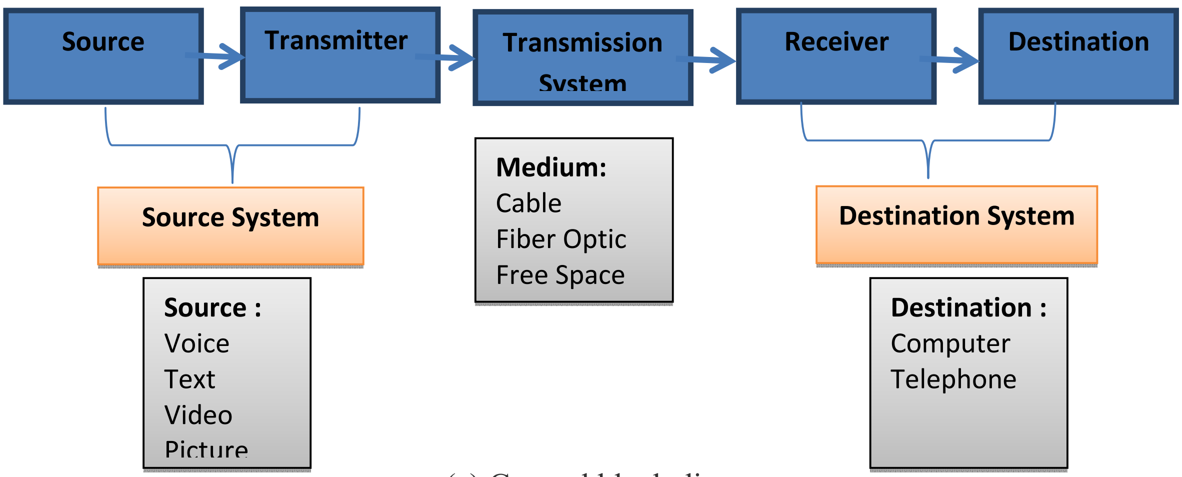
1. Introduction

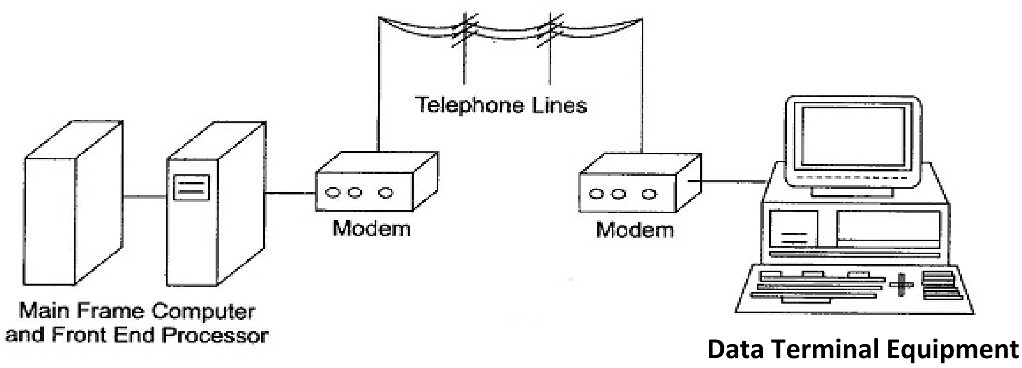
Communication involves passing information from a source to a destination, like from one computer to another or between devices. This transfer of data from one machine to another is known as Data Communication, where both the sender and receiver must understand the data correctly (see figure 1). For communication to work between devices, they have to agree on how the data should look, and these rules are called a protocol. A communications protocol must cover aspects like the transmission media used,the rate of transmission(measured in baud or bps), whether the transmission is to be synchronous or asynchronous, and whether data is to be transmitted in half-duplex or full-duplex mode. To get a grasp of this, we'll explore some basic concepts and terms related to data transmission in this chapter.

2. Definition

Data transmission means sending digital information between two devices using electronic systems. This information can take different forms like electric signals, radio waves, or light.



(a) General block diagram



(b) Example

Figure 1. Data Communication Block Diagram

The sourcegenerates data to be transmitted.

The transmission medium is the physical path by which a message travels form sender to receiver.

