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The Effect Of Transmitter Channel State Information (CSIT) On The MIMO Capacity Performance

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Abstract

Wireless communication systems employing multiple antennas at both the transmitter and receiver have been shown to offer significant gains over single-antenna systems. It is shown that the ergodic capacity and outage capacity increases linearly with respect to $N_R N_T$. It is also shown that the capacity is improved when the channel state information (CSI) is known at the transmitter for MIMO system and for all values of SNR. In this work, MIMO system has been studied in detail and simulated for different cases and concentrated on the capacity performance when the channel state information is known (Water filling) and when the CSI is unknown to T_X (Equal power allocation).MIMO system was described and simulation results (using MATLAB computer simulation program) were presented and discussed.

Keywords; Single Input Single Output (SISO), Multiple Input Multiple output (MIMO). SNR, Ergodic and Outage Capacity, CSIT .

الملخص

أنظمة الاتصالات اللاسلكية التي تستخدم هوائيات متعددة في الارسال والاستقبال أعطت مكاسب كبيرة مقارنة بنظام الهوائي الواحد . وتبين أن استيعاب قدرة اركودك واستيعاب قدرة الانقطاع تزداد خطيا نسبة الى $N_R N_T$. وتظهر أيضا أن استيعاب القدرة تتحسين عندما يعرف معلومات حالة القناة (CSI) في الارسال لنظام الإدخال والإخراج المتعدد MIMO system ولكل قيم نسبة الاشارة الى الضوضاء SNR. في هذا البحث نظام MIMO درس بالتفصيل وتم عمل محاكاة لحالات مختلفة تركزت على اداء قدرة الاستيعاب عندما يعرف معلومات حالة القناة تعبئة المياه (Water filling)، وعندما لا يعرف معلومات حالة القناة تخصيص القدرة المتساوي (Equal power allocation) . لقد تم عرض ومناقشة النتائج لنظام MIMO باستخدام برنامج المحاكاة الحاسوبي MATLAB 2009a .

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. To overcome the limited capacity of conventional SISO systems, by the use of multiple antennas a multiple input multiple output (MIMO) systems, offers greater capacity than SISO counterparts. The multiple antennas can be used to increase the communication realibility by diversity or to increase the data rate by spatial multiplexing or a combination of both. Multiple antenna has performance and capacity enhancements without the need for additional power spectrum [1] .

