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Pre-coding techniques for enhanced codebooks on electricity information collection networks

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Abstract: In recent years, electricity information collection networks have increasingly adopted multiple-input multiple-output (MIMO) technology. This enhances both the system's bit rate and spectrum efficiency without the need for additional bandwidth. MIMO technology can provide higher information throughput and transmission reliability for electricity information collection networks. However, MIMO systems based on three-core cables correlate highly with their sub-channels. This paper proposes an improved MIMO codebook precoding method based on electricity information collection networks. Considering the channel interaction, a correlation matrix is introduced, spatial correlation is introduced into the channel model, and the existing random vector quantisation (RVQ) codebook and singular value decomposition (SVD) precoding are modified using spatial correlation. Simulation results indicate that the algorithm, by utilising a codebook index, effectively lowers feedback costs. Additionally, the proposed method enhances the BER performance and somewhat increases system capacity.

Keywords: electricity information collection networks; multiple-input multiple-output; MIMO; random vector quantisation; RVQ; singular value decomposition; SVD; precoding.

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1 Introduction

With the development of digital communication technology, power line carrier communication (PLC) technology has been increasingly widely used in building automation, automatic metre reading, intelligent control, the internet of things, and microgrids. Utilising the existing power line architecture to transmit high-quality communication signals effectively has important economic and social benefits. This may become an important means to realise the interflow of energy and information in the future energy internet (Qi et al., 2010; Berger et al., 2011; Corchado et al., 2017; Wang et al., 2021). PLC transmits information through the

presence of power cables. PLC its biggest advantage is that it does not require the addition of other lines to be laid for communication. PLC started to be used in low-rate communication scenarios. After decades of development, especially the application of orthogonal frequency division multiplexing (OFDM) technology in PLC, it has brought PLC into the era of broadband PLC. Although power lines are designed primarily for energy transmission, power information gathering networks still face challenges such as low transmission power, bandwidth limitations, and complex channel environments, severely limiting their application in long-distance and high-capacity information

transmission. Developing smart grid and demand-side management requires establishing a power information collection system consistent with the national grid's technical requirements (Wei et al., 2010). Issues such as decentralised collection points, low load factor, varying load impedance, and low power factor negatively affect the communication performance of these systems (Jiang, 2010). Due to the significant impact of these technologies on system operation, it is crucial to evaluate the communication performance of different technologies. The communication architecture of these systems is categorised into remote and local communication (Li and Liu, 2010). Remote communication connects the main system to the main concentrator using mediums such as fiber optics and various wireless networks, including broadband PLCs. Local communication connects the concentrator to the metering equipment through low-voltage PLCs, short-range wireless, and RS485 communications.

Currently, mode-specific communication performance testing relies on static testbeds. Related literature (Zhao et al., 2019; Li et al., 2019; Vu and Paulraj, 2007) tested PLC communication and wireless parameters such as throughput and packet loss in detail. The lack of standardised content and methods in these platforms makes it impossible to compare different communication modes under the same conditions. In our paper, we specifically discuss PLC systems in power information-gathering networks. This paper provides an in-depth look at the use of PLC technology in data acquisition and communication, highlighting its key role in the smart grid environment.

Conventional power communication techniques use a single-input-single-output (SISO) architecture that utilises phase and neutral wires as signal transmission carriers. However, it can work in multiple-input multiple-output (MIMO) systems that can increase the capacity and change the system's stability. It has been demonstrated that the capacity of PLC systems is increased by utilising MIMO technology. MIMO-PLC technology creates multiple transmit and receive ports by combining phase, neutral, and PLC wires to achieve broadband communication. Establishing a channel model that can correctly reflect the actual situation of MIMO power line communication is the basis for rationally designing power line communication systems, realising high-capacity information transmission, reducing construction costs, and correctly analysing and evaluating channel characteristics. According to the studies (Chen et al., 2020; Sun et al., 2021; Guo et al., 2021), MIMO systems' potential increase in data rate and system capacity compared to SISO architectures has been widely recognised. However, electromagnetic coupling may lead to a high correlation between sub-channels, causing interference and reducing the overall channel capacity. Particularly in three-phase transmission lines, voltage fluctuations in one conductor may cause voltage variations in neighbouring conductors due to electromagnetic induction (Nikfar and Vinck, 2013), further affecting performance.