The receiverconverts the received signal in an interpretable form fordestination

The destination takes incoming data

3. Terminology in Data Transmission

The transmission of data from one machine to another in a way that both the sender and the receiver correctly understand the data is referred to as **Data Communication**.

Channel

In communication, a channel refers to the pathway connecting two computers or devices, encompassing the necessary elements for transferring electronic information between locations. This can involve the physical medium like coaxial cable, or a specific frequency within a larger channel or wireless medium. Channel capacity denotes the highest reliable information transfer rate over time. Two fundamental channel types exist: Analog, which utilizes sinusoidal or non-sinusoidal waves (e.g., commercial radio); and Digital, which employs pulsed wave signals (e.g., public telephone systems).

Baud

Named after its inventor J.M.E. Baudot, the term "baud," pronounced as "bawd," represents the count of signaling elements occurring per second. At slower speeds, a single bit is encoded within each electrical change. Baud quantifies the bits transmitted per second, e.g., 300 baud conveys 300 bits per second (abbreviated as 300 bps). Under asynchronous communication, requiring 10 bits per character, this corresponds to 30 characters per second (cps). For rates below 1,200 baud, dividing by 10 reveals characters per second. At higher speeds, multiple bits can be encoded per electrical change. 4,800 baud might allow 9,600 bits per second. Hence, higher data transfer speeds are typically denoted in bits per second (bps), not baud. For instance, a 9,600 bps modem may function at 2,400 baud.

Bandwidth

Bandwidth refers to the data or signals that a transmission medium can convey in a set time. It depends on length, medium, and signaling method. High bandwidth enhances throughput and performance. Media with high capacity possess high bandwidth; those with limited capacity have low bandwidth. It's computed from a medium's highest to lowest frequencies. Digital devices measure bandwidth in bits or bytes per second (bps), while analog devices use cycles per second (Hertz or Hz). Bandwidth is crucial for I/O devices; a fast disk drive can be hindered by a low-bandwidth bus.

Frequency

Frequency signifies the cycles a signal finishes in a second. The measurement unit is the Hertz (Hz), named after mathematician Heinrich Hertz. One Hz equals one cycle/second. Kilohertz (kHz) is 1000Hz, and Megahertz (MHz) is 1000 kHz or 1000000Hz.

Binary rate

The binary rate measures the speed of digital data transfer, expressed in bits per second (bit/s, b/s, or bps). Its main multiples are:

- Kilobits per second (kbit/s), equivalent to 1000 bit/s.
- Megabits per second (Mbit/s), equivalent to 1000 kbit/s.
- Gigabits per second (Gbit/s), equivalent to 1000 Mbit/s.

4. Modes of data transmission

Data transmission from source to destination occurs through various methods. The modes of data transmission can be categorized as follows:

- Parallel and Serial Communication.
- Asynchronous, Synchronous, and Isochronous Communication.
- Simplex, Half-duplex, and Full-duplex Communication.

Serial and Parallel Communication

In the realm of communication between devices, the exchange of commands, data, and control information is a constant requirement. When it comes to transmitting such elements from sender to receiver, two primary options exist: serial communication and parallel communication.

Serial Communication

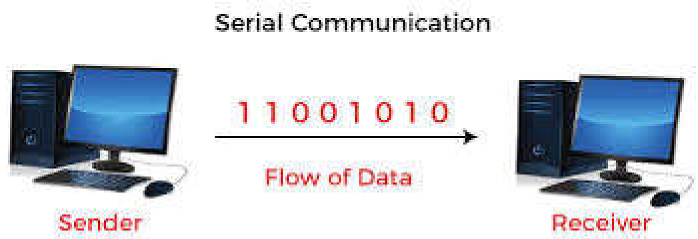


Figure 2. Serial Communication

Serial data transmission involves transmitting bits sequentially, as depicted in Figure 1, usually starting with the least significant bit (LSB). During serial transmission, characters or bytes are separated and sent bit by bit, necessitating hardware to convert data from parallel to serial. Upon arrival, the bits are gathered, organized into bytes in the destination's memory, requiring conversion from serial to parallel.

Unlike parallel transmission, serial transmission necessitates just one circuit linking the two devices. This attribute makes serial transmission well-suited for long-distance communication.

