

Technical English

For Information and Communication
Engineering

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Unit Nine

Multiple Access Techniques:
FDMA, TDMA and CDMA



概述

- 通信系统中复用的必要性
- 三种主要的复用技术：频分复用，时分复用，码分复用
- **CDMA**的基本思路
- 前向和后向链路的区别



time slot	时隙
round robin	循环签名, 循环赛
allot	分配
buffer	缓冲器
burst	爆发
correlate	相关
spur	刺激, 激励
jamming	干扰
pseudo random noise	伪随机噪声
chip	码片
modular-2	模2的
synchronization	同步
matrix	矩阵
dimension	维数
power	幂



使许多用户同时使用同一个固定的无线电频带

Multiple access schemes are used to **allow many simultaneous users to use the same fixed bandwidth radio spectrum**. In any radio system, the allocated bandwidth is always limited. For mobile phone systems the total bandwidth is typically 50MHz, which is **split in half to provide the forward and reverse links of the system**. Sharing of the spectrum is required in order to increase the user capacity of any wireless network.

分成两半用以提供系统的前向和反向连接



FDMA, TDMA and CDMA are the three major methods of sharing the available bandwidth to multiple users in wireless system. There are many extensions, and hybrid techniques for these methods, such as OFDM, and hybrid TDMA and FDMA systems. However, an understanding of the three major methods is required for understanding of any extensions to these methods.

FDMA: frequency division multiple access

TDMA: time division multiple access

CDMA: code division multiple access

OFDM: orthogonal frequency division multiplexing



In Frequency Division Multiple Access (FDMA), the available bandwidth is subdivided into a number of narrower bands. Each user is allocated a unique frequency band in which to transmit and receive. During a call, no other user can use the same frequency band. Each user is allocated a forward link channel (from the base station to the mobile phone) and a reverse channel (back to the base station), each being a single way link.



每个信道只支持一个用户

The transmitted signal on each of the channels is continuous allowing analog transmissions. The bandwidths of FDMA channels are generally low (30kHz) as each channel only supports one user. FDMA is used as the primary breakup of large allocated frequency bands and is used as part of most multi-channel systems. Figures 9.1 and 9.2 show the allocation of the available bandwidth into several channels.

FDMA作为大多数多信道系统的一部分用于初步分割分配到的宽频带。



Time Division Multiple Access (TDMA) divides the available spectrum into multiple time slots by giving each user a time slot in which they can transmit or receive.

Figure 9.3 shows how the time slots are provided to users in a round robin fashion, with each user being allotted one time slot per frame.¹

图9.3显示如何以一种循环复用的方式把时隙分配给用户，每个用户每帧分得一个时隙。



缓冲和爆发方式

TDMA systems transmit data in a buffer and burst method, thus the transmission of each channel is non-continuous. The input data to be transmitted is buffered over the previous frame and burst transmitted at a higher rate during the time slot for the channel.²

待发送的输入数据在前一帧期间被缓存，在分配给该信道的时隙中以较高速率爆发式发送出去。



TDMA不能直接传送模拟信号因为它需要使用缓冲

TDMA cannot send analog signals directly due to the buffering required, thus is only used for transmitting digital data. TDMA can suffer from multipath effects as the transmission rate is generally very high. This leads the multipath signals causing inter-symbol interference.



TDMA is normally used in conjunction with FDMA to subdivide the total available bandwidth into several channels. This is done to reduce the number of users per channel allowing a lower data rate to be used. This helps reduce the effect of delay spread on the transmission.



将基于FDMA的各信道进一步用TDMA划分，从而多个用户可以在同一信道上发送信号

Figure 9.4 shows the use of TDMA with FDMA. Each channel based on FDMA is further subdivided using TDMA so that several users can transmit over one channel. This type of transmission technique is used by most digital second generation mobile phone systems. For **GSM**, the total allocated bandwidth of 25MHz is divided into 125 channels using FDMA, each having a bandwidth of 200kHz. These channels are then subdivided further by using TDMA so that each 200kHz channel allows 8-16 users.

