Principle and Analysis of Anti-interference and Anti-fading Techniques in Mobile Communication

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Abstract. In recent years, with the rapid development of mobile communication, anti-interference and anti-fading has always been an important research topic in mobile communication. There is a lot of interference in mobile channel, and the signal will fade because of various reasons. Designers must consider these factors in the design, development and production of mobile communication systems, so the corresponding anti-interference and anti-fading measures should be studied to ensure that the interference level does not exceed the threshold compared with useful signals during the operation of the system, or ensure that the transmission error rate is within a certain range. This paper introduces diversity technique, error correcting code, spread spectrum, adaptive equalization, digital modulation technique and so on. The advantages and disadvantages of different diversity techniques are analyzed, and their performances in common digital mobile communication systems are compared. Different types of error correcting codes are introduced, and their principles are analyzed. Then, other anti - interference and anti - fading techniques and their principles are briefly introduced. Finally, this paper analyzes the development direction of anti-interference and anti-fading techniques in the future mobile communication.

Keywords: Mobile communication, Diversity reception, Error correcting code, FSK, Spread spectrum

1. Introduction

In 1897, the Italian engineer Guglielmo Marconi used radio to communicate information between land and tugboats. This is the beginning of mobile communication. Mobile communication has a history of more than 120 years. In recent years, the development of radio has been particularly rapid, and has been widely used in a variety of fields. In mobile communication, radio waves are the medium of information transmission. This kind of transmission medium allows the users in communication to move freely in a certain range and their positions are not restricted. However, the propagation characteristics of radio waves are generally very poor. Because, first of all, the operation of the mobile communication environment is very complex, the waves will not only dispersion loss increased with the increase of propagation distance, and will be affected by terrain, ground objects of shelter "shadow effect", and the signal after more reflection, will received from multiple paths to reach place, the multipath signal amplitude, phase and time of arrival is different, They superimpose each other to produce level fading and delay spread. Secondly, mobile communication is often carried out in the fast movement, which will not only cause Doppler frequency shift, generate random frequency modulation, but also make the wave propagation characteristics occur fast random fluctuation, seriously affect the quality of communication. Therefore, the mobile communication system must be reasonably designed according to the characteristics of mobile channel.

In addition to some common external interference, such as antenna interference, industrial interference and channel noise, there will be interference of one kind or another between the system itself and different systems. In mobile communication systems, there are often multiple user stations working in the same area, and the base station will also have multiple transceivers working in the same place, which will cause interference between these stations. As the system of mobile communication network is different, the interference will be different. To sum up, these interferences include adjacent channel interference, intermodulation interference, co-channel interference, multiple access interference, and near-far effect. Therefore, in the mobile communication system, how to combat and reduce the impact of these harmful interference is crucial.

Anti-interference is an important research topic in mobile communication. In mobile channel, in addition to a lot of environmental noise and interference, there are also radio interference, such as adjacent channel interference, co-channel interference and intermodulation interference. In the design, development and production of mobile communication network, it is necessary to anticipate the various interference intensities in the network operation environment, and take effective measures to ensure that the interference level does not exceed the predetermined threshold compared with the useful signal, or ensure that the transmission error rate does not exceed the predetermined order of magnitude during the network operation.

Similarly, anti-fading is also an important research in mobile communication. In mobile channel, there are many scatterers, so the received signal is composed of multiple waves. Direct, reflected or scattered waves form an interference field at the receiving site, causing deep and fast fading of the signal, which is called fast fading. In addition, due to the constant movement of the mobile station, the terrain and ground objects on the radio wave propagation path are constantly changing, so the local median is also changing. The fading caused by this change is much slower than the fast fading caused by the multipath effect, so it is called slow fading.

The anti-interference and anti-fading methods used in mobile communication systems are various, mainly including error detection and correction code, diversity techniques, adaptive equalization technology, modulation A modulation technique with resistance to intersymbol interference and delay spread, spread spectrum and frequency hopping techniques, etc.

