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ENVIRONMENTAL ANALYSIS OF MIMO CHANNEL CAPACITY UNDER VARIABLE FACTORS

Raad H. Thaher

Ministry of Higher Education and Scientific Research-Baghdad-Iraq
E-mail: raadthaher@yahoo.com

ABSTRACT

Digital communication using MIMO has been one of the most promising research areas in wireless communications nowadays as it offers a lot of promises for future wireless communications. MIMO seems to be the only technology that is advancing the wireless industry from 3G to 4G systems. In this work MIMO system has been studied in great detail and simulated for different cases and we concentrated on the performance of its capacity under several environmental conditions. MIMO system offers significant gains in performance over traditional wireless communication systems. Spatial multiplexing increases system throughput without consuming frequency spectrum and spatial diversity makes the link more robust. MIMO system was described and simulation results were presented and discussed. Multiple antenna techniques are a key to boosting the performance of modern wireless systems.

يتضمن هذا البحث تحليل النظام متعدد المداخل-متعدد المخارج لأنه يمثل التكنولوجيا الوحيدة التي يمكن بواسطتها تطوير الأنظمة اللاسلكية من الجيل الثالث إلى الجيل الرابع للهواتف النقالة. وقد تم في هذا البحث استخلاص نتائج المحاكاه للنظام تحت تأثير عدة عوامل وتم التركيز على سعة هذا النظام تحت نفس الظروف المختلفة وبما يجعل النظام متين دون فقدان الطيف الترددي كما موضح في النتائج المبينة في متن البحث .وقد تم وصف هذا النظام وعرض النتائج ومناقشتها

Keywords: MIMO, spatial multiplexing, capacity, diversity, SNR

1. INTRODUCTION

The field of wireless communication systems and networks has experienced explosive growth and wireless communications has become an important part in every day life. Furthermore, wireless internet multimedia access will rise rapidly in the next few years due to the rapidly increasing number of wireless communication subscribers, and the huge increasing use of wireless devices [1]. Wireless LAN and mobile telephones have been identified as the main reasons for the growth. New applications such as widespread wireless broadband internet access have been always the main reason for the demand for ever faster wireless communications. Nowadays the telecommunications industry has experienced phenomenal growth, specifically in the field of wireless communications [4]. This growth has been fueled by the widespread popularity of wireless telephones and wireless computer networking. However, there are limits to growth, i.e the finite resource of radio spectrum used for wireless communications [4,5]. Therefore, considerable effort has been invested in making more efficient use of it. Using the spectrum more efficiently caters for the ever increasing demand for faster communications since more bits per second can be transmitted using the same bandwidth.

There have been a number of challenges facing the design of future generation of wireless systems such as re-configurability to varying a scenario in terms of propagation conditions, traffic models, mobility, transceiver architectures, mobile terminal resources (i.e .battery life time) as well as quality of service requirements for different services and interference conditions [3]. Important aspects such as system architecture, implementation and complexity limitations need to be taken into account in the design of wireless communication systems and particularly in the design techniques of smart antennas [3]. Finally the requirement for future generation systems operating in multi-technology networks introduces a further set of challenges related to the design of smart antenna systems, which have shown a great improvement in meeting the demands desired, as it enhances the performance and facilitates the interoperability across different wireless technologies [3,4].

For the immediate future, a new refinement of that wireless technology promises to resolve many of the original concerns and offers even greater throughput and reliability called MIMO (Multiple–Input, Multiple–Output) which involves the use of two or more antennas on both transmitters and receivers. As the advent into the information age continues, it is found that there has always been an inherent need to improve the current standards of communication. These improvements are mainly targeted towards communication. In this area two strategies are always implemented and tested, that is either we improve the quality of what we have or we increase the quantity. This is where MIMO, SIMO (Single-Input, Multiple Output), MISO (Multiple Input, Single Output), and SISO (Single Input, Single Output) systems come into application. It has been recently acknowledged that by using MIMO systems it is possible to increase the available bandwidth that is being used without having to change the standards and hardware so much. This comes as a result of maximum possible bandwidth, for the current methods employed, being reached.

2. WIRELESS PROPAGATION ENVIRONMENTS

There are two main categories for wireless signal propagation; line of sight (LOS) and non-line of sight (NLOS). LOS propagation requires a path where both transmitter and receiver are visible to one another without any obstraction as shown in Fig. 1. Non line of sight (NLOS) is a term often used in radio communications to describe radio channel or link where there is no visual line of sight (LOS) between the transmitting and the receiving antennas.