这些信道又用TDMA进一步分割，每一个200kHz的信道可容纳8~16个用户。



Code Division Multiple Access (CDMA) is a spread spectrum technique that uses neither frequency channels nor time slots. In CDMA, the narrow band message (typically digitized voice data) is multiplied by a large bandwidth signal which is a pseudo random noise code (PN code).

窄带的消息（典型的是数字语音）被乘以一个宽带的伪随机噪声（PN码）信号



发射的信号通过与发送者用的同样PN码相关而恢复出来。

All users in a CDMA system use the same frequency band and transmit simultaneously. The transmitted signal is recovered by correlating the received signal with the PN code used by the transmitter. Figure 9.5 shows the general use of the spectrum using CDMA.



CDMA technology was originally developed by the military during World War II. Researches were spurred into looking at ways of communicating that would be secure and work in the presence of jamming. Some of the properties that have made CDMA useful are:

- **Signal hiding and non-interference with existing systems**
- **Anti-jam and interference rejection**
- **Information security**
- **Accurate ranging**
- **Multiple user access**
- **Multipath tolerance**

当时研究人员受到激励以寻求安全和能够在干扰中正常工作的通信方式。



For many years, spread spectrum technology was considered solely for military applications. However, with rapid developments in LSI and VLSI designs, commercial systems are starting to be used.



系统处理增益是指扩频系统通过扩频和反扩频的性质所表现出来的增益或信噪比的提高。

One of the most important concepts required in order to understand spread spectrum techniques is the idea of process gain. **The process gain of a system indicates the gain or signal to noise improvement exhibited by a spread spectrum system by the nature of the spreading and despreading process.³** The process gain of a system is equal to the ratio of the spread spectrum bandwidth used to the original data bit rate.



Thus, the process gain can be written as:

$$G_p = \frac{BW_{\text{RF}}}{BW_{\text{info}}}$$

where BW_{RF} is the transmitted bandwidth after the data is spread, and BW_{info} is the bandwidth of the information data being sent.

其中 BW_{RF} 是数据扩展以后的发射带宽， BW_{info} 是所发送信息数据的带宽



Figure 9.6 shows the process of a CDMA transmission. The data to be transmitted (a) is spread before transmission by modulating the data using a PN code. This broadens the spectrum as shown in (b). **In this example the process gain is 125 as the spread spectrum bandwidth is 125 times greater than the data bandwidth.** Part (c) shows the received signal.

在本例中处理增益为125因为扩频带宽是数据带宽的125倍。



它包括要求的信号加上背景噪声，以及其他CDMA用户或无线电信号源的干扰。

This consists of the required signal, plus background noise, and any interference from other CDMA users or radio sources. The received signal is recovered by multiplying the signal by the original spreading code. **This process causes the wanted received signal to be despread back to the original transmitted data.** However, all other signals which are uncorrelated to the PN spreading code used become more spread. The wanted signal in (d) is then filtered removing the wide spread interference and noise signals.

Figure 9.6

这一过程使需要的信号反扩频恢复成原来的发射数据。



其码片频率高于数据的比特率

CDMA is achieved by modulating the data signal by a pseudo random noise sequence (PN code), **which has a chip rate higher than the bit rate of the data.** The PN code sequence is a sequence of ones and zeros (called chips), which alternate in a random fashion. The data is modulated by modular-2 adding the data with the PN code sequence. **This can also be done by multiplying the signals, provided the data and PN code are represented by 1 and -1 instead of 1 and 0.** **Figure 9.7** shows a basic CDMA transmitter.

也可以通过与信号相乘得到，只要数据和PN序列都用1和-1表示而不是1和0。



短的PN码（典型长度10~128码片）
可用于调制每一个数据比特。

The PN code used to spread the data can be of two main types. A short PN code (typically 10-128 chips in length) can be used to modulate each data bit. The short PN code is then repeated for every data bit allowing for quick and simple synchronization of the receiver. Figure 9.8 shows the generation of a CDMA signal using a 10-chip length short code.



Alternatively a long PN code can be used. Long codes are generally thousands to millions of chips in length, thus are only repeated infrequently. Because of this they are useful for added security as they are more difficult to decode.

