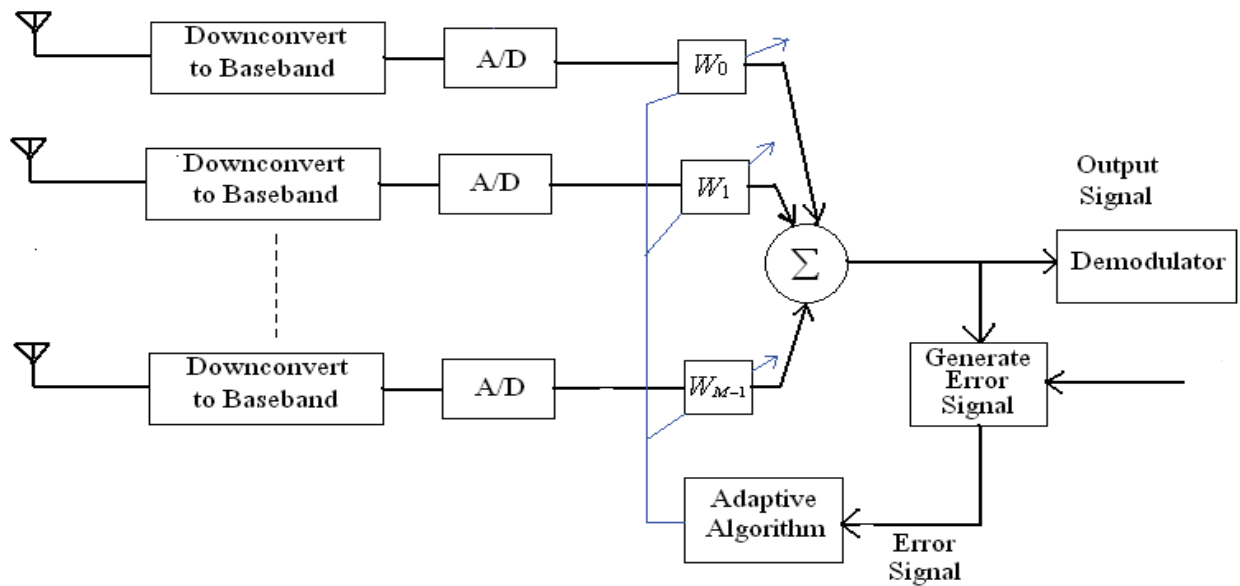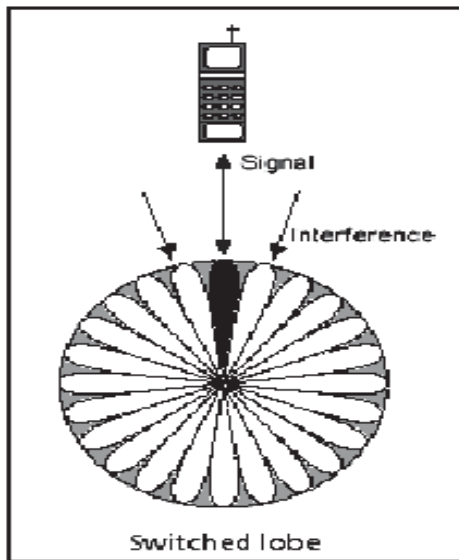
Figure (1) Smart antenna block diagram
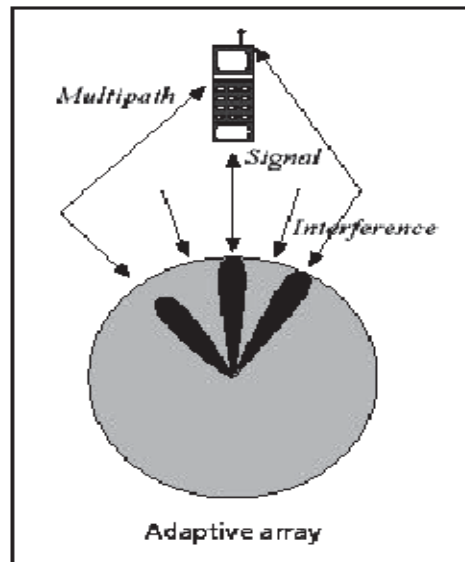
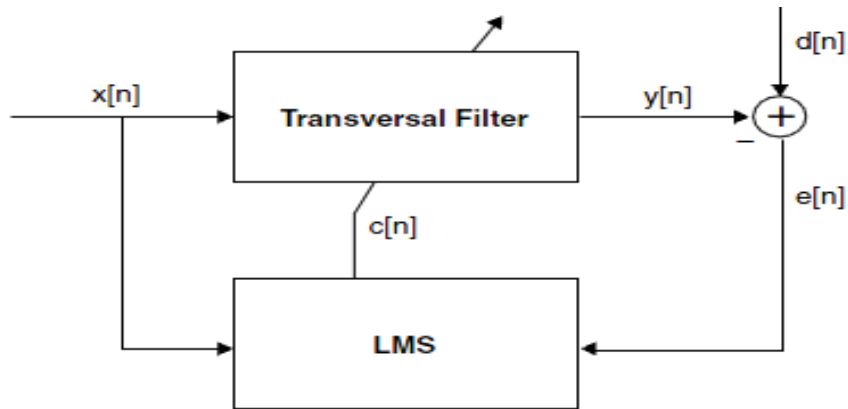**Figure (2a) Switched beam system**   **Figure (2b) Adaptive array system**

Figure (3) The LMS-algorithm
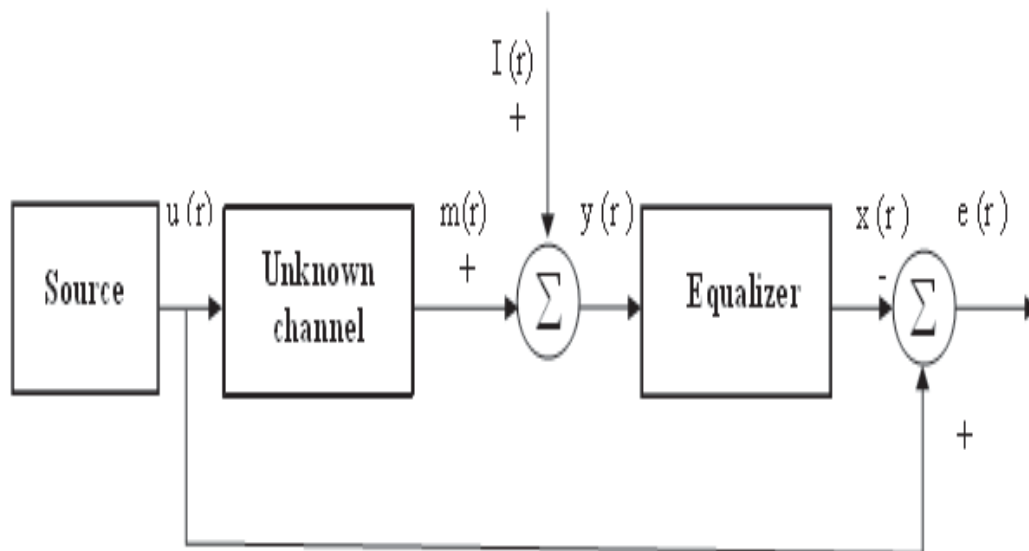
Figure (4) The ASA-Model
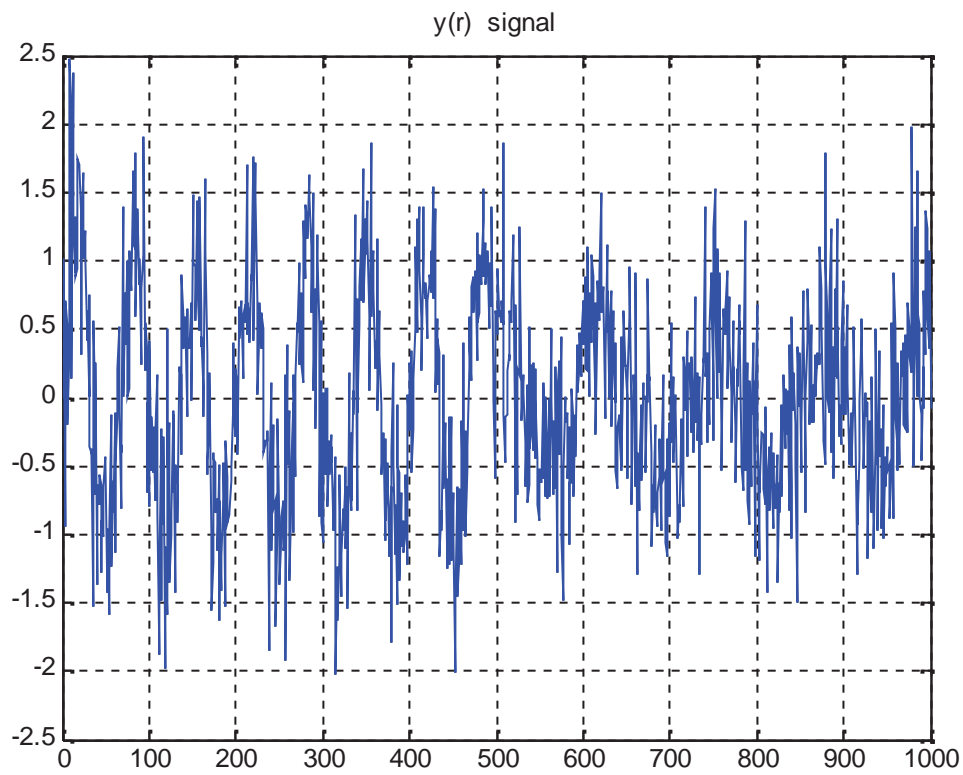