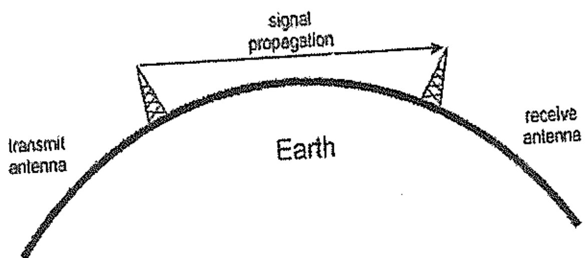


Fig. 1 LOS Propagation

2.1. Mulipath Fading

Wireless communications suffer from more hostile transmission medium, whose behavior varies overtime and from location to location. Due to reflection, diffraction and scattering of radio waves, a transmitted signal may arrive at the receiver in many paths (as shown in Fig. 2) with different time delays depending on the distance traveled [5]. Coherent addition of these multipath signals causes rapid and severe amplitude fluctuation in the received narrowband signal when the receiver moves over a short distance, giving rise to the phenomenon of fast fading

The power of the signal at the receiver will be less than the power transmitted. In LOS medium this happens because of the distance between the transmitter and receiver. The further the distance the more distortion will happen to the signal. In non LOS the signal is further hampered because the signal at the receiver is a combination of different versions of transmitted signal that propagate through different paths. This is called multipath fading. It occurs due to the reflections from the ground and surrounding structures in the environment. The signal received by the receiver at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, phases and angles of arrival. These multipath components combine as vectors at the receiver and cause the signal received to distort or fade. Even if the receiver is stationary, the received signal may fade due to movement of surrounding objects in the radio channel.

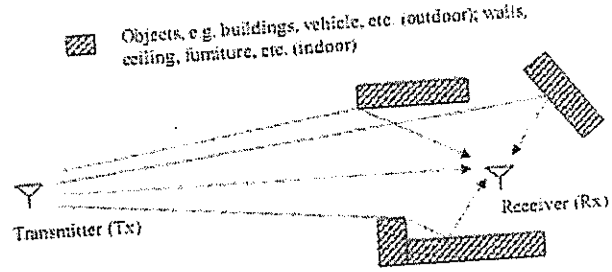


Fig. 2 Multipath Propagation

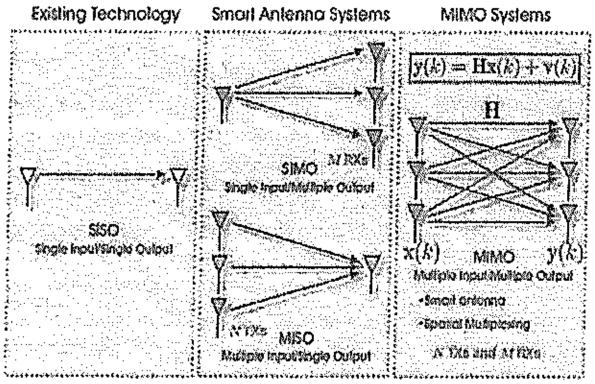
2.2. Conventional Antenna System

2.2.1. SISO (Single-input, Single-output) system

SISO refers to antenna system with single antenna at both the transmitter and receiver. This system can reach 1Gbps transmission rates by employing sufficiently high bandwidth along with coding and modulation that achieves the required spectral efficiency. However, there are some limitations associated with the various phenomena that occur not only in WLAN but also in outdoor Wireless Wide Area Networks (WWAN).

2.2.2. SIMO (Single-Input, Multiple-Output) system, MISO (Multiple-input, Single output) system:

In these systems multiple antennas at the receiver and/or the transmitter in a wireless network. It promises higher data rates at longer ranges without consuming extra bandwidth or transmits power [10]. Such technology, popularly known as smart antenna technology, offers a variety of advantages which if exploited correctly can enable multiplicative gains in network performance. Smart antenna technology [10] provides a wide variety of options, ranging from SIMO architectures that collect more energy to improve the signal to noise ratio (SNR) at the receiver, to MIMO architectures (which will be described later) that create multiple data paths over a link. Figure 3 shows different antenna systems.



Figure(3) SISO,SIMO,MISO and MIMO systems

3. The MIMO (Multiple–Input, Multiple–Output) System

The growing demand for wireless services and bandwidth has shown need for evolution of cellular systems to higher operating frequencies. Moreover, demand for higher degree of flexibility, yields smaller systems operating in unlicenced ISM (WLAN, Bluetooth.. etc) bands [13,14]. Also cellular is not the only wireless service on the earth. Researchers expect fixed wireless access to become an established alternative to fiber (in less dense populated areas) covering wideband services (web access, data, digital video …etc) [14]. The need for higher throughput has lead to deep investigations and researches into Rx-T x diversity (MIMO) antenna systems. Such systems can yield fully independent/parallel channels in a scattering environment [8,15]. Most investigations of such have focused on mobile (licensed band) or transportable (WLAN) situations. Multiple antenna schemes are becoming a key part in almost every wireless standard. For example, the UMTS-CDMA standard uses transmit diversity to improve the link quality in outdoor environments [16]. Designing very high speed wireless links which have the capability of good quality-of- service and range capability in Non Line of Sight (NLOS) environments have taken large space among recent researches and have produced many engineering challenges.

The use of multiple antennas at transmitter and receiver, popularly known as multiple –input multiple output (MIMO) wireless is an emerging cost-effective technology that offers high data rate wireless communications, near 1Gigabit/second (gbps) transmission rates and making it a reality [8]. Moreover, this technology has shown outstanding performance in resolving many of the other limitations associated with the existing systems (SISO) [8,19].

Power limitations as well as the size and the speed of wireless portable devices are some of the main limitations and challenges faced by the existing wireless communications and particularly cellular systems. In general, bandwidth limitation, propagation loss, time variance, noise interference and multipath fading in wireless communication make the wireless channel a narrow pipe in which it is difficult to accommodate the growing flow of data [19].

