

Smart Antenna Technology for 5g Wireless Communications

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Abstract

The implementation of smart antenna techniques in advanced wireless systems like 5G Mobile Communications, is expected to have a significant impact on the efficient utilization of the spectrum, the minimization of the cost of establishing new wireless networks, the optimization of service quality, and realization of the transparent operation across multi technology wireless networks. Nevertheless, its success relies on two considerations that have been often overlooked when investigating smart antenna technologies: first, the smart antennas features need to be considered early in the design phase of future systems (top-down compatibility); second, a realistic performance evaluation of smart antenna technique needs to be performed according to the critical parameters associated with future systems requirements (bottom-up feasibility). In this paper an overview of the different types of smart antenna techniques are discussed with an insight to switched beam array and adaptive antenna array elaborated with necessary equations.

Keywords: *Smart antennas; LMSE; MMSE*

INTRODUCTION

In 20th century mobile radio communication used in military communication only. Later in 1946 “car based telephone system” was

first telephone system introduced. Single antenna were used on top of high building. Single channel used for sending and receiving similar to half duplex system,

were only transmission or reception was possible over a channel. success of mobile communications is mirrored by a rapid pace of technology innovation. Since its initiation in the late 1970s, mobile wireless communication has come across from analog voice calls to current modern technologies adept of providing high quality mobile broadband services with end-user data rates of several megabits per second over wide areas and tens, or even hundreds, of megabits per second locally. The 1st generation was announced in initial 1980's. It has a data rate up to 2.4kbps. From the second generation (2G) mobile communication system debuted in 1991 its data rate is 64kbps to the 3G system first launched in 2001, the wireless mobile network has transformed from a pure telephony system to a network that can transport rich multimedia contents(data rate is 5-30Mbps).

The 4G wireless systems were designed to fulfill the requirements of International Mobile Telecommunications- Advanced (IMTA) using IP for all services In 4G systems, an advanced radio interface is used with orthogonal frequency-division multiplexing (OFDM), multiple-input multipleoutput (MIMO), and link adaptation

technologies. 4G wireless networks can support data rates of up to 1 GB/s for low mobility, such as nomadic/local wireless access, and up to 100 Mb/s for high mobility, such as mobile access. Long-Term Evolution (LTE) and its extension, LTE-Advanced systems, as practical 4G systems, have recently been deployed or soon will be deployed around the globe.

Future fifth generation wireless communication networks will make an important difference and will add more services and benefits to the world over 4G. It will be more advanced that will interconnect the entire world and it will give birth to worldwide wireless web. We can even hook our phone with our laptop for broadband internet access. 5G technology will provide very high band width that the users have never experienced before. The 5G technology has all type of advanced features which makes it a most powerful tool of wireless communications.[1]

Smart antenna technology is introduced in wireless communication, since it gives enhanced communication system performance, including channel capacity and coverage range. It also improves the link quality for transmission and reception

by multipath propagation and reduced fading. Smart antenna is combination of antenna arrays with digital signal processing algorithm, to make antenna smart. There are two types of smart antenna Switched beam antenna and Adaptive array antenna.

Since Wireless communication is one of the most rapidly growing industries. The high demand for wireless communication services had led to an increase in system capacity. Then most elementary solution would be to increase bandwidth; however, this becomes ever more challenging as the electromagnetic spectrum is becoming increasingly congested. The ever-increasing demand for increased capacity in wireless communications services has led to

developments of new technologies that exploit space selectivity. This is done through smart-antenna arrays and the associated adaptive beam forming algorithms. Smart antenna systems provide opportunities for higher system capacity and improved quality of service among other things.

II. METHODOLOGY

A. Switched beam antenna

Switched beam antenna forms multiple fixed beam with heightened sensitivity in particular directions. These antenna systems detect signal strength chose from one of predetermined, fixed beam and switch from one beam to another as mobile moves throughout the sector.

