Advanced Communication Systems using Phased Array and MIMO Antennas

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Abstract— In this paper, we analyzed the performances of phased array antenna and multiple input multiple output (MIMO) antennas for 4G LTE mobile communication systems. The system capacity using both the antennas is computed. For Computing the Capacity of the MIMO system we need to first compute the Singular Value decomposition of the Chanel Co-efficient. It means decomposing a matrix into a product of three simpler matrices. We can co-relate it to other matrix decompositions such as Eigen decomposition, principal components analysis (PCA), and non-negative matrix factorization (NNMF). From the simulation results validates the effectiveness of MIMO antennas for advanced wireless communication systems.

Key words: Antenna, Capacity, LTE, MIMO, Phased Array, SISO

I. INTRODUCTION

A. Phased Array Antenna

A phased array antenna uses an array of antennas. Each antenna forming the array is known as an element of the array. The signals induced on different elements of an array are combined to form a single output of the array. This process of combining the signals from different elements is known as beamforming. The direction in which the array has maximum response is said to be the beam-pointing direction. Thus, this is the direction in which the array has the maximum gain. When signals are combined without any gain and phase change, the beam-pointing direction is broadside to the linear array, that is, perpendicular to the line joining all elements of the array. By adjusting the phase difference among various antennas one is able to control the beam pointing direction. The signals induced on various elements after phase adjustment due to a source in the beam-pointing direction get added in phase. This results in array gain (or equivalently, gain of the combined antenna) equal to the sum of individual antenna gains [1]-[5].

Adaptive arrays mostly employ phased arrays to automatically sense and eliminate unwanted signals entering the radar's Field of View (FOV) while enhancing reception about the desired target returns. For this purpose, adaptive arrays utilize a rather complicated combination of hardware and require demanding levels of software implementation. Through feedback networks, a proper set of complex weights is computed and applied to each channel of the array. A successful implementation of adaptive arrays depends heavily on two factors: first, a proper choice of the reference signal, which is used for comparison against the received target/jammer returns. A good estimate of the reference signal makes the computation of the weights systematic and effective. On the other hand, a bad estimate of the reference signal increases the array's adapting time and limits the system to impractical (non-real time) situations. Second, a fast (real time) computation of the optimum weights is essential. There have been many algorithms developed for this purpose. Nevertheless, they all share a common problem, that is, the computation of the inverse of a complex matrix. This drawback has limited the implementation of adaptive arrays to experimental systems or small arrays [6]-[10].

II. DEVELOPMENTS OF SMART ANTENNAS FOR ADVANCED WIRELESS COMMUNICATION SYSTEMS

Recently, the application of smart antenna arrays has been suggested for mobile communication systems, to overcome the problem of limited channel bandwidth, satisfying a growing demand for a large number of mobiles on communication channels. Smart antennas when used appropriately, help in improving the system performance by increasing channel capacity and spectrum efficiency, extending range coverage steering multiple beams to track many mobiles and compensating electronically for aperture distortion. Usually, in the transmitting mode, the array focuses energy in the required direction, which helps to reduce multipath reflections and delay spread [11]-[14]. In the receiving mode, however, the array provides compensation in multipath fading by adding the signals emanating from other clusters after compensating for delays, as well as by canceling delayed signals emanating from directions other than that of the desired signal. System complexity and cost is decreased by the use of smaller number of base stations. The increase in the efficiency, which is defined as the amount of traffic a given system with certain spectrum allocation could manage-, is a result of the capacity of the antenna array to provide virtual channels in an angle domain. This is referred to as Spatial Division Multiple Access (SDMA), which means that it is possible to multiplex channels in the spatial dimension, just as in the frequency and time dimensions. This increase is achieved by using spatially selective transmission [15]-[20].

The major digital wireless cellular systems in operation today are the pan-European Global System for Mobile communications (GSM) and its extension, DCS-1800; the Japanese PDC System, which uses time division multiple access (TDMA); and the North American IS-95 system, with code-division multiple access (CDMA). In all these systems, antenna arrays with spatial processing can provide substantial additional improvement.