As a consequence of that, there has been hard work done by scientists and researchers in developing new techniques that improve the efficiency and combat various types of channel impairments. An example of that is building a cellular structure that allows frequency reuse and antenna arrays (Smart antennas) that provide spatial diversity and beam forming [21,22,23]. Because the request for wireless access to the internet and future generation wireless systems is leading to the need for much higher capacities than that achieved by this system. MIMO can improve spectral efficiency and tackle the various types of channel impairments mentioned above as the concept of MIMO rises to further improving channel capacity and quality of service. However, the idea of separating signal transmission in a temporal and spatial domain is not new [19,21,23]. The SIMO system achieves higher capacities, while the MISO increases data rate. Transmie diversity is an earlier technology moving to the MIMO system.

Digital communication using MIMO has been one of the most promising research areas in wireless communications nowadays as it offers a lot of promises for the future of wireless communication. Moreover MIMO seems to be the only technology that is advancing the wireless industry from 3G to 4G systems [22]. Multiple antennas can be used to increase the antenna gain by beamforming, to provide diversity gain through some forms of antenna combining, to increase the data rate by spatial multiplexing, or to suppress interference by null steering [16,22]. Two of these techniques, spatial multiplexing and spatial diversity can be applied in both indoor and outdoor environments [16].

MIMO is a communication concept of having antennas at both the receiver and the transmitter of radio link as shown in Fig. 4. The idea behind MIMO is that signals on the transmit antennas at one end and that at the receiving end antennas outstanding are combined in such a way that the quality of the signal (Bit Error Rate) or the data rate (Bit/sec) of the communication system will be improved [19,25].

MIMO employs multiple transmit and receive antennas, and hence the transmission capacity can be increased linearly with the number of antennas, as will be seen from the simulation results. In order to ensure an effective approach to the increasing capacity, space-time coding and space-time algorithms are implemented with MIMO system. However space-time a coding is coding technique that is designed for use with multiple transmit antennas [13]. It provides diversity at the receiver and coding gain over uncoded system while sacrificing the bandwidth [13,28]. This aim can be achieved through this technique by introducing temporal and spatial correlation into signals transmitted from different antennas. MIMO system is able to provide the enormous capacity increase that will enable high speed mobile internet access and enhanced-capacity capacity wireless local loops. Figure 5 shows the schematic diagram of the MIMO communication system. The main idea in MIMO system is space-time signal processing in which time dimension is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, where actual spatial dimension is brought by 'Smart antennas' a popular technology for improving wireless transmission [19,29]. So MIMO system can be viewed as an extension of the so-called smart antennas.

The magic of MIMO lies in its ability to take multipath propagation, pitfall. of wireless transmission , which used to be an unavoidable byproduct of radio communications, and covert it into a distinct advantage that actually multiples transmission speed and improves throughput [6].

MIMO effectively takes advantages of random fading and when available, multipath delay spread for multiplying transfer rates. It should be noted that the presence of multipath in our environment due to scatters is one of the main reasons that limit the performance of today's system. It should be clear that MIMO wireless communication systems are advantageous in which they enable the capacity of the wireless link between the transmitter and receiver to be improved compared with SISO systems. The multipath rich environment enables multiple orthogonal channels to be generated between the transmitter and receiver [18]. Data for a single user can then be transmitted over air in parallel over those channels, simultaneously using the same bandwidth. Consequently, higher spectral efficiencies are achieved than with non-MIMO systems [1,18]. MIMO systems retain all the properties of SIMO/MISO systems, since in some sense the optimization of the transmitting and receiving antenna elements is carried out as a superset of that of SIMO/MISO. In reality, MIMO systems offer advantages which go far beyond that of conventional smart antennas [22].