Figure (5) The received signal y (r)
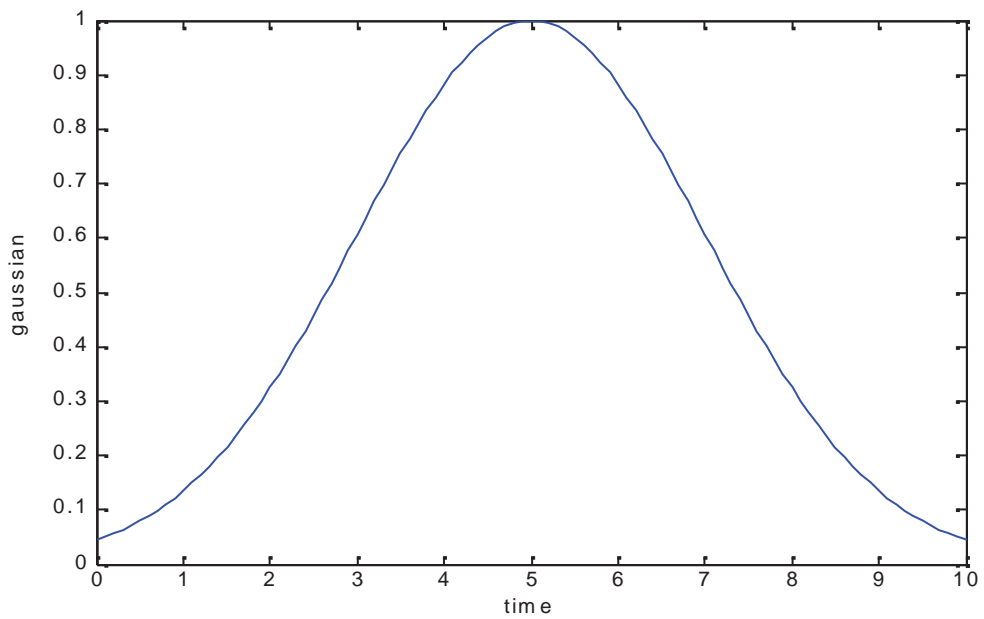
Figure (6) The standard deviation
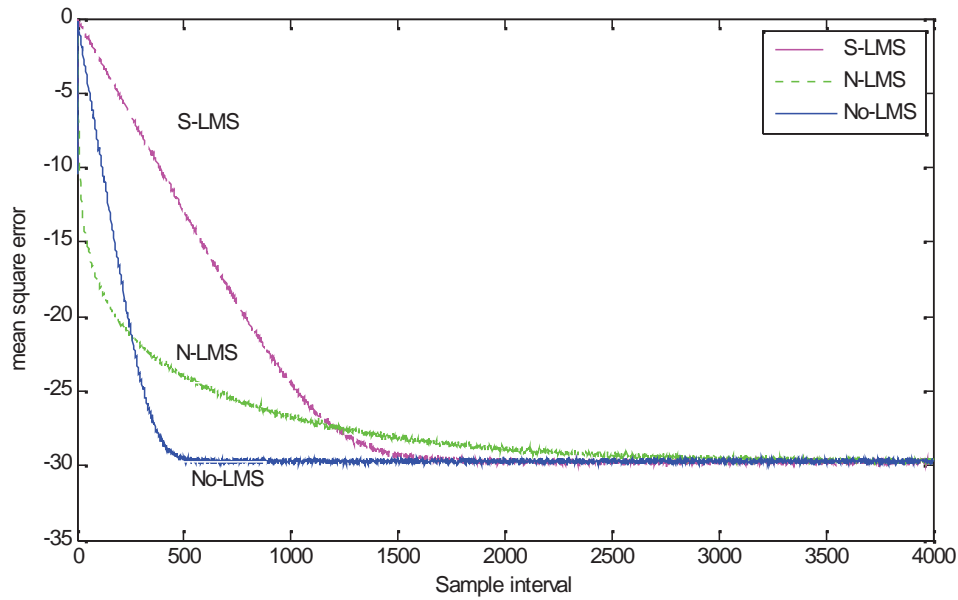
