电子科技大学
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Course: **Digital Signal Processing**

Why frequency spectrum is meaningful and some engineering applications of signal spectrum

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ABSTRACT

Communication systems require a certain amount of signal bandwidth to operate. In different parts of the world, different organizations allot parts of the overall frequency spectrum to different uses. So, the spectrum is allotted to various purposes: analog TV broadcasts for example get a certain slot, FM radio gets a certain slot, AM radio gets a certain slot, cellular communications get certain slots, and so one.

Also, in many parts of the world, international agreements are required so that communications systems in neighboring countries are not interfering with each other.

This report is about the importance of frequency spectrum, and some engineering applications of signal spectrum, especially in mobile cellular communications where some techniques employ signal spectrum for operation of the systems.

Introduction

Nowadays, the world becomes increasingly wireless in terms of communications. With cordless phones, cell phones, wireless internet, GPS devices, etc, allocation of the available frequency spectrum to each technology becomes increasingly contentious and then important. Each user community (usually manufacturers of the wireless equipment) wants more bandwidth in order to be able to sell and service more units. For any given slot of bandwidth, there is a limited amount of data that can be shared in that bandwidth, so vendors want more bandwidth so they can handle more devices in a given area.

This report addresses the importance of frequency spectrum and how the signal spectrum is used in some engineering applications. The report then constitutes of two parts. The first part concerns with the importance of frequency spectrum, and the second part talks about some engineering applications of signal spectrum. Multiple access techniques in mobile cellular communication systems are the applications which are addressed.

1- Importance of frequency spectrum

1.1 Signal and Frequency

A signal is a physical quantity which varies with respect to time, space and contains information from source to destination. In communication systems, signal processing, and electrical engineering, a signal is a function that conveys information about the behavior or attributes of some phenomenon.

Except for DC signals, all signal carriers have a definable frequency or frequencies. Signals also have a property called wavelength, which is inversely proportional to the frequency. This is given by the relation $\lambda = \frac{c}{f}$, where λ is the wavelength of the signal, c c the speed of the signal in free space, and f the frequency of the signal.

An important tool called **Fourier transform** is used to examine the frequency content of a signal.

The Fourier transform of a continuous signal $x(t)$ (using the frequency variable f) is $X(t) = \int x(t) e^{j2\pi ft} dt$

1.2 Frequency spectrum analysis of a signal

The frequency spectrum of a time-domain signal is a representation of that signal in the frequency domain. The frequency spectrum can be generated via a Fourier transform of the signal, and the resulting values are usually presented as amplitude and phase, both plotted versus frequency. It means that any signal that can be represented as amplitude that varies with time has a corresponding frequency spectrum.

Spectrum analysis, also referred to as frequency domain analysis or spectral density estimation, is the technical process of decomposing a complex signal into simpler parts. That is, in frequency domain, any signal can be represented as a combination of weighted and shifted fundamental frequencies. Any process that quantifies the various amounts (e.g. amplitudes, powers, intensities, or phases), versus frequency can be called spectrum analysis.

Spectrum analysis can be performed on the entire signal. Alternatively, a signal can be broken into short segments (sometimes called frames), and spectrum analysis may be applied to these individual segments. The Fourier Transform (FT) of a function produces a frequency spectrum which contains all of the information about the original signal, but in a different form. This means that the original function can be completely reconstructed (synthesized) by an Inverse **Fourier Transform (IFT)**. And for perfect reconstruction, the spectrum analyzer must preserve both the amplitude and phase of each frequency component. In practice, nearly all software and electronic devices that generate frequency spectra apply a **Fast Fourier Transform (FFT**), which is a specific mathematical approximation to the full integral solution.

1.3 Use and importance of frequency spectrum

In communication systems, a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. The signal is transmitted on a bandwidth considerably larger than the frequency content of the original information. And the receiver correlates the received signals to retrieve the original information signal.

This technique is used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise and jamming, to prevent detection, and to limit power flux density.

The spectrum is then the range of radio frequencies available. The electromagnetic spectrum for example extends from below the low frequencies used for modern radio communication to gamma radiation at the short-wavelength (high-frequency) end, thereby covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. The diagram below shows the full frequency spectrum.

