STUDY OF THE EFFECT OF ANTENNA POLARIZATION DECOUPLING ON THE QUALITY INDICATORS OF THE MIMO CHANNEL WITH DUAL POLARIZATION

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Abstract

This article presents the results of a study of the effect of polarization decoupling on the quality indicators of dual-polarized MIMO antennas. Estimates of the impact on the capacity and on the error probability of MIMO channels with dual polarization are given. It is shown that the use of antennas with improved polarization decoupling provides additional opportunities for improving the quality and noise immunity of modern communication channels.

Introduction

Further development of communication systems requires the search for effective methods to ensure the quality of communication channels and electromagnetic compatibility. Using different polarizations can provide additional benefits in terms of electromagnetic compatibility. The focus is on cross-polarization isolation between channels and the effect on channel quality parameters. It is proposed to choose antennas with the minimum required values of the cross-polarization coefficient, which limit the given channel bandwidth. In wireless communications, multiple-input and multiple-output (MIMO), is a method for improving the quality, capacity, and reliability of a radio link using multiple transmission and receiving antennas to exploit multipath propagation. MIMO technology has become an essential element of wireless communication standards including IEEE 802.11n (Wi-Fi), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), WiMAX (4G), and Long Term Evolution (4G LTE).

Shannon-Hartley's channel capacity theorem is applied to provide the upper bound of the data rate given a certain bandwidth and signal to noise ratio (SNR). However, the cross-polarization discrimination (XPD) of the radio wave is not considered to resolve the capacity problem in the previous investigations. For a radio wave transmitted with a given polarization, the ratio of the power received with the expected polarization to the power received with the orthogonal polarization is called cross-polarization discrimination.

I MIMO technology

In wireless communications, multiple-input and multiple-output (MIMO), is a method for improving the quality, capacity, and reliability of a radio link using multiple transmission and receiving antennas to exploit multipath propagation, as shown in Fig. 1. MIMO technology has become an essential element of wireless communication standards including IEEE 802.11n (Wi-Fi), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), WiMAX (4G), and Long Term Evolution (4G LTE).

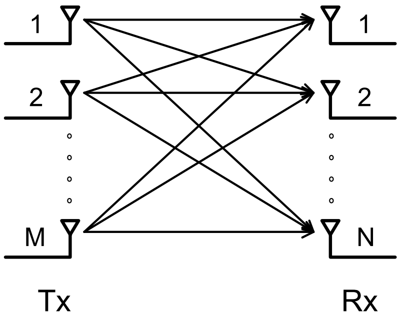

Fig. 1 Schematic diagram of MIMO technology.

Two popular approaches for communicating in the MIMO channel are diversity and multiplexing. Spatial multiplexing, is an approach where the incoming data is divided into multiple substreams and each substream is transmitted on a different transmit antenna, as shown in Fig. 2. This is motivated by the capacity improvement of the communication channels. Spatial multiplexing was first proposed by Paulraj and Kailath in 1994. Initial spatial multiplexing systems were narrow-band with small delay spread, then, spatial multiplexing is being considered for wideband channels in conjunction with OFDM modulation.

MIMO diversity, on the other hand, is an approach where information is spread across multiple transmit antennas to maximize the diversity advantage in fading channels. This is motivated by the desire to reduce the probability that a fade on any one of the transmit-receive antenna links will cause a codeword error. In diversity, each pair of transmit-receive antennas provides a signal path from transmitter to receiver, as shown in Fig. 3. By sending the same information through different paths, multiple independently-faded replicas of the data symbol can be obtained at the receiver end. Hence, more reliable reception is achieved.

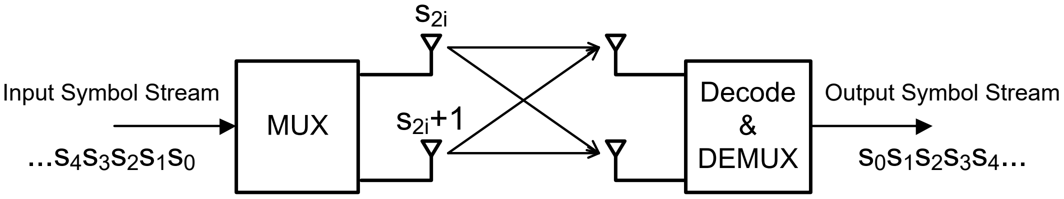

Fig. 2 Schematic of a spatial multiplexing system.