In recent years, with the advantages of low cost, wide distribution, and no additional wiring, electricity line communication can provide high-speed broadband communication services and complement wireless LAN technology to improve the service quality of home access networks (Qi et al., 2010). Research has demonstrated that MIMO systems offer improved data transfer rates and increased capacity compared to conventional SISO architectures. However, electromagnetic coupling can cause significant correlation between sub-channels, leading to interference and limiting channel capacity (Corchado et al., 2017). As a result, efforts to effectively mitigate interference and reduce receiver complexity have become key focus areas in developing broadband power information collection networks. The paper (Jiang et al., 2024a) introduces the NNBoost, which is a machine-learning model that predicts SDN performance before deployment, achieving lower errors across key metrics such as RTT and S2C traffic using real-world and synthetic datasets. The paper (Jiang et al., 2024b; Hu et al., 2024) discusses the FedSL-LSTM model within satellite-terrestrial integrated networks for managing sequential data, showing improved classification performance and effectively addressing privacy and communication efficiency.

The transmitter can obtain CSI by using the principle of up-down channel reciprocity in the MIMO-PLC system or by receiving station feedback. MIMO systems can be divided into single-user and multi-user systems according to the number of users. In this paper, the precoding algorithm of the MIMO-PLC system is considered.

Linear precoding can be categorised into two types: non-codebook based precoding and codebook based precoding. The term 'codebook' refers to the set of precoding matrices stored at both ends of the transceiver, and there are a limited number of these matrices. In non-codebook precoding, the number of precoding matrices is unlimited, and the precoding matrices are designed to conform to the appropriate design rules. In codebook-based precoding, precoding matrices are no longer computed in real-time but are selected directly from a fixed set of codebooks. Compared with direct feedback CSI or precoding matrices, the index number-only approach greatly reduces the feedback overhead and facilitates the application in real systems. In terms of precoding techniques, the paper (Vo, 2015) proposes a MIMO precoding scheme based on orthogonal spatial multiplexing OSM, which introduces orthogonality between transmitted symbols by rotating the transmitted symbols, which helps in maximum likelihood detection for single-symbol decoding at the receiver side. However, the complexity of maximum likelihood detection is still too high for practical applications. The paper (Wu et al., 2015) proposes a block diagonalised precoding method to solve the co-channel interference problem in wideband MIMO-PLC systems. However, this paper proposes the constraint of zero interference, and its applicability is limited. In the paper (Winger, 2001), a precoding codebook is constructed in vector quantisation based on Lloyd's

algorithm, but the algorithm requires multiple iterations and is too complex.

In MIMO communication systems, spatial correlation is a key factor that significantly affects the channel's transmission characteristics and the system's overall performance. The spatial correlation is jointly determined by the physical distance between multiple antenna elements and the propagation environment, and the spatial correlation of the channel is enhanced when the antenna elements are closely spaced or when the propagation environment has some similarity. This enhanced spatial correlation can decrease the merging effect of the signals at the receiving end, thus limiting the channel capacity enhancement. Especially in PLC systems, the channel correlation is particularly significant due to the power line's physical characteristics and the surrounding environment's complexity, which puts higher requirements on the design and performance of MIMO systems. This paper discusses the spatial correlation characteristics of MIMO channels. The spatial correlation directly affects the channel capacity and system performance. Theoretically, the capacity of a MIMO channel grows linearly with the number of sensors, but as the inter-channel correlation increases, the maximum capacity that a MIMO system can achieve decreases. To solve the electromagnetic coupling and crosstalk problems, this paper contributes the following key aspects to the research and application of MIMO PLC systems by proposing a linear precoding method based on spatial correlation:

- Optimised precoding design: this study introduces a linear precoding method based on spatial correlation to effectively deal with the channel capacity limitation problem caused by spatial correlation enhancement in conventional MIMO systems. This method significantly reduces inter-signal interference and improves signal discrimination by fine-tuning the signal processing strategy between antennas, thus enhancing the overall communication efficiency of the system.
- Reformed RVQ codebook: in this paper, we make innovative reforms to the traditional RVQ codebook and achieve a significant reduction of system overhead in the communication process by simplifying the feedback mechanism - only the index number is fed back - which reduces the computational load of the system. This reform reduces the computational load of

the system and enhances the real-time operation, making the system more suitable for high-performance application scenarios requiring real-time data transmission.

- SVD precoding based on spatial correlation optimisation: in this study, the spatial correlation feature is used to adapt and optimise the SVD precoding deeply. This optimisation enables the SVD precoding to be more accurately adapted to the actual channel environment, improving the precoding efficiency and the overall system performance.

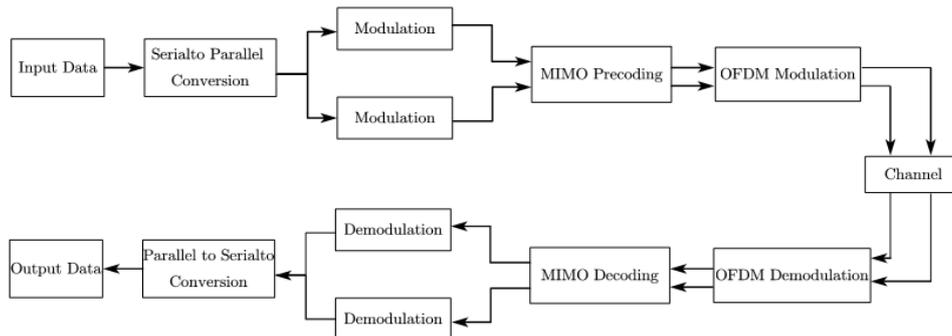
Overall, the contribution of this study not only promotes the advancement of power line communication technology but also provides new perspectives and technical paths for the theoretical study and practical optimisation of the MIMO system.

- The structure of this paper is as follows: Section 2 introduces the channel model of the MIMO power information acquisition network; Section 3 analyses in detail the precoding scheme based on improved channel correlation and proposes the adaptive RVQ and SVD precoding algorithms; Section 4 demonstrates the simulation results and their impacts on the system performance; and, finally, Section 5 summarises the main conclusions of the study.

2 MIMO-PLC channel model

Currently, most modems used in electricity information collection networks are only configured in a SISO configuration. However, in Europe, China, and many other regions, home transmission cables are typically three-wire configurations, including firewire (Phase, P), neutral wire (N), and protective earth (PE), as shown in Figure 1. Multiple sending and receiving ports can be constructed using these three differential phase lines and common mode paths to realise MIMO electricity information collection networks. This MIMO configuration can improve the efficiency of information transmission, enhance the system's anti-interference ability in a complex electricity environment, and significantly improve reliability and real-time data acquisition.

Figure 1 MIMO PLC system block diagram



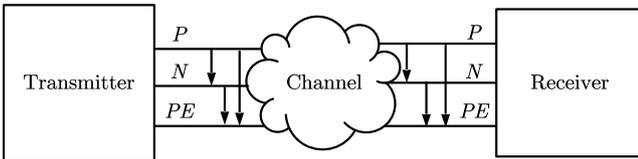
MIMO communication technology is very mature in the field of wireless communication. We can also apply MIMO technology to enhance channel capacity by replacing the transmit and receive ports with signal transmission interfaces and converting wireless channels into power line channels for electricity information collection networks.

