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Deep Fading Effect On an Individual Link of 4 × 4 Mimo Communication Systems

تأثير التخميد العميق على كل رابط في قناة أنظمة الاتصالات المتعددة المداخل والمخارج (4 × 4)

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Abstract

The hottest issue of next generation communication systems is data throughput improvement for any wireless channel conditions. Multi-Input Multi-Output (MIMO) systems are the key technology for the next generation communication systems. Bill Lab Layered Space Time (BLAST) system achieves high data rates with acceptable BER performance over a good channels state. However, when the wireless channel has a considerable fading then the performance will be decreased and at a deep-fading state the system may fail to transmit any signal. This paper studies and compares the conventional 4 × 4 Vertical BLAST system capacity and bit error rate (BER) performance at Maximum Likelihood (ML) receiver through a simulation. It also studies the effect of a transmit-link deep-fading on the effective signal to noise ratio, system BER and system capacity in 4 × 4 VBLAST system in a comparative way with the conventional 4 × 4, 3 × 4, 2 × 4 and 1 × 4 VBLAST system. Considering that every possible case of transmit link deep fade lower than -20dB fading gain is equivalent to switching off this transmit link and mostly all of its power will be wasted. MATLAB software has been used as the main platform for system simulation.

Keywords: Wireless Communication, MIMO, Deep Fading, Channel Fading, Rayleigh Fading, VBLAST.

ملخص

تسعى هذه الدراسة للكشف عن اهمية تحسين معدل نقل البيانات في انظمة الاتصالات بغض النظر عن ظروف القناة اللاسلكية، لان انظمة الاتصالات ذات المداخل والمخارج المتعددة تعتبر التكنولوجيا الاساسية في انظمة الاتصال في الاجيال القادمة من هذه التكنولوجيا، ولما كان نظام بيل المتعدد الطبقات الزمكاني (البلاست) يحقق معدل بيانات عالياً – مع نسبة خطأ مقبولة – حال كون القناة اللاسلكية في حالة جيدة، فإن هذا لا يمنع تراجع الاداء إذا عانت القناة اللاسلكية من تخميد وإن كان التخميد عميقاً قد يتعرض النظام للفشل في ارسال البيانات بصورة صحيحة. ومن هنا فإن الدراسة تسعى لفحص ومقارنة سعة ومعدل الخطأ في نظام 4 × 4 بلاست العمودي حال استخدام نظام الأفضلية المثلى في عملية الاستقبال. كما تسعى ايضا لدراسة تأثير وجود تخميد عميق في أحد قنوات الارسال الاربعة على معامل نسبة الاشارة الي الضوضاء، وكذلك معدل الخطأ ومتوسط سعة القناة، اخذةً بعين الاعتبار أن معامل التخميد إذا قل عن -٢٠ ديسبل فانه يكافئ حالة قطع الارسال عبر القناة، وأن طاقة الارسال المستخدمة في هذه الحالة ستضيع هباءاً. وقد استخدم الباحث برنامج الماتلاب كاساس للمحاكاة في هذه الدراسة.

Introduction

The concept of exploiting the multipath channel rather than attempting to mitigate its effects was emerged in [1]. It was demonstrated theoretically that it is possible to exploit the multipath channel and thereby increase the information capacity of a wireless link through receive and transmit diversity using multiple receivers and multiple transmitters (MIMO) system [2].

This promise of MIMO channels is remarkable. By adding more antennas at the transmitter and/or receiver, a wireless link in the multipath fading environment can have a higher information rate than a Single-Input –Single-Output (SISO) wireless link in an additive white Gaussian noise channel.

Recently, there are efforts on realizing both capacity and robustness gains simultaneously. In [3], the researchers established that there is a tradeoff between these two types of gains based on how fast error probability can deteriorate and how rapidly data rate can increase with signal to noise ratio (SNR) [4].

Fading is wireless channel impairment. Wireless communications occur in the public space, where signal transmissions suffer from many factors such as path loss, shadowing, fading, etc. As a result, the wireless channel has time-varying condition and capacity. Thus transmission techniques such as adaptive transmission will play an important role in increasing the throughput. Adaptive transmission is one of the key enabling techniques in the new generation standards for wireless systems that have been developed to achieve high spectral efficiency on fading channels [5]. Adaptive modulation, antenna subset selection and switching systems are considered as common adaptive schemes for MIMO communication systems in high data rate next generation.

In this paper, a full study of 4 × 4 VBLAST system is introduced regarding to the performance and Shannon capacity.

