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Layered space-time coding (LSTC) technology and its application in mobile communication systems[1]

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Abstract. With the increasing demand for wireless mobile communications and increasing number of users, wireless communication services have also been increased from the original language services to the multimedia services, but the characteristics of communications have restricted its development. In order to improve the efficiency and quality of its communication, the research on the layered space-time coding technology and its application in mobile communication systems were proposed in this dissertation. Through the construction and simulation application of layered space-time coding, it can be seen that the layered space-time coding can reduce the number of error bits in the system and increase the diversity and coding gain of the system, moreover, the amplitude of the gain increases accordingly with the increase of the number of transmitting and receiving antennas. Therefore, layered space-time coding technology can effectively improve the utilization of communications and quality of services in mobile communication systems.

Key words. Layered space-time, coding technology, mobile communication system, technology research.

1. Introduction

With the continuous progress of human society and the continuous development of science and technology, modern communication technology has very obvious individual characteristics, and mobile communication can adapt to and meet the needs of modern communications, which is one of the fastest growing technologies in the world. The continuous development of mobile communication technology is to realize the purpose that people can communicate with any person at any place and any time [1]. With the advent of the information age, information transmission is becoming more and more important in various communication technologies, and

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it is also the support technology of other technologies. Therefore, the demand for information technology in various countries is getting higher and higher, and more efforts are devoted to the development of modern communication technologies and the construction of modern comprehensive communication networks.

But in mobile communication technologies, the channel has very complex characteristics, and it needs to be transmitted by multiple functions in the process of information expositions; in addition, there are many fading phenomena in the process of transmissions, which seriously affect the performance of mobile communications [2]. With the popularization and promotion of the information technology, the users of mobile technology continue to increase. The communication service has developed from the simple voice service to the multimedia communication service, which makes the communication spectrum resources become tense. Therefore, how to improve the utilization rate of spectrum resources and reduce the degree of declines under the influence of various factors has become a hot spot and focus of researches, and it has also promoted the continuous development of communication technologies [3].

2. State of the art

In the long history of communication technology, if the history of the improvement of frequency usage is the phylogeny of wireless communication, the history of the improvement of frequency utilization and the expansion of the number of users is the phylogeny of mobile communication. This development process not only meets the increasing demand, but also improves the density of global mobile communications and the efficiency of frequency utilizations [4]. The history of mobile communication can be divided into three stages. The first stage was marked by the emergence of the first analog cellular mobile phone, which was represented by the analog and frequency division multiple access cellular system technology in northern Europe, the United States and the United kingdom. However, it has the disadvantages of small capacity, the single service and the poor security, etc., and it is not consistent with the rapid development of mobile communication businesses [5]. Therefore, in order to get better development, communication technology entered the second generation of digital mobile devices, and capacity and function were improved through the digital technology. However, the second generation digital mobile communication technology is divided into European system and North American system, and the implementation technologies of the two systems are different and incompatible with each other. Although it has multi-mode and multi-frequency terminal products, it still cannot achieve the purpose of communications at any time and place and with any person [6]. In 1985, the third generation digital mobile communication concept was proposed by ITU, the earliest name was the future public land mobile communication system, then its name was changed into the international mobile communication system IMT-2000, because the system was commercially available and the frequency band was 2000 MHz [7]. The goal of the third generation mobile communications is to achieve seamless coverage, connectivity and roaming in all areas of the world with a unified frequency band, thereby improving the quality of services and the security performance of mobile communications and providing users with multimedia business services, so that the terminal mobile phone structure is simpler and more convenient to carry, its price is more affordable, and the adaptability is stronger [8]. This undoubtedly can solve the problems of the first and second generation mobile communication systems, however, the core network of the third generation mobile communication is still based on the core network structure of the second generation mobile communication system, therefore, the third generation mobile communication system is considered to be a transitional stage [9]. In the following research, the focus of researches is to improve the communication quality and speed of data transmissions.