Figure 2 shows the MIMO-PIAN channel model. Traditional modems based on a SISO configuration usually use only a set of phase lines, the live-neutral line, for signal sending and receiving. However, most home transmission cables use three-phase wire configurations, namely live wire (P), neutral wire (N), and protection ground wire (PE). With these three differential phase lines, we can form a MIMO-PIAN configuration. The power line channel consists of live wire (P), neutral wire (N), and ground wire (PE). Choose any two of the three wires to combine to form three groups of interface configurations: live wire – neutral wire (P-N), neutral wire – ground wire (N-PE), and live wire – ground wire (P-PE). To comply with Kirchhoff's voltage law, which states that one branch voltage must be a linear combination of other branch voltages, the transmitter of a MIMO-PIAN system supports a maximum of two port configurations. As shown in Figure 2, all three receiving ports are available at the receiving end. In addition, the fourth receiving path, the common mode path (CM), should be considered. CM signals are generated in an unbalanced network, and signals from any sending end L can be received at these four receiving ports (Stadelmeier et al., 2008). In short, the MIMO-PLC configuration supports 2×4 MIMO configuration at most. Therefore, the MIMO-PLC system model is usually 2×2 or 2×3 . In this paper, MIMO-PLC system is selected as the research object, and 2×2 MIMO-PLC system is selected as the research object, whose channel transmission matrix is

$$\mathbf{H}(f) = \begin{bmatrix} h_{11}(f) & h_{12}(f) \\ h_{21}(f) & h_{22}(f) \end{bmatrix} \quad (1)$$

where $h_{pq}(f)$ represents the complex channel coefficient between the p receiving port and the q receiving port of frequency f . In $\mathbf{H}(f)$, $h_{11}(f)$ and $h_{22}(f)$ are defined as the same channel, and $h_{13}(f)$ and $h_{21}(f)$ are defined as the cross channel. The f is omitted below.

Figure 2 MIMO-plan channel model



Because the power lines are fixed in the wall layout, the wire spacing is small, and the channel correlation is strong, the electromagnetic coupling between the adjacent wires will introduce crosstalk, i.e., the signal sent from any sending port can be received on all four receiving ports. According to the channel characteristics, power line channels can be divided into co-channel (such as PN-PN)

and cross-channel (such as PN-NE). For the precoded MIMO PALN system composed of N_T sending ports and N_R receiving ports, assuming that the channel state \mathbf{H} is fully known, the 2×2 space multiplexed precoding system is shown in Figure 3, and the vector received by the MIMO-PLC system is

$$\mathbf{Y} = \mathbf{H}\mathbf{F}\mathbf{x} + \mathbf{N} \quad (2)$$

where \mathbf{x} represents the sending signal, \mathbf{F} represents the precoding matrix, \mathbf{H} represents the channel transmission matrix, \mathbf{N} represents the noise, represents the receiving signal.

3 Precoding scheme based on channel correlation improvement

3.1 MIMO spatial correlation

Generally, due to the symmetrical structure of the household power line's three-conductor configuration, the cross channels in a 2×2 MIMO-PLAN system exhibit a strong correlation. A similar pattern is also observed between the same channels. The MIMO-PLC system has four channels, represented by a matrix.

$$\mathbf{H}(f) = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad (3)$$

The multi-input-output PLC channel model represented by equation (3) does not consider the correlation between channels and is independent of each other. However, electromagnetic coupling and crosstalk exist between adjacent multi-input and output power communication channels. Kirchhoff's law is obeyed at the signal-receiving end, so channels must interact.

In this section, we explore the spatial characteristics of MIMO PLC channels, where 'space' refers to multiple input and output terminals. We focus on the general f -channel scenario, omitting the index f where unnecessary. The primary step in spatial correlation analysis is to compute the singular value of the channel coefficient in the frequency domain. We decompose the channel matrix of the stator carrier into $\mathbf{H} = \mathbf{U}\mathbf{S}\mathbf{V}^H$, where $(\cdot)^H$ denotes the conjugate transpose. The matrix \mathbf{S} contains only two non-zero elements on its main diagonal. The singular values $\lambda^{(i)}(i = 1, 2)$ represent the singular values of \mathbf{H} . Channel taps are assumed to have zero mean (Stadelmeier et al., 2008).