It has been shown that adaptive arrays provide a better range increase than switched beam (multi beam) antennas, since switched-beam antennas require less complexity, particularly with respect to weight/ beam tracking, they appear to be preferable for CDMA. In contrast, adaptive arrays are more suitable for TDMA applications, especially in the environments with large angular spread [21]. The wireless local area network (WLAN) market has also been a breeding ground for smart antenna developments, driven by the limitation of 802.11 products and the amazing rate of growth of 802.11 deployments. 802.11b, or wireless fidelity (Wi-Fi), is being adopted virtually everywhere and 802.11a and 802.11g provide interesting higher throughput alternatives to 802.11b.Virtually every access point currently uses switching diversity. A number of companies have been looking at using beam forming to boost the range of 802.11 systems and some have been looking at increasing the range of using directional antennas, with the access point providing coverage in sectors. However, this sectorization comes with increased cost and complexity. Several wireless LAN start-ups have looked at implementing SDMA for 802.11, achieving up to five times the range and up to eight times the capacity of conventional access points [22]-[25].

The highest level of smart antennas, in terms of complexity and performance, is called multiple-input/multiple-output (MIMO). In these types of systems, both the transmitter and receiver have multiple antennas, which allows for significantly better performance than other smart antenna techniques. Under rich scattering environment, MIMO systems have the potential to achieve capacities inconceivable by single-input/single-output (SISO) systems. MIMO for mobile application is an exciting research area and may become a key technology for future wireless system. This makes it one of the most exciting developments to have occurred in wireless communications. Within a short duration it has matured from a research topic into a technology to find a place in upcoming wireless communication standards. However, this is not really compatible with current PCS/3G or 802.11 standards, so it mainly is being looked out for fixed wireless (multipoint, multimedia distribution systems, local multipoint distribution system) scenarios. Several companies have been created recently that are trying to commercialize MIMO systems and numbers of large companies are also studying this area. [26] - [29].

A key technology in supporting high data rates in 4G systems, Multiple-Input Multiple-Output (MIMO) enables multi-stream transmission for high spectrum efficiency, improved link quality, and adaptation of radiation patterns for signal gain and interference mitigation via adaptive beamforming using antenna arrays [30]-[32]. The coalescence of HSPA and LTE will increase the peak mobile data rates of the two systems, with data rates exceeding 100 Mbps, and will also allow for optimal dynamic load balancing between the two technologies [8]. As the demand for capacity in mobile broadband communications increases dramatically every year, wireless carriers must be prepared to support up to a thousand-fold increase in total mobile traffic by 2020, requiring researchers to seek greater capacity and to new wireless spectrum beyond the 4G standard [33]. To improve the existing LTE network, the wireless technology roadmap now extends to IMT-Advanced with LTE-Advanced needed to meet IMT-Advanced requirements, which will be theoretically capable of peak through put rates that exceed 1 Gigabit per second (Gbps). LTE-Advanced supports heterogeneous networks with co-existing large macro, micro, and pico cells, and Wi-Fi access points. Low cost deployment will be realized by self-organizing features and repeaters/relays As fifth generation (5G) is developed and implemented, we believe the main differences compared to 4G will be the use of much greater spectrum allocations at untapped mm-wave frequency bands, highly directional beamforming antennas at both the mobile device and base station, longer battery life, lower outage probability, much higher bit rates in larger portions of the coverage area, lower infrastructure costs, and higher aggregate capacity for many simultaneous users in both licensed and unlicensed spectrum (e.g. the convergence of Wi-Fi and cellular). The backbone networks of 5G will move from copper and fiber to mm-wave wireless connections, allowing rapid deployment and mesh-like connectivity with cooperation between base stations.

III. MULTIPLE-INPUT MULTIPLE OUTPUT (MIMO)

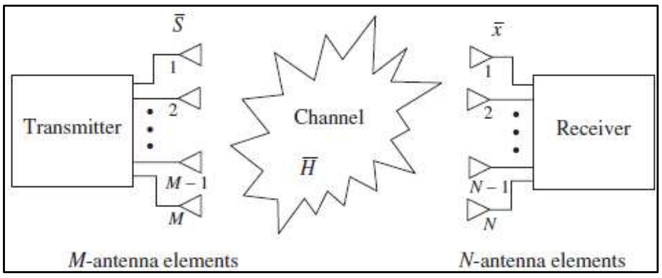


Fig. 1: Block representation of MIMO [35].