3. Methodology

Multipath propagation and frequency selective fading are typical characteristics of wireless transmissions, which will be seriously disturbed in the process of data transmissions, resulting in overall performance degradations [10]. In the past solutions, the main focus is on the elimination of multipath propagation factors, and the effect is limited. Diversity technology is the most effective way to improve the multipath effect, and its primary function is to provide a copy of the signal in some forms, while for the receiving end, multiple independent or highly unrelated paths carry out the transmission of the same signal and merge according to a specific method, so that the probability of judgment error is greatly reduced [11]. In this process, diversity has two implications for decentralized transmission and centralized processing. The most important condition in decentralized transmission is the correlation, which mainly depends on the channel condition during transmissions. The main implementation of centralized processing is to design signal processing at both ends of transceivers [12]. In diversity technology, there are different technical classifications through different classification standards. Table 1 shows the technical classification of diversity techniques.

As shown in Table 1, time diversity and frequency diversity are the symbols which carry the information are sent repeatedly through different time slots. In this case, the spacing of the adjacent two slots is greater than the correlation time$\Delta t$of the channel. Or the interleaving is carried out by using error correcting coding, so that the signal will introduce redundancy in the time domain to achieve time diversity [13]. If the signal is transmitted in a multi-carrier manner, the spacing between the two carriers which are adjacent is greater than the related bandwidth Δf of channel. Therefore, it can be seen from the above that time diversity and frequency diversity can improve the performance of the whole communication system on the basis of the reduction of frequency utilizations. Spatial diversity can be achieved by the simultaneous use of multiple transmitting antennas and multiple receiving antennas without decreasing the frequency [14]. The main principle is that multiple antennas are placed at one or two terminals of the transmitter and receiver, and the distance between each antenna is far enough. Typically, it is 10 times of the carrier wavelength. In this case, antennas are unrelated, so that the multiple independent communication channels between the receiver and transmitter can be built. What can be seen from above is that the spatial diversity does not introduce redundancy in the time domain, and it does not introduce redundancy in the frequency domain during the process of diversity, so that the utilization rate of the frequency is not reduced, and the transmission is improved.

Table 1. Technical classification of diversity techniques

<table>
<tr><td>Diversity classification and standard</td><td colspan="4">Diversity type</td></tr>
<tr><td rowspan="2">Diversity purpose</td><td colspan="4">Macro diversity is achieved through level design of systems, such as power control, so as to achieve long-term anti-decline purposes</td></tr>
<tr><td colspan="4">Micro diversity is a technique that can resist short-term fading and cover a large number of signal processing</td></tr>
<tr><td rowspan="2">Signal transmission mode</td><td colspan="4">Explicit diversity, for example, delaying the diversity schemes</td></tr>
<tr><td colspan="4">Implicit diversity, such as the coded interleaving schemes</td></tr>
<tr><td rowspan="9">The form of obtaining multiple signals</td><td>Time diversity</td><td colspan="3">It uses the channel time selectivity, and the main forms are the channel coding, interleaving and ARQ retransmission, which has better fast fading times</td></tr>
<tr><td>Frequency diversity</td><td colspan="3">The frequency selectivity of the channel is mainly achieved by merging different multipath delay components on the same signal, such as equalization, frequency hopping and Rake reception (DS-CDMA). But the diversity gain is limited in non-frequency selective channels</td></tr>
<tr><td rowspan="7">Space diversity</td><td>Space angle diversity</td><td colspan="2">Smart antenna</td></tr>
<tr><td>Polarization diversity</td><td colspan="2">Vertical and horizontal polarization (single antenna implementation</td></tr>
<tr><td rowspan="5">Space position diversity</td><td rowspan="2">Receiving diversity</td><td>Selective diversity (Max, SNR) and handoff diversity</td></tr>
<tr><td>Linear combination diversity (MMSE, MRC)</td></tr>
<tr><td rowspan="3">Transmitting diversity</td><td>Feedback mode (weighted emission in TDD system)</td></tr>
<tr><td>Feed-forward and training method (space-time / combination of frequency coding and optimal reception of channel estimations)</td></tr>
<tr><td>Blind schemes (combining channel coding with phase sweeping and frequency offset, and it requires extended bandwidth)</td></tr>
</table>