The remaining of the paper is organized as follows. In Section II, diversity techniques were suggested and analyzed in detail, including diversity reception principle, performance analysis and comparison in DPSK system. In Section III, various common error correcting codes were briefly introduced. In Section IV, the adaptive equalization technique, various common modulation techniques, and spread spectrum technique are briefly stated. Finally, Section V concludes the current status and the development direction of anti-interference and anti-fading techniques.

2. Diversity Reception

2.1. A brief introduction of fading

In mobile communication, mobile stations are often affected by various obstacles and other moving objects, resulting in the signal of the receiving point being synthesized by multiple signals, as shown in Figure 1. Fading is the phenomenon that the field intensity at the receiving point fluctuates randomly due to the interference of random multipath rays. Fading is the main factor that affects the quality of communication. The depth of fast fading can reach 30-40dB. If only increasing the transmit power to overcome fading, 1000-10000 times more is needed, which will cause interference to other stations. Diversity reception is an effective method to resist fading and improve the reliability of communication system.

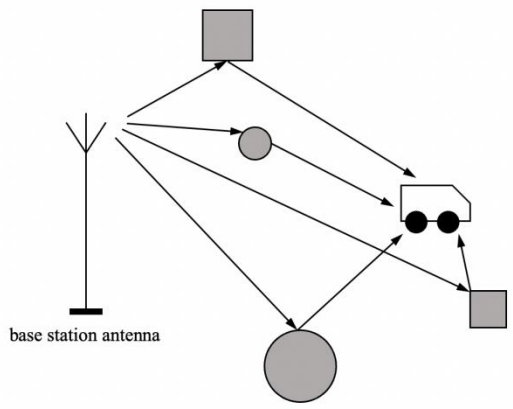


Figure 1. The mobile station receives multiple signals

2.2. Principle of diversity reception

Diversity reception refers to a method by which the receiver performs specific processing on multiple signals with independent fading characteristics (carrying the same information) received by the receiver to reduce signal level fluctuation. Diversity has two meanings: one is decentralized transmission, so that the receiver can obtain multiple statistically independent fading signals carrying the same information; The second is centralized processing, that is, the receiver receives several statistically independent fading signals to merge to reduce the impact of fading. In mobile communication, there are two main types of diversity: macro diversity and micro diversity.

"Macro diversity" is mainly used in cellular communication systems, also known as "multi-base station" diversity. This is a kind of to reduce the influence of slow fading diversity technique, its practice is to put more stations set up in different geographic position on the diagonal (such as cell), and make them in different directions, the base station and a mobile station in the community to communicate (can choose which one of the best communication base station). Obviously, as long as the signal propagation in all directions is not subject to severe slow fading caused by shadow effects or terrain at the same time, which can be prevented by the erection of base station antennas, this method can keep the communication uninterrupted.

"Micro diversity" is a diversity technique to reduce the influence of fast fading, which is often used in various wireless communication systems. Both theory and practice show that wireless signals separated in space, frequency, polarization, field component, Angle and time exhibit mutually independent fading characteristics. Therefore, "Micro diversity" can be divided into 6 types:

1) Spatial Diversity: If the same signal is received at any two different positions, if the distance between the two positions is large enough to a certain extent, the fading of the received signals at the two locations is unrelated.

2) Frequency Diversity: To transmit the same information at more than two different frequencies to achieve frequency diversity.

3) Polarization Diversity: To achieve diversity, the transmitter and receiver can transmit and receive signals separately with two antennas located in proximity but with different polarizations.

4) Field Component Diversity: By receiving three field components of E field and H field of electromagnetic wave, the diversity effect can be obtained.

5) Angle Diversity: The electromagnetic wave passes through several different paths and reaches the receiver at different angles, and the receiver uses multiple receiving antennas with sharp direction to separate signals from different directions. Because these components have mutually independent fading, the Angle diversity is realized.

