Some Physical Layer Aspects of Digital Communication Systems

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The past two decades have witnessed remarkable progress in communication technologies, and one of the main drivers for this progress has been the need to achieve higher data rates.

Researchers believe that this trend will continue into the future and are therefore directing their research in the area of 5G communication systems [1]. Although technology standards continue to evolve, the fundamental concepts of communication systems remain unchanged. Keeping this in mind, some of the key physical layer concepts of digital communication systems are presented in this article.

The basic goal of any communication system is to ensure that the message signal is received in the same way as it was intended. Depending on the nature of the signal, communication systems can either be classified as analog or digital. Message signals in the real world are analog in nature, and if these signals are to be processed in a digital system, then the use of a converter (A/D or D/A) is essential at the transmitter as well as the receiver. An A/D converter basically carries out the operation of sampling, quantizing and coding. The output of the sampling operation produces a signal that is discrete only in time and is carried out in accordance with Nyquist rule. The Nyquist rule states that to prevent aliasing, the sampling frequency should be at least twice the highest frequency component of the message signal [2]. The quantization process helps to divide the continuous amplitude of the signal into discrete levels. Due to the nature of this process, there is an error that is inherently introduced and is known as the quantization error. Increasing the number of discrete levels would minimize the quantization error, but it may also increase the complexity of the system and, subsequently, the cost. Hence there is always a tradeoff involved in the design of such converters.

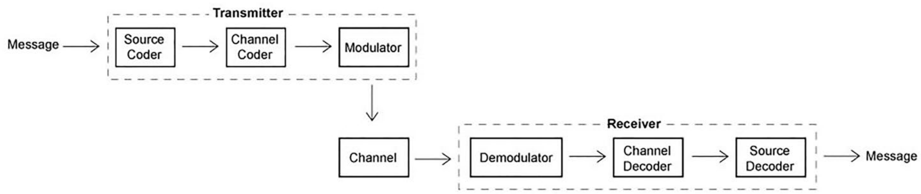

Fig.1. Block Diagram of a Digital Communication System

A general block diagram of a digital communication system is shown in Fig.1. The source coder block in the transmitter section reduces the number of transmitted bits, so that the available bandwidth is efficiently utilized. Channel coding, on the other hand, introduces some redundant bits with an aim of helping the receiver correct and detect errors during transmission. The modulator block that follows that channel coder block carries out the operation of modulation. In modulation, one of the parameters of a carrier wave is varied in accordance with the message signal. Depending on the parameter varied, there are three broad categories of modulation: amplitude shift keying (ASK); frequency shift keying (FSK); and phase shift keying (PSK). Within each one of these, there might be different types of modulation, like binary phase shift keying (BPSK) or quadrature phase shift keying (QPSK). Quadrature Amplitude Modulation (QAM) is another type of modulation that is a combination of amplitude shift keying and phase shift keying. In the block diagram one can observe that corresponding to each block in the transmitter section, there is another block in the receiver section that carries out the reverse operation (e.g., decoding, demodulation).

The effects of noise on a digital communication system cannot be ignored, since it is present in all electronic systems. Noise is any unwanted signal that interferes with our signal of interest, and it arises due to the random motion of electrons. A detailed analysis on the nature of noise signal requires familiarity with concepts such as stochastic/random process. Stark and Woods [3] provide a good overview on the different concepts that are used to mathematically analyze noise signals. In technical literature, noise is frequently assumed as Additive White Gaussian (AWGN) since it simplifies the task of analyzing the system performance. It is termed “white” due to the fact that it is present across all frequencies of interest—analogous to the nature of white color.

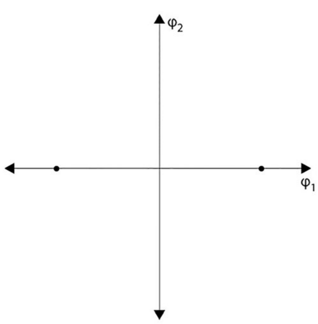

Fig.2. BPSK modulation

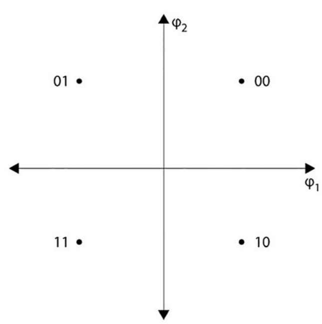

Fig.3. QPSK modulation

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Constellation diagrams are frequently used to visualize and analyze different digital modulation schemes. Before constructing any constellation diagram, one needs to choose a set of orthogonal basis functions. Once the basis functions are finalized, any signal can be represented in terms of these basis functions, and they can subsequently be mapped on an N-dimensional plane. Fig.2 and Fig.3 show the constellation diagram for BPSK and QPSK modulation schemes, respectively. In these figures, φ1 and φ2 represent the orthogonal basis functions, and the constellation points represent the symbols. In BPSK, a single bit is transmitted per symbol; whereas in QPSK, two bits are transmitted per symbol. Mathematically it can be shown that both the schemes are equivalent when they are compared in terms of BER (bit error rate).

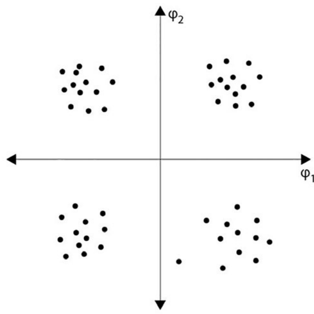

Fig.4. Impact of noise on QPSK modulation

In Fig.3, gray coding has been used while assigning the bits to each constellation point. In gray coding, adjacent symbols differ by only a single bit, and this technique helps minimizing the bit error rate. Fig.4 illustrates a typical scenario when noise is taken into consideration. One can observe that the constellation points are no longer concentrated at a single location. In fact, they are scattered across the plane. To facilitate the process of decision making, this two-dimensional plane can be split into four quadrants. The receiver, which carries out the process of decision making, would be able to accurately decode each symbol as long as it is perfectly located within its own quadrant.

As we move towards higher order modulation schemes such as 16 QAM or 64 QAM, the decision regions are further reduced, since the constellation points are now placed close to each other. This subsequently increases the probability of bit error, and one can conclude this fact by referring to the BER curves in [4]. Hence we can conclude that even in the selection of modulation scheme, there is a tradeoff involved. Higher modulation schemes offer the capacity to transmit more bits per symbol, but it comes at a cost of an increased BER.

References:
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