**CAPITULO 2**

2.1 THE THEORETICAL BASIS FOR DATA COMMUNICATION

Information can be transmitted on wires by varying some physical property such as voltage or current. By representing the value of this voltage or current as a single-valued function of time, f(t), we can model the behavior of the signal and analyze it mathematically.

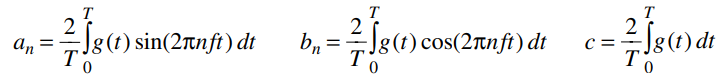
**2.1.1 Fourier Analysis**

Text

Description automatically generated with low confidenceAccording to the Fourier Series any reasonably behaved periodic function, g(t) with period T, can be constructed as the sum of a (possibly infinite) number of sines and cosines

Text

Description automatically generatedThe amplitudes (aⴖ) can be computed for any given g(t) by multiplying both sides of the equation by sin(2πkft) and then integrating from 0 to T.

The results of the operation are as follows:

**2.1.2 Bandwith limited signals**

The relevance of all of this to data communication is that real channels affect different frequency signals differently. The wave amplitude values are of interest because their squares are proportional to the energy transmitted at the corresponding frequency. No transmission facility can transmit signals without losing some power in the process.

Usually, for a wire, the amplitudes are transmitted mostly undiminished from 0 up to some frequency fc [measured in cycles/sec or Hertz (Hz)], with all frequencies above this cutoff frequency attenuated. The width of the frequency range transmitted without being strongly attenuated is called the **bandwidth**.

The bandwidth is a physical property of the transmission medium that depends on, for example, the construction, thickness, and length of a wire or fiber.

The bandwidth is still the width of the band of frequencies that are passed, and the information that can be carried depends only on this width and not on the starting and ending frequencies. Signals that run from 0 up to a maximum frequency are called baseband signals. Signals that are shifted to occupy a higher range of frequencies, as is the case for all wireless transmissions, are called passband signals.

For digital transmission, the goal is to receive a signal with just enough fidelity to reconstruct the sequence of bits that was sent. For example, given a bit rate of b bits/sec, the time required to send the 8 bits in our example 1 bit at a time is 8/b sec, so the frequency of the first harmonic of this signal is b /8 Hz. This data rate is the end result of using the analog bandwidth of a physical channel for digital transmission.

Analog bandwidth (Hz) ≠ Digital bandwidth (bits/sec)

**2.1.3 The maximum data rate of a channel**

Nyquist proved that if an arbitrary signal has been run through a low-pass filter of bandwidth B, the filtered signal can be completely reconstructed by making only 2B (exact) samples per second. For example, a noiseless 3-kHz channel cannot transmit binary signals at a rate exceeding 6000 bps.

maximum data rate (non-noisy channel) = 2B log2 V bits/sec

There is always random (thermal) noise present due to the motion of the molecules in the system. The amount of thermal noise present is measured by the ratio of the signal power to the noise power, called the **SNR (Signal-to-Noise Ratio)**.

Usually, the ratio is expressed on a log scale. The units of this log scale are called **decibels (dB)**.

maximum data rate (noisy channel) = B log2 (1 + S/N)

Diagram

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2.2 Guided Transmission Media

The purpose of the physical layer is to transport bits from one machine to another. Various physical media can be used for the actual transmission.

Media are roughly grouped into guided media (fiber optics), unguided media (satellites), and lasers through the air.

**2.2.1 Magnetic Media**

One of the most common ways to transport data from one computer to another is to write them onto magnetic tape or removable media. Although this method is not as sophisticated as using a geosynchronous communication satellite, it is often more cost effective, especially for applications in which high bandwidth or cost per bit transported is the key factor.

**2.2.2 Twisted Pairs**

For many applications an online connection is needed. One of the oldest and still most common transmission media is **twisted pair**. A twisted pair consists of two insulated copper wires, typically about 1 mm thick. The wires are twisted together in a helical form, just like a DNA molecule. Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, the waves from different twists cancel out, so the wire radiates less effectively. A signal is usually carried as the difference in voltage between the two wires in the pair.

