Applied Science Periodical ISSN 0972-5504
Volume - XXV, No. 1, February 2023
Journal website: www.internationaljournalsiwan.com
ORCID Link: https://orcid.org/0009-0008-5249-8441
Google Scholar: https://scholar.google.com/citations?user=BRweiDcAAAAJ&hl=en
Refereed and Peer-Reviewed Quarterly Periodical

Performance of Smart Antenna in Wireless Systems

by **Surendra Kumar Roy,** *Department of Physics,*
Supaul College of Engineering, Supaul - 852131, India
E-mail : skroyphy@gmail.com

(Received: January 17, 2023; Accepted: February 20, 2023;
Published Online: February 28, 2023)

Abstract:

Demand for wireless communications has grown exponentially, during the last seven years, with such rapid growth. The most important problem for wireless communications is how to increase channel capacity. This paper considers a method of eigenvalue distribution, which is based on eigenvalue decomposition (EVD), for obtaining some insight into how different channel papameters affect the performance of antenna arrays. Eigenvalue decomposition is extremely important in analyzing most uplink and downlink processing algorithms for antenna arrays. The present approach greatly simplifies analysis, and can be equally applied to receiving diversity, transmitting diversity, and MIMO system.

Keywords: Smart antenna and Wireless systems.

Introduction:

Recently, there has been both a technology push and a market pull for gigabit wireless communication systems operating in the millimeter-wave frequency bands.

Smart-antenna arrays have recently been given new impetus by the migration to fourth-generation (4G) systems, and the proposals for fifth-generation (5G) standards [1-7]. Most systems of the 4^{th} generation and beyond will feature base-station (BS) antenna arrays. Antenna arrays are very suitable for base stations stations because of the size problem of the mobile station (MS). Smart antennas extract more capacity from current / future wireless-network resources, and their implementation, at least at base stations, results in a more efficient network. Today, one challenge for these systems is the limited radio-frequency spectrum that is available. Today's wireless cellular systems will require a ten-fold to forty-fold increase in spectral efficiency and capacity to affordably deliver true Internet content. Approaches that increase spectral efficiency are therefore of great interest. Smart-antenna techniques, such as multiple-input multiple-output (MIMO) systems to provide customers with increased data throughput for highly -capable wireless data-communication systems: MIMO systems use Multiple, antennas at both the transmitter (transmitting diversity, TD) and receiver (receiving diversity, RD) to increase the capacity of the wireless channel.

Formulation:

It is essential for the transmission channel to be satisfactorily characterized, additionally, the characterisation should take into account the intended application for the channel, i.e. whether it is used for either narrowband or wideband transmission. Consider an M-element uniformly linear array (ULA) of antennas, shown in Fig. 1.

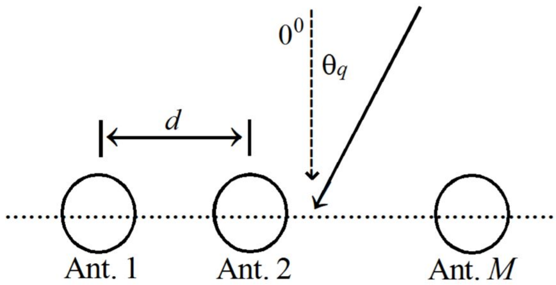

Fig. 1

The elements are equally spaced at a distance d, and a plane wave arrives at the array from a direction θ off the array's broadside (i.e., at an angle θ to a line perpendicular to the array). The angle θ is called the angle-of-arrival (AOA) of a given ray, i.e., the angle between the arriving signal and the normal to the array. For a uniform linear array, the steering vector is given by

$$a(\theta) = \left\{1,\ \exp\left[-j\frac{2\pi}{\lambda}d\sin\theta\right],\ ....,\ \exp\left[-j\frac{2\pi}{\lambda}(M-1)d\sin\theta\right]\right\}^{r} \qquad (1)$$

where a^T denotes the vector transpose operation, $\lambda = c/f_c$ is the wavelength of the carrier frequency, f_c and c is the velocity of light ($c = 3 \times 10^8$ m/s).

