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SOME LIMITATIONS OF EVALUATING DUAL-POLARIZED MIMO CHANNEL CAPACITY

This article discusses possible bandwidth limitations of a radio access channel using MIMO technology with polarization-orthogonal channels, or dual polarization channels. The main attention is paid to the presence of cross-polarization isolation between channels, or cross-polarization relation, or Cross Polar Discrimination. The indicated ratio is determined mainly by the design features of the antennas. It is proposed to choose antennas with the minimum required values of cross-polarization ratio, which limit a given channel bandwidth.

Keywords: *SNR, SNIR, dual polarization channels, Channel capacity, Cross Polar Discrimination.*

Introduction

Formulation of the problem. 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. Therefore, the problem is the effect of cross-polarization isolation on the polarization of the MIMO antennas on the bandwidth of the radio channel.

The subject of research is MIMO-technologies with polarization-orthogonal channels for mobile and fixed communication systems of the new generation. Increasing system capacity without increasing transmission power or bandwidth has made the MIMO system unique and efficient for data transmission. However, the obtained bandwidth limitations due to the final solution by polarization are insufficiently studied. The study of the possibility of using an increase in the number of antennas of MIMO systems with polarization-orthogonal antennas is insufficient, so the topic of work related to the study of limiting the bandwidth of the MIMO channel with dual polarization antennas is relevant.

Analysis of recent research and publications. In recent years, the use of MIMO technology with polarization-orthogonal channels has become a promising field of research for next-generation mobile and stationary communication systems [1–3]. An increase in system capacity without increasing transmit power or bandwidth has made the MIMO system unique and efficient in transmitting data. However, the resulting bandwidth limitations due to the final isolation by polarization have not been sufficiently studied. In works [4–12] attention is paid to the polarization decoupling, however, only if there is a 2×2 configuration using the MIMO. Studies of the possibility of using an increase in the number of antennas of MIMO systems with polarization-orthogonal antennas have not been sufficiently conducted.

The aim of the article is to study the limitations of the possibility of increasing the throughput of a radio access system using MIMO antennas with polarization orthogonal antennas.

Statement of basic materials

1. 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).

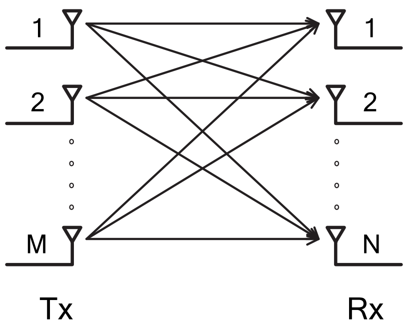

Fig. 1. Schematic diagram of MIMO technology

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.

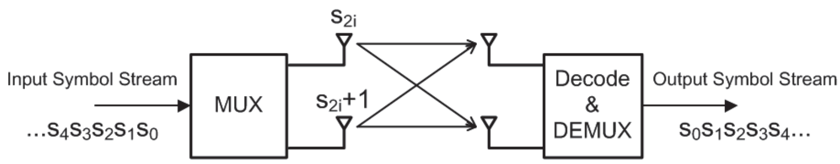

Fig. 2. Schematic of a spatial multiplexing system

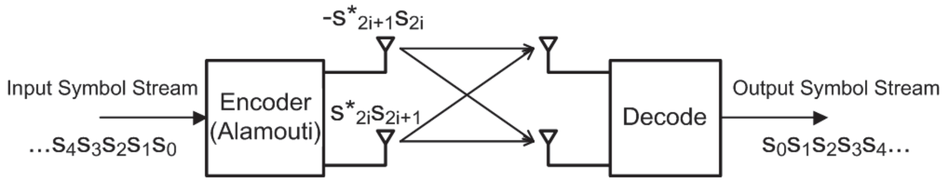

Fig. 3. Schematic of a diversity system (Alamouti scheme)

2. 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). 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 (XPD), which is given by

$$XPD = 10\left(d_{xp}\right) = 10\log\frac{P}{P_+}, \quad (1)$$

where P_+ is the power of the orthogonal interference component caused by the XPD. When the XPD of the receiving antenna is considered, the receiving SNR should be replaced by the signal to noise and interference ratio (SNIR) to derive the channel capacity. The SNIR can be expressed as

$$r_{sni} == \frac{P}{n_0 B + P_+} = \frac{1}{\frac{1}{r_{sn}} + \frac{1}{d_{xp}}} = \frac{r_{sn} d_{xp}}{r_{sn} + d_{xp}}. \quad (2)$$