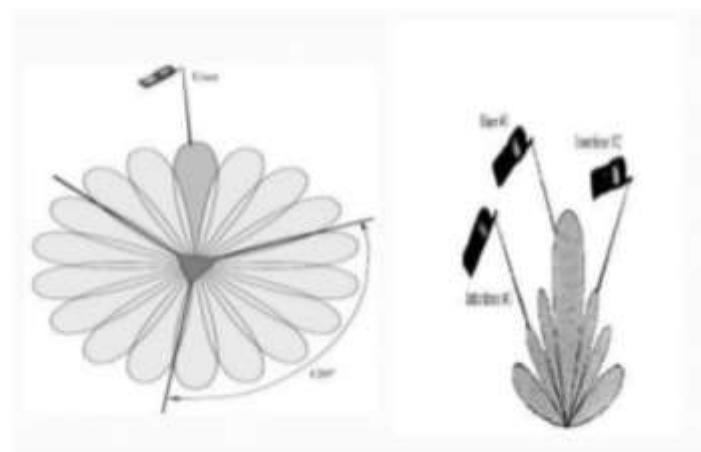


Fig.1: Switched Beam System Coverage Pattern(sector)

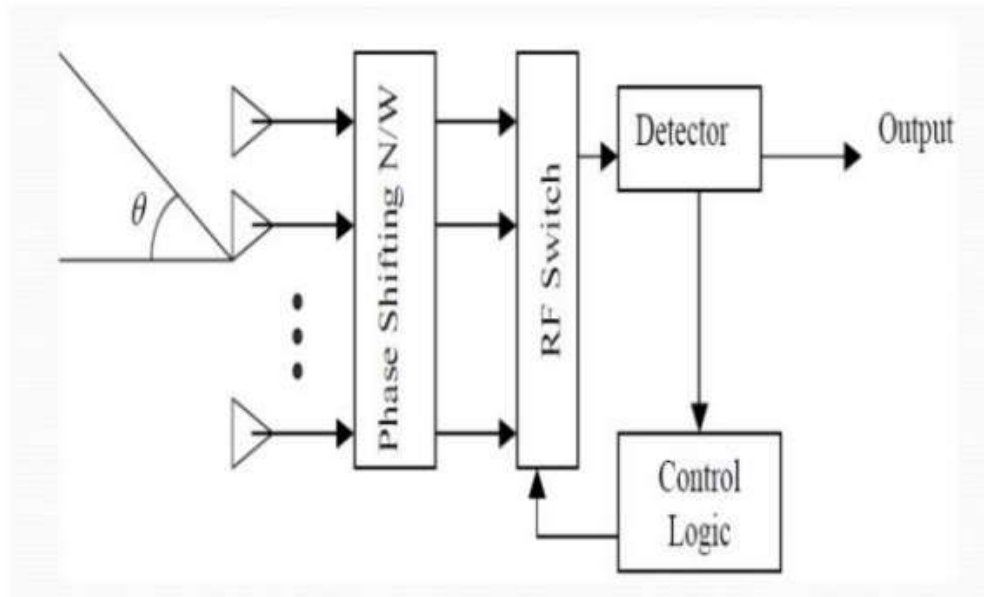


Fig2: Block diagram of Switched Beam System

PSN which forms multiple beams looking in certain directions. RF switch actuates the right beam in desired direction. The selection of right beam is made by control logic which is governed by an algorithm. The algorithm which scans all the beams and selects the one strongest receiving signal based on measurement made by detector.

The overall goal of switched beam system is to increase the gain according to the location of the user.

B. Adaptive array antenna

Adaptive antenna technology represents the most advanced smart antenna approach by using a variety of new signal processing algorithm. It provide optimal gain, simultaneously identifying tracing and minimizing interfering signal.

In block diagram D/c converts from RF to IF. ADC converts analog to digital for future processing. W's is complex weights contains amplification and phase information.[5]

