Lecture 13: Modulation Techniques for Mobile Radio

Digital Modulation Techniques

Analog vs. Digital Modulation

Due to the following many advantages of digital communications over analog communications, modern cellular phones use digital modulation rather than analog modulation:

1. Digital communications provide secured communications,
2. Advancement in design and manufacturing of digital integrated circuits and digital signal processors (DSP) made digital communications cheaper than analog communications. These advancements made it possible to implement digital modulation techniques completely in software rather than in hardware (this allows the possibility of updates to modulation algorithms without the need for hardware redesign and replacements)
3. Digital communications provide higher immunity to noise and channel effects through the use of repeaters,
4. Digital communications provide easier multiplexing of various types of signals together such as audio, video, and data
5. Digital communications allow the use of error correction to control the probability of error

Digital Modulation

In digital communications, the digital information signal is represented by a sequence of symbols. The symbols may take any value of a some power of 2 number of possibilities equal to m (for example, one of 2, 4, 8, 16, 32, 64, or 128 possibilities). In this case, each symbol carries a number of bits equal to n that is related to m by

$$n = \log_2 m$$

For the previous values of m possibilities, the corresponding number of bits is 1, 2, 3, 4, 5, 6, or 7 bits. The purpose of the demodulator part of the communication system is to detect which of the m symbols was transmitted for each received symbol with the least possible probability of error.

What is Digital Modulation/Demodulation

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Factors Affecting the Choice of the Digital Modulation Technique

As mentioned above, the purpose of a digital communication system is modulate/demodulate the information signal to provide the lowest possible probability of error using the lowest amount of transmitted signal power possible (lowest signal to noise ratio) and lowest amount of bandwidth. This means that the communication system should provide the best communication possible by spending the least amount of money possible. Simply stated, a good communication system should

1. Provide the least possible probability of error using the least amount of signal power
2. Provide the highest transmission rate using the least amount of bandwidth
3. Provide the best immunity to channel impairments using the cheapest possible equipment

Unfortunately, the requirements above are clearly contradicting each other. So, the design of a communication system involves a tradeoff process between these contradicting requirements.

Some modulation techniques provide better probability of error for a particular signal power compared to other techniques while some others provide efficiency in terms of bandwidth. So, usually the demand on the communication system determines which modulation technique to go with.

Power Efficiency and Bandwidth Efficiency

Performance of a particular modulation technique is measure using two criteria: Power efficiency and Bandwidth efficiency.

Power Efficiency: is the ability of a modulation technique to operate at a specific probability of error using the lowest amount of transmitted power (or the ability of a modulation technique to provide the lowers probability of error at a specific amount of signal power). The power efficiency (sometimes called energy efficiency) η_P is usually measured in terms of the required energy of a transmitted bit E_b over the noise power spectral density N_0 (i.e., E_b/N_0) needed to provide a particular probability of error.

Note that E_b has the units of (Joules) and N_0 has the units of (Watts/Hz).

Bandwidth Efficiency: is the ability of a modulation technique to transmit a specific amount of data per second using the smallest amount of channel bandwidth (or the ability of a modulation technique to transmit the highest amount of data per second using a specific amount of channel bandwidth). The bandwidth efficiency η_B (has the units of bits per second per Hz, or simply bits) is usually measured as the data rate R_b (in bit/s) over the bandwidth B (Hz) used to transmit this data:

$$\eta_B = \frac{R_b}{B} \quad \text{bps/Hz}$$

Channel Capacity

It appears that high values of bandwidth efficiencies can be achieved by simply compacting more bits in each transmitted symbol. That is, make the value of m extremely large (for example, $m = 2^{1000}$) so that each symbol carries a large number of bits and therefore, increase the data rate. This is in theory true for a completely noiseless channel. For noisy channels, which is always the case, this is not possible. Unfortunately, Shannon proved in 1948 that each channel has a fundamental channel capacity C of data that you cannot exceed. He proved that for a particular channel with a specific signal to noise ratio (S/N or SNR), it is possible to transmit data below this channel capacity C using some coding algorithm that will insure a small probability of error as low as you wish (only if you can find that coding algorithm). If you try to exceed the channel capacity C, the probability or error you get increases uncontrollably. Therefore, the maximum bandwidth efficiency $\eta_{B(\text{Max})}$ that you can get for a channel with a specific SNR is:

$$\eta_{B(\text{Max})} = \frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right) \quad \text{bps/Hz}$$

Tradeoff between Power Efficiency and Bandwidth Efficiency

There are two main techniques that allow us to tradeoff power efficiency with bandwidth efficiency:

1. Using error control coding increases the amount of data to be transmitted over a particular bandwidth (reduces bandwidth efficiency) but it reduces the probability of error in the transmitted data allowing the use of lower power to achieve a fixed probability of error (increases power efficiency).
2. Using a larger value of number of symbols m increases the transmitted data over the bandwidth (increases bandwidth efficiency) but it requires the use of higher power to achieve the same probability of error (reduces power efficiency).

Using these two techniques allows us to strike a balance between power efficiency and bandwidth efficiency.

Exercise:

The V.92 modem you use in your computer has a maximum speed of 56 kbps (kilo bits per second). If the channel it uses to transmit data has passband from 300 Hz to 3400 Hz, what is the minimum S/N ratio of the downstream channel when the modem is connected at the maximum rate? What is the minimum S/N when the modem is connected at 28 kbps? What is the minimum S/N for the upstream connection of the modem knowing that the maximum S/N for that connection is 33.6 kbps? What is the bandwidth efficiency of the downstream channel of the modem assuming maximum connection speed? What is the bandwidth efficiency of the upstream channel of the modem assuming maximum connection speed?