所以它们有益于增加安全性，因为更难以解码。



The forward link, from the base station to the mobile, of a CDMA system can use special orthogonal PN codes called Walsh code, for separating the multiple users on the same channel. These are based on a Walsh matrix, which is a square matrix with binary elements, and dimensions which are a power of two.

CDMA系统中从基站到移动电话的前向链路可以使用称为Walsh码的特殊正交码来将同一信道的多用户分开。



It is generated from the basis that Walsh(1) = $W_1 = 0$ and that:

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

where W_n is the Walsh matrix of dimension n . For example:

$$W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

Hadarmard matrix

Walsh matrix



Walsh codes are orthogonal, which means that the dot product of any two rows is zero. **This is due to the fact that for any two rows exactly half the number of bits match and half do not.**

这是因为任何两行之间都有一半的比特相同，另一半不同。

Hadarmard matrix

Walsh matrix



Each row of a Walsh matrix can be used as the PN code of a user in a CDMA system. **By doing this the signals from each user is orthogonal to every other user, resulting in no interference between the signals.**⁴ However, in order for Walsh codes to work the transmitted chips from all users must be synchronized.

这一处理过程使每一用户的信号与所有其他用户的信号正交，因而相互之间没有干扰。



在时间上相对于其他所有Walsh码移动了超过约十分之一的码片周期

If the Walsh code used by one user is **shifted in time by more than about 1/10 of chip period, with respect to all the other Walsh codes**, it loses its orthogonal nature. This results in inter-user interference.⁵ **For the forward link signals for all the users originate from the base station, allowing the signals to be easily synchronized.**

对于前向链路，所有用户的信号源自基站，因此它们很容易同步。



因为从各用户发出的信号并不像前向链路那样由同一个源产生

The reverse link is different to the forward link because the signals from each user do not originate from a same source as in the forward link. The transmission from each user will arrive at a different time, due to propagation delay and synchronization errors. Due to the unavoidable timing errors between the users, there is little point in using Walsh codes as they will no longer be orthogonal.⁶ For this reason simple pseudo random sequence which are uncorrelated, but not orthogonal are used for the PN codes of each user.

由于用户之间不可避免的定时偏差，Walsh码几乎没用，因为它们之间不再正交。



The capacity is different for the forward and the reverse links because of the differences in modulation. The reverse link is not orthogonal, resulting in significant inter-user interference. For this reason the reverse channel sets the capacity of the system.⁷

由于这一原因，反向信道限制了系统的容量。



结合课文的思考题

- **Why is multiplexing necessary in communication systems?**
- **Name the three major multiplexing techniques.**
- **Briefly describe the principle of CDMA.**
- **Why is capacity of a CDMA system set by the reverse link?**



Exercises

An image may be defined as a two-dimensional function, $f(x, y)$, where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point. When x, y , and the amplitude values of f are all finite, discrete quantities, we call the image a digital image.

图像可定义为二元函数 $f(x, y)$ ，其中 x 和 y 是空间坐标，在任一坐标位置 (x, y) 处的幅度 f 称为图像在该点的强度或灰阶。当 x, y 以及 f 幅度值都是有限的离散量时，我们称之为数字图像。



Exercises

The field of digital image processing refers to processing digital images by means of a digital computer. Note that a digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are referred to as picture elements, image elements, pels, and pixels. Pixel is the term most widely used to denote the elements of a digital image. We consider these definitions in more formal terms in Chapter 2.

数字图像处理这一领域是指用数字计算机处理数字图像。注意，一幅数字图像由有限个单元组成，每一单元具有其特定的位置和取值。这些单元称为图像单元，即像素。像素是表示图像单元时使用最广的术语。我们将在第二章中用更正式的术语来讨论这些定义。



Exercises

Vision is the most advanced of our senses, so it is not surprising that images play the single most important role in human perception. However, unlike humans, who are limited to the visual band of the electromagnetic (EM) spectrum, imaging machines cover almost the entire EM spectrum, ranging from gamma to radio waves.