Parallel Communication

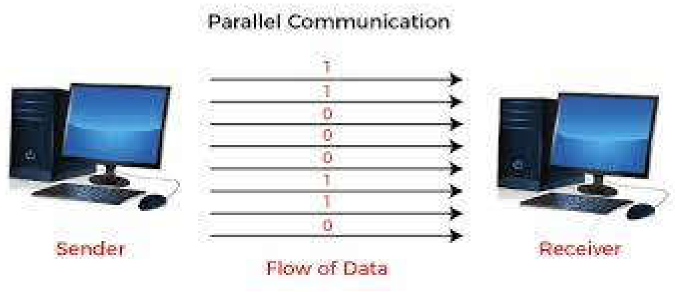


Figure 3. Parallel Communication

In parallel transmission, all bits of a byte are simultaneously sent on separate wires, as depicted in Figure 2. This method necessitates multiple connections between devices, enabling rapid data transfer. However, parallel transmission is costly due to the need for numerous wires in both sending and receiving equipment. Moreover, it demands high precision which becomes challenging to maintain over extended distances.

5. Asynchronous, Synchronous and Isochronous Communication

One of the primary challenges in data transmission is synchronizing the receiver (destination) with the sender (source). This issue is particularly pronounced in serial communication. The receiver must accurately identify the start of each new character in the bit stream it receives; failure to do so can lead to misinterpretation of the incoming data. Three methods employed for synchronization are:

- Asynchronous Communication
- Synchronous Communication
- Isochronous Communication

Asynchronous Communication

Asynchronous communication transmits individual characters one at a time, enclosed by a start bit and 1 or 2 stop bits. Each frame commences with a start bit, which aids the receiving device in adjusting to the signal's timing. The message's initiation can occur at any moment. Messages are kept concise to prevent synchronization issues during transfer. Asynchronous communication is commonly employed for transmitting character data, especially for irregularly timed input such as keyboard typing. A standard character data frame includes four components:

1. **Start bit**: Initiates the frame and facilitates receiving device synchronization.
2. **Data bits**: Comprising 7 or 8 bits during character data transmission.

3. **Parity bit(s)**: Optionally used for basic transmission error detection.
4. **Stop bit or bits**: Marks the conclusion of the data frame.

Error detection in asynchronous transmission involves the use of parity bits. Parity techniques can identify errors affecting a single bit; however, errors impacting two or more bits might escape detection through parity methods.

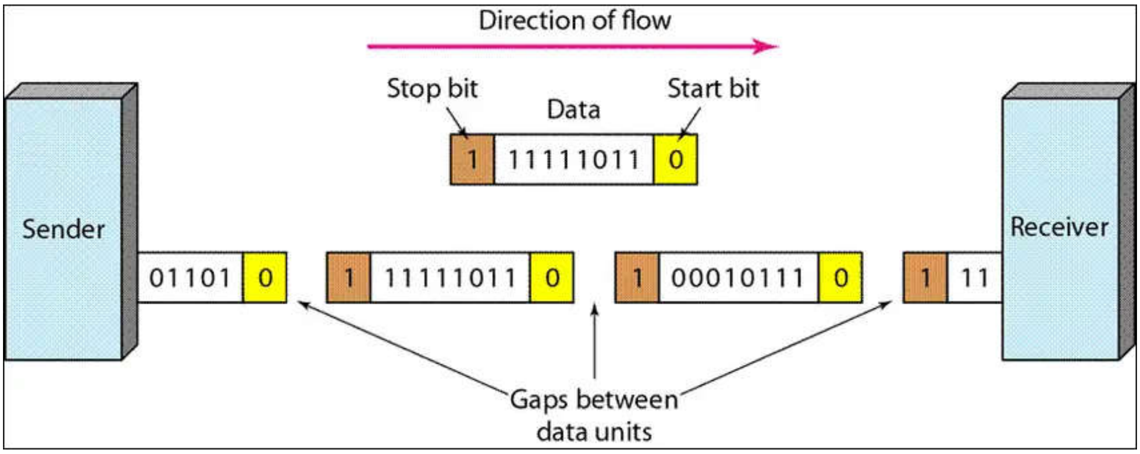


Figure 4. Asynchronous communication

Advantages of Asynchronous Communication:

- Asynchronous transmission is simple, cost-effective, and well-suited for transmitting small, irregularly timed frames (e.g., keyboard data entry).
- Since each character is self-contained, corruption of one character during transmission doesn't affect its neighboring characters.