2. The MIMO (Multiple Input Multiple Output) System

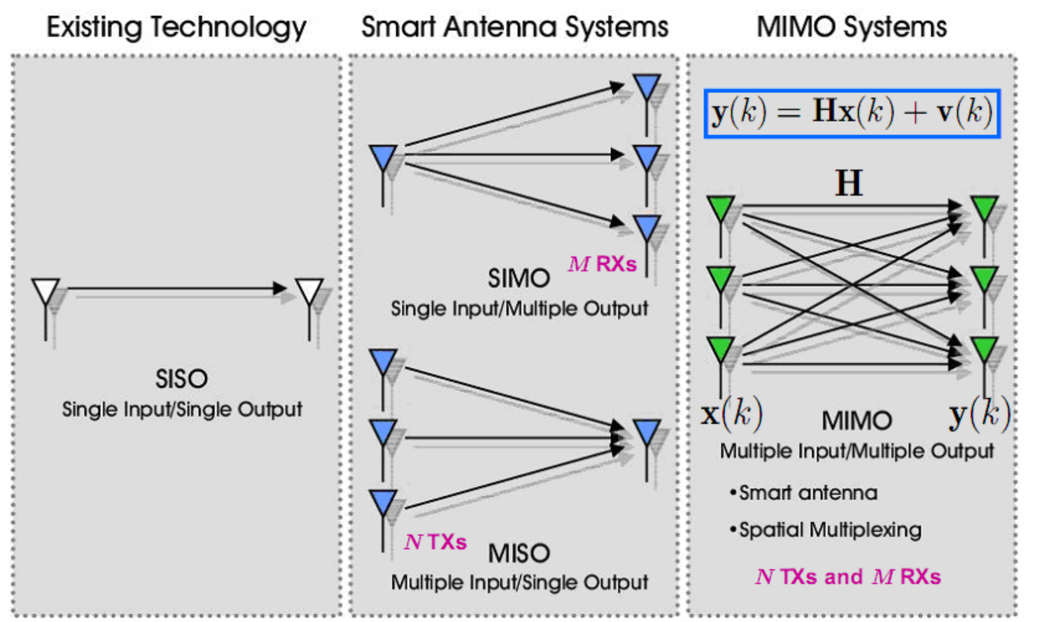
2.1 Conventional Antenna System

2.1.1 SISO (Single Input Single Output) System

SISO refers to antenna system with single antenna at both the transmitter and receiver. This system can reach 1 Gb/S 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 in outdoor wireless wide area networks (WWAN) [2,3] .

2.1.2 SIMO(Single Input, Multiple Output), MISO(Multiple Input ,Single Output) systems

In these systems multiple antennas at the receiver and/or the transmitter in a wireless network. It promoises higher data rates at longer ranges without consuming extra bandwidth or transmits power[1], such technology popularly known as smart antenna, offers a variety of advantages which if expoited correctly can enable multiplicative gains in network performance. Figure (1) shows different antenna systems .



Figure(1) SISO,SIMO,MISO,and MIMO system

3. The MIMO (Multiple Input Multiple Output) System

The use of multiple antennas at transmitter and receiver sides popularly known as Multiple Input Multiple Output (MIMO) wireless is an emerging cost effective technology that offers high data rates wireless communications, near 1 Gigabit/second transmission rate, Moreover this technology resolve many limitations associated with SISO system [1,4]. MIMO is a communication concept of having antennas at both the receiver and the transmitter of radio link as shown in Figure (2)

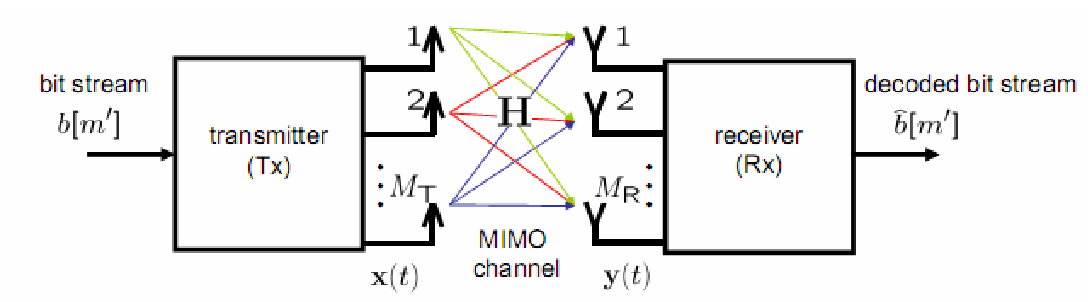


Figure (2) The MIMO channel

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[4]. MIMO system can increase the transmission capacity with the number of antennas , as will be seen from the simulation results.

3.1 MIMO Capacity

The system is described by the matrix equation

$$y = \sqrt{\frac{E_S}{T}} HS + n \qquad \text{...(1)}$$

Where

E_s is the total energy available at the transmitters
y is the R * 1 vector of signals received on the R antenna
S is the T * 1 vector of signals transmitted on the T antenna
n is the R * 1 noise vector consisting of independent complex Guassian distributed element with zero mean and variance σ^2
H is the R * T channel matrix

When the channel is known at the transmitter, the maximum capacity of a MIMO channel can be achieved using the water filling principle[5]. On the transmit convariance matrix, the capacity is then given by

$$C = E_H \left\{ \sum_{i=1}^{k} \log_2 \left(1 + \in_i \frac{\rho}{NT} \sigma_i^2 \right) \right\} \qquad \text{...(2)}$$

And for $N_R \neq N_T$

$$C = N \log_2 (\sigma + 1) \qquad \text{...(3)}$$

E_H denotes that the exception is taken with respect to resemble statistics of H. Where ϵ_i is a scalar representing the portion of the available transmit power going into the sub channel. ρ is average SNR.