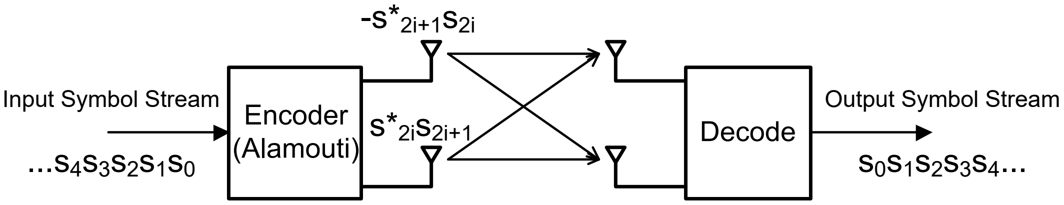

Fig. 3 Schematic of a diversity system (Alamouti scheme).

II Channel capacity

Shannon-Hartley's channel capacity theorem is applied to provide the upper bound of the data rate given a certain bandwidth and signal to noise ratio (SNR). It demonstrates that the effect of a transmitter power constraint, a bandwidth constraint, and additive noise can be associated with the channel and incorporated into a single parameter, called the channel capacity. For a single-input and single-output (SISO) channel, in the case of an additive white (spectrally flat) Gaussian noise interference, an ideal band limited channel of bandwidth B has a capacity C given by

$$C_s = B\log_2\left(1+\frac{P}{n_0 B}\right)=B\log_2\left(1+r_{sn}\right) \quad \text{bps} \tag{1}$$

where P is the average transmitted power and N0 is the power-spectral density of the additive noise, and rsn is the receive SNR. The significance of the channel capacity is as follows: If the information rate R from the source is less than C, then it is theoretically possible to achieve reliable transmission through the channel by appropriate coding. On the other hand if R>C, reliable transmission is not possible.

When the channel has m transmitting antennas and 1 receiving antenna (MISO), when the users transmitting at equal power over the channel, the channel capacity is given by

$$C_{m1} = B\log_2\left(1+\frac{r_{sn}}{m}\sum_{i=1}^{m}\left|h_i\right|^2\right) \quad \text{bps} \tag{2}$$

where hi is the channel complex gain of the i-th transmitting antenna to receiving antenna. While the channel has 1 transmitting antennas and n receiving antenna (SIMO), the channel capacity is given by

$$C_{1n} = B\log_2\left(1+r_{sn}\sum_{i=1}^{n}\left|h_i\right|^2\right) \quad \text{bps} \tag{3}$$

where hi is the channel complex gain of transmitting antenna to the i-th receiving antenna. For a MIMO channel with m transmitting antennas and n receiving antennas, when the users transmitting at equal power over the channel and the users are uncorrelated. Then, the channel capacity is given by

$$C_{mn} = B\log_2\left[\det\left(\boldsymbol{I}_n + \frac{r_{sn}}{m}\boldsymbol{HH}^H\right)\right] \quad \text{bps} \tag{4}$$

where I is an N×N identity matrix, H is the N×M channel matrix, HH is transpose conjugate. When M>>1 and N>>1, and the bandwidth is normalized, then, the channel capacity can be simplified as

$$C_{mn} \approx \min\left(m,n\right)\log_2\left(1+r_{sn}\right) \quad \frac{\text{bps}}{\text{Hz}} \tag{5}$$

As a result, when the SNR of the receiving antenna is certain, compared to the capacity of a SISO channel, the capacity of a MISO channel is slightly improved when the channel has a gain of hi≈1, the channel capacity of a SIMO system will be improved logarithmically as the number of receiving antennas increases, while for the MIMO channel, its capacity can be linearly improved as the minimum number of receiving and transmitting antennas increases, as shown in Fig. 4. In the simulation, the receiving SNR is set as 20 dB, and the channel gain is set as hi=1.

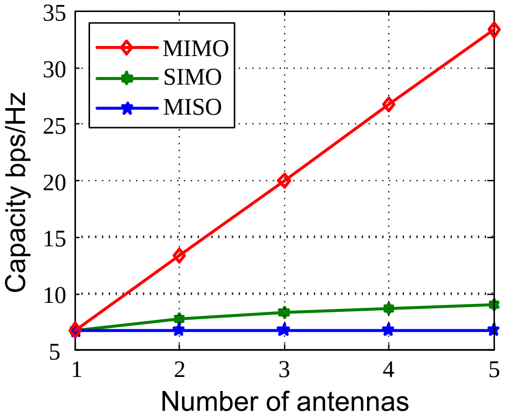

Fig. 4 Channel capacity of SISO, SIMO and MIMO systems

Fig. 5 shows the simulation results of the channel capacity with different configurations when the receiving SNR changes. As can be seen, the capacity will be improved when the SNR increases. For the

SIMO systems, the capacity will be increased by 1 bps/Hz when the number of the receiving antennas increases twice, as the results of 1×2 and 1×4 channels shown in the figure. While for the MIMO system, when the minimum number of receiving and transmitting antennas increases twice, the channel capacity will be also increased two times, as the results of 2×2 and 4×4 channels shown in the figure.