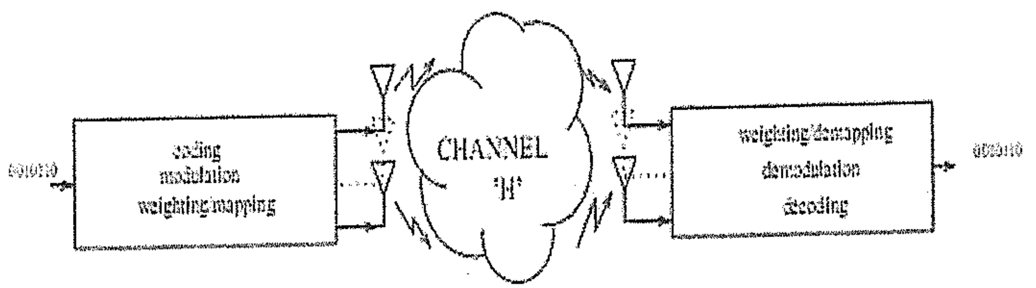


Fig. 4 MIMO wireless transmission system

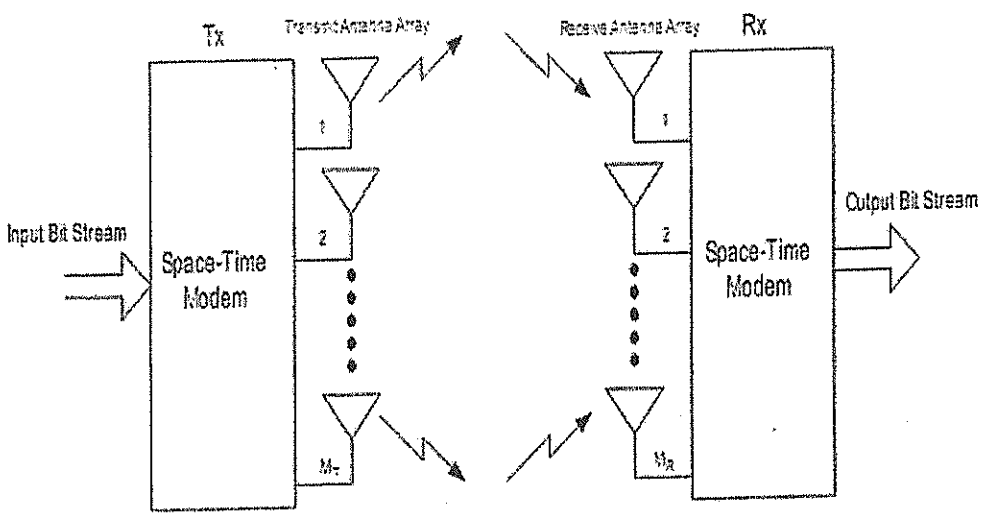


Fig. 5 Schematic diagram of MIMO communication system.

Multiple antennas at both the transmitter and the receiver creat a matrix channel (of size the number of receive antennas times the number of transmit antennas). The key advantage lies in the possibility of transmitting over several spatial modes of the matrix channel within the same time-frequency slot at no additional power expenditure [22,31,33].

MIMO is also planned to be used in mobile radio telephone standards such as recent 3GPP and 3GPP2 standards. In 3GPP, High–speed Packet Access plus (HPSA+) and long term Evolution (LTE) standards take MIMO into account [34,22]. MIMO systems are currently considered for applications in second generation broadband wireless fixed cellular networks [35]. Another great application of MIMO is undoubtedly the next generation broadband packet-based cellular networks.

4. THE MIMO MODEL

Consider a transmitter with NT transmit antennas and a receiver with NR receive antennas as shown in Fig.6. In the transmitter, a data stream is demultiplexed into Nt independent substreams. The channel can be represented by the NT*NR matrix H whose elements Hntnr. The Rayleigh flat fading model is assumed throughout the work. The baseband NR-dimensional received signal vector

R(k) =[r1(k), r2(k),………,rNR(k)]T at sampling instant k may be expressed by

$$R(k) = H.x(k) + n(k) \qquad (1)$$

Where

$$H=\begin{bmatrix} h_{11} & \cdots & h_{N_T1} \\ \vdots & \ddots & \vdots \\ h_{1N_R} & \cdots & h_{N_TN_R} \end{bmatrix},\ r(k)=\begin{bmatrix} r_1(k) \\ \vdots \\ r_{N_R}(k) \end{bmatrix},\ x(k)=\begin{bmatrix} x_1(k) \\ \vdots \\ x_{N_T}(k) \end{bmatrix},\ n(k)=\begin{bmatrix} n_1(k) \\ \vdots \\ n_{N_R}(k) \end{bmatrix}. \qquad (2)$$

X(x) =[x1(k) ,x2(k) ….,Xnt(k)] denotes the transmit symbol vector with equally distributed transmit power and n describes the zero mean additive noise. The subscript T is the transposed matrix.

4.1. MIMO Channel

The general MIMO channel is shown in Figure (7). The model for uncorrelated flat fading is mostly used through this work. However, correlated xhannel is also considered and simulation is carried out to investigate the MIMO capacity with correlated channel.