6) Time Diversity: If the time interval of each transmission is large enough, the receiver will combine the same signal received repeatedly, and the fading effect can be reduced. In addition, time diversity is also beneficial to overcome the signal fading phenomenon caused by Doppler effect in mobile channel. Since its fading rate is related to the moving speed and working wavelength of the mobile station, to make the retransmitted digital signal have independent characteristics, it is necessary to ensure that the retransmission time interval of the digital signal satisfies the following relationship:

$$\Delta T \geq \frac{1}{2f_m} = \frac{1}{2(v/\lambda)} \tag{1}$$

Where: f_{m} is the fading frequency, v is the moving speed of the mobile station, and λ is the working wavelength.

2.3. Diversity combining modes

Combining refers to the receiver receiving M (M≥2) diversity signals, how to use these signals to reduce the influence of fading. Generally, a linear combining is used to sum the input M independent fading signals and then combine the output.

Assuming that the voltage of M input signals is $r_1(t)$, $r_2(t)$, …, $r_M(t)$, the output voltage $r(t)$ of the combining is:

$$r(t) = a_1\, r_1(t) + a_2 r_2(t) + \cdots + a_M\, r_M(t) = \sum_{k=1}^{M} a_k r_k(t) \tag{2}$$

Where, a_k is the weighting coefficient of the k[th] signal.

Choosing different weighting coefficients can constitute different combining methods. There are three common combining methods:

1) Selection Combining: Selection combining refers to detecting the signals of all diversity branches and selecting the signal of the branch with the highest SNR as the output of the combiner. It can be seen from Equation (2) that in the selective combiner, only one term of the weighting coefficient is 1, and the rest are all 0.

Selective combining is also called switch addition. This method is simple and easy to implement. However, the fading resistance is not as good as other methods because the signal of the unselected branch is discarded.

2) Maximal Ratio Combining: Maximum ratio combining is the best combining method. To write easily, the signal envelope $r_k(t)$ of each branch is denoted by r_k. The weighting coefficient a_k of each branch is proportional to the signal envelope r_k and inversely proportional to the noise power N_k, i.e.

$$a_k = \frac{r_k}{N_k} \tag{3}$$

Thus, the signal envelope output by the maximum ratio amalgamator can be obtained as:

$$r_R = \sum_{k=1}^{M} a_k r_k = \sum_{k=1}^{M} \frac{r_k^2}{N_k} \tag{4}$$

Where, the subscript R represents the maximal ratio combining. The process is shown in the Figure 2.

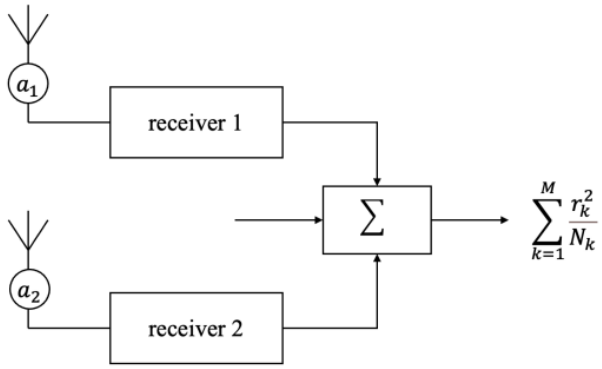


Figure 2. The Process Diagram of Maximal Ratio Combining

3) Equal-gain Combining: Equal-gain combining does not need to weight the signal, the signals of each branch are equal-gain addition. The equal-gain combining method is simple to implement, and its performance is close to the maximal ratio combining.

The signal envelope of the output of the equal-gain combiner is:

$$r_E = \sum_{k=1}^{M} r_k \tag{5}$$

Where, the subscript E represents the equal-gain combining. The process is shown in the Figure 3.