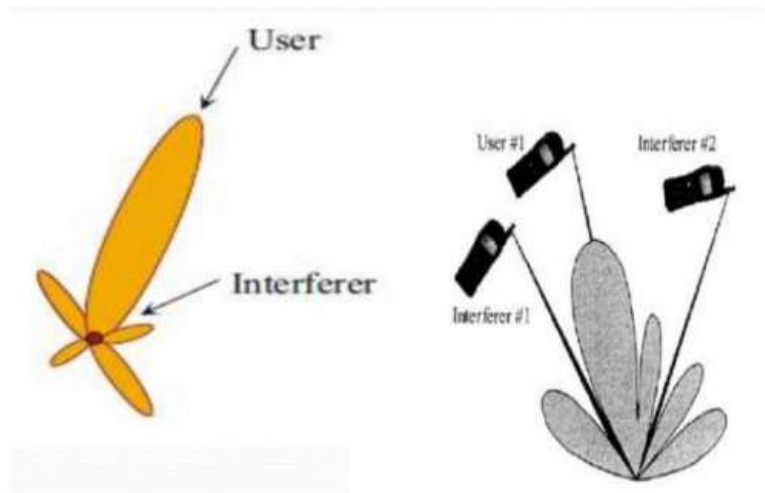


Fig.3: Adaptive Array System Coverage pattern

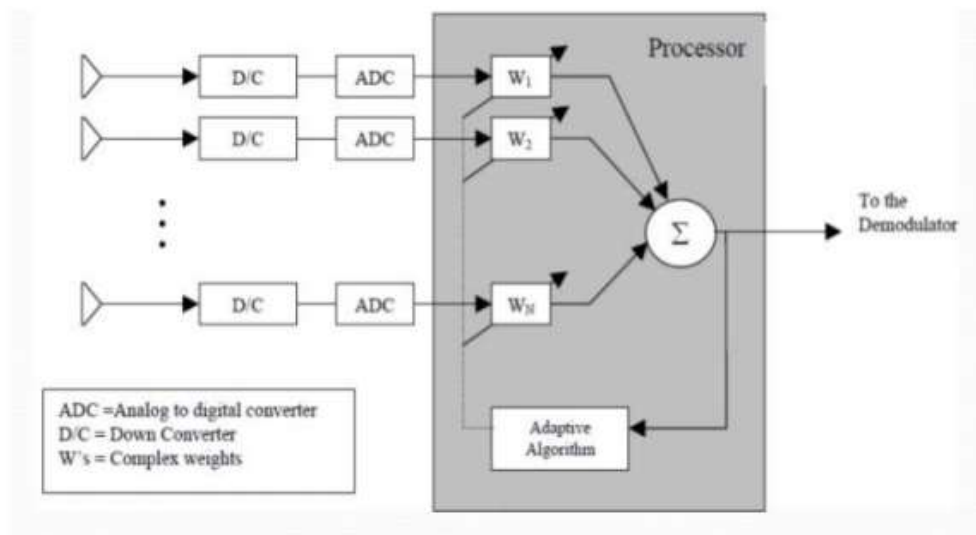


Fig.4: Block diagram of Adaptive Array antenna

C. Beam forming Algorithm

There are different types of Smart antenna algorithms, like Minimum Mean Square Error [MMSE] and Least Mean Square Error [LMSE]. The general methodology of beam forming consists of an array of M antenna elements or beam former. A beam former is a collection of sensors or antennas which are linearly arranged so that their output can be steered electronically. The received signal at these sensors is used to compute the complex weights which are adaptively updated based on signal samples.[3]

Let us consider the output of the array $x(n)$ is the weighted sum of the received signals $x_k(n)$ at the array elements and the array weights $W_k(n)$, where $k=1,2, \dots, M$ and M is number of antenna elements. The array weights $(W_1, W_2, \dots, W_M)$ are iteratively

computed based on array output $y(n)$, a reference signal $d(n)$ that approximates the desired signal and previous weights. The array output is given by,

$$y(n) = W_H(n)$$

where, W_H denotes the hermitian transpose of the weight vector W .

The received signal $x(n)$ is given by

$$y(n) = a^H(n) \theta(n) + \sum a(n) i(n) + n(n)$$

where, a^H is the desired steering vector, $d(n)$ is the reference signal, $a(n)$ is the interference steering vector, $i(n)$ is the interference signal and $n(n)$ is the noise signal. The error $e(n)$ is used to calculate new weights and is given by