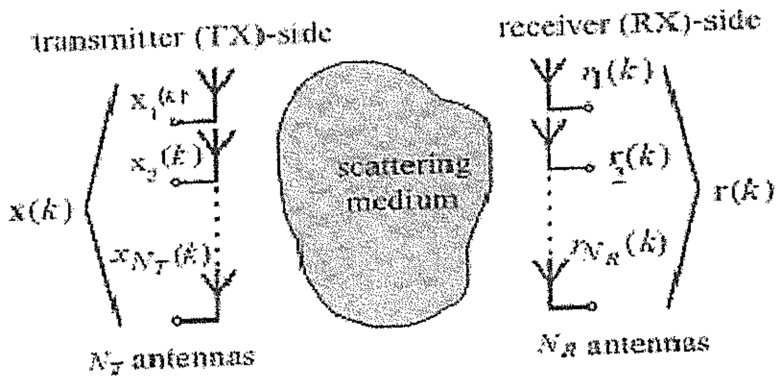


Fig. 6 The MIMO model

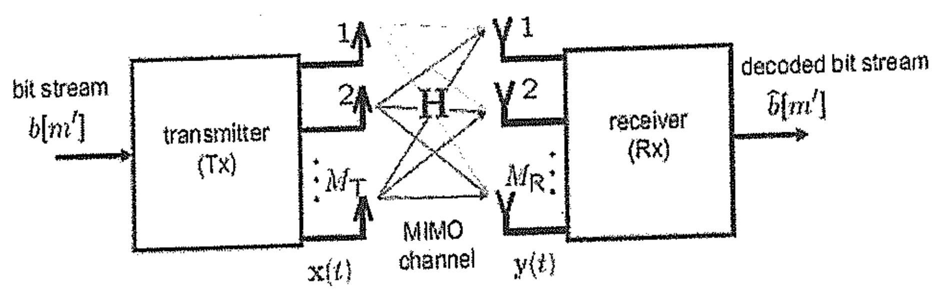


Fig. 7 MIMO channel

4.3.1 Uncorrelated channels

There are many factors which affect the desired performance of MIMO system [15]. One of these factors is the wireless propagation channel which has a profound effect on the performance of multiple-input multiple-output communication architecture, specifically impact on the MIMO channel capacity. In ideal condition, i.e when the channel is uncorrelated (independent fading at both transmitting and receiving ends, i.e rich scattering) and of high, the MIMO capacity is maximum and it scales linearly as the number of Tx/Rx antennas.

The channels are assumed to be independent in space (uncorrelated), constant over a block of symbols and independent from block to block. This gives the so-called identically distributed (i..i.d) block fading Rayleigh matrix model. In practice, proximity of the antennas in MIMO system will introduce some level of correlation. However, in H the channel matrix is so far assumed to contain all independent fading coefficients.

4.3.2. Correlated channels

The channel correlation decreases the capacity and, at some point, it is the dominant effect. The channel gains are often assumed to be independent. This is only true if both the transmitter and receiver are surrounded by a rich scattering environment and antenna spacing is large enough [15]. It should be pointed out that this effect depends on the propagation channel as well as on the antennas themselves (which are a part of the propagation channel) [9,15]. In an outdoor scenario the base station is usually placed high above potential scatterers; on the other hand, space limitations of the mobile device may also introduce correlation among antennas. Correlations at the receiver always reduce the ergodic channel capacity. A capacity is still decreased for high SNR due to the smaller number of independent strong subchannels. However, for low SNR correlations turn out to be beneficial for channel capacity as the transmitted power can be concentrated into directions that are advantageous on average.

4.4. MIMO Capacity

The MIMO capacity is defined as the maximum mutual information (the maximum being taken over all possible transmitted vectors [15]. The channel capacity is a convenient measure to analyze the potential gain of MIMO systems compared to SISO systems. For data rates below the capacity, arbitrary small error probabilities can be achieved if the codeword are allowed to be sufficiently long, whereas this is impossible for rates exceeding the capacity [3].

In fading environment the instantaneous capacity is a random variable and depends on the channel coefficients. If coding is performed over many different fading states it usually suffices to know the ergodic capacity, i.e the average overall channel realizations. However, there are several definitions of the MIMO channel capacity [9,15,19], depending on the scenario considered. The main differences between these definitions are due to the following.

Channel state information (CSI) may be available at the receiver (Rx), Transmitter (Tx), both or not at all. Ergodicity assumption states that, when the channel is random, its capacity is random too (i.e ergodic capacity may be defined if ergodicity assumption is employed. MIMO network may also be defined when there are several users which interfere with each other.

There are mainly three scenarios of interest;

1- Channel with CSI at Transmitter and Receiver (waterfilling algorithm)
2- Channel with no CSI at the transmitter and perfect CSI at receiver
3- Channels with partial CSI at the transmitter and receiver.

4.4.1. Capacity of conventional antenna systems

According to Shannon capacity of wireless channels, given a single channel corrupted by an additive noise at level of SNR , the capacity is given by;

$$C = \log_2[1 + SNR] \text{ [Bps/Hz]} \quad (3)$$

In practical case of time varying and randomly fading wireless channel, the capacity can be written as;

$$C = \log_2[1 + SNR \cdot |H|^2] \text{ [Bps/Hz]} \quad (4)$$

where H is the 1*1 unit-power complex Gaussian amplitude of the channel .In the single-input multiple-output (SIMO) systems, the channel vector H is 1*NR and the capacity is expressed by;

$$C = \log_2[1 + SNR \cdot \mathbf{HH}^*] \text{ [Bps/Hz]} \quad (5)$$

In the multiple-input single-output (MISO) systems, the channel vector H is 1*NT and have the same capacity equation;

$$C = \log_2[1 + SNR \cdot \mathbf{HH}^*] \text{ [Bps/Hz]} \quad (6)$$

It is obvious that the capacity of SIMO system is increased due to the spatial diversity which reduces fading and SNR improvement (the SNR improvement is limited) [9,19,39]. The ergodic capacity grows more or less logarithmically with the signal to noise ratio (SNR).

For MIMO system with Nt transmit and NR receive antennas, the capacity can be derived from the equation;

$$C = \log_2\left[\det[\mathrm{I}_{N_R} + \frac{SNR}{N_T} \cdot \mathbf{HH}^*]\right] \text{ [Bps/Hz} \quad (7)$$

And for large NT=NR=N the capacity is asymptotic to

$$C \approx N\log_2[1+SNR] \text{ [Bps/Hz]} \quad (8)$$

Therefore, the capacity increases linearly with the number of transmit antennas.