And when the channel is unknown to the transmitter (no CSIT).

$$C = E_w\{\log_2 \det(I_r + \frac{\rho}{NT} w)\} \qquad \ldots(4)$$

where $w = \begin{Bmatrix} HH^* & N_r < N_t \\ H^*H & N_r > N_t \end{Bmatrix}$

Where I_r = the identity receiver matrix. If our bandwidth is W Hz, the maximum achievable data rate over this bandwidth using MIMO techniques is WC bits/s [6] .

3.2 Ergodic Capacity

This is the time-averaged capacity of a stochastic channel. It is found by taking the mean of the capacity values obtained from a number of independent channel realization[7,8] .

3.3 Outage Capacity

The q% outage capacity is defined as the capacity that is guaranteed for (100- q)% of the channel realization. It represents another measure of the channel capacity hence the instantaneous capacity[5].

$$C_{ins} = \sum_{i=1}^{N} \ln(1 + \frac{P}{\sigma^2 t})\lambda_i \qquad \ldots(5)$$

where λ_i is the eigen value matrix.

4. Equal Transmit Power Allocation

In this case, the power allocated to sub channel i is given by $Pi = P/t$, $i = 1, 2, \ldots, t$, and P_{ri} is given by[7].

$$P_{ri} = \frac{\lambda_i P}{t} \qquad \ldots(6)$$

Thus the channel capacity (5) can be written as

$$C = \sum_{i=1}^{r_o} \ln\left(1 + \frac{\lambda_i P}{t\sigma^2}\right) = \ln \prod_{i=1}^{r_o} \left(1 + \frac{\lambda_i P}{t\sigma^2}\right) \qquad nats\ / s / Hz \qquad \ldots(7)$$

5. Water- Filling Principle

Consider a MIMO channel where the channel parameters are known at the transmitter. The ‘‘water-filling principle’’ can be derived by maximizing the MIMO channel capacity under the rule that more power is allocated to the channel that is in good condition and less or none at all to the bad channels.

To determine this optimal energy allocation iteratively through the ‘‘water-filling principle’’[5]. Set the iteration count *p* to 1 and calculate the constant μ:

$$\mu = \frac{M_T}{(r-p+1)}\left[1+\frac{N_o}{E_s}\sum_{i=1}^{r-p+1}\frac{1}{\lambda_i}\right] \qquad \ldots(8)$$

Using this value of μ , the power allocated to the *i*th subchannel is calculated as

$$\gamma_i = \left(\mu - \frac{M_T N_o}{E_s \lambda_i}\sum_{i=1}^{r-p+1}\frac{1}{\lambda_i}\right), i = 1,2,\ldots, r-p+1 \qquad \ldots(9)$$

If the power allotted to the channel with the lowest gain is negative (i.e., $\lambda r\text{-}p\text{+}1<0$), we discard this channel by setting $\lambda r^{opt}\text{-}p\text{+}1=0$ and rerun the algorithm with the iteration count p incremented by 2. The optimal power allocation strategy, therefore, allocates power to those spatial subchannels that are non-negative.

6. Simulation Results and Discussion

The common approach which has been done to investigate the promises of MIMO capacity is to build a MATLAB capacity program that include the basic capacity equations for the system with related different channel equations in a Rayleigh fading channel and simulate the actual capacity performance.

Figure (3) shows a plot of the capacity versus SNR for SISO, MIMO systems. We note that ergodic capacity increases with increasing SNR (dB) and with increasing N_t or N_r . It is observed that at SNR=20dB the capacity varies from 7 bits/s/ Hz for SISO to 21 bits/s/Hz for MIMO (N_r=N_t=4). Hence it is concluded that the capacity growth achieved by MIMO system is the highest compared to other systems yielding remarkable improvement (especially for High SNR).

