

# MIMO Technology is Used to Improve the Security Capacity Stability of Rayleigh Wiretap Channel

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## ABSTRACT

This paper analyzes the security capacity when the Rayleigh channel codec is known, and studies the relationship between the transmit power, the estimation error and the security capacity difference. The results show that the increase of transmit power can make the security capacity difference tend to a stable value, which indicates that the influence of imperfect channel state information on the security capacity tends to be stable. By comparing the transmission power of SISO system and MIMO system, it is proved that MIMO system usually has higher transmission power under the same received power, so it is more suitable for improving the security capacity stability of Rayleigh channel.

## KEYWORDS

Rayleigh wiretap channel; MIMO; Channel State Information; Safe capacity; Physical Layer Security

## 1. INTRODUCTION

Physical Layer Security (PLS) is a new method to protect the security of wireless communication. The Physical Layer Security (PLS) is a crucial component of communication systems, ensuring the security, integrity, and availability of user data in wireless networks. PLS offers security without relying on encryption methods, which can be computationally demanding and susceptible to attacks. It exploits unique characteristics of wireless communication channels, such as fading, interference, and noise, to establish a secure communication link between sender and receiver. By utilizing the inherent features of communication channels and distinguishing between legitimate primary channels and eavesdropping channels, PLS ensures the security of communication systems. As one of the classical channel models, Rayleigh channel is widely used in academic research and practical engineering. It provides a standardized analysis tool for researchers and engineers. In various wireless communication systems (such as cellular networks, Wi-Fi, satellite communications, etc.), Rayleigh channel model is widely used to evaluate system performance and design optimization schemes. Therefore, the security capacity stability analysis of Rayleigh channel is of great significance for physical layer security.

Rayleigh channel model is not comprehensive without considering spatial correlation, and the improvement scheme considering spatial correlation and implementation results are proposed [1]. However, the Rayleigh wiretap channel security capacity stability analysis has not been considered in the literature.

The single-letter capacity formula for MIMO Gauss-Markov fading channels is proved, especially for the case where the noise is uncorrelated across antennas, and a general capacity expression is derived [2]. However, there is little analysis of the factors affecting the security capacity of the wiretap channel and its impact on wireless communication.

Analysis of Physical Layer security performance in correlated Rayleigh fading channels by using Copula theory, the average secrecy capacity (ASC), secrecy outage probability (SOP) and secrecy coverage area (SCR) are studied. At the same time, the asymptotic behavior of SOP at high signal-to-noise ratio (SNR) is studied and analyzed numerically under different dependence structures. Finally, closed-form expressions for ASC, SOP and SCR in correlated Rayleigh channels are derived [3]. However, the influence of wiretap channel has not been taken into account in the literature, so we need to study the influence factors of Rayleigh channel wiretap channel security capacity, such as the relationship between transmission power, estimation error and security capacity difference, in order to improve its security capacity stability.

By studying the effect of triple selectivity on Rayleigh channels and the performance of MIMO systems under these conditions, a new channel model and capacity formula are proposed to describe and calculate the performance of MIMO systems under various selectivity conditions more accurately. The effectiveness of the model and formula is verified by theoretical analysis and simulation results. The accuracy and practicability of the theoretical results are ensured [4-7]. However, in the aspect of channel state information, the research on the influence factors of the security capacity of Rayleigh wiretap channel, and the relationship between the stability of the security capacity and the transmission power is still lack.

In summary, at present, the research on Rayleigh channel capacity at home and abroad mainly focuses on the relatively single communication environment, and mainly aims at the Rayleigh channel security capacity analysis of the main channel. However, there is relatively little research and analysis on the communication environment including eavesdroppers. This paper aims to study the influence of channel state information (CSI) on the known Rayleigh channel capacity of the codec in the Rayleigh wiretap channel, analyze the main factors that affect the security capacity, and propose the corresponding solutions to improve the stability of the security capacity.

Since the secure capacity of Rayleigh channel is one of the indispensable important parameters in Rayleigh channel, improving the secure capacity of Rayleigh channel is of great significance to improve the confidentiality and security of wireless communication system. Therefore, this paper will study the influence on the secure capacity of Rayleigh channel from the relationship between the transmission power of the wiretap channel, the estimation error and the secure capacity difference. I will analyze the capacity of Rayleigh channel known to the codec by channel state information, and analyze the relationship between the security capacity difference and the transmission power by quantitative calculation in the eavesdropping channel. The simulation results show that imperfect channel state information will reduce the capacity of Rayleigh channel, and the impact of this reduction will become larger with the increase of estimation error and transmission power. When the transmit power is large enough, the safety capacity difference in the two channel state information cases will tend to a fixed value, which indicates that the impact of imperfect channel state information on safety capacity will become stable as the transmit power increases.