5. MIMO IMPLEMENTATION

MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the transmitter and the receiver. The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed [29,40]. MIMO operates in two modes; Diversity and Spatial Multiplexing.

5.1. Spatial Multiplexing (SM)

Spatial multiplexing occurs when several streams are transmitted simultaneously from the transmitter to the receiver, both equipped with multiple antennas. It should be noted that the multiple streams are transmitted simultaneously at the same time and frequency. Transmitter and/or receiver processing make sure that they are separated in the spatial (or antenna) dimension.

Spatial multiplexing scheme exploits the rich scattering wireless channel allowing the receiver antennas to detect the different signals simultaneously transmitted by the transmit antennas [13]. The net advantage of SM is to boost the spectral efficiency of the transmission [16]. Indeed, spatial multiplexing allows increasing the bit rate without consuming more and more time or frequency resources and without increasing the total transmitted power (i.e SM causes the spatial multiplexing gain). MIMO channels offer a linear increase in capacity for no additional power or bandwidth expenditure [8,9,41].

Spatial multiplexing gain (the increase in capacity) can be described by the following formula (where r is the spatial multiplexing gain).

$$C = r\log_2(SNR) \quad (9)$$

The gain is achieved when more than one independent symbol can be transmitted during the same symbol duration [15] (i.e the SM gain is dependent on the number of independent data streams that can be supported reliably i.e the rank H. It should be noted that in spatial multiplexing mode, the transmitter treats each antenna as a separate channel. SM requires uncorrelated multipath. Since multipath fades change moment by moment with motion, there is no assurance that uncorrelated signal paths can always be found. Furthermore, SM is usually employed in situations where the signal-to-noise ratio is relatively high and it does not work well in low SNR environments. The MIMO system implemented using SM turns multipath problem into an advantage to increase the throughput of the network.

The concept of spatial multiplexing is different from that of space-time coding method, which permits to efficiently introduce a space-time correlation among transmitted signals to improve information protection and increase diversity gain [13].

Figure (8) shows that the data stream to be transmitted is distributed among different subchannels, then goes through modulation and mapping, and is transmitted by corresponding antennas. Upon receipt, each receiving antenna receives three signals from the transmit antennas, and then the received signal is processed using signal processing to retrieve the desired signal.

5.2. Spatial Diversity (Better Signal Quality)

Diversity refers to the use of multiple antennas to increase the probability of a high quality signal path between the sender and the receiver. Diversity can be implemented at the transmit end, the receive end or at both ends of the wireless link.

The basic principle of diversity is to use different channels to convey the same information unit from the transmitter to the receiver so that only one information stream is exchanged with better signal quality. The application of diversity is especially useful when the probability that all channels are bad at the same time is low .However, diversity maximize wireless range and coverage [29]. Spatial diversity (also known as antenna diversity) is a very practical, effective and thus widely used method for reducing the effect of multipath fading.

6. RESULTS AND CONCLUSIONS

The common approach which has been done to investigate the promises of MIMO capacity is to build a MATLAB capacity code that includes the basic capacity equation for the system with the related different channel equation and simulate the actual capacity performance.

Figure (9) shows the plot of capacity and signal to noise ratio (SNR) for MIMO, MISO, and SISO systems. The parameter values are

NT = NR=2 for MIMO, NR=2, NT=1 for SIMO, NR=NT=1 for SISO. It is observed that at SNR =20dB the capacity varies from 6b/s/Hz for SISO to 11.2 b/s/Hz for2*2 MIMO system and MISO system offer smaller capacity .Hence it is concluded that the capacity growth achieved by MIMO system is the highest compared to other systems yielding a remarkable improvement (especially for high SNR).