Suppose the base station uses a uniform linear array of M elements to receive signals from different locations. Equation (1) describes the spatial impulse response of the array to a waveform impinging from different directions at θ_q, $q = 1....Q$, where Q is the number of scattered signals (components) contributing to the channel. The m^{th} entry of the vector $h(t)$ is the complex scalar representing the amplitude and phase of the channel between the mobile transmitting antenna and the m^{th} antenna element of the receiver (i.e., h_m, $m=1, 2, ..., M$). The $M \times 1$ channel vector is the sum of a number of plane waves, and it may be written as

$$h(t) = \sqrt{\frac{P_i}{Q}} \sum_{q=1}^{Q} \alpha_q \exp[j(\phi_q + 2\pi\upsilon_q t)]a(\theta_q) \qquad (2)$$

where P_i is the average transmitted power. The received wave-form is made up of Q rays (components), with amplitudes α_q phases ϕ_q, Doppler frequencies υ_q, and angles of arrival θ_q, α_q is the amplitude of the q^{th} component, and, it is chosen to be equal for all Q. We assume an environment of a large number of scatterers, Q, so that the Rayleigh-fading channel model is appropriate. This means that for large Q, the statistics of each entry of $h(t)$ can be approximated by a Rayleigh distribution. ϕ_q is the random phase of the q^{th} component uniformly distributed within $[0, 2\pi]$. $u_q = v/\lambda$ is Doppler-frequency shift of the q^{th} component, where v is mobile's velocity. $a(\theta_q)$ is the array steering vector of the q^{th} component as it impinges on the base-station uniform linear array (i.e., the array's response to the q^{th} component). The probability density function (PDF) of Rayleigh distribution is

$$p(r) = \begin{cases} \frac{r}{b}\exp\left(-\frac{r^2}{2b}\right), & r \geq 0, \\ 0, & r < 0 \end{cases} \qquad (3)$$

where b the mean received power of the electric field. The commutative distribution function (CDF) can be written as

$$P[r \leq R] = 1 - \exp\left(-\frac{R^2}{2b}\right) \tag{4}$$

Rician Distribution:

When stochastic-variable components with a Rayleigh distribution are added to a steady (non-fading) component, such as a line-of-sigh propagation path, the single envelope is said to be Rician distributed. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. The PDF of the Rician distribution is expressed as

$$p(r) = \frac{r}{b}\exp\left[-\frac{(A^2+r^2)}{2b}\right] I_0\left(\frac{rA}{b}\right), \tag{5}$$

where I_0 is the modified Bessel function of the first kind and zeroth other, A is the line-of-sight peak value, and b is the mean received power.

Eigenvalue Distribution:

The eigenvalue distribution is a function of several channel parameters, including the angle-of-arrival and angle-spread distributions, the number of multipath components, the antenna spacing, the Doppler frequency, the channel correlation (multipath coherence), and the geometry of the antenna array. If $h(t)$ is zero mean (i.e., $E[h(t)] = 0$), the instantaneous mean channel correlation matrix of the M by M array is defined as

$$R_{hh} = E[h(t)h^H(t)] = \frac{1}{Q}\sum_{q=1}^{Q} h(\theta_q)h^H(\theta_q) \tag{6}$$

The notation $[\cdot]^H$ denotes the Hermitian or complex-conjugate transpose. The matrix R_{hh} specifies the correlation between the entries of $h(t)$. If R_{hh} is a diagonal matrix, then the branch signals are uncorrelated.

It is more convenient to use the eigenvalue decomposition of R_{hh}. The eigenvalue decomposition is highly useful for interpretation in the smart-antenna context.

The mean channel-covariance matrix, R_{hh}, has the eigenvalue decomposition

$$R_{hh} = U \Lambda U^H \tag{7}$$

where $\Lambda = \text{diag}(\lambda_1, ..., \lambda_M)$ is an $M \times M$ diagonal matrix of real, non-negative eigenvalues of R_{hh} and $(\lambda_1 > \lambda_2 > ... > \lambda_m)$, $U = [u_1, ..., u_M]$ is an $M \times M$ matrix, and the u_m are the eigenvectors corresponding to the nonzero eigenvalues of λ_m. λ_1 is the largest or dominant eigenvalue, and u_1 is the corresponding dominant eigenvector. The eigenvalue ratio (EVR) of R_{hh} is defined as

$$EVR = \frac{\lambda_{\max}}{\lambda_{\min}} = \frac{\lambda_1}{\lambda_M}. \tag{8}$$

If the eigenvalue ratio is small, this indicates that the signals are approximately uncorrelated. If the eigenvalue ratio is large, the matrix R_{hh} is close to being singular.

An important parameter is the trace of R_{hh}, i.e., the sum of the eigenvalues: Trace = $Trace = \Sigma_{m=1}^{M} \lambda_m$. The number of non-zero eigenvalues is equal to the rank, r, of R_{hh}.