**Figure (7) MSE versus the sample interval
for CF = 0.2**
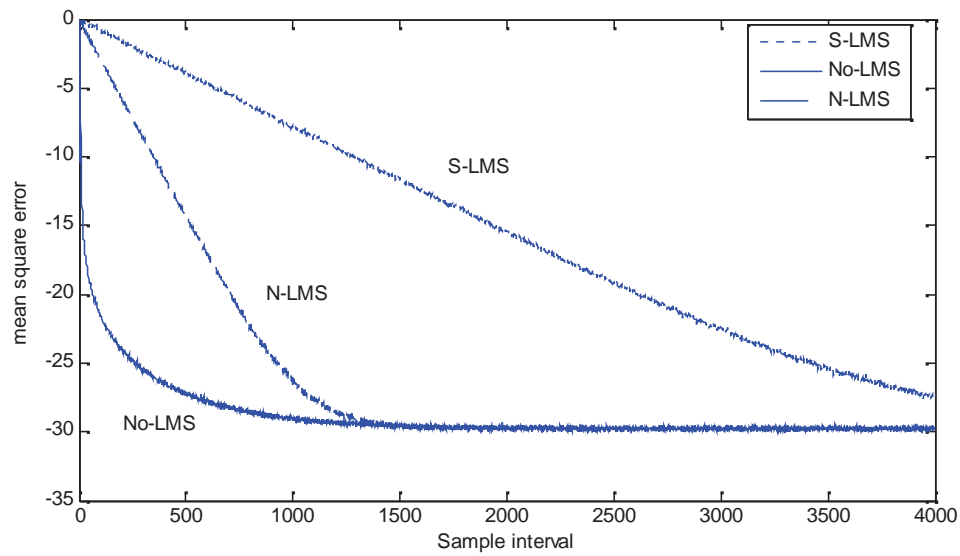
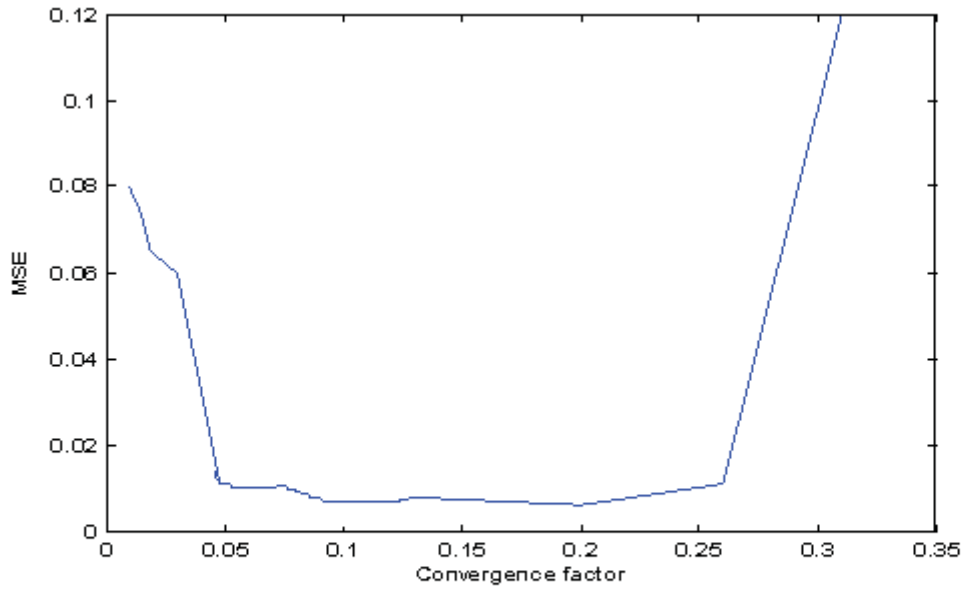**Figure (8) MSE versus the sample interval
for CF ≤0.04**
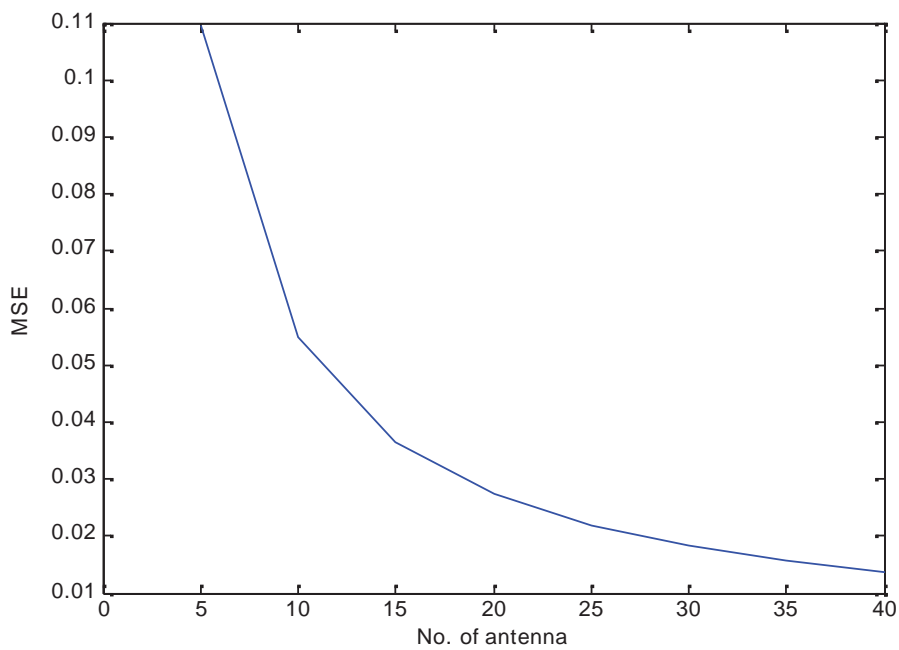