Diagram

Description automatically generatedTwisted pairs can be used for transmitting either analog or digital information. The bandwidth depends on the thickness of the wire and the distance traveled, but several megabits/sec can be achieved for a few kilometers in many cases.

**2.2.3 Coaxial Cable**

Another common transmission medium is the coaxial. It has better shielding and greater bandwidth than unshielded twisted pairs, so it can span longer distances at higher speeds.

A coaxial cable consists of a stiff copper wire as the core, surrounded by an insulating material. The insulator is encased by a cylindrical conductor, often as a closely woven braided mesh. The outer conductor is covered in a protective plastic sheath.

Diagram

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The construction and shielding of the coaxial cable give it a good combination of high bandwidth and excellent noise immunity.

**2.2.5 Fiber Optics**

Fiber optics are used for long-haul transmission in network backbones, highspeed LANs (although so far, copper has always managed catch up eventually), and high-speed Internet access such as **FttH (Fiber to the Home)**. An optical transmission system has three key components: the light source, the transmission medium, and the detector.

The transmission medium is an ultra-thin fiber of glass. The detector generates an electrical pulse when light falls on it. Since any light ray will be reflected internally, many different rays will be bouncing around at different angles. Each ray is said to have a different mode, so a fiber having this property is called a **multimode fiber**.

However, if the fiber’s diameter is reduced to a few wavelengths of light the fiber acts like a wave guide and the light can propagate only in a straight line, without bouncing, yielding a **single-mode fiber**.

Diagram

Description automatically generatedThe attenuation of light through glass depends on the wavelength of the light (as well as on some physical properties of the glass). It is defined as the ratio of input to output signal power. Light pulses sent down a fiber spread out in length as they propagate. This spreading is called **chromatic dispersion**.

At the center of the cable is the glass core through which the light propagates. The core is surrounded by a glass cladding with a lower index of refraction than the core, to keep all the light in the core.

2.3 Wireless Transmission

**2.3.1 The Eletromagnetic Spectrum**

The radio, microwave, infrared, and visible light portions of the spectrum can all be used for transmitting information by modulating the amplitude, frequency, or phase of the waves. Ultraviolet light, X-rays, and gamma rays would be even better, due to their higher frequencies, but they are hard to produce and modulate, do not propagate well through buildings, and are dangerous to living things.

The terms LF, MF, and HF refer to Low, Medium, and High Frequency (10 MHz), respectively. Clearly, when the names were assigned nobody expected to go above 10 MHz, so the higher bands were later named the Very, Ultra, Super, Extremely, and Tremendously High Frequency bands.

In **frequency hopping spread spectrum**, the transmitter hops from frequency to frequency hundreds of times per second. It is popular for military communication because it makes transmissions hard to detect and next to impossible to jam.

**2.3.2 Radio Transmission**

Radio waves also are omnidirectional, meaning that they travel in all directions from the source, so the transmitter and receiver do not have to be carefully aligned physically.

2.5 Digital Modulation and Multiplexing

The process of converting between bits and signals that represent them is called **digital modulation**. We will start with schemes that directly convert bits into a signal. These schemes result in **baseband transmission**, in which the signal occupies frequencies from zero up to a maximum that depends on the signaling rate.

Then we will consider schemes that regulate the amplitude, phase, or frequency of a carrier signal to convey bits. These schemes result in **passband transmission**, in which the signal occupies a band of frequencies around the frequency of the carrier signal.

Channels are often shared by multiple signals. After all, it is much more convenient to use a single wire to carry several signals than to install a wire for every signal. This kind of sharing is called **multiplexing**.