Space coding techniques in space diversity can be divided into trellis space-time codes, packet space-time codes and layered space-time code coding techniques. Layered space-time code (LST) can solve the problems existing in the wireless channel through the propagation of wireless channel, so that it can be used in more abundant propagation path environments [15]. The system in layered space-time codes does not process fading at the beginning of the signal, but it considers them as different sub channels in different propagation paths, so that they can transmit information in parallel. At the same time, the multiplicative interference and the signal interference are eliminated by the linear decision feedback equalizer at the receiving end of the information through the fading characteristics of different channels. This is an effective solution to high-speed data transmission of wireless communications, which has a broad application prospect.

In the process of layered space-time coding for mobile communications, the encoding process is simple, and coding error correction is also required. In order to keep the efficiency of information transmission, encoding is adopted to reduce the bit error rate by means of encoding and decoding, which requires the decoder to be relatively simple and friendly. Although the layered space-time codes have great advantages in bandwidth utilizations, the characteristic matrix in the acceptance process of signals will depend on the channel, thus resulting in adverse effects on the performance of the system, reducing the performance of the system, and limiting its future development. Layered space-time decoding has two kinds of maximum likelihood decoding and zero forcing detection and decoding. Considering the characteristics of the two kinds of decoding, the maximum likelihood decoding is chosen to be studied and analyzed.

According to the error correcting decoding theory, the channel coding input sequence can be set as M, and the output sequence of a channel encoder that is the input sequence of the channel can be set as C. At the same time, the input of the channel decoder that is the output sequence of the channel is R, the output sequence of the channel decoder is $\hat{M}$, and the interference sequence is E. In the process of decoding, the decoder will generate an estimation sequence $\hat{C}$ that is related to C base on R, and when $\hat{C} = C$ and $\hat{M} = M$, the decoding of the decoder is correct. When the given receive sequence is R, the error probability of the conditional decoding of the decoder is defined as the formula

$$P\left(E\,|R\right) = P\left(\hat{C} \neq C\,|R\right). \tag{1}$$

The error probability of the decoder can be obtained by formula (1), as shown in the equation

$$P_E = \sum_R P\left(E\,|R\right) P\left(R\right). \tag{2}$$

In the formula, the $P\left(R\right)$ is the probability of acceptance of R, and it is independent of the decoding mode, thus, the decoding error probability is minimized by the best decoding laws, as shown in two following formulae

$$\min P_E = \min_R P\left(E\,|R\right) = \min_R P\left(\hat{C} \neq C\,|R\right) , \tag{3}$$

$$\min_R P\left(\hat{C} \neq C\,|R\right) \Rightarrow \max P\left(\hat{C} = C\,|R\right) . \tag{4}$$

What can be seen from the formula is that the input R needs to choose the maximum code word C_i though the decoder in 2^k code words, so that which can be used as the estimation sequence $\hat{C}$ of C in $P\left(\underset{\mathrm{i}}{\hat{C}} = C\,|R\right)$, and $i = 1, 2, ..., 2^k$. Then it is in accordance with the Bayes formula, as shown in the formula

$$P\left(C_r\,|R\right) = \frac{P\left(C_i\right) P\left(R\,|C_i\right)}{P\left(R\right)} . \tag{5}$$

It can be found that if the probability $P\left(C_i\right)$ of the information transmitting terminal for the firing of each code word is the same, and $P\left(R\right)$ has nothing to do with the way of decoding, then

$$\max_{i=1,2,\ldots,2^{\mathrm{k}}} P\left(C_i\,|R\right) \Rightarrow \max_{i=1,2,\ldots,2^{\mathrm{k}}} P\left(R\,|C_i\right) . \tag{6}$$

