Low Complexity Anti-Interference Transmission Model in Massive MIMO Systems

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Abstract. With the development of wireless communication, wireless communication technology plays an irreplaceable role in modern instrument measurement and communication. However, the complex electromagnetic been an important factor affecting wireless communication quality with the number of devices increasing. Especially in the industrial field and modern city, electromagnetic interference (EMI) is a serious issue in wireless data transmission. Besides, user interference will also reduce the communication performance with the increasing number of equipment users. In this paper, a low-complexity data transmission model is proposed. First, the direct sequence spread spectrum (DSSS) technology is utilized to oppose narrowband electromagnetic interference and noise interference. Nevertheless, the DSSS be affected by multi-user interference (MUI) due to the number of users increasing. Based on DSSS and ZF precoding, the DSSS-ZF structure is proposed to resist interference. The simulation platform utilized the Software Defined Radio (SDR) and channel emulators (CE) to measure our DSSS-ZF model. The results show that the DSSS-ZF structure model can effectively defeat interference and improve the reliability of communication in complicated electromagnetic environment.

1. Introduction

With the rapid development of information technology, one of the key elements of Internet of Things (IoT) is the reliability of wireless communication system. The transmission and collection of wireless signals are widely used in the industrial system [1][2]. However wireless communication systems are susceptible to the influence of electromagnetic interference (EMI). Anti-interference techniques of the wireless communication is crucial issue in modern communication field.

Spread spectrum (SS) technology has attracted wide attention in the field of military communication due to its robust anti-interference and good confidentiality [3][4]. With the development of the last two decades, spread spectrum communication technology is more and more widely used in the industrial field. Nowadays, most SS systems adopt the direct sequence spread spectrum technology (DSSS) [5][6], which has strong anti-jamming performance and can accomplish multiple access transmission through different SS codes. When the number of users in the communication links is small, the orthogonally of the SS sequence between users is perfect and the multi-user interference (MUI) is limited [7][8]. However, with the number of users increases in the wireless communication systems, the strength of the MUI will increase sharply, and the performance of the communication systems will deteriorate. In addition, the application of multi-user MIMO is an important trend in modern wireless communication systems.

The goal of multi-user MIMO is to transmit data for each user with a high rate. Theoretically, the performance of the system is improved in terms of data throughput and link reliability as the number of users increases. However, the complexity of the system increases as well. Therefore, there is a need for a low-complexity anti-interference transmission model in Massive MIMO systems to improve the reliability of communication in complicated electromagnetic environment.
of antennas increasing at the transmitter or receiver. In a multi-user MIMO system, the base station (BS) is equipped with multiple antennas and serves many users. The BS communicates with each other users in a separate time and frequency resource. The higher data rate can be achieved when the communication is linked in the same time-frequency resources. The multi-user MIMO rapid development of the data rate, brought certain negative factors. The main bad impact of the communication system is MUI. Especially, the massive MIMO is utilized to promote the spectral efficiency and data throughput by deploying large scale arrays with antennas at the BS [9]. The MUI is becoming an unavoidable issue in the limited time-frequency resource.

Precoding schemes utilize channel matrix between the BS and users to suppress MUI. According to the different modes of precoding schemes, precoding schemes are divided into linear and non-linear. The non-linear precoding algorithm is obtained by the non-linear procedure of the matrix, with high complexity, including DPC, THP [10][11]. Linear precoding technology is one of the most widely used technique because of its low complexity and easy implementation in massive MIMO systems. Also, the linear precoding technique can achieve a nonlinear precoding performance due to the channel property of asymptotical orthogonally in massive MIMO. The main linear precoding algorithm includes the zero-forcing (ZF) precoding, MF precoding, and MMSE precoding. The ZF precoding algorithm [12-14], based on zero-forcing, is the typical precoding. It has widely appliance in wireless communications.

In this paper, a dual-domain interference suppression strategy method is proposed. Firstly, the ZF precoding technology is utilized to resist the influence of MUI in spare domain. The DSSS technology is utilized to resist the influence of EMI in code domain. Therefore, the DSSS-ZF structure is proposed. The DSSS-ZF model has the robust ability of anti-jamming ability in wireless communication systems. DSSS technology resists the impact of EMI, and precoding technology opposes the influence of MUI and multi-path fading. The bit-error-rate (BER) and capacity performance of the DSSS-ZF model is analyzed in massive MIMO systems. And the complexity analysis of the precoding technology is analyzed.