$$\mathbf{E}[h_{i,j}] = 0 \quad (4)$$

where $\mathbf{E}[\cdot]$ is the expectation. Second-order statistics are more complex. Channel taps cannot be considered independent. This simplifies understanding the network's topology, as the wires are of almost equal length and often follow similar routes. Additionally, Kirchhoff's law must be satisfied by the receiver. These factors can be effectively represented using the channel covariance matrix.

$$\mathbf{R}_h = \mathbf{E}[\mathbf{vect}(\mathbf{H})\mathbf{vect}(\mathbf{H})^H] \quad (5)$$

where \mathbf{R}_h has size $N_t N_r \times N_t N_r$ and provides information about all channel tap pairs. The operator (\cdot) aligns the columns of a matrix of size $N_r \times N_t$ to form a column vector of length $N_r \times N_t$. Spatial correlation is introduced into the channel model to achieve the model's accuracy further.

It is assumed that the channel correlation matrix of the sender and receiver are \mathbf{R}_t and \mathbf{R}_r . According to the definition in (Veronesi et al., 2011), the correlation matrix of the sender and receiver is clearly expressed as

$$\mathbf{R}_t = \begin{bmatrix} 1 & \rho_t \\ \rho_t & 1 \end{bmatrix}, \mathbf{R}_r = \begin{bmatrix} 1 & \rho_r \\ \rho_r & 1 \end{bmatrix} \quad (6)$$

where, ρ_t, ρ_r is the channel correlation coefficient. By introducing (6) into equation (3), the frequency response of the MIMO-PLC channel is obtained

$$\mathbf{H} = (\mathbf{R}_r^{1/2})^H \cdot \tilde{\mathbf{H}} \cdot \mathbf{R}_t^{1/2} \quad (7)$$

where $\tilde{\mathbf{H}}$ is the $N_r \times N_t$ matrix representing the unrelated MIMO channel coefficients. Therefore, the precoding system is shown in Figure 3. Therefore, the channel covariance matrix can be written as

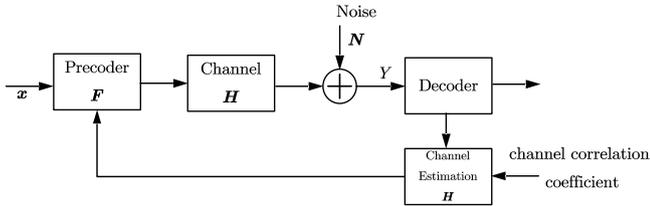
$$\mathbf{R}_h = \mathbf{R}_t \otimes \mathbf{R}_r \quad (8)$$

where \otimes is the Kronecker product. We choose standardisation

$$\text{tr}(\mathbf{R}_t) = N_t \quad (9)$$

$$\text{tr}(\mathbf{R}_r) = N_r \quad (10)$$

Figure 3 MIMO-PLC system with precoding



3.2 Adaptive RVQ basic precoding scheme

In the MIMO-PLC system, it is very important to use the improved quantised codebook (RVQ) to adapt the spatial correlation of the channel. This improved quantisation strategy is designed to better match the complex channel characteristics in the powerline communication environment by fine-tuning the codebook vector. For MIMO-PLC systems, the RVQ codebook is improved by considering the channel covariance matrix to ensure that the precoded vectors are highly consistent with the actual conditions of the channel. The channel covariance matrix reflects the correlation between the channel components, including the inherent crosstalk and noise characteristics in power lines. Based on this correlation information, the RVQ codebook vector is adjusted to reencode the signal more precisely, improving transmission efficiency and reducing bit error rates. We will use the spatial improvement RVQ codebook

precoding method called adaptive RVQ based precoding (A-RVQ).