Figure (4) shows the effect of the number of transmitting antennas when the number of receiving antennas is 4 on the capacity for fixed SNR values (0,5,10,15)dB. Figure (5) shows the effect of the number of receiving antennas when the number of transmitting antennas is 4 on the capacity for fixed SNR values (0,5,10,15)dB. However, In both graph it is indicated that the capacity increases with N_T & N_R and the best value for the case of 4×4 system because it is not practical to use high values of N_R & N_T .

Figure (6) shows the ergodic capacity versus number of receiving antenna (1,2,3,4) and the number of transmitting antennas (2,4,6,8,16) at SNR=10 dB when the CSI is known at the transmitter and when the channel is unknown. It is concluded that the capacity is improved when the CSI is known to T_X and increasing number of receiving antennas for a (4×4) system which gives 12 bps/Hz where as the corresponding value is 11 bps/Hz when the CSI is unknown to T_X.

The effect of CSIT(Known & Unkown) on the outage capacity for (1,5,10,15)% are considered in figure (7). It is concluded that the outage capacity for (4×4)system and CSIT is known is the best. At SNR=16dB and for Known CSIT. The maximum capacity 14.5 bps/Hz for 1% outage capacity,15bps for 5% outage capacity,16bps for 10% outage capacity, 17 bps for 15% outage capacity.

The ergodic and outage capacity for any number of N_T and N_R of a MIMO in a Rayleigh fading channel considering no CSIT(equal power allocations) and perfect CSIT (water filling allocation) is shown in figures (8,9,10,11) respectively. It is concluded that ergodic capacity and outage capacity is better when CSIT is known (water filling) and generally the ergodic capacity is better and the approximately conceded for (4×4)as shown in figure (11) {i-e 20 bps/Hz at SNR=18dB).

Figure(12) compares the capacity of MIMO system when the CSIT is known and CSIT is unknown. It is observed that the capacity increases linearly with (N_R× N_T) and the capacity is better for water filling algorithm {maximum capacity 21bps/Hz for (4×4) case }at SNR=20dB.

Figure(13) shows the 3-dimensional surface of capacity versus SNR versus the bandwidth. Figure (14) shows the outage probability versus SNR for 5bps/Hz capacity for SISO,MISO,SIMO,MIMO and it is observed that the outage probability is better for MIMO(4×4) water filling.

7. Conclusion

From our work it can be concluded that MIMO system offers significant gain in performance over traditional wireless communication system. MIMO system give better capacity improvement for all values of SNR , and N_T× N_R {from figure (3) 21 bps/Hz for 4×4 system, 7bps/Hz for SISO system }and it is also indicated that MIMO system with 4×4 is the best one.The effect of CSI at T_x was investigated and it was showed (proven) that the MIMO system offer better performance when the CSI is known for all values of SNR and all values of (N_R×N_T). It was also concluded that the ergodic capacity and outage capacity for water filling case (i-e CSI is Known to T_X) gives better capacity than the equal power allocation (CSI is unknown to T_X)

counter part. From our results it is recommended to use the MIMO system with 4×4 to get better performance.