视觉是我们最发达的感觉，所以毫不奇怪图像在人的感知中起到了特殊重要的作用。然而，不像人（的视觉）那样受到电磁频谱中可见频带的限制，成像设备可覆盖从伽玛射线到无线电波的几乎整个电磁频谱。



Exercises

They can operate on images generated by sources that humans are not accustomed to associating with images. These include ultrasound, electron microscopy, and computer-generated images. Thus, digital image processing encompasses a wide and varied field of applications.

这些设备可用于那些人们不习惯将之与图像联系起来的源所产生的图像，包括超声，电子显微镜，以及计算机生成的图像。因此数字图像处理包括广泛而多样的应用领域。



Exercises

- **In a properly designed DC amplifier the effect of transistor parameter variation, other than I_{co} , may be practically eliminated if the operating point of each stage is adjusted so that it remains in the linear operation range of the transistor as temperature varies.**

1. transistor

2. amplifier

3. I_{co}

4. parameter



Exercises

- **It will show that our reliance on computer technology and our quick transition into a knowledge-based economy has left us vulnerable to attack, and that vulnerability creates difficult political dilemmas that must be dealt with should we wish to continue following the currents of the Third Wave.**
 1. **we should wish to carry on following the Third Wave currents**
 2. **whether or not do we wish to follow the Third Wave currents as usual**
 3. **if we wish to follow the Third Wave currents as usual**
 4. **must we wish to continue following the currents of the Third Wave**



Exercises

- **Kevin Kelly argues that cultural advances, like the printing press “prepared a possibility space that allowed human minds and bodies to shift so that some of what it once did biologically would afterwards be done culturally.”**
 1. **some biological tasks would be done such that they can affect the culture in the future**
 2. **once biological work is done, the aftermath would be basically cultural**
 3. **some of the jobs in biology would then be carried out in a cultural fashion**
 4. **certain previous physical jobs would be carried out in an intelligent manner**



Exercises

- **Modulation is the systematic variation of some attribute of a carrier waveform such as the amplitude, phase, or frequency in accordance with a function of the message signal.**
 1. in terms of a message carried by the signal
 2. according to the behavior of the signal
 3. due to the performance of the signal
 4. in relation with a quantity derived from the signal



Exercises

- **Not until recently had anyone demonstrated a unified approach that not only allows previously obtained complicated results to be simplified both analytically and computationally but also permits new results to be obtained for special cases that had resisted solution in a simple form.**
 1. that had resistance against formality of sample solutions
 2. that had prevented people from obtaining simple-form solutions
 3. that had restricted solution to a simple form
 4. that had resolved in the form of simplified solution

Exercises



- **Off-the-shelf multimedia platforms reduce various tailor made components facing end users by packaging the needed functionality into a single product.**
 1. **Specially manufactured multimedia platforms**
 2. **Multimedia platforms mounted on the shelf**
 3. **Readily available multimedia platforms**
 4. **Multimedia platforms that are taken from the shelf**



Assignment 1

- **Recently, TCP/IP wireless LAN is becoming popular in indoor applications, such as in stock exchange halls where mobile users demand a high-speed wireless data access to the network and voice capabilities for telephone conversations. To deploy such a network, a mathematical framework is helpful to compare the capacity of the TCP/IP wireless LAN performance with voice and data services in different scenarios. Therefore, for an asynchronous wireless LAN with the TCP/IP protocol, we need to find an answer to the following two questions. 1) What is the number of network telephone calls that can be carried with a given amount of data traffic? 2) What is the maximum data traffic per user for a given number of voice users?**



Assignment 2

- **Surveillance for a variety of applications in civilian and military environments raises a great demand for innovative sensors and sensor configurations based on cutting edge technologies such as knowledge-based (KB) signal and data processing, wireless networking, robotics, advanced computer architecture, and supporting software languages. Improved sensor signal and data processing will be gained from KB and *a priori* information, multiple processing paradigms, and sensor fusion. While the exact form of this prior knowledge is problem dependent, a KB system consists of a knowledge base containing information specific to a problem domain and an inference engine that employs reasoning to yield decisions.**