Through this research, we hope to provide more powerful theoretical support and practical guidance for future communication systems, and improve the security and confidentiality of communication systems.

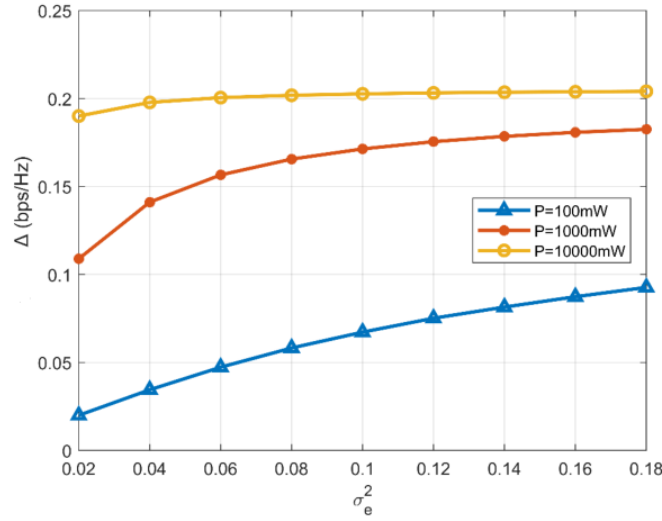
## 2. METHOD

### 2.1. Analysis of the Relationship Between Transmit Power and Security Capacity

Firstly, the security capacity difference of the Rayleigh wiretap channel model under perfect and imperfect channel state information is defined as

$$\Delta = C_{WTC-PSI} - C_{WTC-IPSI}$$

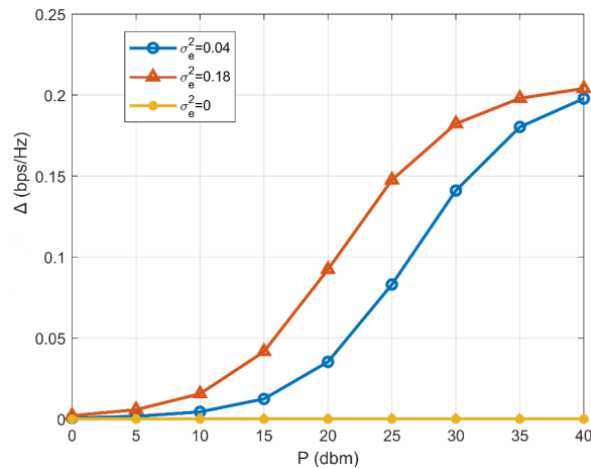
Secondly, the transmission power is defined as  $P$ , the security capacity difference is defined as  $\Delta$ , and the variance of the estimation error is defined as  $\sigma_e^2$ . The simulation results show that in the case of different transmission power values,



**Figure 1.** Plot of the variance between the safe capacity difference and the estimation error for different values of the transmit power

The gain of the perfect channel is fixed  $G \sim CN(0,1)$ , the noise power of the main channel and the eavesdropper channel is set as  $\sigma_{\eta_1}^2 = 15mW, \sigma_{\eta_2}^2 = 5mW$ , and the transmission power is selected  $P = 100mW, 1000mW, 10000mW$ , the step size is 0.02, and the variance of the estimation error is  $\sigma_e^2 = [0.02:0.18]$ . According to the image, under the same estimation error, the larger the transmission power, the larger the difference of security capacity. Through the comparison of the change curves in the three cases, it can be found that the larger the transmission power, the smoother of the curve  $\sigma_e^2$  with the change  $\Delta$ .

Next, let be 0.04, 0.18 and 0,  $\sigma_{\eta_1}^2$  and  $\sigma_{\eta_2}^2$  keep constant, and the change diagram of safe capacity difference and transmit power is obtained as follows



**Figure 2.** Plot of the change of the relationship between the safety capacity difference and the transmit power when the variance of the estimation error takes different values

When  $\sigma_e^2 = 0$ , there is no channel estimation error, and the safety capacity difference is equal to 0 regardless of any factor. It can be found from the other two curves that, in general, the safety capacity difference at  $\sigma_e^2 = 0.18$  is always greater than that at  $\sigma_e^2 = 0.04$ , and the change trend of the two curves first slowly rises with the increase of transmission power. Then, there is a significant increase in the

interval of  $P = [15:35]$ , and when the transmission power tends to infinity, the difference between the two security capacities starts to level off and approximately tends to the same value. From Figs. 1 and 2, it can be found that imperfect channel state information will reduce the security capacity of the Rayleigh wiretap channel. The impact of this reduction increases with the estimation error and the transmit power for a certain range of transmit power. However, when the transmit power is large enough, the safety capacity difference will tend to a fixed value, indicating that the influence of imperfect channel state information on the safety capacity tends to be stable at this time.