8. References:

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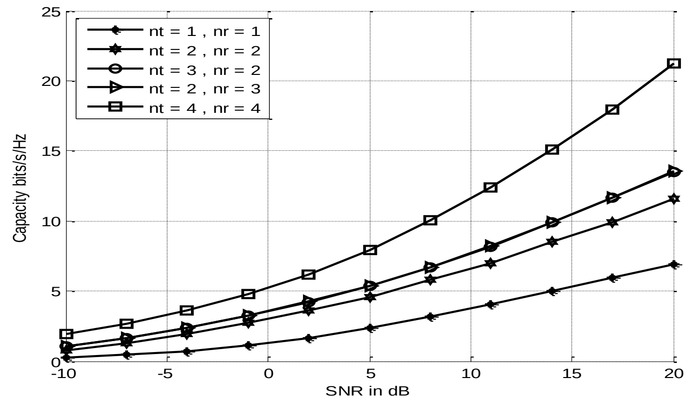
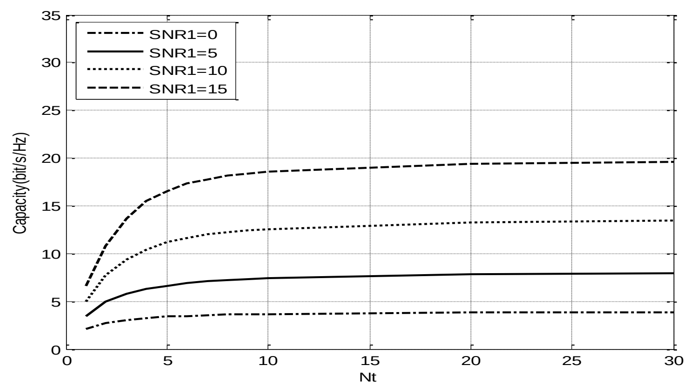
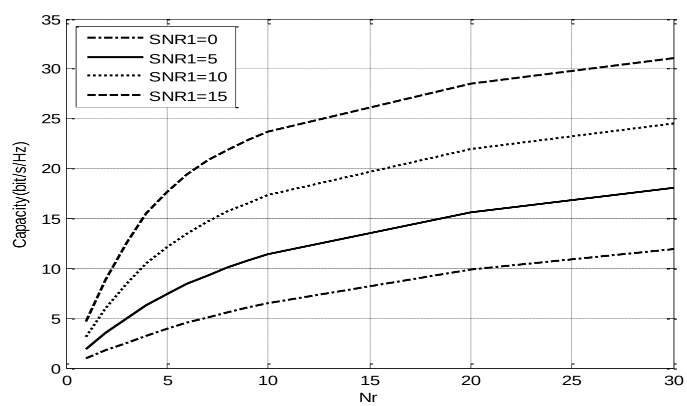


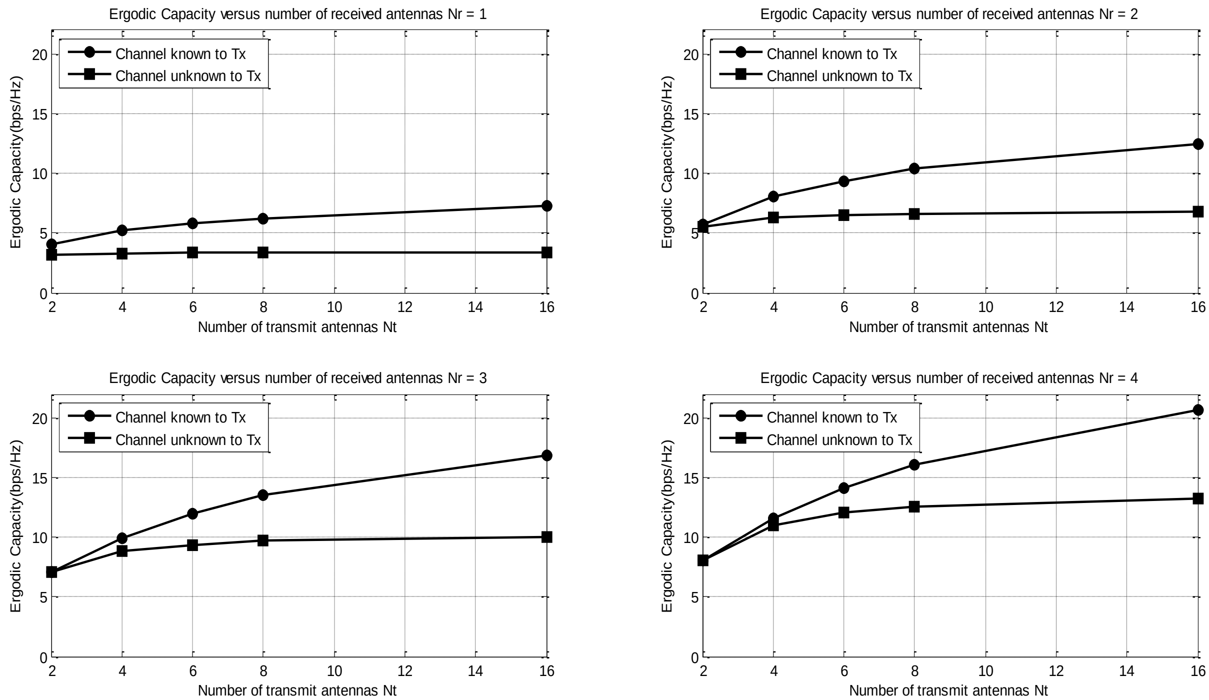
Figure(3) Ergodic capacity based WaterFilling algorithm for different antenna configurations MIMO system in a Rayleigh Fading Channel