For the traditional RVQ-based codebook $w = \{w_1, w_2, \dots, w_{2^B}\}$, the unit norm sequence vector $w_i \in \mathbb{C}^{N_t \times 1}$ is randomly generated independently of uniformly distributed selection vectors on the complex unit sphere. The adjustment process considers the channel covariance matrix \mathbf{R}_h , and each vector w_i is adjusted by the square root of the covariance matrix to adapt to the specific characteristics of the channel. The adjusted codebook vector c can be expressed as

$$c_i = \frac{\mathbf{R}_h^{1/2} w_i}{\|\mathbf{R}_h^{1/2} w_i\|} \quad (11)$$

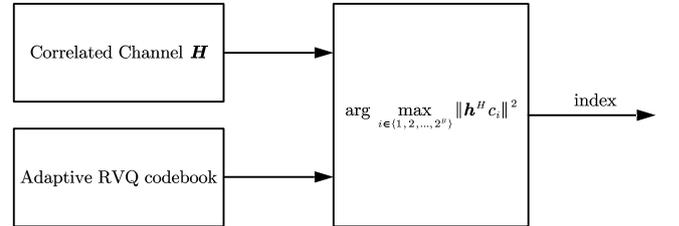
where $\mathbf{R}_h^{1/2}$ is the square root of the channel covariance matrix \mathbf{R}_h , ensuring that the adjusted codebook vector maintains the unit norm.

To use an improved codebook quantisation, a codebook vector c_i is chosen to match the current channel state best \mathbf{H} . The quantisation index F can select the optimal vector by the following equation.

$$F = \arg \max_{i \in \{1, 2, \dots, 2^B\}} \|\mathbf{h}^H c_i\|^2 \quad (12)$$

where \mathbf{h} is the channel state vector and is some column vector of \mathbf{H} . $\|\cdot\|$ represents the Euclidean norm of the vector, a process that maximises the match between the precoded vector and the current channel. Figure 4 illustrates the original approach of the adaptive RVQ codebook.

Figure 4 Illustration of the adaptive codebook original approach



3.3 Adaptive SVD basic precoding scheme

In the MIMO-PLC system, it is one of the key techniques to optimise the channel matrix decomposition considering the channel's spatial correlation. Specifically, improving singular value decomposition (SVD) through a spatial correlation matrix can describe the transmission characteristics of real channels more accurately. We call this precoding Adaptive SVD Basic precoding, or A-SVD for short.

First, given the spatial correlation matrix \mathbf{R}_t and \mathbf{R}_r of the sender and receiver, we adjust the original channel matrix, i.e., \mathbf{H} in equation (7) is used for SVD decomposition, denoted as \mathbf{H}_{mod} , to reflect the actual transmission environment. The adjusted channel matrix \mathbf{H}_{mod} is decomposed by a singular value,

$$\mathbf{H}_{mod} = \mathbf{U} \mathbf{S} \mathbf{V}^H \quad (13)$$

where \mathbf{U} and \mathbf{V} is the left and right singular vector matrix and \mathbf{S} is the singular value matrix. To optimise the system performance, we filter according to the band of singular values and only retain the singular values that contribute the most to the system performance. Set a threshold k , usually the largest singular value, and select all singular values greater than this threshold.

$$k = \min \left(\arg \left(\frac{\text{diag}(\mathbf{S})}{\max(\text{diag}(\mathbf{S}))} \right) \right) \quad (14)$$

This step effectively improves the representation efficiency of the channel matrix and reduces the noise introduced by singular values.

3.4 Capacity calculation

The communication capacity of a MIMO system is the maximum rate at which the system can transmit information over a given physical channel at a specific signal-to-noise ratio (SNR). For MIMO-PLC systems, this usually involves utilising multiple transmission and receive ports to increase the throughput and robustness of the channel.

For MIMO-PLN systems, the channel capacity can be calculated by the following equation.

$$C = \log_2 \left(\det \left(I_{N_R} + \frac{E_s}{N_T \sigma^2} \mathbf{H}\mathbf{H}^H \right) \right) \quad (15)$$

where, I_{N_R} is the $N_R \times N_R$ unit matrix, E_s is the total energy of the sent signal, N_T is the number of transmission ports, σ is the background noise.