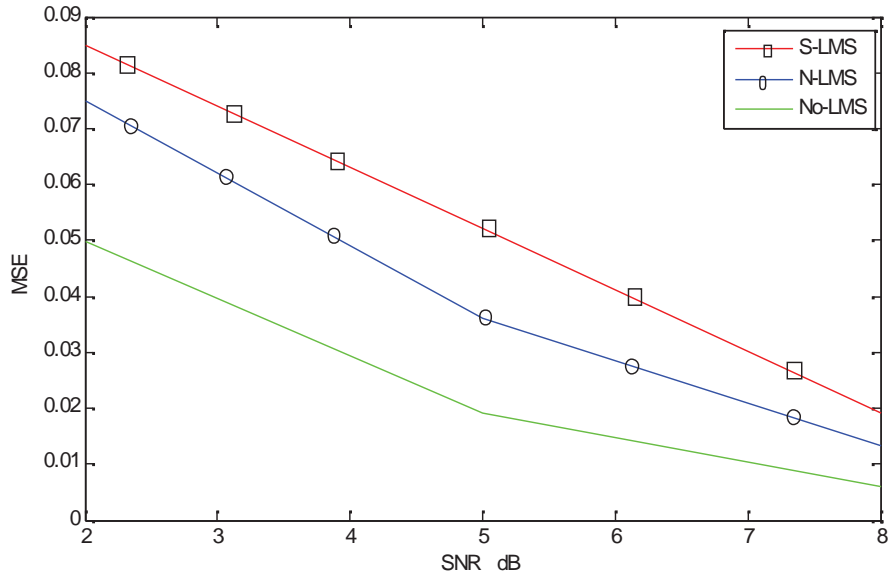**Figure (9) MSE versus the convergence factor**

Figure (10) MSE versus the number of antennas

Figure (11) Error versus the signal to noise ratio