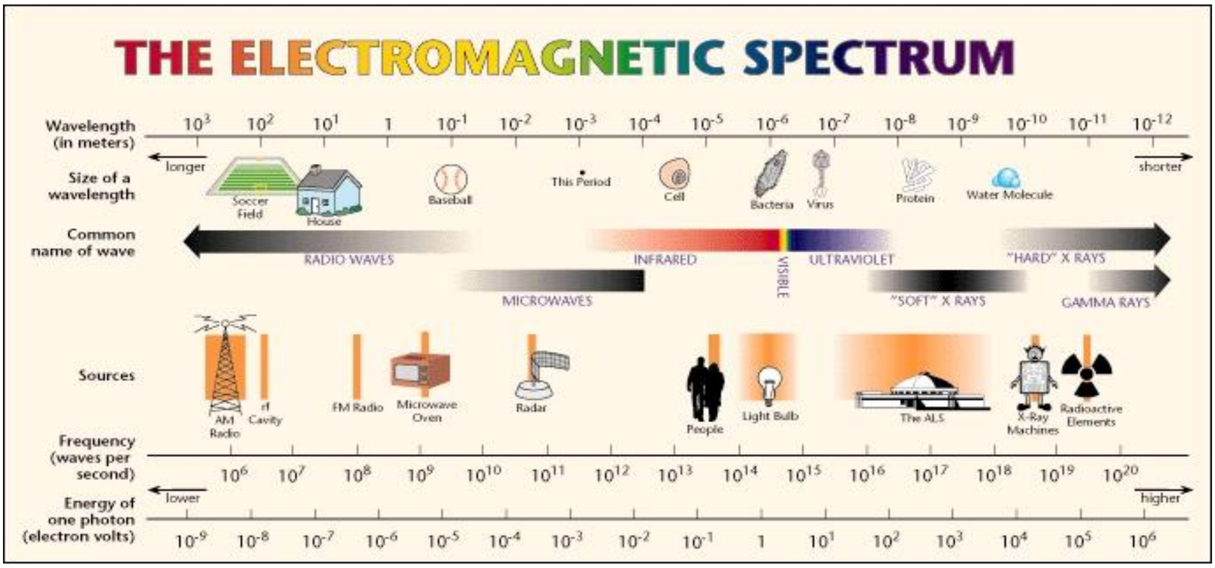

Figure 1: Electromagnetic Spectrum

Sometimes, spectrum allocation includes the geographic area in which the frequency band is used. There are hundreds of applications for radio signals, with new ones coming along all the time. Also, different frequencies have different properties. Higher frequencies can carry more bits of data per second, some frequencies fade in air more than others, and some require bigger antennas or more expensive electronics in the receiver, and so on.

2-Engineering applications of signal spectrum: Multiple access techniques in mobile cellular communication

Mobile cellular communication systems use free space as communication channel. Various frequency bands are used according to the services, but the bands are regulated for their use. And the signal spectrum available for data services and systems is extremely scarce, while demand for these services is growing at a rapid pace. Some techniques are then used to increase the spectral efficiency for higher data and good quality of service. These are called **multiple access techniques** and are based on **multiplexing** which is a technique which consists of transmitting several different signals of the same spectral range along a single communication channel, in such a manner that, at the receiving end, the signals are separately recoverable and distinguished from each other. A multiplexing technique is illustrated on figure 2 below.