Thus, if the decoding rules in a decoder can select one which can make the formula (6) become the largest in the 2^k code words, the decoding rule is the maximum likelihood decoding, and $P\left(R\,|C\right)$ is the likelihood function. Because there is a monotonic relation between $\log_b x$ and x, the following formula is derived:

$$\max_{i=1,2,\ldots,2^{\mathrm{k}}} P\left(C_i\,|R\right) \Rightarrow \max_{i=1,2,\ldots,2^{\mathrm{k}}} \log_b P\left(R\,|C_i\right) . \tag{7}$$

In the formula, $\log_b P\left(R\,|C_i\right)$ is the log-likelihood function.

As shown in the following equation, the logarithmic relief ratio of the layered code information bits is:

$$\Lambda\left(b\right) = \log \frac{\sum_{b=1} \prod_{j=1}^{N} \exp\left(-\frac{r_j - \sum_{j=1}^{N_j} \alpha_{i,j} c_i^2}{N_0}\right)}{\sum_{h=1} \prod_{j=1}^{N} \exp\left(-\frac{\left|r_j - \sum_{j=1}^{N_j} \alpha_{i,j} c_i\right|^2}{N_0}\right)} . \tag{8}$$

In the formula, r_j is the information received by the jth antenna, c_i is the signal transmitted by the ith antenna, and $\alpha_{i,j}$ is the channel characteristic factor that is transmitted by the ith antenna and received by the jth antenna.

If C and E are used to represent two different code word matrices, C is the code word matrix to be transmitted, and $\mathrm{prob}\left(C \rightarrow E\right)$ represents the 2-2 average error probability between the two matrices. As a result, in a fast fading environment, the upper limit of $\operatorname{prob}(C \to E)$ is shown in the formula

$$\operatorname{prob}(C \to E) \leq \prod_{r=1}^{l} \left(1 + |c_\tau - e_\tau|^2 \frac{E}{4N_0}\right)^{-m}. \tag{9}$$

In a slow fading environment, the upper limit of $\operatorname{prob}(C \to E)$ is shown in the formula

$$\operatorname{prob}(C \to E) \leq \prod_{r=1}^{\max(C-E)} \left(1 + \Lambda_k \frac{E}{4N_0}\right)^{-m}. \tag{10}$$

Among them, Λ_k is the eigenvalue of the matrix $(C - E)(C - E)^+$.

4. Result analysis and discussion

In this paper, the layered space-time coding technology and its application in mobile communication system were studied. Therefore, simulation experiments were carried out for the proposed hierarchical space-time coding formula model. The performance of layered space-time coding was analyzed and studied by transmitting and receiving signals through wireless communication systems. The following parameters were selected according to the actual radio information transmission:

Firstly, the channel environment was a slow fading channel; value was QPSK modulation; the number of antennas was equal to that of the receiving antenna and the transmitting antenna, namely, $N = M = 2 \mathrm{or} N = M = 4$; error correction codes were 8-status Turbo codes or non-codes, and the polynomial produces by Turbo codes was: $g_0(D) = 1 + D^2 + D^3$ and $g_1(D) = 1 + D + D^3$. According to the layered space-time coding process and the simplified calculation process, the contrast of the bit error rate was obtained, as shown in Figs. 1 and 2. What can be seen from Figs. 1 and 2 is that when the number of antennas was 2, the maximum likelihood algorithm did not make a significant improvement on the overall performance of the system for the non-coding system; when the number of antennas was 4, the maximum likelihood algorithm didn't significantly improve the frame error rate for the non-coding system, but the bit error rate of the system was improved, and it was obviously decreased. This means that the number of error bits that may occur in each frame is decreasing, and it can help to improve the overall performance of the system.