$$e(n) = d(n) - y(n)$$

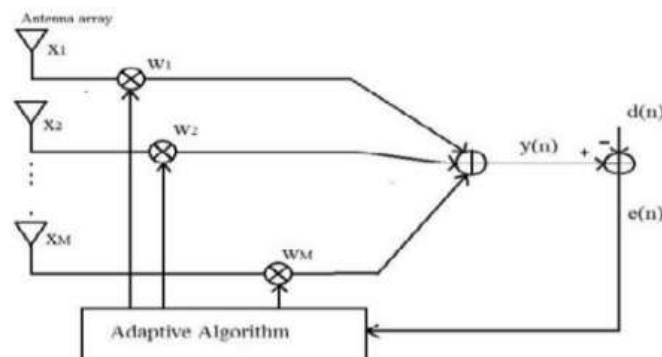


Fig.5: Smart Antenna Receiver

1. Least Mean Square Error[LMSE] Algorithm.

The LMS is an iterative beamforming algorithm that uses the estimate of the gradient vector from the available data. This algorithm makes successive corrections to the weight vector in the direction of the negative of the gradient vector which finally concludes to minimum MSE. This successive correction to the weight vector is the point at which optimum value is obtained that relies on autocorrelation matrix R and cross correlation matrix P of the filter.

The least mean square algorithm is given by:

$$\begin{aligned} y(n) &= (n-1)u(n) \dots\dots\dots (1) \\ e(n) &= d(n)-y(n), \dots\dots\dots (2) \\ w(n) &= w(n-1)+\mu e(n)u^*(n), \dots\dots\dots (3) \end{aligned}$$

where, $y(n)$ is the filter output $e(n)$ is the error signal between filter output and $d(n)$ desired signal at time n . $u(n)$ is the transmitted signal. $w(n)$ is the update function for the LMS algorithm,

where μ is the rate of adaptation, controlled by the processing gain of the antenna array

and denotes the complex conjugate of the input signal $u(n)$.

The convergence conditions imposed on step size μ is given by

$$0 \leq \mu \leq \frac{1}{\lambda_{\max}}, \dots\dots\dots (4)$$

Where, $\lambda_{\max}$ is the largest eigen value of autocorrelation matrix R

$$\text{i.e., } R = E[u(n) u^T(n)]$$

where E is expectation. If μ is chosen to be very small, then convergence becomes slow.

If μ is kept large, then convergence becomes fast, but stability becomes a problem.

The LMS algorithm is initiated with an arbitrary value of $w(0)$ for the weight vector at time $n=0$. The successive corrections of the weight vector eventually leads to minimum value of the mean squared error.[3]

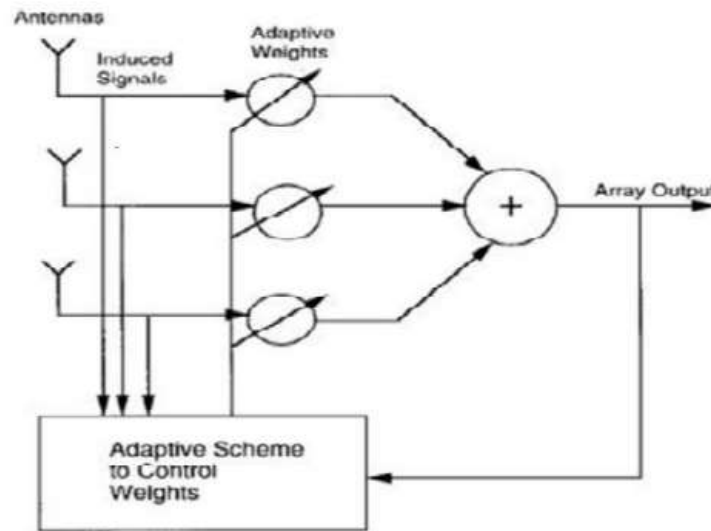


Fig.6: Block diagram of adaptive array system

2. Minimum Mean Square Error

Algorithm (MMSE)

A minimum mean square error (MMSE) estimator describes the approach which minimizes the mean square error (MSE), which is a common measure of estimator quality. The main feature of MMSE equalizer is that it does not usually eliminate ISI (inter symbol interference) completely but, minimizes the total power of the noise and ISI components in the output. A minimum mean square error (MMSE) Algorithm describes the approach which minimizes the mean square error (MSE). The main feature of MMSE Algorithm is that it does not usually eliminate ISI.