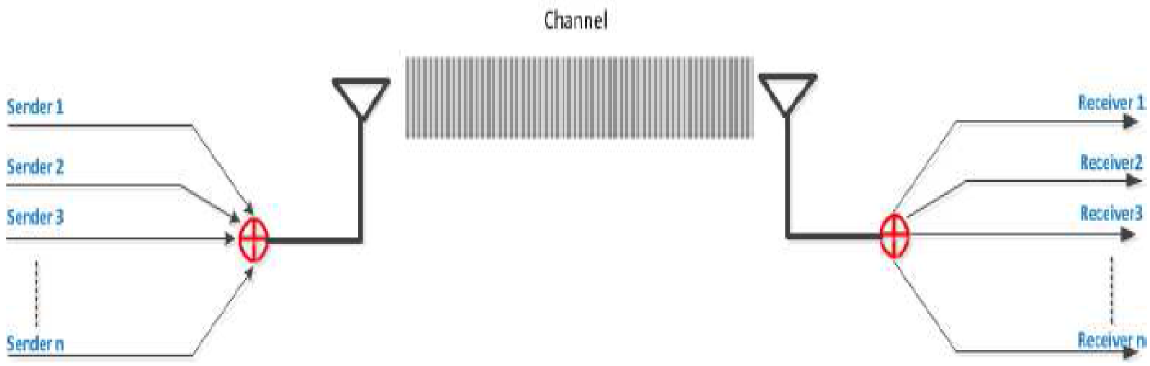

Figure 2: Multiplexing technique

In communication systems, it is often necessary to utilize limited communication channels at the same time, and then the multiple access techniques allow multiple users to communicate simultaneously. The three (3) basic ones are described below.

2.1 Frequency Division Multiple Access (FDMA)

It is a technique whereby each station has its own frequency band, separated by guard bands, and signal receivers tune to the right frequency. It is simple to implement, requires no synchronization, can switch off power when not transmitting, but it is inflexible and results in large power consumption.

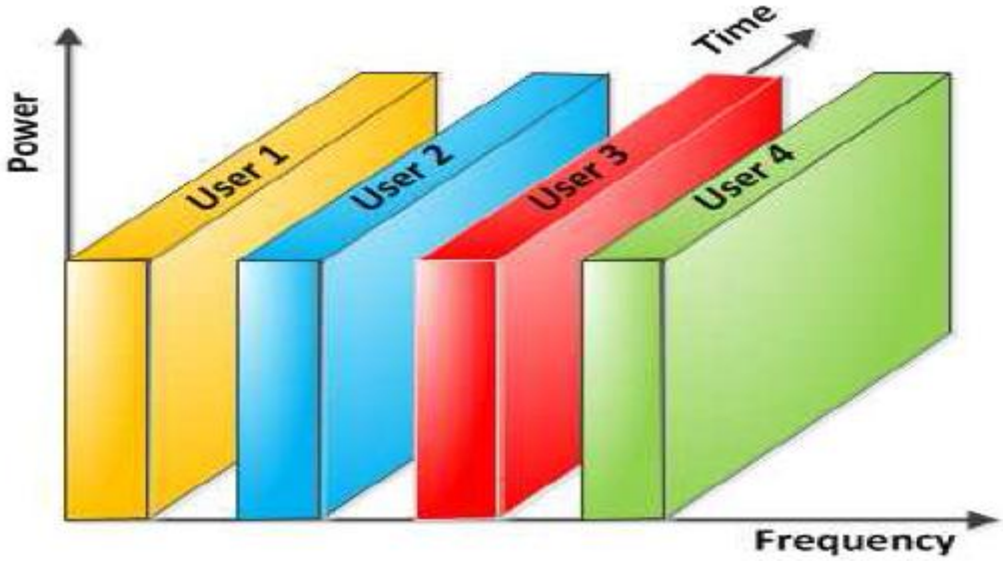

Figure 3: Diagram of FDMA

2.2 Time Division Multiple Access (TDMA)

It is a technique whereby all stations transmit signal on the same frequency, but at different times, and users are assigned time slots. In this technique users can be given different amounts of bandwidth and mobiles can use idle times to determine the best base station. They can also switch off power when not transmitting signal. But it deals with overhead synchronization and greater problems with multipath interference on wireless links.