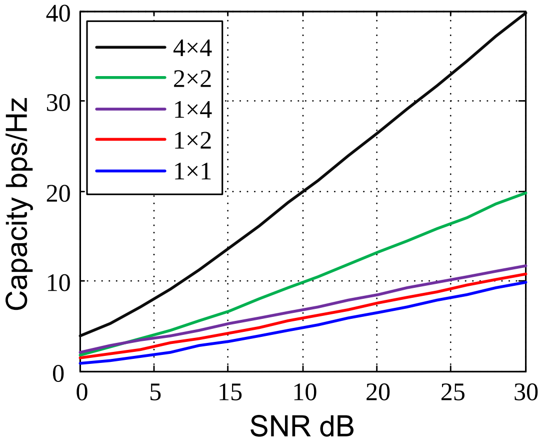

Fig. 5 Channel capacity with different configurations when the receiving SNR changes

Therefore, MIMO technology can be used to efficiently improve the channel capacity of the communication system. Note that, this improvement of capacity is achieved by increasing the complexity of signal processing.

III Modelling Results

In digital communication, probability that an error occurs in transmission of a symbol is called symbol error probability, and it denoted by Pe. It determined by the SNIR of the received signal, the digital modulation and the detection method. For modern advanced digital modulation techniques, arbitrary M-ary symbols will be directly modulated to the RF carrier. For the multiple-FSK (MFSK) signal and coherent detection, multiple-PSK (MPSK) signal and coherent detection, and square quadrature amplitude modulation (MQAM) signal with coherent detection, the symbol error probability can be respectively expressed as

$$P_{eMFSK} = \left(\frac{M-1}{2}\right)\operatorname{erfc}\left(\sqrt{\frac{r_{sni}}{2}}\right) \tag{6}$$

$$P_{eMPSK} = \operatorname{erfc}\left(\sqrt{r_{sni}} \cdot \sin\frac{\pi}{M}\right) \tag{7}$$

$$P_{eMQAM} = \frac{N}{2}\operatorname{erfc}\left(\sqrt{\frac{3r_{sni}}{2(M-1)}}\right) \tag{8}$$

Where N means that, in the constellation of a square MQAM signal, each point has N nearest neighbors, therefore, when M=4, N=2, when M=8, N=3 and when M≥16, N=4. Note that here in M-ary signal, rsni means the SNIR per symbol, while in binary signal, rsni means the SNIR per bit, the relationship between them can be written as

$$r_{sni} \text{ per symbol} = \log_2 M \cdot r_{sni} \text{ per bit} \tag{9}$$

Fig.6 shows the relationship between the SNIR and XPD when SNR is constant (10, 20 and 30 dB). As can be seen, due to the existing of XPD, the signal performance will be deteriorated, the SNIR will be less than the receiving SNR. When the XPD increases, the SNIR will be firstly increased and then keeps unchanged after approaching the SNR level. Fig.6 also shows that, if the antenna has a large SNR, then a high XPD should be provided to guarantee the receiving SNR. For example, when the SNR is 10 dB, the performance can be preserved when the XPD is 20 dB, however, when the SNR is larger than 20 dB, to guarantee the performance, the XPD need to be larger than 30 dB.

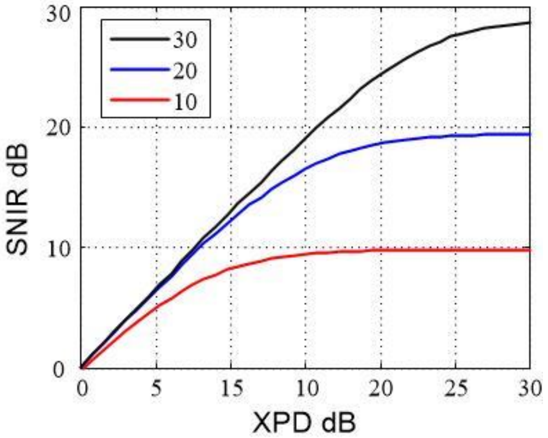

Fig. 6 Relationship between XPD and SNIR when SNR keeps constant.

When the SNIR of the receiving antenna is certain, compared to the capacity of a SISO channel, the capacity of a MISO channel is slightly improved when the channel has a gain of hi≈1, the channel capacity of a SIMO system will be improved logarithmically as the number of receiving antennas increases, while for the MIMO channel, its capacity can be linearly improved as the minimum number of receiving and transmitting antennas increases, as shown in Fig. 7. In the simulation, the channel gain is set as hi=1, and the SNR equals 20 dB while the XPD equals 20 and 30 dB, respectively. As can be seen, then the XPD decreases, the SNIR will be deteriorated, as consequence, the capacity will be decreased.