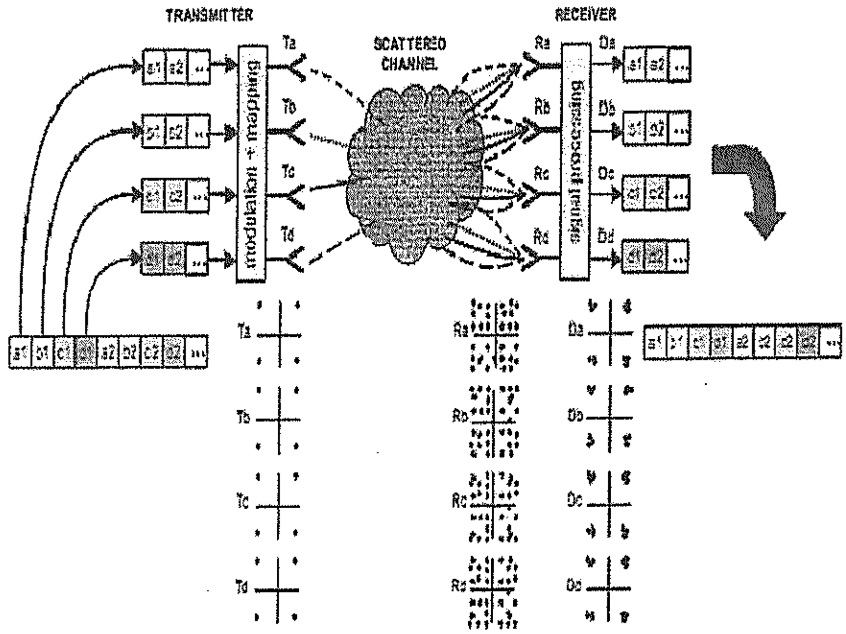


Fig. 8 Basic spatial multiplexing

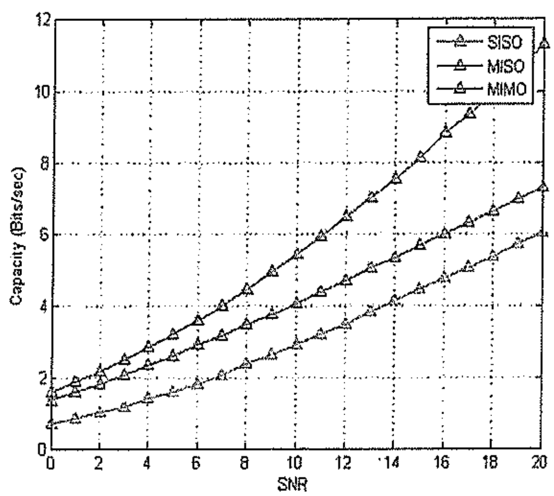


Fig. 9 Plot of capacity and signal to noise ratio (SNR) for MIMO ,MISO, and SISO systems.

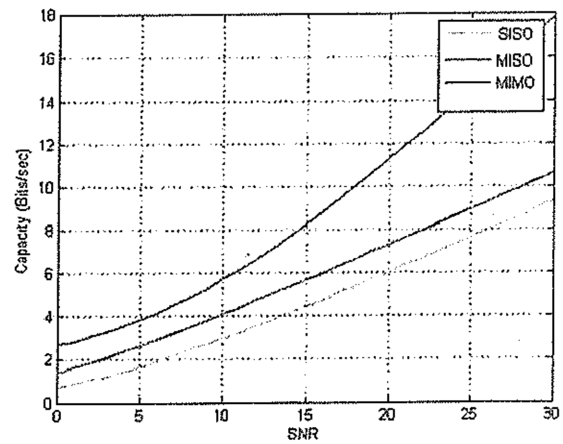


Fig. 10 The ergodic capacity for different antenna configuration as a function of SNR.

Figure (10) illustrates the ergodic capacity for different antenna configuration as a function of SNR, when the channel is known at the transmitter (water filling). It is also observed that the capacity of a MIMO channel appear to be greater than the capacity of MIMO capacity in Fig. 1 when CSI is unknown to the transmitter. The simulation was done on the premise that a rich scattering environment provides independent transmission paths from each transmit antenna to each receiver antenna and hence creating independent channels. Also it is observed that again the MIMO capacity is the highest among the other systems which is N times that is achieved by SISO system.

Figure (11a) shows a plot of the ergodic capacity as a function of number of transmitter and receiver antennas for several values of SNR. It is observed that the capacity increases more with high SNR for large number of antennas due to the fact that capacity increases for high SNR for large uncorrelated channel due to the large number of independent strong subchannels created by large number of transmit antennas. It is concluded that capacity increase linearly with SNR and increase more for large number of antennas.

Figure (11b) shows the variation of the capacity with the number of antennas M for different values of SNR. From the graph it is seen that the capacity increase linearly as the number of antennas increases (e.g for SNR=20 dB for 3 by 3 MIMO system capacity is 16.5b/s/Hz while the capacity achieved by 4*4 MIMO system is 21.9 b/s/Hz for the same SNR value.

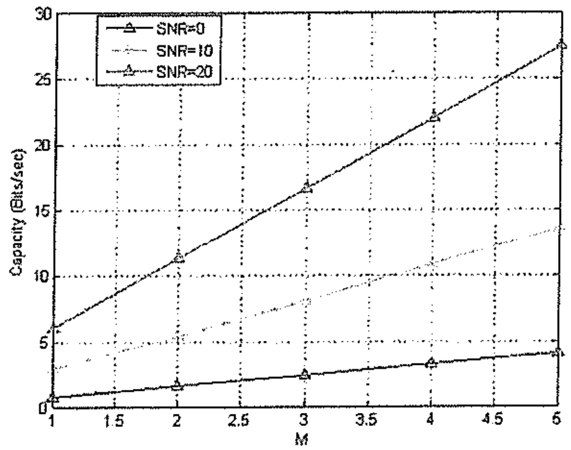


Fig. 11a Plot of the ergodic capacity as a function of number of transmitter and receiver antennas for several values of SNR.

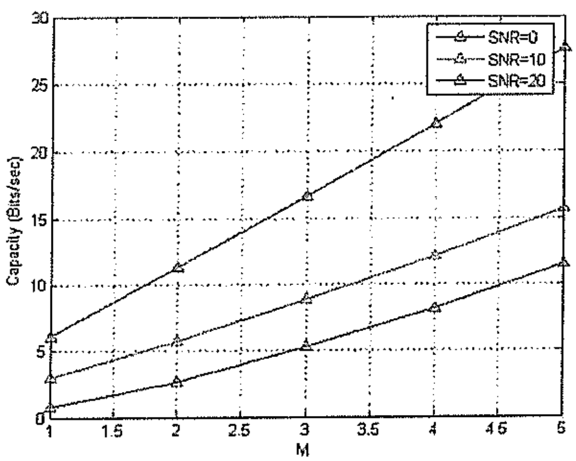


Fig. 11b The variation of the capacity with the number of antennas M for different values of SNR.