## 2.2. The Advantages of Using MIMO System to Improve Transmission Power

Therefore, we need to increase the transmission power to make the security capacity more stable. We can adopt multiple-input multiple-output (MIMO) systems to increase the transmit power, which is higher compared to single-input single-output (SISO) systems. Firstly, we define the channel gain of SISO system as  $h$ , and the transmit power of SISO system as  $P_{SISO}$ , then it receives power is as follows.

$$P_{SISO,recv} = |h|^2 P_{SISO}$$

Thus, the transmission power of SISO system can be obtained as follows.

$$P_{SISO} = \frac{P_{SISO,recv}}{|h|^2}$$

Secondly, in MIMO system, assuming that there are  $M_t$  transmit antennas and  $M_r$  receive antennas, the channel matrix is

$$H = M_t \times M_r$$

Let its transmit power be, then its receive power be

$$P_{MIMO,recv} = E[\|Hx\|^2] = E[\text{tr}(Hxx^H H^H)]$$

Assuming that the covariance matrix of the transmitted signal is, then:

$$P_{MIMO,recv} = \text{tr}(HQH^H)$$

To simplify the calculation, it is assumed that the transmit signal power is uniformly distributed across all transmit antennas, that is  $Q = \frac{P_{MIMO}}{M_t} \mathbf{I}$ , then:

$$P_{MIMO,recv} = \text{tr}\left(H \frac{P_{MIMO}}{M_t} \mathbf{I} H^H\right) = \frac{P_{MIMO}}{M_t} \text{tr}(HH^H)$$

Assuming that the trace of  $HH^H$  is  $\sum_{i=1}^{M_r} \lambda_i$ , where  $\lambda_i$  is the eigenvalue of the channel matrix, then:

$$P_{MIMO,recv} = \frac{P_{MIMO}}{M_t} \sum_{i=1}^{M_r} \lambda_i$$

Therefore, the transmission power of MIMO system is obtained as follows.

$$P_{\text{MIMO}} = \frac{P_{\text{MIMO,recv}} M_t}{\sum_{i=1}^{M_r} \lambda_i}$$

Comparing the transmit power of SISO system and MIMO system, under the same received power, since  $\sum_{i=1}^{M_r} \lambda_i$  is usually larger than  $|h|^2$  even if  $M_t$  and  $M_r$  are larger, in general:

$$\frac{M_t}{\sum_{i=1}^{M_r} \lambda_i} < \frac{1}{|h|^2}$$

Therefore:

$$P_{\text{MIMO}} > P_{\text{SISO}}$$

Upon receipt of this certificate

### 3. CONCLUSION

According to the above proof, under the same received power, the transmission power A of MIMO system is usually higher than that of SISO system B. Therefore, MIMO system is used to increase the transmission power to achieve the stability of improving the channel security capacity. The Outage probability (OP) performance of Single-input single-output (SISO) wireless communication systems assisted by multiple Intelligent reflectors (IRS) has been studied in Rician fading channels. Researchers select the best IRS panel to assist the single-antenna transmission node to send messages to the receiver node. The uplink scenario of this model in the future cellular wireless system is analyzed [8]. Some studies have proposed methods to optimize the waveform and transmit energy when the eavesdropper's channel state information (CSI) is known, so as to minimize the eavesdropper's signal interference plus noise ratio (SINR), while ensuring that the intended receiver's SINR reaches a specified level [9]. Therefore, the MIMO system is better than the SISO system used in [8, 9]. By studying the relationship between the estimation error, the security capacity difference and the transmit power in the Rayleigh wiretap channel, we find that when the transmit power is large enough, the security capacity difference of the wiretap channel in the case of two channel state information tends to a fixed value. This phenomenon indicates that the impact of imperfect channel state information on the safety capacity will gradually become stable as the transmit power increases. Therefore, we adopted a multiple-input multiple-output (MIMO) system to improve the transmission power. Further analysis shows that the MIMO system can achieve higher transmission power than the Single Input Single Output (SISO) system, so as to enhance the security performance of the system. In summary, MIMO systems show more significant advantages in improving the transmit power, thus helping to maintain a stable and higher security capacity under the condition of imperfect channel state information.

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