2. System Model

The DSSS communication has been widely applied in military telecommunications. With the 5G and IoT developing, the impact of interference is harmful to data transmission in the real environment. The DSSS system is a significant technology in the field of anti-interference. The fundamental of the DSSS technology is Shannon’s Theorem:

\[ C = B \log_2(1 + \frac{S}{N}) \]  

Where \( B \) is bandwidth, \( S/N \) is signal-noise-rate (SNR). In the low SNR environment, the data can be transmitted normally as long as the signal bandwidth is large enough. This is the working principle of the DSSS system. The DSSS system is a significant technology in the field of anti-interference. The fundamental of the DSSS system is Shannon’s Theorem:
The procedure of the DSSS technology is shown in the Figure 1, which shows the spectrum change of initial signal in the DSSS system. In Figure 1 (a) (b), the spectrum of the initial signal is processed by SS. The frequency band of the initial signal has widened and the power of initial signal is reduced. Figure 1. (c) shows that the signal is transmitted into the wireless channel and the DSSS signal is influenced by EMI. Figure 1. (d) is the spectrum of receiver signal after despreading. The DSSS signal is rebuilt to the initial signal, and the spectrum of interference and noise will be spread. The despreading procedure makes the interference spectrum expand and the power amplitude decrease, which benefit to filter the inference and noise. In Figure. (f), the receiver signal is filtered to reduce the influence of the interference signal on the transmission signal.

Although the DSSS technology improves anti-jamming ability. The limited length of spread spectrum codes cannot be completely orthogonal with the number of users increases. Especially in massive MIMO systems, the huge number of users cause the serious impact of MUI in data transmission.

2.2. Massive MIMO Systems

MIMO system can improve the transmission rate by deploying many antennas in BS or users. The massive MIMO system, as a significant technology in 5G, deploys the huge number of antennas at the BS and serve more user devices simultaneously. The massive MIMO system was proven to provide the potential capacity to improve the system efficiency in terms of spectrum and energy [2]. As shown in Figure 2, the massive MIMO system includes \( K \) receiver antennas and \( N \) transmit antennas and we usually assume \( N \gg K \).

According to the characteristics of the wireless channel, each receiver antenna receives the data from all transmitting antennas. Therefore, the channel state information (CSI) of wireless channel is denoted by channel matrix between each antenna. The channel matrix \( H \in \mathbb{C}^{K \times N} \) can be expressed as follows:

\[
H = \begin{bmatrix}
    h_{11} & h_{12} & \cdots & h_{1N} \\
    h_{21} & h_{22} & \cdots & h_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    h_{N1} & h_{N2} & \cdots & h_{NN}
\end{bmatrix}
\]

\[
y = \sqrt{\rho} H x + n + J
\]  

(2)

Where \( \rho \) is transmit power, \( n \) denotes the additive Gaussian noise. \( x \) is transmitted data. \( J \) is the EMI.

Since the users are independent with each other, it is difficult to obtain the CSI of other users, this means that it is difficult to collaborate with other users. However, the BS could obtain CSI for all communication users. In Time Division Duplex (TDD) systems, the CSI can be obtained by channel
estimation. In addition, the processing ability of the BS is also much stronger than that of the users. Therefore, we use precoding technology to suppress MUI and improve the performance of the DSSS communication system.

\[ y = \sqrt{P_s} H W_{ZF} s + n + J \]  
\( y' = s' + n + J \)

As shown in Eq.(5), the DSSS-ZF structure could not only decrease the influence of MUI. But also can reduce the noise by ZF precoding amplify.

3. Proposed DSSS-ZF Model
In massive MIMO systems, a large number of antennas cause the impact of MUI becoming serious. The MUI makes the performance of DSSS technology degradation. The ZF precoding improve resist-inference performance, therefore the DSSS-ZF structure is proposed.

3.1. DSSS-ZF structure
The DSSS signal is processed by precoding matrix \( W_{ZF} \). The receiver signal \( y \) as follows:

\[ y = \sqrt{P_s} H W_{ZF} s + n + J \]  
\[ y' = s' + n + J \]

As shown in Eq.(5), the DSSS-ZF structure could not only decrease the influence of MUI. But also can reduce the noise by ZF precoding amplify.

3.2. DSSS-ZF model
The model of the DSSS-ZF model communication systems with \( K \) users and \( N \) receiving antennas are shown in the Figure.2. The transmitter part includes four parts: the QPSK modulation module, the DSSS module, the ZF precoding module and the up-conversion module.