Then, the capacities for SISO, MISO (m transmitting and 1 receiving), SIMO (1 transmitting and n receiving) and MIMO (m transmitting and n receiving) systems can respectively expressed as

$$C_s = \log_2\left(1 + r_{sni}\right), \frac{bps}{Hz} \quad (3)$$

$$C_{m1} = \log_2\left(1 + \frac{r_{sni}}{m}\sum_{i=1}^{m}\left|h_i\right|^2\right), \frac{bps}{Hz} \quad (4)$$

$$C_{n1} = \log_2\left(1 + r_{sni}\sum_{j=1}^{n}\left|h_j\right|^2\right), \frac{bps}{Hz} \quad (5)$$

$$C_{mn} == \min\left(m,n\right)\log_2\left(1 + r_{sni}\right), \frac{bps}{Hz} \quad (6)$$

where r_{sni} is the SNIR, h_i is the channel complex gain of the i-th path.

Fig. 4 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.4 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.

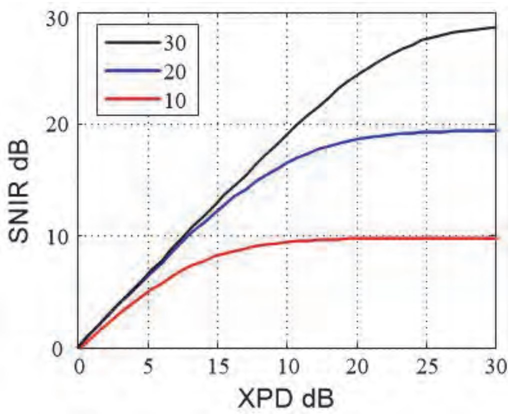

Fig. 4. Relationship between XPD and SNIR when SNR keeps constant

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 $h_i \approx 1$, 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. 5.

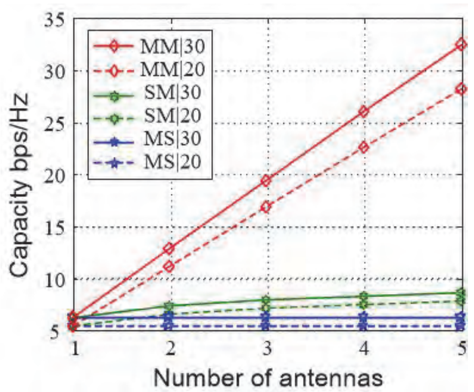

Fig. 5. Channel capacity of SISO, SIMO and MIMO systems

In the simulation, the channel gain is set as $h_i = 1$, and the SNR equals 20 dB while the XPD equals 20 and 30 dB, respectively. As can be seen, when the XPD decreases, the SNIR will be deteriorated, as consequence, the capacity will be decreased.

Fig. 6 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. 4. Furthermore, we compared 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 4.

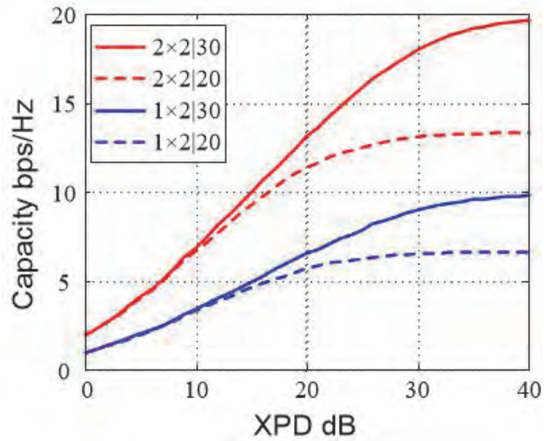

Fig. 6. Channel capacity with different configurations when the XPD changes

So, the XPD of radio wave deteriorate the performance of the received signal, and then decrease the capacity of the communication system. 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. Note that, when the receiving SNR changes larger, the XPD should also be improved to guarantee the maximum channel capacity.

When the XPD of the receiving antenna is considered, the receiving SNR should be replaced by the signal to noise and interference ratio (SNIR) to derive the channel capacity. The results of the study indicate the following: due to the existing of XPD, the signal performance will be deteriorated; the SNIR will be less than the receiving SNR. When the XPD is increased, the SNIR firstly increased and then it is kept unchanged after approaching the SNR level. Note also else, if the antenna has a large SNR, then a high XPD should be provided to guarantee the receiving performance.