Disadvantages of Asynchronous Communication:

- The addition of start, stop, and parity bits to each character increases transmission overhead, consuming bandwidth. Consequently, asynchronous transmission is unsuitable for transmitting large data volumes.
- Successful transmission heavily relies on detecting start bits, which are prone to being missed or occasionally generated due to line interference, potentially leading to transmission failures.
- The speed of asynchronous transmission is constrained by distortion effects.

Synchronous Communication

In synchronous communication, the entire block of data bits is transferred collectively instead of transmitting one character at a time. Transmission commences at predetermined regular intervals. A synchronization signal (sync signal) notifies the receiving station of an incoming frame and aids in synchronization. Sync signals employ distinct bit patterns that won't appear elsewhere in messages, ensuring easy recognition by the receiver. As both transmitter and receiver maintain synchronization during transmission, longer frames become feasible.

Since longer frames are employed, the parity-based error detection method isn't suitable due to its inability to accurately report errors when multiple bits are affected. Therefore, synchronous transmission utilizes the Cyclic Redundancy Check (CRC) technique. The transmitter uses an algorithm to compute a CRC value summarizing the data bits, appending it to the data frame. The receiver recalculates the CRC using the same algorithm and compares it with the frame's CRC. Matching values indicate error-free transmission.

An end bit pattern denotes frame conclusion, similarly designed to be distinct and easily recognizable at the frame's end.

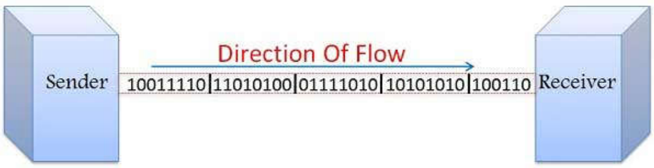


Figure 5. Asynchronous communication

Serial synchronous transmission serves for high-speed computer communication, especially for transmitting large data volumes. It offers these advantages:

- Synchronous transmission is efficient, requiring only 4 additional bytes (for start and end frames) to transmit up to 64 k bits.
- Synchronous transmission is less susceptible to distortion, enabling high-speed usage.

However, it comes with these drawbacks:

- Synchronous transmission is costly due to complex circuitry requirements and implementation challenges.
- In case of transmission errors, the entire data block is lost, not just a single character.
- The sender can't transmit characters as they occur; rather, it needs to accumulate a block before transmission. This makes it unsuitable for irregularly timed character generation.

Isochronous Communication

This approach integrates elements of both asynchronous and synchronous communications. Like the asynchronous method, each character possesses start and stop bits. However, the idle period between characters is not random; it's a precise multiple of one character time interval. If the time to transmit a character (including its parity, start, and stop bits) is represented as 't', the interval between characters can't be random (asynchronous) nor 0 (synchronous), but rather 't', '2t', '3t', and so on, where 'n' is any positive integer. Consequently, the received signal is expected within certain delay bounds, typically Tmin to Tmax.

Advantages of Isochronous Communication:

- Isochronous transmission ensures guaranteed transmission rates and offers a high degree of determinism.
- It boasts low overheads.
- It supports high-speed data transfer.

Disadvantages of Isochronous Communication:

- In isochronous transmission, it's imperative to ensure that the clocking device is fault-tolerant.

5. Simplex, Half Duplex and Full Duplex Communication

This classification of data transmission is based on the fundamental questions of how communication sends data and when it does so. The three primary methods are:

- Simplex.
- Half Duplex.
- Full Duplex, also known as Duplex.