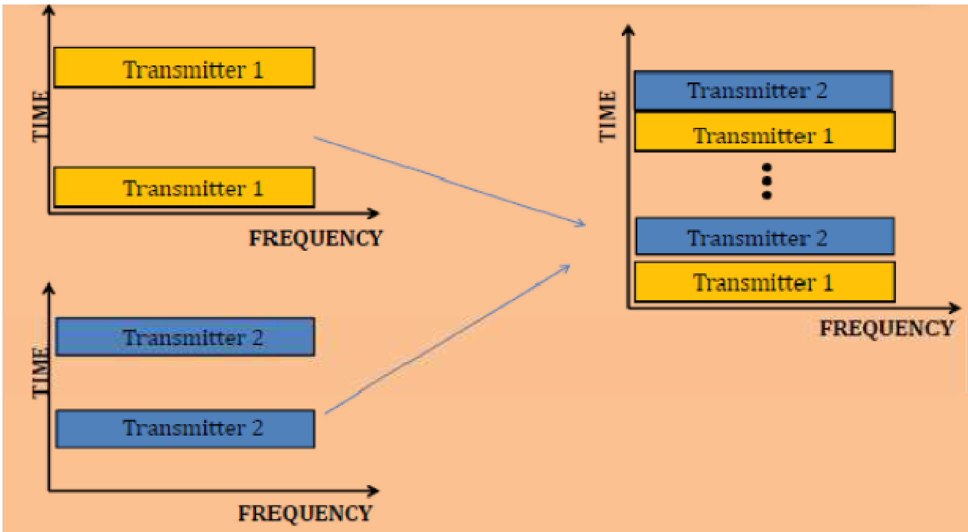

Figure 4: Diagram of TDMA

2.3 Code Division Multiple Access (CDMA)

In this technique, users are separated both by time and frequency and they send orthogonal signals at different frequency at each time slot. The signal is coded by converting a single bit to a code, and the receiver can decipher the bit by the inverse process. This technique is hard to spy, it is immune from narrowband noise, there is no need for all stations to synchronize, and all cells can use all frequencies. But it requires a complex receiver to dispread the signal.

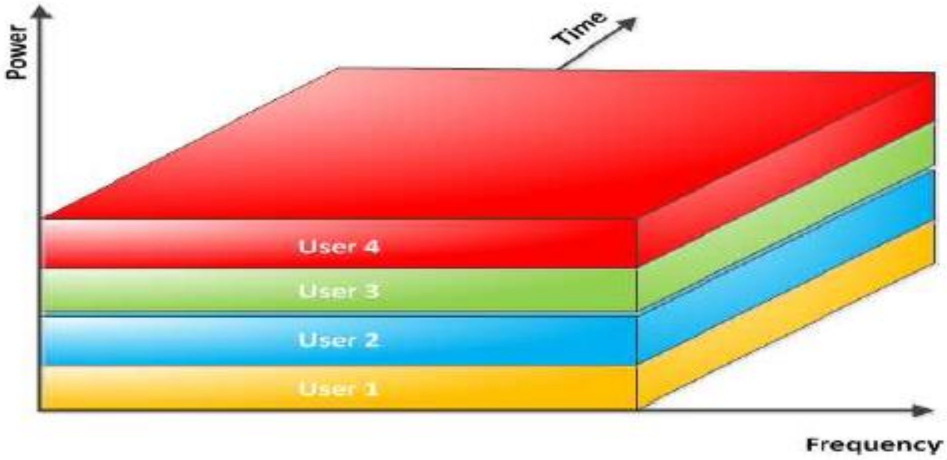

Figure 5: Diagram of CDMA

A comparison study of the above three techniques is summarized in the table below.

Comparison

	FDMA	TDMA	CDMA
Concept	Assigns frequencies to transmission channels at all time , uninterrupted.	Allocates time slot for communication.	Allocates codes with special characteristics to transmitting channels
Time intervals and frequency	Adopts frequency hopping pattern to avoid interference .Sender and receiver agrees in order to access the right frequency.	Easy to access many channels separated in time by the same frequency and then vice versa .	Existing terminals can be active at the same time and placed uninterrupted.
Bandwidth	Needs to be combined with TDMA to allocate frequencies at different time	Synchronising between sender and receiver has to attained within time domain. Time slot has to be allocated for channels in a fixed pattern , hence fixed bandwidth .	The spreading of the signal generated bandwidth in its frequency domain results in a signal with a high and wider bandwidth.
Advantage	Simple to implement	Users can be given different amounts of bandwidth	Hard to spy
Disadvantage	Inflexible	Synchronization overhead	Requires a complex receiver to dispread the signal

Table1: Comparison of FDMA, TDMA and CDMA

Conclusion

The frequency spectrum has an important role in communication engineering, since it deals with information signal to be transmitted.

In mobile cellular communication systems for example, the frequency spectrum can be shared among many different operators. And each operator transmits the signal on an assigned frequency range, employing various spectrum techniques for high and efficient signal transmission rate. When many operators are present, the radio spectrum consists of the sum of all the individual channels, each carrying separate information, spread across a wide frequency spectrum.

But in general, not all bands are allocated to commercial use, though. Some are saved for police or emergency use, some are allocated to military use, and some are even saved for scientific use. And allocating these valuable resources can be a contentious process, often resolved by auction to the highest bidder.

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