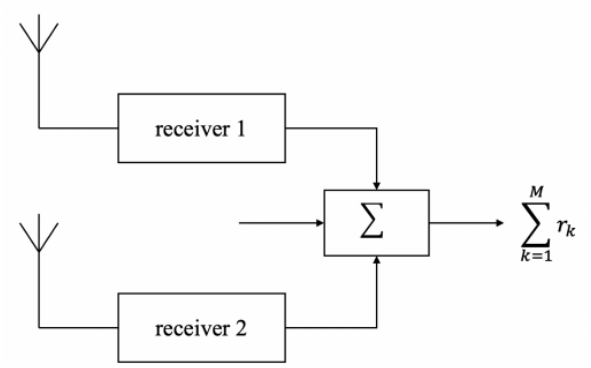


Figure 3. The Process Diagram of Equal-gain Combining

2.4. Performance analysis and comparison in DPSK system

The average bit error rate in DPSK system is analyzed. It is known that under constant parameter channel, the bit error rate of DPSK is

$$P_e(\gamma) = \frac{1}{2}e^{-\gamma} \tag{6}$$

In Rayleigh fading channel, the average bit error rate is

$$\overline{P}_e = \int_0^\infty P_e(\gamma)p(\gamma)\,\mathrm{d}\gamma \tag{7}$$

Where, $p(\gamma)$ is the probability density function of γ, and $p(\gamma)$ of the selection combining is represented by $p(\gamma_s)$. In the selection combining, the probability density $p(\gamma_s)$ of SNR γ_s is

$$p(\gamma_s) = \frac{M}{\gamma_s}\left[1 - e^{-\frac{\gamma_s}{\gamma_0}}\right]^{M-1} \cdot e^{-\frac{\gamma_s}{\gamma_0}} \tag{8}$$

It can be concluded that the average bit error rate $\overline{P}_{e,1}$ in the absence of diversity (M=1) is

$$\overline{P}_{e,1} = \int_0^\infty \frac{1}{2}e^{-\gamma_s} \cdot \frac{1}{\gamma_s}e^{-\frac{\gamma_s}{\gamma_0}}\,\mathrm{d}\gamma_s = \frac{1}{2+2\gamma_0} \tag{9}$$

Similarly, the average bit error rate $\overline{P}_{e,2}$ for the dual-diversity (M=2) can be obtained as

$$\overline{P}_{e,2} = \int_0^\infty \frac{1}{2}e^{-\gamma_s} \cdot \frac{2}{\gamma_s}\left[1 - e^{-\frac{\gamma_s}{\gamma_0}}\right] \cdot e^{-\frac{\gamma_s}{\gamma_0}}\,\mathrm{d}\gamma_s = \frac{1}{(1+\gamma_0)(2+\gamma_0)} \tag{10}$$

When the average CNR $\gamma_0 \gg 1$, then

$$\overline{P}_{e,2} \approx \frac{1}{\gamma_0^2} = 4\left(\overline{P}_{e,1}\right)^2 \tag{11}$$

When M=3, we have

$$\overline{P}_{e,3} \approx 24\left(\overline{P}_{e,1}\right)^3 \tag{12}$$

When M=4, we have

$$\overline{P}_{e,4} \approx 192\left(\overline{P}_{e,1}\right)^4 \tag{13}$$

According to the formulas derived above for calculating the average bit error rate under different diversity numbers, and the bit error rate is significantly improved after the change from no diversity to diversity.

The benefits of bit error rate of DPSK system under the three combining methods compared with the case without diversity is listed in Table 1. It can be seen that the BER improvement is best for the maximal ratio combining and worst for the selection combining.