4 Simulation performance and analysis

The MIMO PLC channel is modelled based on transmission line theory, and the MIMO PLC system simulation link is built for algorithm verification. In our simulation study, we focus on the channel correlation coefficient and its effect on the performance of MIMO-PLC systems. This paper assumes an ideal channel estimation, compares the pre-coding algorithm without improved RVQ with A-RVQ and the unimproved SVD with A-SVD, and simulates the system capacity, rate, and bit error rate. The simulation environment of this paper is MATLAB R2020b. The specific simulation parameters are shown in Table 1.

Table 1 Simulation parameters

Transmitting antenna number N_t	2
Number of receiving antennas N_r	2
Channel correlation coefficient	0.2
Total system bandwidth/MHZ	12
Sampling frequency/MHZ	25
Subcarrier number	512
Subcarrier spacing/KHZ	24.414
Noisy environment	Background noise

Figure 5 Comparison of channel capacity and performance (see online version for colours)

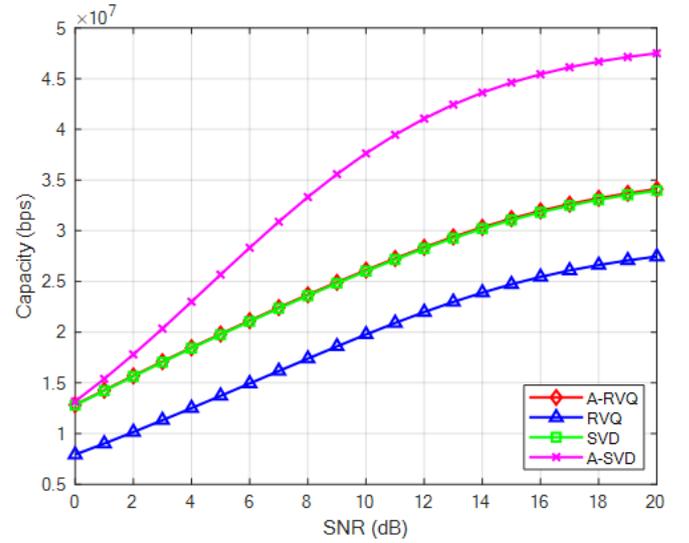
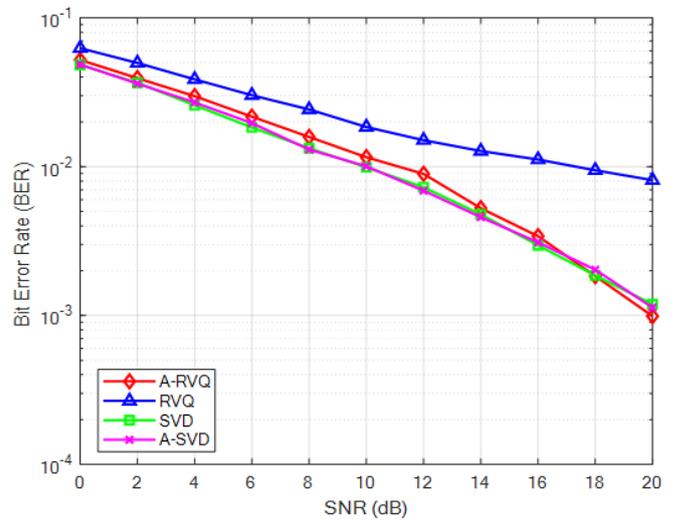