MIMO stands for multiple-input multiple-output communication. This is the condition under which the transmit and receive antennas have multiple antenna elements. This is also referred to as volume-to-volume or as a multiple-transmit multiple-receive (MTMR) communications link. MIMO has applications in broadband wireless, WLAN, 3G, and other related systems. MIMO stands in contrast to single-input single output (SISO) systems. Since MIMO involves multiple antennas, it can be viewed as a space diversity approach to channel fading mitigation. The goal of MIMO is to combine signals on both the transmit and receive ends such that the data rate is increased and/or the ISI and BER are decreased. As was mentioned previously, one diversity option for a SISO system is time diversity. MIMO allows the user to combine time diversity and space diversity. It can be said that MIMO is more than a space diversity option but is a space-time signal processing solution to channel fading. Multipath propagation has been viewed as a nuisance in SISO systems but it is actually an advantage for MIMO systems because the multipath information can be combined to produce a better received signal. Thus the goal of MIMO is not to mitigate channel fading but rather to take advantage of the fading process. Under flat-fading conditions, let us define the M-element complex transmit vector, created by the M-element transmit array, as $s = [s_1\ s_2\ s_3 \ldots s_M]^T$. The elements s_m are phased according to the array configuration and are assumed to be coded waveforms in the form of a data stream [34]-[35].

IV. Antenna Array Signal Model

Let us consider system model with ULA consisting of *'N'* isotropic sensors. Let 'm' (m < *N* be the unconstrained signals impinging on a ULA at directions θ1, θ2 ... θm. Consider'd' as inter element spacing of ULA and its value chosen to be $\lambda / 2$ in order to reduce mutual coupling effects. The narrowband signal received by a linear antenna array with *M* - Omni-directional antenna elements at the time instant *n* can be expressed as

$$x(n) = s(n) + i(n) + n(n) \quad (1)$$

Where $s(n)$, $i(n)$ and $n(n)$ denote the N×1 vectors of the signal of interest (SOI), interference and noise respectively. For simplicity, all these components of the received signal (1) are assumed to be statistically independent to each other. This assumption is fairly practical since the SOI and the signals from interferers (other objects or users) are typically independent. The conventional (forward-only) estimate of the covariance matrix defined as R = $E\{x(n)x^H(n)\} = \sigma^2$ I, where σ^2 is the noise power at a single antenna element, I denotes the identity matrix and $(\cdot)^H$ and E [·] stand for the Hermitian transpose and mathematical expectation respectively.

V. Capacity Computation for 4G LTE

For Computing the Capacity of the MIMO system we need to first compute the Singular Value decomposition of the Chanel Co-efficient. It means decomposing a matrix into a product of three simpler matrices. We can co-relate it to other matrix decompositions such as Eigen decomposition, principal components analysis (PCA), and non-negative matrix factorization (NNMF).

A. *Definition of SVD*

Singular Value Decomposition (SVD) factors an m × n matrix A into a product of three matrices, assuming that all values are known:

$$A = U * D * VT$$

Where,

- U is an m × k matrix, V is an n × k matrix.
- D is a k × k matrix, k is the rank of the matrix A.
- The multiplication (*) is matrix multiplication
- The superscripted T indicates matrix transposition.

B. *Steps for SVD*

*1) The channel co-efficient of a M*M MIMO system can be computed as follows*

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & . & . & . & h_{1M} \\ h_{21} & h_{22} & h_{23} & . & . & . & h_{2M} \\ . & & & & & & \\ . & & & & & & \\ h_{M1} & h_{M2} & h_{M3} & . & . & . & h_{MM} \end{bmatrix}$$

2) Compute the transpose of the channel matrix and is given by

$$H^T = \begin{bmatrix} h_{11} & h_{21} & h_{31} & . & . & . & h_{M1} \\ h_{12} & h_{22} & h_{32} & . & . & . & h_{M2} \\ . & & & & & & \\ . & & & & & & \\ h_{1M} & h_{2M} & h_{3M} & . & . & . & h_{MM} \end{bmatrix}$$

3) The weight matrix is computed by using the following equation

$$W = H * H^T$$

Perform the Eigen value decomposition of W by finding the routes of characteristics equation

$$\|W - \lambda I\| = 0$$

The roots of the above equation are a set of eigen values

$$\lambda_1, \lambda_2, \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots, \lambda_M$$

4) *Find out only the positive valued eigen values*
5) *Find out the square root of each of the positive eigen values.*
6) *Keep the square root values in the diagonal elements format for the matrix known as* $D\ matrix$
7) *The eigen vector is computed for the eigen values are computed and a vector of eigen values is the U matrix*

$$U = [e_1 \ e_2 \ . \ . \ . \ . \ . \ . \ e_M]$$

$$e_i = i^{th} \ eigen \ vector \ for \ matrix \ W$$

8) *The new matrix is again computed by using the following equation call it as* w^T

$$w^T = H^T * H$$

9) *Find the eigne values of* w^T *by solving the following equation*

$$|w^T - \lambda I| = 0$$

10) *The eigen values can be written as*

$$\lambda_1, \lambda_2, \ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots\ldots \ldots, \lambda_M$$