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At the receiver end, the received samples can be expressed as

$$y = Hx + n \dots\dots\dots(1)$$

Where $y = [Y_1 Y_2 \dots Y_{NR}]^T$ is $N_R \times 1$ received samples vector, and $n = [n_1 n_2 \dots]^T$ is the $N_R \times 1$ additive noise vector, H is $N_R \times N_T$ the channel matrix between transmit antennas and receive antennas, and is given by:

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \dots & h_{1,NT} \\ h_{NR,1} & h_{NR,2} & \dots & h_{NR,NT} \end{bmatrix} \dots\dots\dots(2)$$

Let x be an unknown random variable, and

let y be a known random variable.

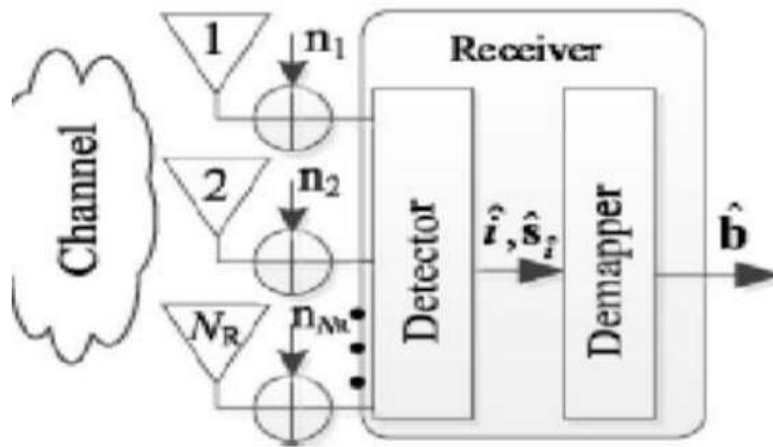


Fig.7: MMSE adaptive array system

An estimator $\hat{x}(y)$ is any function of the measurement y , and its mean square error is given by:

$$\text{MSE} = E \{ (\hat{x} - x)^2 \} \dots\dots\dots (3)$$

where the expectation is taken over both x and y .

The MMSE detector is then defined as the detector achieving minimal MSE. The linear MMSE estimator is the estimator achieving

minimum MSE among all estimators of the form $\hat{Y} = AY + b$. If the measurement Y is a

random vector, A is a matrix and b is a vector.

Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first time slot, the received signal on the first receive antenna is:

$$y_1 = h_{1,1} X_1 + h_{1,2} X_2 + n_1$$

$$= \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \dots\dots\dots (4)$$

The received signal on the second receive antenna is:

$$y_2 = h_{2,1} X_1 + h_{2,2} X_2 + n_2$$

$$= (h_{2,1} \ h_{2,2}) \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \dots\dots\dots (5)$$

Where, y_1, y_2 are the received symbol on the first and second antenna respectively,

h_{11} is the channel from 1st transmit antenna to 1st receive antenna,

h_{12} is the channel from 2nd transmit antenna to 1st receive antenna,

h_{21} is the channel from 1st transmit antenna to 2nd receive antenna,

h_{22} is the channel from 2nd transmit antenna to 2nd receive antenna,

x_1, x_2 are the transmitted symbols and

n_1, n_2 are the noise on 1st and 2nd receive antennas.

The equation can be represented in matrix notation as follows

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \dots\dots\dots (6)$$

Equivalently:

$$y = Hx + n \dots\dots\dots (7)$$

The Minimum Mean Square Error (MMSE) approach tries to find a coefficient W which minimizes the

$$E\{[W_{X-Y}][W_{X-Y}]^H\} \dots\dots\dots (8)$$

Criterion,

H - Channel Matrix and

n - Channel noise

y - Received signal

To solve for x , we need to find a matrix W which satisfies $W_H = I$.

The Minimum Mean Square Error (MMSE) detector for meeting this constraint is given by:

$$W = [(H^H H + N_0 I)^{-1} H^H] \dots\dots\dots (9)$$

This matrix is known as the pseudo inverse for a general $m \times n$ matrix. [4]

CONCLUSION

An overview of different technologies employed in smart antenna is discussed, i.e.

switched beam array and adaptive antenna array. The differences between them and advantages are also elaborated. As a remark different adaptive methods other than LMSE and MMSE can be employed for yielding a better results for a dynamic environment

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