Suppose the initial signal source the \( i \) transmitting antenna is \( a_i(t) \), the complex signal \( d_i(t) \) is obtained from initial signal \( a_i(t) \) in the QPSK modulation. In the DSSS module, the information rate is \( R_i \), the PN code is high-speed pseudorandom code \( c_i(t) \), the chip rate is \( R_c \), \( R_c/R_i \gg 1 \). The DSSS signal \( s_i(t) \) can be expressed as:

\[ s_i(t) = d_i(t) c_i(t) \]  
\[ s_i(t) = d_i(t) c_i(t) \]
\[
s(t) = [s_1(t), s_2(t), ..., s_K(t)]^T
\]  \hfill (7)

As shown in Eq.(7). The precoding module could operate to \( s(t) \). The DSSS signal \( s(t) \) is convert to transmitting signal \( x(t) \) by Algorithm 1. The transmitting signal \( x(t) \) is up-convert and transmit to wireless channel by \( N \) BS antennas.

\[
x(t) = W_{ZF} s(t)
\]  \hfill (8)

The receiver signal \( y(t) \) from the transmitting end can expressed in follows:

\[
y(t) = s'(t) + n(t) + J(t)
\]  \hfill (9)

Where \( s'(t) \) is user data, the natural noise and narrowband interference are expressed by \( n(t) \) and \( J(t) \), respectively. The receiver signal \( y(t) \) is processed by down-conversion, the DSSS dispreading module, filter module and the QPSK demodulation module. The received signal \( y(t) \) is multiplied with the local received pseudo-random code \( c'(t) \), the despreading signal \( y'(t) \) expressed as follow:

\[
y'(t) = y(t)c'(t) = s'(t) + n(t)c'(t) + J(t)c'(t)
\]  \hfill (10)

\[
s'_y(t) = s'_y(t)c'_t(t) = d_i(t)c'_i(t)
\]  \hfill (11)

Assumed the pseudo-random code of receiver has same structure, frequency and phase with transmit pseudo-random code, in the other word, the \( c'_i(t) \) is synchronized with \( c'_i(t) \), so \( c'_i(t)c'_i(t) = 1 \), therefore,

\[
s'_y(t) = d_i(t).
\]  \hfill (12)

For noise signal \( n(t) \) and interference signal \( J(t) \) is spread when the receiver signal \( y(t) \) finish despreading procedure. Since \( n(t) \) and \( J(t) \) are not correlated with the pseudo random code \( c'_i(t) \) (or the correlated is small), the frequency spectrum of interference is broad, when the receiver signal \( y(t) \) through the filter module, the power of the noise and interference signal will reduced. The ability of anti-interference was improved.

4. EXPERIMENT PLATFORM ARCHITECTURE

This system consists of two main subsystems: Software Defined Radio (SDR) and Channel Emulators (CE). The block of experimental procedures of the DSSS-ZF model is shown in Figure 3.

![Figure 3. The block of experimental measures](image-url)
4.1. SDR Platform
The SDR equipped a large number of DSP and field-programmable gate array (FPGA) devices, the SDR platform is defined as the set of hardware and software. The SDR is the crucial technology for exhibiting our work because it makes the wireless communication systems more flexible and efficient. The DSSS, QPSK, and precoding functions are very convenient in SDR platform [15].

4.2. Channel Emulators(CE)
The CE is typically used to emulate the radio channel between the transmitter and the receiver for air-interface testing in wireless communication [16]. The CE contains 8 Virtex-7 FPGAs, each Virtex-7 FPGA connect other FPGA based on JESD-204b and Aurora 64B/66B. The data transmission utilizes peripheral component interconnect express (PCIe) to link CPU. In massive MIMO systems testing, the BS and mobile terminal antenna can be configured with customized methods in the CE.

In our experiment, the CE received the transmitted data and add three types of interference in communication systems. Includes tone-interference, multi-tone interference and band interference. In addition. The upconverter UC0218T and downconverter DC0218T are used to connect the channel emulator and VI V3X. Due to the CE frequency is 1.8 GHz, the frequency of our SDR is 200MHz, and therefore, the upconverter and downconverter are exploited to connect SDR and CE.