As shown in Figs. 3 and 4, the performance of the maximum likelihood algorithm and the ZF detection algorithm were compared. The two algorithms were in the 8-status Turbo code environment. Figure 3 shows the comparison of the frame error rates of the two algorithms, and Fig. 4 shows a comparison of the bit error rates. As can be seen from the comparison in Fig. 3, the frame error rate of the Turbo code concatenation was 10^{-2}. When the number of transmitting and receiving antennas was 4, the maximum likelihood algorithm obtained gains and the gain amplitudes were in the range of 9-12 dB. When the number of antennas received was 2, the maximum likelihood algorithm gains were about 2 dB. What can be seen from Fig. 3

is that the algorithm's advantages were not obvious, but the advantages shown in Fig. 4 were obvious. On the one hand, the algorithm improved the error propagation caused by decoding layer by layer to a certain extent, and reduced the number of error bits in the system; on the other hand, the number of error bits of per frame was more likely to be used by level connections of the system.

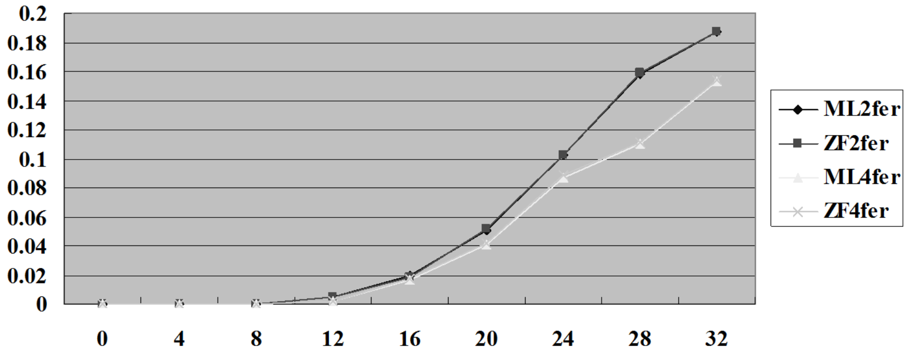

Fig. 1. Comparison of bit error rates of ML and ZF without encoding the system

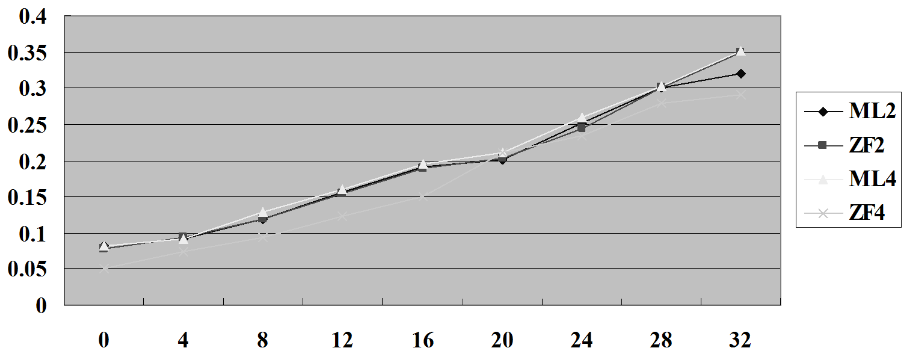

Fig. 2. Comparison of the performance of the non-coding system ML and ZF

Then, the performance of the system was compared when the number of transmitting and receiving antennas was 2 and 4 respectively. When the maximum likelihood algorithm was used, the diversity gain and coding gain obtained by the system whose number of transmitting and receiving antennas was 4 were larger than that of the system whose number of transmitting and receiving antennas was 2. As for the ZF algorithm, when the number of transmitting and receiving antennas was 2, the performance of the system was better than that of the system whose number of transmitting and receiving antennas was 4. The reason is that the performance of ZF algorithm is more dependent on the detection accuracy of the upper layer, so when the antenna number increases, it will likely reduce the accuracy, thus resulting in the gain loss of the diversity and encoding of the system. As far as the maximum likelihood algorithm is concerned, the algorithm is different from the ZF algorithm.