Mimo Systems

Let H be the channel matrix of $N \times M$ dimensions, where M is a number of transmit antennas and N is a number of receive antennas. In the ideal case, each path is assumed to be statistically independent from others. Herein, consider a transmitted vector $x = [x_1, x_2, x_3 ......x_M]^T$, the vector is then transmitted via a MIMO channel characterized by the channel matrix H whose element $h_{i,j} \approx CN(0,1)$ is random Gaussian complex channel coefficient (fading gain) between the j^{th} transmit and i^{th} receive antennas with zero mean and unity variance. The received vector $r = [r_1, r_2, r_3 .....r_N]^T$ can then be given as following:

$$\boldsymbol{r} = \boldsymbol{Hx} + \boldsymbol{n} \tag{1}$$

Eq. (1) can be expressed as:

$$\begin{pmatrix} r_1(k) \\ r_2(k) \\ \vdots \\ r_N(k) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & \dots & h_{1M} \\ h_{21} & h_{22} & \dots & h_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1} & \dots & \dots & h_{NM} \end{pmatrix} \begin{pmatrix} x_1(k) \\ x_2(k) \\ \vdots \\ x_M(k) \end{pmatrix} + \begin{pmatrix} n_1(k) \\ n_2(k) \\ \vdots \\ n_N(k) \end{pmatrix} \tag{2}$$

Capacity of MIMO Systems

It was shown by Shannon that the attainable capacity for a flat fading Single Input Single Output (SISO) communication system is

$$C_{SISO} = log_2(1 + \gamma|h^2|) \text{ bps/Hz}, \tag{3}$$

where γ is the average *SNR* of one receive antenna and h denotes the fading gain.

In 1998, Foschini has demonstrated that the capacity of the flat fading channel of the MIMO communication systems is given by [6]:

$$C_{MIMO} = log_2(det\,|\,\boldsymbol{I}_N + \frac{\gamma}{M}\boldsymbol{H}^H\boldsymbol{H}|) \text{ bps/Hz}, \tag{4}$$

with the assumption that numbers of transmit and receive antennas are equal. This theoretical capacity expression for MIMO systems points out that the capacity may be increased linearly with the number of antennas [7]. Thus capacity for MIMO systems is increased in comparison to SISO systems, where the capacity increases logarithmically with *SNR*.

Now what happens to *BER*, Capacity and SNR_{eff} of this system if one or more transmit links suffer from a considerable fading.

The effective average received *SNR* of 4 × 4 MIMO system is equal to [8]

$$SNR_{eff} = \frac{E_s\|H\|_F^2}{MN_o} = SNR\|H\|_F^2 \tag{5}$$

Where SNR_{eff} is the average received signal to noise ratio of four receive antennas.

In other words, in decibel eq. (5) will be

$$[SNR_{eff}]_{dB} = [SNR]_{dB} + 10\log\|H\|_F^2$$

where $\|H\|_F^2$ is the Frobenius norm [9] which is equal to

$$\|H\|_F = \sqrt{\sum_{j=1}^{N}\sum_{i=1}^{M} h_{ij}^2} \qquad (6)$$

The individual contribution of each receive antenna to the effective *SNR* is through the contribution of $\|H\|_F^2$ [10].

Fading Concept

From a practical perspective, the performance of any transceiver, signal processing algorithm, channel code, etc., depends on the channel it is operating in [11].

The salient feature of wireless transmission is the randomness of the communications channel, which leads to random fluctuations in the received signal commonly known as fading.

Transmission through free space undergoes absorption, reflection, refraction, diffraction, and scattering. These factors are greatly affected by the ground terrain, the atmosphere, and the objects in their path, such as buildings, bridges, hills, trees, etc. These multiple physical phenomena are responsible for most of the characteristic features of the received signal [12]. On the other hand, changes in the propagation environment, e.g., due to mobility in wireless communications, introduce channel time variation, which could be very harmful. Mitigating these fading channel effects constitutes a major challenge in current and future communication systems.

Fading is the result of interference between two or more attenuated versions of the transmitted signal arriving at the receiver in such a way that these signals are added destructively [13]. Strong destructive interference is frequently referred to as a **deep fade** and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio [12].

Mathematically, fading is usually modeled as a time-varying random change in the amplitude and phase of the transmitted signal. Examples of fading models for the distribution of the attenuation are Nakagami fading, Weibull fading, Rayleigh fading, Rician fading, dispersive fading models and Log-normal shadow fading [14]. Slow fading and fast fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes [14]. Flat fading and frequency-selective fading are two terms often used to describe the fading over a certain bandwidth. Flat fading means that all frequency components of the signal will experience the same magnitude of fading but frequency-selective fading means that different frequency components of the signal experience decorrelated fading [12,14].