Table 1. Comparison of average bit error rate of three combining methods

Diversity number M	*Selection Combining*	*Equal-gain Combining*	*Maximal Ratio Combining*
1	$\overline{P}_{e,1}$	$\overline{P}_{e,1}$	$\overline{P}_{e,1}$
2	$4\left(\overline{P}_{e,1}\right)^2$	$2.5\left(\overline{P}_{e,1}\right)^2$	$2.5\left(\overline{P}_{e,1}\right)^2$
3	$24\left(\overline{P}_{e,1}\right)^3$	$6.4\left(\overline{P}_{e,1}\right)^3$	$4\left(\overline{P}_{e,1}\right)^3$
4	$192\left(\overline{P}_{e,1}\right)^4$	$16\left(\overline{P}_{e,1}\right)^4$	$8\left(\overline{P}_{e,1}\right)^4$

To sum up, the performance of equal-gain combining is similar to that of maximal ratio combining, but the circuit implementation is simpler. Especially in the adjustment of weighting coefficient, the former is far simpler than the latter, so in common communication systems, equal-gain combining is more practical. And when diversity number M is small, selection combining is still the method to consider.

3. Error Correcting Code

3.1. A brief introduction of error correcting code

Nowadays, all kinds of mobile communication systems adopt error correcting codes for anti-interference and anti-fading. It is necessary and possible to use error-correcting codes in digital signal transmission. For example, BCH coding and even parity code are used in wireless paging system. AMPS and TACS also use BCH codes in various formats. In CDMA mobile communication system, convolution code is used. Therefore, it is very important to study error correction codes.

3.2. Error detecting code

There are two kinds of common error detection methods, one is parity check, the other is Cyclic Redundancy Check (CRC). The basic idea of error detection is that the sender adds L check bits calculated according to certain rules after K information bits according to the given rules, and the receiver recalculates L check bits on the received information bits. The received check bit is compared with the locally recalculated check bit. If the check bit is the same, the transmission is correct. Otherwise, the transmission is incorrect. Two types of error detection codes are described in detail below.

1) Parity Check Codes

Parity check code is one of the simplest check codes. It is used to detect whether errors occur during data transmission. It has two check methods: odd check and even check.

Odd Parity check: There are an odd number of 1s in the source stream and parity bits.

Even Parity check: There are an even number of 1s in the source stream and parity bits.

It has only one check bit, either 0 or 1, and its check code can be placed before the stream. Here's an example of parity check code:

Suppose the input information bit is $\{S_1, S_2, S_3\}$, the check bit is $\{C_1, C_2, C_3, C_4\}$, the check rule is $C_1 = S_1 \oplus S_3, C_2 = S_1 \oplus S_2 \oplus S_3, C_3 = S_1 \oplus S_2, C_4 = S_2 \oplus S_3$.

Assuming the message sequence is {100}, and the generated check sequence is {1110}, so the message sequence sent is {1001110}. Suppose it travels over a mobile channel, the receiver picks up {1011110}, so the local check sequence calculated based on the received message bit {101} is {0011}. Obviously, it is different from the received check sequence {1110}, means the received sequence is wrong.

2) Cyclic Redundancy Check

Cyclic Redundancy Check generates L-bit check bit sequence $(C_{L-1}, C_{L-2}, \ldots, C_1, C_0)$ by CRC algorithm according to the input bit sequence $(S_{K-1}, S_{K-2}, \ldots, S_1, S_0)$.

The CRC algorithm is as follows:

The input bit sequence is expressed as the coefficients of the following polynomials:

$$S(D) = S_{K-1}D^{K-1} + S_{K-2}D^{K-2} + \cdots + S_1D + S_0 \quad (14)$$

Where D can be viewed as a delay factor, D 'corresponds to the position of bit S_i.

Let the generating polynomial of the CRC check bit is:

$$g(D) = D^L + g_{L-1}D^{L-1} + \cdots + g_1D + 1 \quad (15)$$

Then the check bit corresponds to the coefficient of the following polynomial:

$$C(D) = \text{Remainder}\left[\frac{S(D)\cdot D^L}{g(D)}\right] = C_{L-1}D^{L-1} + \cdots + C_1D + C_0 \quad (16)$$

Where, Remainder[ ] stands for taking the remainder.