Figure (12) shows the capacity of a 4*4 MIMO system in the case when the channel state information (CSI) is known to the transmitter that is water filling algorithms as well as the case when CSI is unknown to the Tx. From the graph it is observed that it is an advantageous for the Tx to know CSI because it offers slightly greater capacity than the case when CSI is unknown.

If Tx knows the CSI as the Tx in both cases will allocate the power to the subchannels equally as noise become less and all the suchannels are in good conditions. Therefore, it is advantageous for Tx to know CSI when SNR is small and hence some of the subchannels will have much noise and the Tx will need to identify the good condition channels so that much power will be allocated to them to forward the signal to Rx.

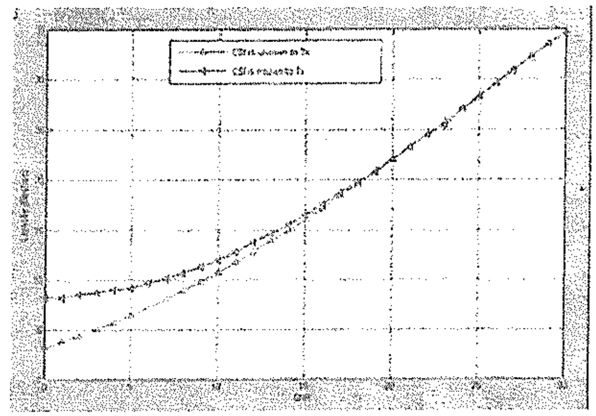


Fig. 12 The capacity of a 4*4 MIMO system.

Figure (13) shows the capacity and SNR for correlated and uncorrelated channel for 2 by 2 MIMO system for NT=NR=2. It can be observed that MIMO achieves better capacity performance in the case of uncorrelated channel (corr=0) as compared to the other values obtained at the different correlated values. Correlation between the transmitted and received signals decreases the independent propagation paths and as a result, decrease the information transferred.

We conclude that correlations always reduce the ergodic channel capacity and a rich scattering environment is required in order to achieve high MIMO capacity.

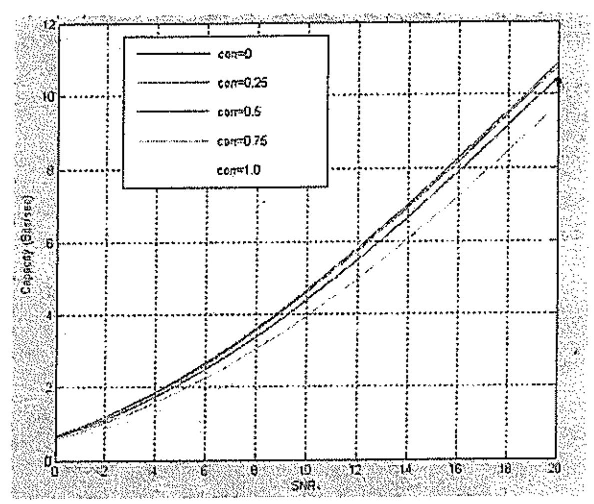


Fig. 13 The capacity and SNR for correlated and uncorrelated channel.

Figure (14) illustrates the capacity of MIMO systems compared to that of SISO system in Line-of-sight (LOS) that is rican channel. It is observed that the performance of MIMO system becomes slightly identical to that of the SISO system when each of Tx sees the Rx with no obstacles or scatters between them. It is observed that the capacity increases dramatically with decreasing channel correlations.

Scattering environment is required in order to achieve high MIMO capacity .This is due to the fact that N by N MIMO system with uncorrelated channel in a very scattering environment will create N sub channels in its scenario and hence achieving capacity equal to N times that achieved by SISO system using the same bandwidth and the same power allocacated.

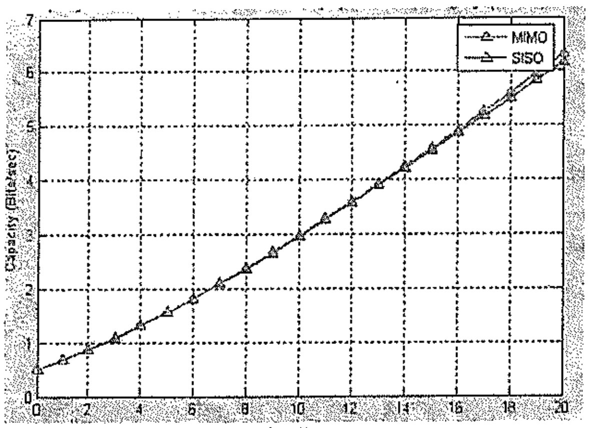


Fig. 14 The capacity of MIMO systems compared to that of SISO system in Line-of-sight (LOS) that is rican channel.

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