In eq. (2) the j^{th} transmit link deep fading means a low gain magnitude of column j of the channel matrix and the i^{th} receive link deep fading means a low gain magnitude in row i of the channel matrix. Cancelling column j or row i of $\boldsymbol{H}$ have the same effect on the Frobenius norm of $\boldsymbol{H}$ (Eq. (6)), this lead to the result that a deep fading occurred at the transmitter side or at the receiver side has the same effect on the average SNR_{eff} and the average capacity of the system.

Results and Discussion

This paper has focused on a 4 × 4 MIMO system as a case study in MIMO communication systems. In this study the effects of a flat Rayleigh deep fading on different transmit links are simulated and analyzed. A comparative study has been done using the simulation results for the received SNR_{eff}, performance and capacity of the normal 4 × 4, n × 4 MIMO systems (n=1, 2, 3 and 4) and the various link deep fading cases.

The simulated channel is a 4×4 Rayleigh Channel with unity variance so eq. (6) states that the average Frobenius norm of H is 16, so the effective SNR eq. (5) of 4×4 MIMO channel is 16 times the received SNR for one receive link. If SNR = 14 dB then from eq. (5) SNR_{eff}= 14 $+10log_{10}16$ = 26.02 dB on average and the average Frobenius norm of 3×4 channel is 12 eq. (6) then SNR_{eff} = 14 $+10log_{10}12$ = 24.8 dB on average.

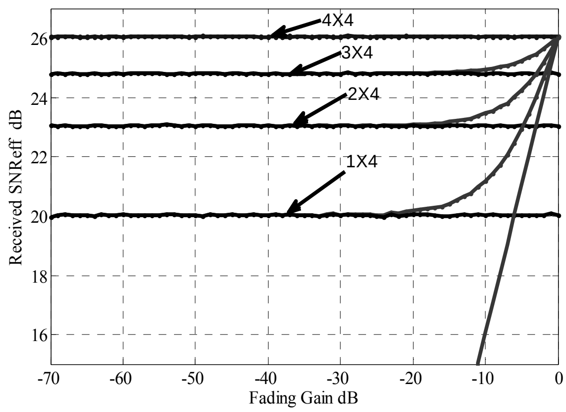

Figure (1): Effect of Tx links fading on SNR_{eff} for SNR = 14 dB.

Case 1: If transmit link 4 is under deep fading condition, this means that the 4th column of channel matrix has lower overall gain magnitude then all symbols transmitted from this antenna will be received with high error probability which will increase the overall BER of the system. Fig. 1 will show the deep fading effect on the effective SNR.

It is seen from Fig. 1 that a 4×4 VBLAST SNR_{eff} decreases as the fading gain decreases, until it reaches a 3×4 VBLAST at fading lower than -20 dB, the maximum decreasing of SNR_{eff} of 4th Tx link fading at 14 dB SNR is about 1.2 dB.

As a result, 3×4 channel and 4×3 channel have the same effect on SNR_{eff} since the average Frobenius norm of 3×4 and 4×3 channel is the same, it can be inferred that a deep fading of one Tx link or one Rx link have the same effect on SNR_{eff} and average capacity.

Case 2: if transmit link 3 and 4 are under deep fading condition, all symbols transmitted from these antennas will be received with a high error probability which makes the overall *BER* of the system so bad. The maximum decrease in SNR_{eff} is about 3 dB at 14 dB *SNR*. In other words the faded Tx links will act as switched off.

Case 3: At -20 dB fading of 2nd & 3rd &4th Tx links all symbols transmitted from 2&3&4th Tx antennas will be received with high error probability. This means that the overall BER of faded 4 × 4 system is as bad as seen from Fig. 1. In this case the maximum decrease of SNR_{eff} at 14 dB *SNR* is about 6 dB.

Case 4: for all links faded case SNR_{eff} will be worse more and more and then the transmitter will be seemed invisible.

Now Fig. 2 will show the effect of different transmit link deep fading cases on the average system capacity.

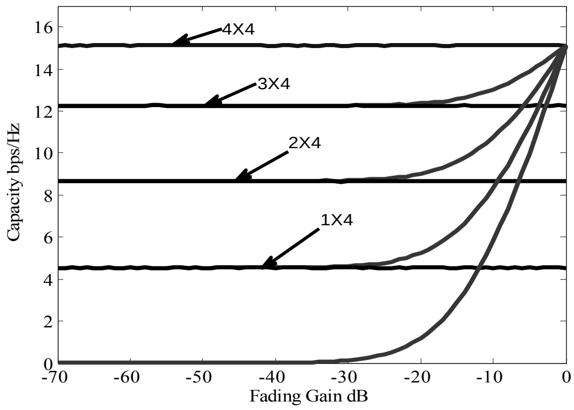

Figure (2): Effect of Tx links fading on Capacity for *SNR* = 14 dB.