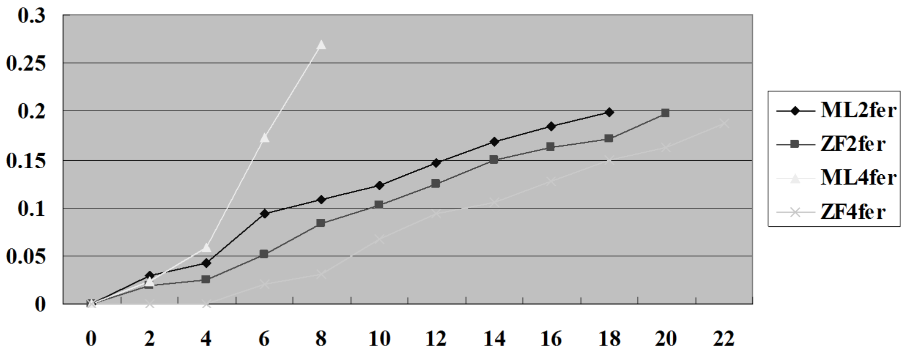

Fig. 3. Comparison of bit error rates of coded systems ML and ZF

Although the probability of error propagation also presents, the algorithm considers the influence of the channel characteristic matrix and noise in equilibrium, so as to improve error propagations, and when the number of transmitting and receiving antennas increases, the gain is more pronounced.

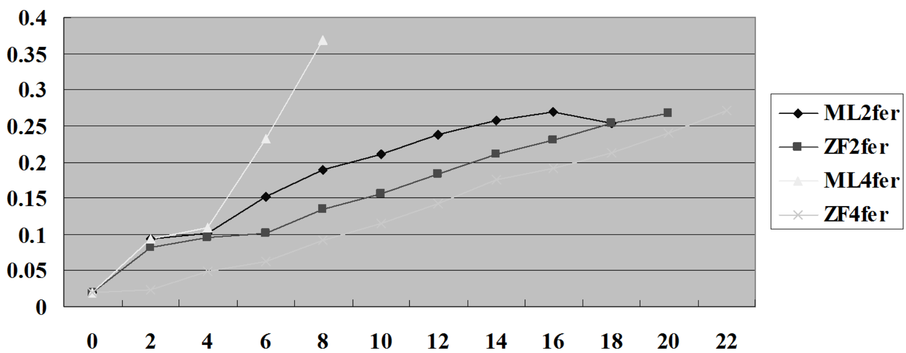

Fig. 4. Comparison of performances of coding systems ML and ZF

To sum up, layered space-time coding can effectively improve the performance of the system by using the channel propagation characteristics, reduce the number of error bits in each channel and improve the diversity and coding gain of the system, thus achieving the probability of error propagations of the system. Although the maximum likelihood algorithm studied in this paper can improve the performance of the system, it has high complexity, and it is difficult to calculate and operate, so it needs further improvements and researches.

5. Conclusion

With the continuous progress of human society, the demand for mobile communications is higher and higher, so as to meet the communication needs of individuals.

At the same time, the users of mobile communications develop rapidly, and the services have been increased from the original language services to the multimedia services. How to improve the efficiency and service quality of mobile communications has become the focus of future development. Therefore, research on the layered space-time coding technology and its application in mobile communication systems were proposed in this thesis. The layered space-time coding, decoding and other modules were built, and the wireless communication features were used to improve the efficiency and quality of communications. Compared with other diversity techniques, the simulation results show that layered space-time coding technology can be hierarchically constructed without reducing the efficiency of frequency usage. Furthermore, the maximum likelihood algorithm can reduce the number of error bits and increase the diversity and coding gain by using the characteristics of wireless communications. And the more the number of transmitting and receiving antennas is, the greater the amplitude of the gain is, and the better the performance of the system is. However, the layered space-time coding model constructed in this paper still has deficiencies, and it has a high degree of fickleness, which will cause some restrictions on its future development, so it needs further improvements and researches.

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