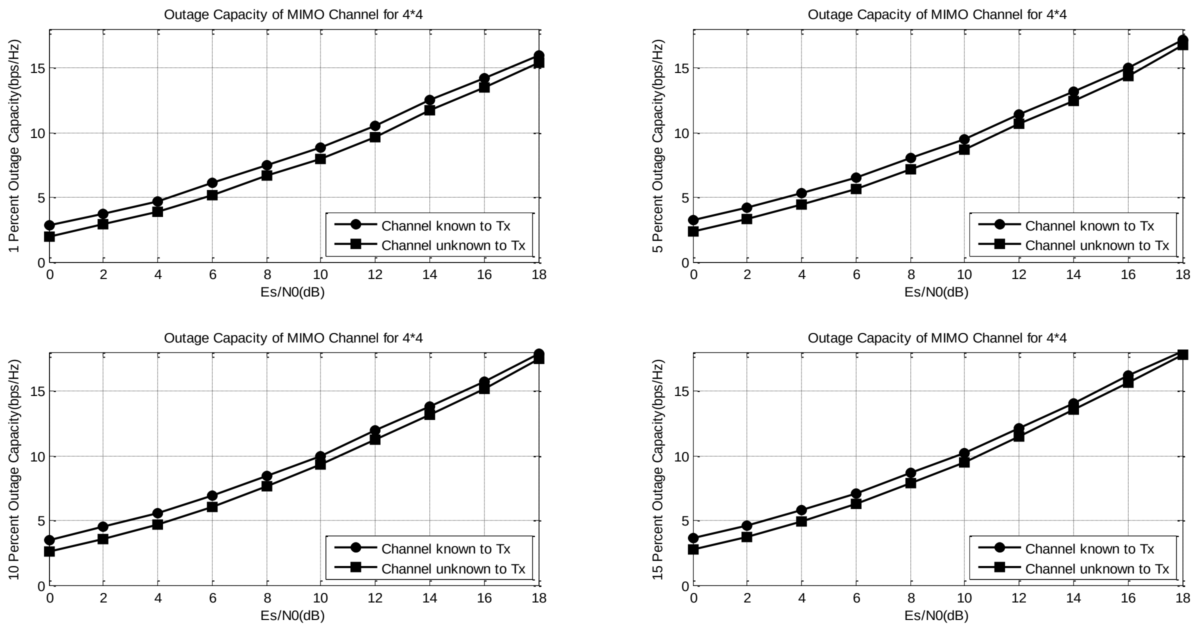
Figure(4) Capacity of MIMO system when the number of receiving antenna is 4 and increasing the number of transmitting antenna [1 2 3 4 5 6 7 8 9 10 20 30]