The selection of generating polynomials is not arbitrary. It must make the generated check sequence have strong error detection ability. Here, several commonly used L-order CRC generating polynomials are given:

a) CRC – 16 (L=16):

$$g(D) = D^{16} + D^{15} + D^2 + 1 \quad (17)$$

b) CRC – CCITT (L=16):

$$g(D) = D^{16} + D^{12} + D^5 + 1 \quad (18)$$

c) CRC – 32 (L=32):

$$g(D) = D^{32} + D^{26} + D^{23} + D^{22} + D^{16} + D^{12} + D^{11} + D^{10} + D^8 + D^7 + D^5 + D^4 + D^2 + D + 1 \quad (19)$$

CRC – 16 and CRC – CCITT will generate a 16-bit check bit, and CRC – 32 will generate a 32-bit check bit.

3.3. Convolutional code

Convolutional codes are grouped, but different from block codes, the n encoded symbols in convolutional codes are not only related to the k information in the current segment, but also related to the information in the previous (N-1) segment. In the encoding process, and are associated with each other. Therefore, the number of symbols nN in N time is often called the constraint length of such a code. This kind of code error correction ability is strong, not only can correct the random error, but also can correct the sudden error. A (2, 1, 2) convolutional code encoder is shown in Figure 4.

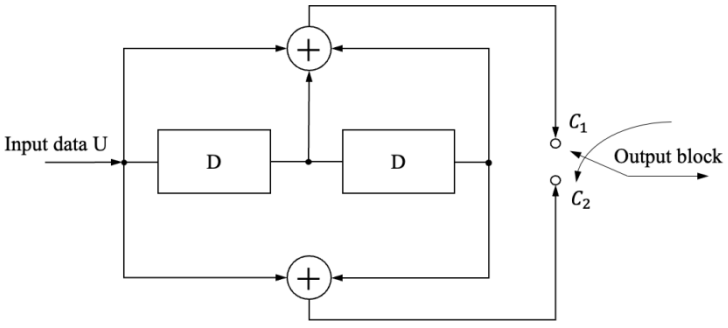


Figure 4. (2, 1, 2) Convolutional Code Encoder

3.4. Interleaved code

The role of interleaved codes is to transform the channel, and its implementation methods include block interleaving, frame interleaving, random interleaving, mixed interleaving and so on. A kind of block interleaver is shown in Figure 5.

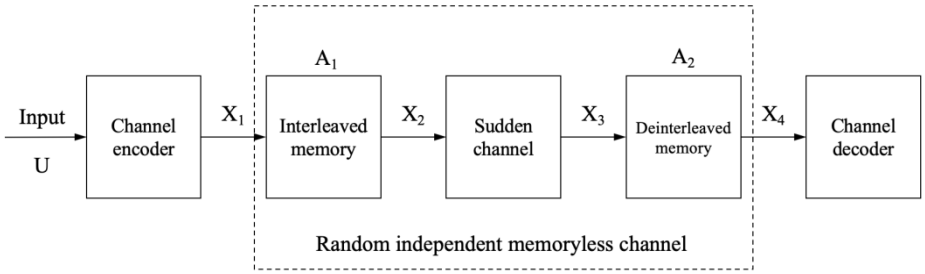


Figure 5. Block diagram of grouping interleaver implementation

4. Other Techniques

4.1. Spread spectrum

In spread spectrum communication, the spread code is modulated at the origin, so that the frequency band width of the signal is much larger than the necessary bandwidth of the transmitted information. At the receiving end, the same spread code is de-expanded to recover the transmitted information data. The spread spectrum communication system extends the signal spectrum at the origin and recovers the transmitted information after the unspread at the receiver. This process brings the benefit of SNR, that is, the output SNR of the receiver is greatly improved compared with the input SNR, thus improving the anti-interference ability of the system. Therefore, the ratio of the output SNR and the input SNR can be used to characterize the anti-interference ability of the spread spectrum system. The analysis shows that the anti-interference ability of various spread spectrum systems is generally proportional to the ratio of the spread spectrum signal bandwidth B to the information bandwidth B_m. Engineering is often expressed in decibels (dB), i.e

$$G_p = 10 \lg \frac{B}{B_m} \tag{20}$$

G_p is the processing gain of the spread spectrum system, which represents the degree of improvement in the signal to noise ratio of the spread spectrum system. Therefore, G_p is an important performance index of spread spectrum system.