Case 1: If transmit link 4 is under deep fading condition, the average capacity of the system will be decreased until it reaches a 3 × 4 system capacity (equivalent to switching off the faded Tx link) at fading lower than -20 dB, also there is a loss about 3 bps/Hz in capacity as shown in Fig. 2, in other words at fading lower than -20 dB the faded Tx links will be act as switched off.

Case 2: if transmit link 3 and 4 are under deep fading condition, the capacity of the system will decrease until it reaches a 2 × 4 system capacity at fading lower than -20 dB and there is a loss in capacity of 6.3 bps/Hz (from simulation results in Fig. 2) when the fading gain of 3^{rd} & 4^{th} (or any two) Tx links is lower than -30 dB.

Case 3: At deep fading of 2^{nd} & 3^{rd} &4^{th} Tx links there is a 10.5 bps/Hz loss in capacity when the fading gain of 2^{nd} & 3^{rd} & 4^{th} (or any three) Tx links is lower than -30 dB also a 4 × 4 faded system capacity decreased until it reaches a 1 × 4 system capacity.

Case 4: for all transmit links deeply faded case a great loss of capacity occurs and the system capacity will decrease more and more until it reaches 0 bps/Hz (all transmit power is wasted). This means that it is equivalent to switching off all TX antennas for fading gain less than -30dB then the transmitter will be disappeared.

Now Fig. 3 will show the effect of different transmit link deep fading cases on the system performance (BER).

The BER performance when any link is faded to -20 dB will suffer of high errors which cause a very weak BER compared to the conventional 4 × 4 VBLAST as shown in Fig. 3.

A one link faded system need about a 10 dB improvement in SNR to achieve the performance of conventional 4 × 4 system and a 2 links faded system need about 15 dB improvement and a 3 links faded system need about 17 dB improvements while all links faded system need about 20 dB improvements in SNR. But anyone can notice that there is a large difference between the conventional 4 × 4 system performance and one link faded system while the hole get closer between other faded transmit links systems this means that the simple solution to mitigate the problem of one link deep faded is switching it off since it will waste the power in addition to get much worse BER.

Conclusion

In MIMO technology, system performance is improved using spatial diversity techniques. However with spatial multiplexing the channel capacity is linearly increased as independent data streams are transmitted from the multiple transmit antennas and received by multiple antennas at the receiver.

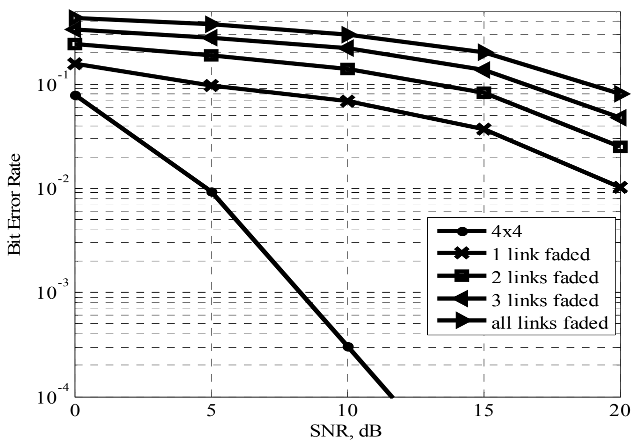

Figure (3): Effect of Tx links fading on Bit Error Rate.

When wireless channel goes under deep fading conditions, simulation results and equation (5) (theoretically) show that the transmit link deep fading has the same effect on the effective *SNR* and the average capacity as the receive link deep fading. In addition, the case of one transmit link deeply faded (low gain column of the channel matrix) has the same effect on Frobenius norm of the channel matrix if this case replaced with one receive link deeply faded (low gain row of the channel matrix). The SNR_{eff} and the system capacity slightly decreased in transmit link deep fading cases with a small difference for the capacity case. In contrast, the system performance in normal conditions will be affected greatly if one transmit link deeply faded then the effect will be lower if two transmit link deeply faded and so on, this result lead us to preferring switching off this faded link due to its great effect on performance. In case of deep fading of all transmit links there is no valuable solution except for some *SNRs* there is some bits per second could be saved.

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