Result and Discussion:

It shows the extent to which propagation effect in a radio environment influence the capacity of wireless systems and outlines possible counter measures for mitigating multipath effects in such systems. The eigenvalue ratio decreased with an increase in angle spread and when the angle of arrival was closer to the array's broadside. It also decreased with an increase in the number of path components. Also, an increased angle spread ($\Delta > 120°$) tended to increase the eigenvalue ratio of R_{hh}. The lowest eigenvalue ratio was obtained when $\Delta = 120°$ (uncorrelated channels). The highest eigenvalue ratio was obtained when $\Delta = 0°$ (correlated channels). When the channel paths were uncorrelated (large angle spread, e.g., $\Delta = 120°$), the off-diagonal terms of R_{hh} were small. In this case, the correlation was low, R_{hh} approached an identity matrix, and therefore all the eigenvalues of R_{hh} were approximately equal, Figure 2 confirms this fact.

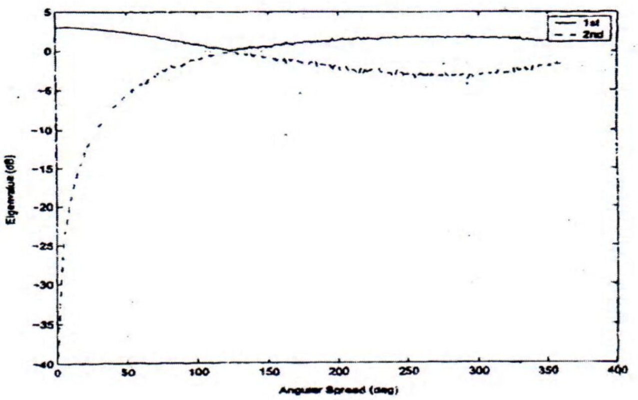

Fig. 2

In the case of wider angle spread (i.e., $\Delta > 0°$), each covariance matrix R_{hh} will have multiple eigenvalues and eigenvectors. In fact, the eigenvalues are unequal, which should be taken into account in analyzing antenna arrays. The eigenvalue decomposition of the R_{hh} of the channel provides information on the constituent random processes present in the signal, and their amplitudes.

For small values of Δ the off-diagonal terms become large and the eigenvalue ratio becomes very large. When the channels are correlated ($A = 0°$), all but one of the eigenvalues equal zero, i.e., there is only one non-zero eigenvalue. When this takes place at the receiving end, all the columns in the channel vector have the same amplitude. This affects the capacity, if $\Delta = 0°$, then the determinant of R_{hh} equals zero and the rank equals one.

For small values of Δ, there is a dominant eigenvalue, and all other eigenvalues have smaller amplitudes.

Conclusion:

The frequency-selective behavior of the radio channel is readily obtained by observing the co-relation between two signals at different frequencies at the receiver. The analysis of the eigenvalue distribution gives a very useful approach for predicting the fundamental limits of wireless communications. This approach can also be applied to many signal-processing algorithms, such as channel and parameter estimation, MIMO, and information theory of smart antennas. MIMO for mobile applications is an exciting research area, and may become a key technology for future wireless systems. MIMO uses parallel channels. The parallel channels are formed either in a natural way, due to radio-wave propagation.

If their frequency separation is sufficiently large. The spectrum of the output signal can be obtained by multiplying the spectrum of the input signal by the channel's transfer function.

References:

1. Roy, S. Kr. : "Electromagnetic waves and Antenna technology", Novelty publication, 2014.
2. I.E. Telatar : "Capacity of Multi-Antenna Gaussian Channels", Bell labs Technical Memorandum, 2015.
3. G.J. Foschini : "Layered Space-Time Architecture for Wireless Communication", Bell Labs Technical Journal, 1, Autumn 2016, pp. 41-59.
4. V. Tarokh, N. Seshadri and A.R. Calderbank : "Space-Time Codes for High Data Rate Wireless Communication: Performance Criterion and code Construction", IEEE Transactions on Information Theory, 44, March 2018, pp. 744-765.
5. S.M. Alamouti : "A Simple Transmit Diversity Technique for Wireless Communications", IEEE JSAC, 16, October 2018, pp. 1451-1458.
6. A.S. Dakdouki, et al. : "Towards Reliable, High-Bandwidth and High-Speed Data Communication: Space-Time Coding", under revision 2021.
7. J.S. Thompson : Bearing Estimation Techniques for Improved Performance Spread Spectrum Receivers, PhD dissertation, University of Edinburgh, 2015.