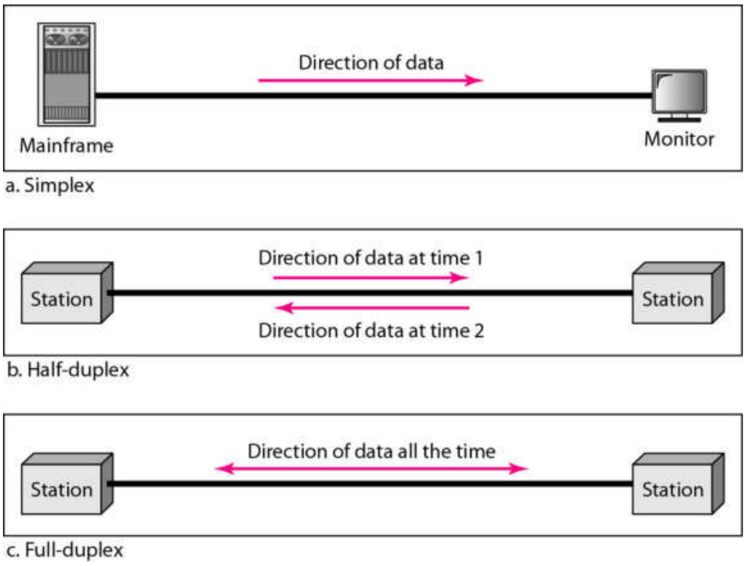


Figure 6. Simplex, Half Duplex and Full Duplex communication

Simplex

The simplest signal flow technique is the simplex configuration. In simplex transmission, one of the communicating devices can solely send data, while the other is exclusively a receiver. Communication occurs in a single direction (unidirectional), with one party functioning as the transmitter and the other as the receiver, as depicted in Figure 3. Examples of simplex communication include basic radio broadcasts and public television broadcasts, where you can receive data from stations but cannot transmit data back. For instance, a television station emits electromagnetic signals without anticipating or monitoring a response from the television sets. This channel design is straightforward and cost-effective to establish.

Half Duplex

Half duplex is two-way communication, but only one party can transmit data at a time. Unlike simplex mode, where only one device can send, both devices can transmit in half duplex, though not simultaneously. This configuration offers simplex communication in both directions over a single channel (Figure 4). When one device sends data, the other must receive, and vice versa. Turns are taken for sending data, necessitating a turnaround time as the device switches from receiving to transmitting. This introduces a delay, making half duplex slower than simplex. However, it's more versatile as both devices can send and receive.

Note the distinction between simplex and half duplex: Half duplex permits two-way communication with one party transmitting at a time, while simplex is one-way communication with a dedicated transmitter and receiver.

For instance, a walkie-talkie functions in half duplex mode, allowing one party to talk at a time.

Many modems offer a choice between half-duplex and full-duplex modes. The suitable option depends on the program used for data transmission through the modem.

Full Duplex

Full duplex entails simultaneous data transmission in two directions. In this mode (Figure 5), both devices can send and receive data concurrently. Achieving this requires independent transmitting and receiving capabilities at both ends of the communication channel. Simultaneous bi-directional communication optimizes channel throughput without necessitating increased bandwidth. For instance, a telephone operates in full duplex, enabling both parties to converse simultaneously. Conversely, a walkie-talkie is half duplex, allowing only one party to transmit at a time.

Many modems offer a choice between full-duplex and half-duplex modes, depending on the communications program in use.

6. Analog and digital data transmission

We understand that signals can be broadly categorized as Analog and Digital. The ways these signal types can be transmitted from a source to a destination also fall into two categories:

- Analog data transmission and Digital data transmission.

Analog Signal

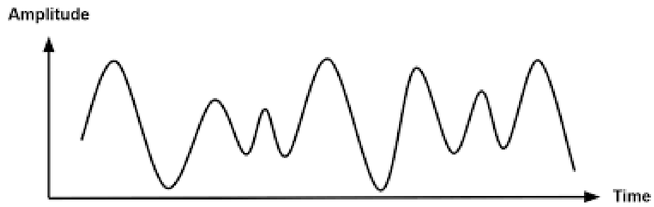


Figure 7. Analog signal

Analog signals exhibit continuous variations in one or more values, representing data through these fluctuations. Analog signals are continuous and can be depicted using sine waves. Human voice, video, and music exemplify analog signals, characterized by changing amplitude (volume) and frequency (pitch). For instance, human voice generates a continuously varying analog signal containing multiple frequencies, which is transmitted analogously. Amplifiers are utilized to counter the signal attenuation during transmission. However, amplifiers amplify both the original signal and accompanying noise. Consequently, signal distortion can lead to irreversible loss.