The general principle of spread spectrum communication is shown in Figure 6. The input message is initially modified by the message to form a digital signal, followed by a sequence of spectral codes generated by a distributed frequency generator to adjust the digital signal to extend the signal range. The carrier bandwidth references (e.g. PSK, QPSK, OQPSK, etc.) are then modified and sent to the antenna through radio frequency power amplification. At the receiver end, the broadband ratio-frequency signal received by the receiver antenna is passed through the high-frequency amplifier and the input circuit into the frequency converter, and then converted into intermediate-frequency signal. Then it is de-expanded by the locally generated spread spectrum code sequence, which is the same as the origin, and finally it is restored to the original information output after the information demodulation.

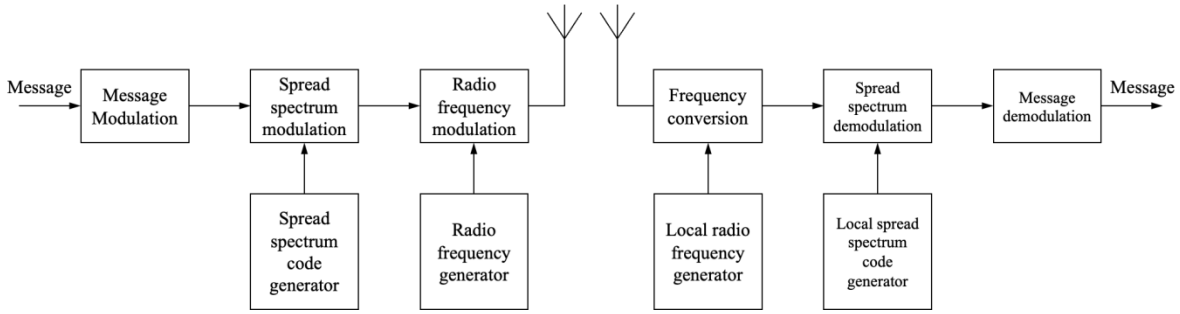


Figure 6. Principle of spread spectrum communication

The spread spectrum communication system is compared with the ordinary digital communication system, which is more spread spectrum modulation and reconciliation. According to the different ways of spreading spectrum, the current spread spectrum communication system can be divided into: DS, FH, TH, Chirp, and the combination of the above methods.

4.2. Digital frequency modulation

In mobile communication, there are many kinds of modulation methods, such as FSK, PSK, QAM and so on. Here only FSK is introduced.

1) FSK

Let the bitstream input to the modulator be $\{a_n\}$, with $a_n = \pm 1$,$n = -\infty \sim +\infty$. The output signal form (nth bit interval) of FSK is

$$s(t) = \begin{cases} \cos(\omega_1 t + \varphi_1), & a_n = +1 \\ \cos(\omega_2 t + \varphi_2), & a_n = -1 \end{cases} \tag{21}$$

That is, when the input is the signal "+1", the output frequency is the sine wave of f_1; When the input sign "-1" is null, the output frequency is a sine wave of f_2.

Let $g(t)$ be a rectangular pulse of width T_s and

$$b_n = \begin{cases} 1, & a_n = +1 \\ 0, & a_n = -1 \end{cases} \tag{22}$$

$$\overline{b_n} = \begin{cases} 0, & a_n = +1 \\ 1, & a_n = -1 \end{cases} \tag{23}$$

Then S (t) can be expressed as

$$s(t) = \sum_n b_n g(t - nT_s)\cos(\omega_1 t + \varphi_1) + \sum_n \overline{b_n} g(t - nT_s)\cos(\omega_2 t + \varphi_2) \tag{24}$$