4.3. Experimental Procedures
Step1: Initially, the numbers of BS antennas and users are set $N_t$ and $N_r$ in SDR and CE, the power and frequency of interference are set in CE.
Step2: In the SDR platform, the initial data $d(t)$ is modulated by QPSK module, then we get QPSK signal $dt$, and then the $dt$ is spread with the PN code $ct$, the DSSS signal $st$ can be get in Eq.(6).
Step3: Get the channel matrix $H$ from CEs, utilized the ZF precoding to process DSSS signal $st$.
Step4: Set the power and frequency of noisy and interference in CE. Use upconverter to transmit $s(t)$ into channel emulator. And then we can get receiver $y(t)$.
Step5: SDR receive the $y(t)$ from downconverter, utilize DSSS disspreading and filter module, and QPSK demodulation to get initial signal $a(t)$.
Step6: Calculate the BER and capacity of communication systems by PC with Window 7.

5. Measurement Result, and Discussion
In this section, the results on the performance of the DSSS-ZF model relying on SDR and CE. A vector signal generator and a signal analyzer are set in JXIV3X. A down-converter and up-converter link SDR with CE. The SDR and CE are equipped with Windows 7. Therefore, the data analyzer is completed in Matlab 2014a.

The parameters of the DSSS-ZF model are listed in Table 1, the DSSS module, QPSK module, precoding, and band-filter are configured in SDR, the channel parameters, interference type and interference power are configured in CE.

| Experimental Parameters          | Experimental Set       |
|----------------------------------|------------------------|
| Massive MIMO System              | 256×32                 |
| PN code                          | M sequence             |
| Upconverter                      | 200M/1800MHz           |
| Downconverter                    | 1800M/200MHz           |
| interference                     | multi-tone(10dB)       |
| modulation                       | QPSK                   |
| DSSS length                      | 32,64,96,128           |
| carry wave frequency             | 1.8GHz                 |
In order to obtain the performance of the DSSS-ZF structure, the DSSS-ZF structure are tested in our experimental platform. The DSSS-ZF structure uses different length PN codes. However, the different lengths of PN codes will affect the operation of the entire communication transmission system. A large number of users causes the PN codes without completely orthogonal. And the anti-interference ability of the DSSS system is reduced.

In Figure 4, we show the anti-interference performance with four PN code lengths. In Figure 4(a-d), as the length of PN code increases. The BER of DSSS-ZF structure is faster reducing with SNR increases. The system's anti-interference ability is stronger as the PN code length increases. In addition, from the four figures in Figure 4, the DSSS-ZF structure has better anti-interference ability.

However, according to Eq.(1), the accuracy is based on sacrificing spectral efficiency. Therefore the PN code length influence of transmission capacity. In Table 2, the capacity of DSSS-ZF structure has lower capacity than ZF precoding. At low SNR, the longer PN code could be adopt to transmit data. When interference power is low, the PN code length is small, it does not even need to apply DSSS. Therefore, the length selection is crucial in DSSS-ZF structure. In some crucial data measure field, the transmission accuracy is more important than transmission rate when interference power is large.

| Code length | BER DSSS-ZF | BER ZF precoding | Capacity DSSS-ZF | Capacity ZF precoding |
|-------------|-------------|------------------|-----------------|-----------------------|
| 0           | 0.3699      | 0.3705           | 96.05           | 96.08                 |
| 32          | 0.1397      | 0.3705           | 32.58           | 96.08                 |
| 64          | 0.0351      | 0.3654           | 16.08           | 96.28                 |
| 96          | 0.0117      | 0.3776           | 10.64           | 95.97                 |
| 128         | 0.0055      | 0.3782           | 9.83            | 96.48                 |
| 160         | 0.0003      | 0.3705           | 6.587           | 96.05                 |
| 192         | 0.0003      | 0.3705           | 5.486           | 96.35                 |

Figure 4. The BER performance in different code length. (a) DSSS-ZF structure with code length is 32. (b) DSSS-ZF structure with code length is 64. (c) DSSS-ZF structure with code length is 96. (d) DSSS-ZF structure with code length is 128.

6. Conclusion
In this paper, the low complexity data transmission scheme based on the DSSS-ZF model is proposed. The DSSS-ZF structure are utilized to resist the noise and interference. The DSSS-ZF structure used the DSSS technology to reduce noise, it resist interference and the amplify noise of the ZF precoding. Also, due to the ZF precoding solving the MUI, the DSSS performance is improved. And then, we exploit the SDR and CE for verification of the DSSS-ZF model in massive MIMO systems. And the
experimental results show that the DSSS-ZF model has higher resist interference ability. Therefore the DSSS-ZF model has better performance in the complex communication environment.

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