This form of transmission isn't suitable when high accuracy is crucial. It's commonly employed in telephony where slight communication distortion is acceptable. Analog techniques excel at capturing the nuanced aspects of the real world. Yet, despite advanced electronic equipment, perfect replication of analog signals remains unattainable. Audio and video recordings in third and fourth generations display noticeable degradation over time.Converting analog signals into digital format enables indefinite preservation of original audio or video data within specified error limits. This digital transformation safeguards data integrity, allowing copying without degradation. Once analog signals are precisely measured and digitized, storage and transmission maintain their integrity, thanks to the accuracy of digital methods.

Digital Data Transmission

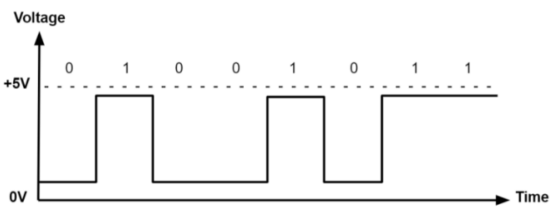


Figure 8. Digital Data Transmission

Digital data transmission encompasses systems based on discrete data or events. Computers function as digital machines, discerning between two fundamental values: 0 and 1, representing off and on. Representing intermediary values, like 0.25, is not straightforward. All data processed by computers is encoded digitally as sequences of zeroes and ones.

Output from computers takes the form of digital signals. The bandwidth of digital signals is virtually infinite compared to mediums with limited bandwidth. However, when signals enter a medium, only specific frequencies allowed by the medium's bandwidth can be used. Signal distortion occurs during transmission, rendering the signal unrecognizable over extended distances. Repeaters, hardware devices, regenerate digital signals. They detect signal values at intervals to reconstitute the 0s and 1s, preventing information loss. The number of repeaters depends on the source-to-destination distance. A line with properly spaced repeaters is termed a digital line.

Converting information, music, voice, and video into binary digital form allows precise electronic manipulation, preservation, and high-speed regeneration. Copies of computer files remain identical to the original. This advantage underscores the power of digital processing.

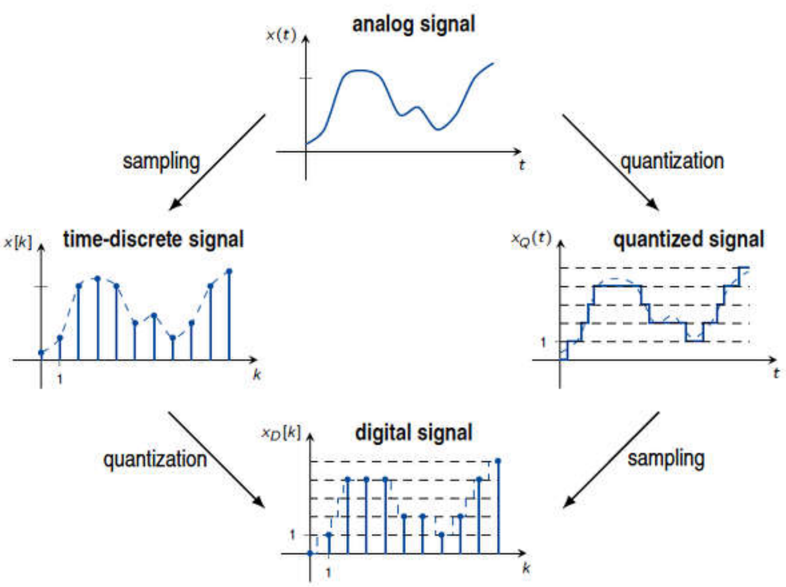


Figure 9. Analog to Digital Data conversion

7. Transmission impairments

When data is transmitted from a transmitter to a receiver, there is a possibility of transmission errors. If the transmission media were perfect, the receiver would receive the exact signal that the transmitter sent. Unfortunately, media are not perfect, so the received signal may sometimes differ from the transmitted signal. Transmission lines experience three main issues:

- Attenuation.
- Delay distortion.
- Noise.

Attenuation

Attenuation refers to the loss of energy as a signal propagates outward. On guided media (such as wires and optical fibers), the signal decreases logarithmically with distance. At short distances, attenuation is minimal, allowing the original signal to be recognized with relatively little distortion. However, attenuation increases over longer distances as some of the signal's energy is absorbed by the medium. This loss is quantified in decibels per kilometer (dB/km). The extent of energy loss varies with frequency, and higher frequencies experience greater attenuation.