Let the spectrum of $g(t)$ be $G(\omega)$ and the probability of an taking +1 and -1 be equal, then the power spectrum expression of $s(t)$ is

$$\begin{aligned} P_s(f) = {} & \frac{1}{16} f_s[|\, G(f + f_1)\,|^2 + |\, G(f - f_1)\,|^2] + \\ & \frac{1}{16} {f_s}^2 |G(0)\,|^2 [\delta(f + f_1) + \delta(f - f_1)] + \\ & \frac{1}{16} f_s[|\, G(f + f_2)\,|^2 + |\, G(f - f_2)\,|^2] + \\ & \frac{1}{16} {f_s}^2 |G(0)\,|^2 [\delta(f + f_2) + \delta(f - f_2)] \end{aligned} \tag{25}$$

The first and second terms indicate that part of the power spectrum of FSK signal is shifted from 0 to f_1 by the power spectrum of $g(t)$, and there is a carrier frequency component at f_1. The third and fourth terms indicate that the other part of the power spectrum of FSK signal is shifted from 0 to f_2 by the power spectrum of $g(t)$, and there is a carrier frequency component at f_2. The bandwidth of FSK signal is

$$B = |f_2 - f_1| + 2f_s \tag{26}$$

2) MSK

MSK is a special form of FSK, whose frequency difference is the minimum frequency difference that satisfies the two frequencies orthogonal to each other (that is, the correlation function is equal to 0), and requires the phase continuity of FSK signal. The frequency difference is $\Delta f = f_2 - f_1 = \frac{1}{2T_b}$, that is, the modulation index is

$$h = \frac{\Delta f}{\frac{1}{T_b}} = 0.5 \tag{27}$$

Where T_b is the width of the input bitstream.
Possible phase trajectories of MSK are shown in Figure 7.

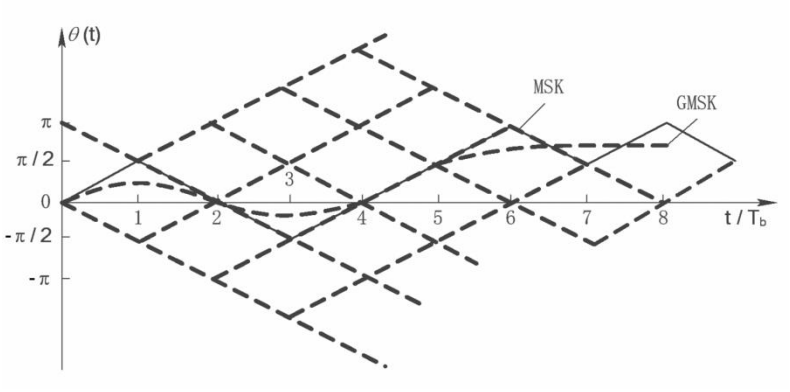


Figure 7. Possible phase trajectories of MSK and GMSK

4.3. Adaptive equalization

Equalization techniques refer to various algorithms and implementation methods used to deal with ISI. In a mobile environment, due to the time-varying multipath propagation characteristics of the channel, serious intersymbol interference is caused, so equalization technology is needed to overcome the intersymbol interference. An adaptive equalizer is a time-varying filter that must dynamically adjust its characteristics and parameters so that it can track channel changes.

5. Conclusion

To sum up, there are many kinds of anti-interference and anti-fading techniques applied in mobile communication at present, such as diversity reception, error correcting codes and so on. There are also many techniques not mentioned in this paper. Anti-interference and anti-fading are key topics in the field of mobile communication. Now entering the commercial era of 5G, mobile communication needs to increase the transmission rate according to the transmission conditions under the premise of ensuring the transmission quality. With higher speeds and smaller latencies, the 6G technology for the future of mobile communications holds great promise. Anti-interference and anti-fading techniques will always be one of the important research topics. When designing and using a new technique, it is important to consider not only its performance, but also its implement ability and system complexity.

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