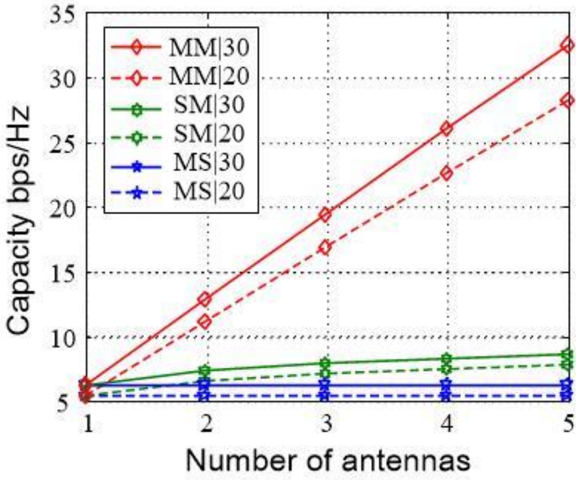

Fig. 7 Channel capacity of SISO, SIMO and MIMO systems.

Fig. 8 shows the capacity of 1×2 and 2×2 channels when the XPD changes and the SNR keeps constant (20 and 30 dB). As can be seen, when the XPD increases, the capacity is firstly increased and then keeps constant. This is caused by the relationship between the XPD and the SNIR, as shown in Fig. 1. Furthermore, we compare the two results of the 2×2 or 1×2 channels, it can be seen that, when the SNR changes larger, to obtain maximum capacity, a larger XPD should be provided, which is consistent with the analysis in Fig 6.

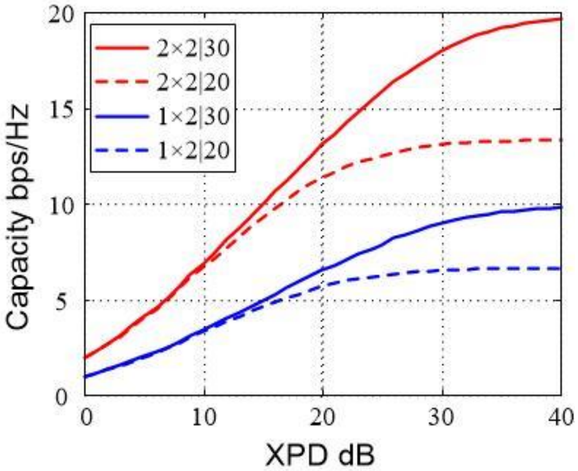

Fig. 8 Channel capacity with different configurations when the XPD changes.

Fig. 9 shows the error probability of the advanced digital modulations when the SNR per bit equals 20 dB. Symbol error probability of the MPSK signal is mostly sensitive to the modulation order. When the modulation order increases, the requirement of the XPD for the receiving antenna will be enhanced. For example, to keep Pe=10-5, when the modulation order improved from 4 to 16, the XPD of MFSK should be enhanced from 13 to 14 dB, the XPD of MQAM should be enhanced from 13 to 21 dB, while the XPD of MPSK should be increased from 13 to 28 dB.

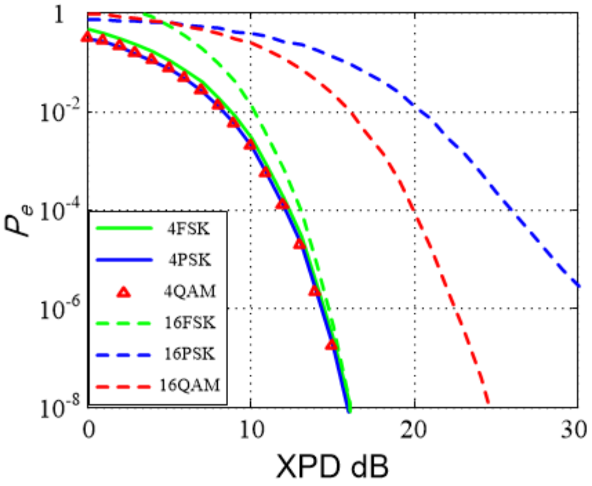

Fig. 9 Error probability of high order modulations when SNR per bit equals 20 dB.

Conclusion

The XPD of radio wave will deteriorate the performance of the received signal, decrease the channel capacity, and worsen the error probability of the recovered digital signal for the MIMO communication systems. When the XPD is considered, MIMO technology still can be used to efficiently improve the channel capacity of the communication system as well as a certain XPD level is provided. When the receiving SNR increased, the XPD should also be improved to guarantee the maximum channel capacity, on the other hand, the XPD can be relaxed to guarantee a given symbol error probability.

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