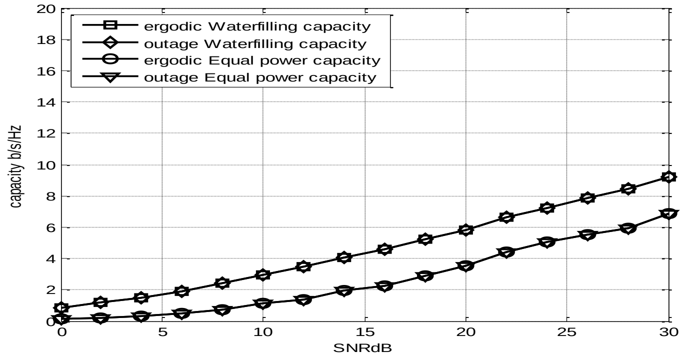
Figure(5) Capacity of MIMO system when the number of transmitting antenna is 4 and increasing the number of receiving antenna [1 2 3 4 5 6 7 8 9 10 20 30]



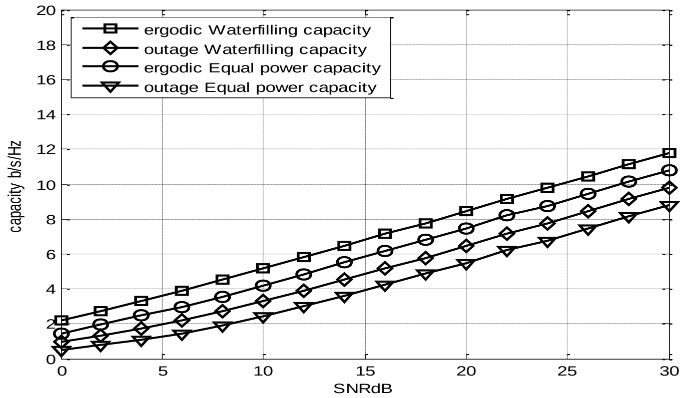
Figure(6) Ergodic Capacity versus number of transmit and received antennas when the channel is known and unknown to the transmitter when SNR=10 dB



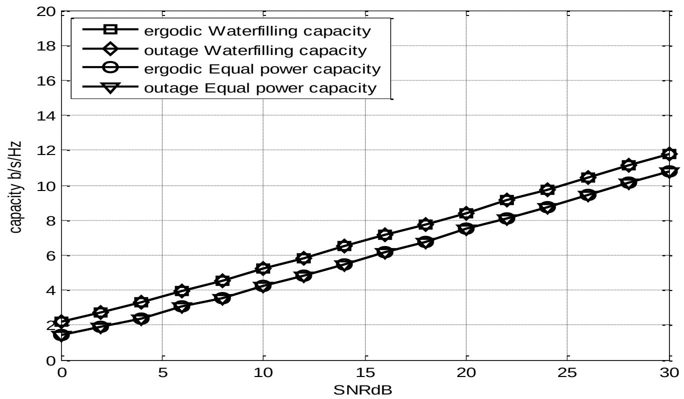
Figure(7) [1, 5, 10 and 15] Percent Outage Capacity of 4*4 MIMO system when the channel is known and unknown to the transmitter



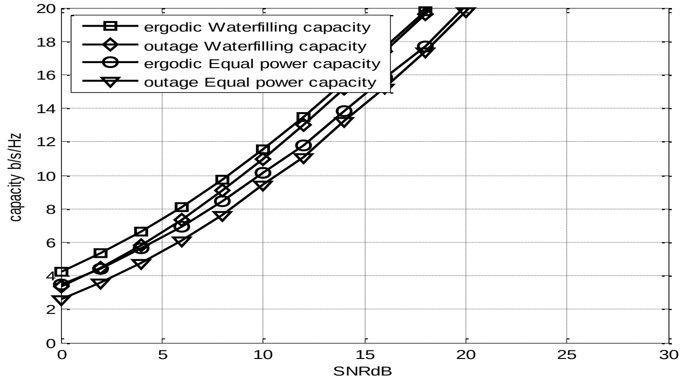
Figure(8) Ergodic and Outage Capacity of a SISO system Rayleigh channel considering no CSIT (equal power allocation) and perfect CSIT(waterfilling power allocation)