When attenuation is significant, the receiver might struggle to detect the signal, or the signal's strength could drop below the noise level. In many cases, a medium's attenuation properties are understood, which allows for the placement of amplifiers to mitigate frequency-dependent attenuation. While this approach is helpful, it can never fully restore the signal to its original shape.

Delay Distortion

Delay distortion arises from the fact that signals of varying frequencies travel at differing speeds along the medium. Any intricate signal can be broken down into various sinusoidal signals of different frequencies, thus establishing a frequency bandwidth for each signal.

One characteristic of signal propagation is that the highest speed of frequency travel occurs at the center of this bandwidth, while it is slower at both ends. Consequently, at the receiving end, signals with different frequencies within a given bandwidth will arrive at varying times. If these received signals are measured at a specific moment, they will not precisely resemble the original signal, potentially leading to misinterpretation.

For digital data, the rapid components from one bit might catch up to and surpass the slower components from the preceding bit. This mixing of the two bits increases the likelihood of incorrect reception.

Noise

Noise represents undesired energy originating from sources apart from the transmitter. Thermal noise results from the random movement of electrons within a wire and is an inevitable occurrence. Crosstalk arises due to inductive coupling between two closely situated wires. Occasionally, during a telephone conversation, you might hear another conversation in the background — this is crosstalk. Lastly, impulse noise occurs due to spikes on the power line or other factors. In the case of digital data, impulse noise can lead to the erasure of one or more bits.

Concept of Delays

The average delay required to transmit a packet from its source (origin) to its destination significantly impacts the performance of a data network. Considerations of delay heavily influence the selection and effectiveness of network algorithms, including routing and flow control. Due to these reasons, comprehending the nature and mechanisms of network delay, as well as its dependence on network characteristics, becomes crucial.

Substantial delay poses a significant challenge for data transfer. The overall delay can be classified into two types. The first type is fixed delay, representing the inherent delay due to factors like buffering and link capacity. The second type is variable delay, arising from packet queuing within routers, congestion, and similar factors. Among the various types of delay, this discussion will focus on Transmission delay and Propagation delay.

- ***Transmission delay***

Transmission delay is the delay that arises from link capacities. When routers support resource reservation methods, transmission delays can likely be maintained at a level that satisfies the overall delay constraint of 200 ms.

During data transmission, a minimal delay is always present due to the capacity of the links through which the data traverses. However, the most substantial portion of transmission delay typically stems from packet queuing within routers. This delay is quite variable and hinges on both the number of routers along the path and the load on these routers.

- ***Propagation delay***

Satellite microwave systems can extend their reach to remote locations on Earth and also establish communication with mobile devices. Given that the signal travels over a considerable distance (approximately 36,000 km), there exists a delay of about 5 ms between the signal's transmission and reception. This time delay is referred to as propagation delay. Such delays are present in all communication channels, no matter how small they may be.

Propagation delay signifies the time interval between the transmission of the last bit at the source node of the link and the reception of the last bit at the destination node. This delay is proportional to the physical separation between the transmitter and the receiver. In specific cases, like a satellite link or a high-speed connection, it can become notably substantial.

The propagation delay is reliant on the physical attributes of the link and remains unaffected by the volume of traffic carried by the link.

8. Transmission media and its characteristics

Various physical media facilitate the transmission of information between different locations. Each medium offers unique advantages in terms of bandwidth, delay, cost, installation, and maintenance. Transmission media are broadly classified into guided media, which encompass copper wire and fiber optics, and unguided media, which include radio and lasers.

Magnetic Media

One of the frequently employed methods to transfer data from one computer to another involves writing the data onto magnetic tape or floppy disks, physically transporting these tapes or disks to the target machine, and subsequently reading them back in. Although this approach may not be as advanced as utilizing a geosynchronous communication satellite, it often proves to be significantly more cost-effective. This is particularly true for scenarios where high bandwidth or the cost per transported bit are crucial considerations.

Figure 10. Magnetic Media

Twisted Pair

Although the bandwidth characteristics of magnetic tape are excellent, the delay characteristics are poor. Transmission time is measured in minutes or hours, rather than milliseconds. For numerous applications, an online connection is imperative. The oldest and still the most prevalent transmission medium is the twisted pair. A twisted pair consists of two insulated copper wires, usually around 1 mm thick. The primary purpose of twisting these wires is to mitigate electrical interference from nearby similar pairs.