11) *The eigen vectors for each of the eigen values are found out and is given by*

$$V = [e_1 \ e_2 \ . \ . \ . \ . \ . \ . \ e_M]$$

$$e_i = i^{th} \ eigen \ vector \ for \ matrix \ W$$

12) *The Capacity for the MIMO based rate adaptation scheme is computed using the following formula*

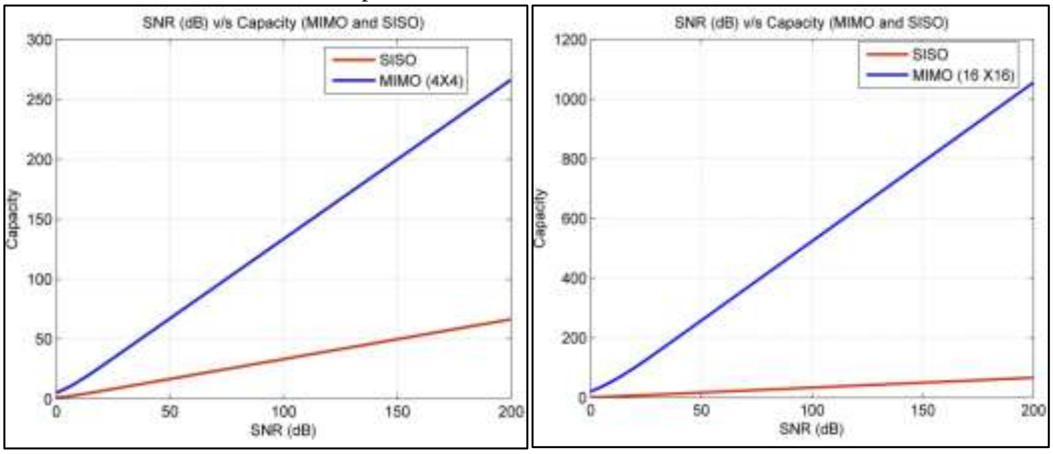
$$C_{MIMO} = \log 2(1 + \frac{SNR * \lambda_i}{N_t})$$

$$SNR = signal \ to \ noise \ ratio \ in \ DB$$

$$\lambda_i = i^{th} \ eigen \ value$$

$$N_t = Number \ of \ transmitte \ rs$$

Figure 2 shows the performance of wireless system for single and MIMO antennas and figure 3 shows the effect of antenna array size over beamwidth of radiation pattern.



(a) (b)

Fig. 2: System capacity using SISO and MIMO: (a) (4x4) (b) 16x16

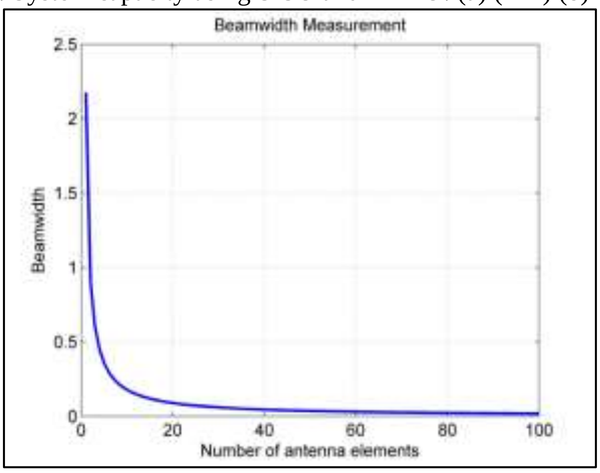


Fig. 3: Performance of radiation pattern over number of antenna elements

From the figures 3 and 4, we note that the performance of wireless system improves as the numbers of antenna elements are increased and meanwhile the beam width of pattern of array decreases with increase in antenna array size.

VI. CONCLUSION

We discussed the reasons why smart antennas have not been planned in second-generation systems. Next, we discussed developments of smart antennas with respect to wireless third generation and advanced technique MIMO. Also, the expected capacity of wireless communication system for both single and MIMO antennas. It is observed that performance of MIMO antenna outperformers the single antenna.

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