The research results indicate the capacity limitation at SNR more than XPD of MIMO antennas. Under such conditions, increasing the signal strength no longer significantly improves capacity. The limiting SNR approaches the value of the XPD.

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. The XPD of radio wave will deteriorate the performance of the received signal, and then decrease the capacity of the communication system.

Conclusion

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. Note that, when the receiving SNR changes larger, the XPD should also be improved to guarantee the maximum channel capacity.

MIMO technology with polarization-orthogonal channels can be used to effectively improve the bandwidth of a communication channel when XPD less than the expected SNR. Therefore, designing of communication channels with MIMO dual polarization antennas need pay some attention to the features of the antennas with minimum XPD.

So, the research results indicate certain limitations on the channel capacity due to the presence of spurious polarization of polarization-orthogonal channels. This forces us to pay more attention to the design of antennas with the smallest possible presence of spurious polarization coupling.

The scope of the research results is the design of communication channels using MIMO technology with double polarization antennas, as well as the development of algorithms for compensation and signal processing taking into account the parasitic effect of cross-polarization signal of double polarization antennas.

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ДЕЯКІ ОБМЕЖЕННЯ ОЦІНЮВАННЯ ПРОПУСКНОЇ ЗДАТНОСТІ МІМО-КАНАЛУ ПОДВІЙНОЇ ПОЛЯРИЗАЦІЇ

О.О. Мартинчук, Г.М. Зубрицький, Сюань Лі, О.О. Мартинчук

У статті розглянуто можливі обмеження пропускної здатності каналу радіо доступу за допомогою технології MIMO з поляризаційно-ортогональними каналами або каналами подвійної поляризації. Основна увага приділяється наявності перехресної поляризації між каналами, або кросової поляризації, або ж крос-поляризаційного відношення. Зазначене співвідношення визначається переважно конструктивними особливостями антен. Пропонується вибирати антени з мінімально необхідними значеннями коефіцієнта перехресної поляризації, які обмежують задану пропускну здатність каналу.

Предметом дослідження являються MIMO-технології з поляризаційно-ортогональними каналами для мобільних і стаціонарних систем зв'язку нового покоління. Збільшення ємності системи без збільшення потужності передачі або смуги частот зробило систему MIMO унікальною та ефективною для передачі даних. Однак отримані обмеження пропускної здатності внаслідок кінцевої розв'язки за поляризацією недостатньо вивчені. Дослідження можливості використання збільшення кількості антен систем MIMO з поляризаційно-ортогональними антенами проведено недостатньо, тому і тема роботи, що пов'язана з дослідженням обмеження пропускної здатності MIMO каналу з антенами подвійної поляризації, є актуальною.

Метою статті є вивчення обмежень можливості збільшення пропускної здатності системи радіо доступу з використанням антен MIMO з MIMO з поляризаційними ортогональними антенами.

Результати досліджень свідчать про наявність обмеження пропускної здатності при значеннях відношення потужності сигналу до потужності шуму більше, ніж величина розв'язки по поляризації поляризаційно-ортогональних антен MIMO. За таких умов збільшення потужності сигналу вже не дозволяє значно покращити пропускну здатність. Граничним значенням відношення потужності сигналу до потужності шуму буде таке, коли воно наближається до величини розв'язки за поляризацією.

Область застосування результатів дослідження – проектування каналів зв'язку з використанням технології MIMO з антенами подвійної поляризації, а також розробка алгоритмів компенсації та обробки сигналів з врахуванням паразитного впливу крос-поляризаційного сигналу антен подвійної поляризації.

Ключові слова: *SNR, SNIR, подвійні поляризаційні канали, ємність каналу, крос-поляризаційне відношення.*

НЕКОТОРЫЕ ОГРАНИЧЕНИЯ ОЦЕНКИ ПРОПУСКНОЙ СПОСОБНОСТИ МИМО-КАНАЛА ДВОЙНОЙ ПОЛЯРИЗАЦИИ

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В статье рассматриваются возможные ограничения полосы пропускания канала радиодоступа с использованием технологии MIMO с поляризационно-ортогональными каналами или каналами с двойной поляризацией. Основное внимание уделяется наличию кросс-поляризационной развязки между каналами. Указанное соотношение определяется в основном конструктивными особенностями антенн. Предлагается выбирать антенны с минимально возможными значениями коэффициента кросс-поляризационной развязки, которые ограничивают данную ширину полосы канала.

Ключевые слова: *SNR, SNIR, поляризационно-ортогональные каналы, емкость канала, развязка по поляризации.*