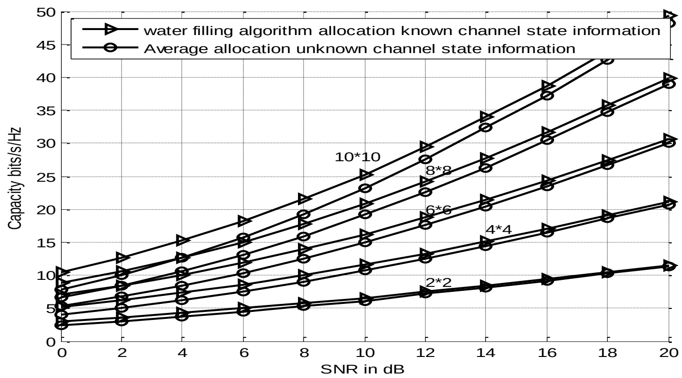
Figure(9) Ergodic and Outage Capacity of a 4*1 MISO system Rayleigh channel considering no CSIT (equal power allocation) and perfect CSIT(waterfilling power allocation).



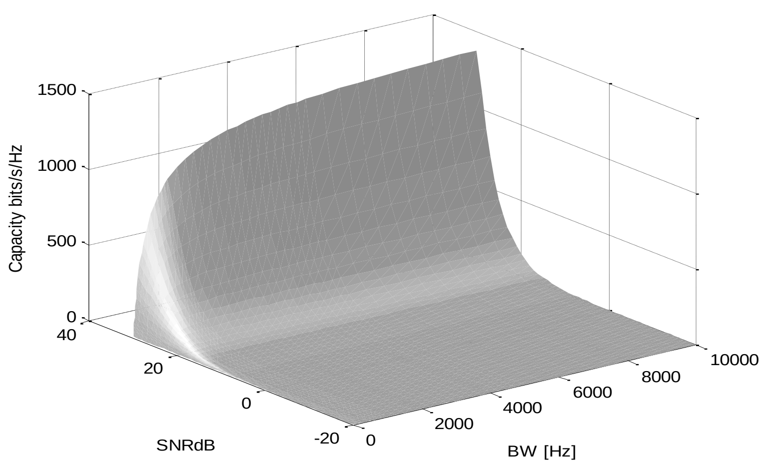
Figure(10) Ergodic and Outage Capacity of a 1*4 SIMO system Rayleigh channel considering no CSIT (equal power allocation) and perfect CSIT(waterfilling power allocation)



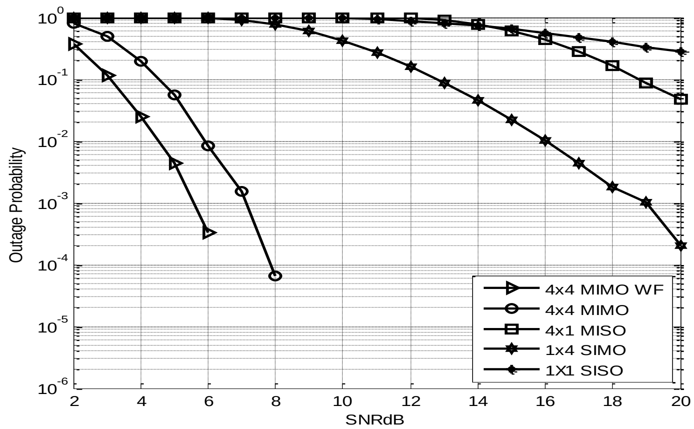
Figure(11) Ergodic and Outage Capacity of a 4*4 MIMO system Rayleigh channel considering no CSIT (equal power allocation) and perfect CSIT(waterfilling power allocation).



Figure(12) MIMO Capacity for Nt equal to Nr with known channel state information (waterfilling algorithm) and unknown channel state information (Average allocation power)



Figure(13) three dimensional plot of Capacity versus bandwidth and SNRdB



Figure(14) Outage probability versus SNRdB for 5 bps/Hz in a Rayleigh Fading channel.