**2.5.1 Baseband Transmission**

The most straightforward form of digital modulation is to use a positive voltage to represent a 1 and a negative voltage to represent a 0. For an optical fiber, the presence of light might represent a 1 and the absence of light might represent a 0. This scheme is called **NRZ (Non-Return-to-Zero)**. At about halfway through the sent bit signal, the voltage is turned down to zero, and based on the next bit the voltage will change.

This signal will not look exactly like the signal that was sent. It will be attenuated and distorted by the channel and noise at the receiver. To decode the bits, the receiver maps the signal samples to the closest symbols.

-------Bandwith Efficiency-------

With NRZ, the signal may cycle between the positive and negative levels up to every 2 bits. This means that we need a bandwidth of at least B/2 Hz when the bit rate is B bits/sec.

One strategy for using limited bandwidth more efficiently is to use more than two signaling levels. By using four voltages, for instance, we can send 2 bits at once as a single **symbol**. We call the rate at which the signal changes the **symbol rate** (a.k.a. baud rate) to distinguish it from the **bit rate**.

-------Clock Revovery-------

For all schemes that encode bits into symbols, the receiver must know when one symbol ends and the next symbol begins to correctly decode the bits. One strategy is to send a separate clock signal to the receiver. However, a separate clock line could prove wasteful, so a clever trick used here is mixing the clock signal with the data signal by XORing them together so that no extra line is needed.

When it is XORed with the 0 level it makes a low-to-high transition that is simply the clock. This transition is a logical 0. When it is XORed with the 1 level it is inverted and makes a high-tolow transition. This transition is a logical 1. This scheme is called **Manchester encoding** and was used for classic Ethernet.

As a step in the right direction, we can simplify the situation by coding a 1 as a transition and a 0 as no transition, or vice versa. This coding is called **NRZI (Non-Return-to-Zero Inverted)**, a twist on NRZ.

A well-known code to do this is called **4B/5B**. Every 4 bits is mapped into a 5-bit pattern with a fixed translation table. The five bit patterns are chosen so that there will never be a run of more than three consecutive 0s.

This scheme adds 25% overhead, which is better than the 100% overhead of Manchester encoding.

An alternative approach is to make the data look random, known as scrambling. In this case it is very likely that there will be frequent transitions. A scrambler works by XORing the data with a pseudorandom sequence before it is transmitted.

**2.5.2 Passband Transmission**

For wireless channels, it is not practical to send very low frequency signals because the size of the antenna needs to be a fraction of the signal wavelength, which becomes large.

This means that we can take a **baseband** signal that occupies 0 to B Hz and shift it up to occupy a **passband** of S to (S + B) Hz without changing the amount of information that it can carry, even though the signal will look different. To process a signal at the receiver, we can shift it back down to baseband, where it is more convenient to detect symbols.

Diagram

Description automatically generated with medium confidenceIn **ASK (Amplitude Shift Keying)**, two different amplitudes are used to represent 0 and 1. Similarly, with **FSK (Frequency Shift Keying)**, two or more different tones are used. In the simplest form of **PSK (Phase Shift Keying)**, the carrier wave is systematically shifted 0 or 180 degrees at each symbol period. Because there are two phases, it is called **BPSK (Binary Phase Shift Keying)**. ‘‘Binary’’ here refers to the two symbols. Were there to be four phases it would be called **QPSK (Quadrature Phase Shift Keying)**.

We can combine these schemes and use more levels to transmit more bits per symbol.

In the three examples that are shown, the points give the legal amplitude and phase combinations of each symbol. The phase of a dot is indicated by the angle a line from it to the origin makes with the positive x-axis. The amplitude of a dot is the distance from the origin. This figure is a representation of QPSK.

This kind of diagram is called a **constellation diagram**. In the middle, we can see a modulation scheme with a denser constellation. Sixteen combinations of amplitudes and phase are used, so the modulation scheme can be used to transmit 4 bits per symbol. It is called **QAM-16**, where QAM stands for **Quadrature Amplitude Modulation**.

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