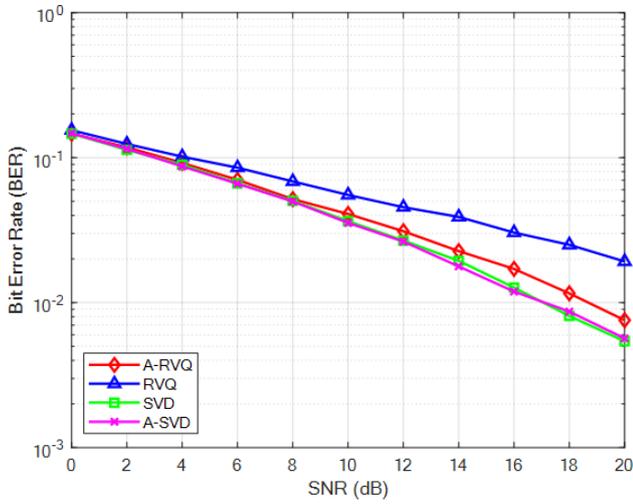
Figure 6 Comparison of BER performance of BPSK (see online version for colours)



As can be seen from Figure 5, there are significant differences in channel capacity performance of different precoding algorithms under the change of SNR. First, A-SVD (enhanced singular value decomposition precoding) shows optimal capacity performance, and with the increase of SNR, the capacity of A-SVD increases significantly faster than other schemes. This is because A-SVD uses channel correlation and SVD decomposition to use available channels efficiently. Second, the performance of SVD precoding is inferior to A-SVD but still better than RVQ and A-RVQ, indicating that SVD can provide a better channel decoupling effect. In contrast, the performance of RVQ and A-RVQ is close and lower than SVD and A-SVD, especially in the case of high SNR. The capacity increase is small, which indicates the limitations of random codebook precoding methods, although A-RVQ introduces improvements, its improvement effect is not as significant as SVD class precoding methods. The enhanced SVD precoding has obvious performance advantages under

different SNRS and is suitable for MIMO-PLC systems with high channel correlation.

Figure 7 Comparison of BER performance of QPSK (see online version for colours)



In the MIMO-PLC system, the bit error rate performance of RVQ, A-RVQ, SVD, and A-SVD precoding techniques is evaluated by BPSK and QPSK modulation modes. The simulation results show that the bit error rate of the A-RVQ algorithm is better than RVQ under BPSK modulation, which is due to the spatial correlation information introduced by A-RVQ in the design of precoded codebook and can adapt to the channel characteristics more accurately. At the same time, SVD and A-SVD algorithms also show excellent performance, especially A-SVD, which maintains a low bit error rate at all SNR levels, indicating that SVD-based algorithms can effectively utilise channel SVD to optimise channel utilisation.

The SVD algorithm directly decomposed the channel matrix by a singular value. It reduced the channel interference and noise by diagonalising the channel matrix, which can theoretically maximise the channel capacity. Compared with ordinary SVD, the A-SVD algorithm further optimises the channel utilisation efficiency by combining the spatial correlation information of the channel. This optimisation enables A-SVD to perform better than ordinary SVD in high SNR environments, especially regarding system capacity and bit error rate performance.

For QPSK modulation, because each symbol carries more information (two bits), the system is more susceptible to noise, so the bit error rate is higher than that of BPSK modulation. However, A-RVQ and A-SVD also show low bit error rates under QPSK modulation, confirming the effectiveness of these algorithms in optimising precoding strategies. Especially in the high SNR range, the performance advantages of A-RVQ and A-SVD are more significant, which provide more stable signal detection capabilities and higher data transmission efficiency.

5 Conclusions

In this paper, the application of MIMO technology in a power line communication system is deeply studied, especially for the spatial correlation problem of the power line channel in the MIMO-PLC system, and an improved precoding technology is proposed and verified. The research shows that the improved RVQ (A-RVQ) and SVD (A-SVD) precoding technology can significantly improve the performance of power line communication systems by introducing spatial correlation information. Simulation results verify the effectiveness of these precoding techniques in improving channel capacity and reducing bit error rate.

We plan to explore optimisation methods for spatial correlation and test other coding techniques in power line communication systems in future work. Additionally, given the physical constraints and interference issues of power lines, we will investigate more interference mitigation techniques and adaptive transmission strategies to enhance the overall performance and reliability of the system.

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