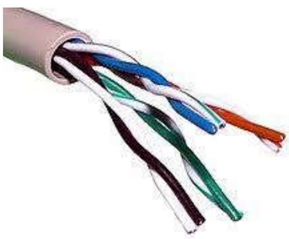


Figure 10. Twisted pairs

The telephone system employs twisted pairs extensively. Virtually all telephones are linked to the telephone company office through a twisted pair. Twisted pairs can cover several kilometers without requiring amplification. However, for longer distances, repeaters are necessary. When multiple twisted pairs run in parallel for extended distances — such as all the wires connecting an apartment building to the telephone company office — they are bundled together and encased in a protective sheath. The twisting prevents interference between the pairs within these bundles.

Twisted pairs can serve for either analog or digital transmission. The bandwidth is contingent on the wire thickness and distance traveled, but in many cases, several megabits per second can be achieved for a few kilometers.

Twisted pair cable holds the following advantages:

- Offers adequate performance and the lowest cost per meter compared to other cable types.
- Due to their cost-effectiveness during installation, twisted pairs remain popular and are likely to retain their wide usage for years to come.

Baseband Coaxial Cable

Another prevalent transmission medium is the coaxial cable, commonly referred to as 'coax.' This type of cable offers better shielding compared to twisted pairs, enabling it to cover longer distances at higher speeds.

A coaxial cable is composed of a rigid copper wire serving as the core, encircled by an insulating material. This insulator is then surrounded by a cylindrical conductor, often in the form of a closely woven braided mesh. The outer conductor is further protected by a plastic sheath. A visual representation of a coaxial cable's cross-section can be seen in Figure 9.

The construction and shielding of coaxial cable grant it a favorable combination of high bandwidth and excellent noise immunity. The achievable bandwidth is influenced by the length of the cable. For 1-km cables, data rates of 1 to 2 Gbps are feasible. Longer cables can also be utilized, but primarily at lower data rates or with intermittent amplification. Coaxial cables were once extensively employed in the telephone system; however, they have largely given way to fiber optics for long-haul routes. Nonetheless, coaxial cable still retains wide use for cable television and certain local area networks.

Broadband Coaxial Cable

The alternative form of coaxial cable system utilizes analog transmission over conventional cable television wiring, often referred to as broadband. While the term 'broadband' originally stems from the telephone realm, where it designates anything wider than 1 MHz, within the computer networking context, 'broadband cable' pertains to any cable network employing analog transmission.

Because broadband networks leverage standard cable television technology, the cables can accommodate frequencies of up to 300 MHz (and often even up to 450 MHz). Due to the utilization of analog signaling, these cables can extend for nearly 100 km. This analog signaling is less sensitive than digital signaling. To transmit digital signals on an analog network, each interface necessitates electronics that convert outgoing bit streams into analog signals, and incoming analog signals back into bit streams. Depending on the nature of the electronics, approximately 1 bps might occupy about 1 Hz of bandwidth. At higher frequencies, advanced modulation techniques enable the transmission of multiple bits per Hz.

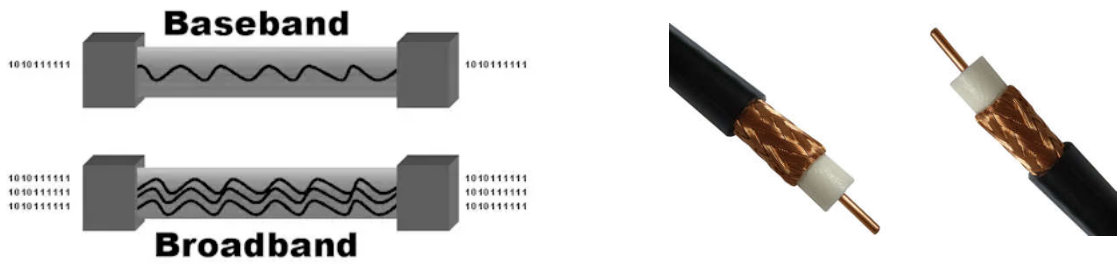


Figure 10. Coaxial Cables

Optical Fiber

Fiber optic cable consists of fine strands of silicon glass fiber, finer than a human hair, coated with a refractive surface. Signals are converted into light pulses before transmission. When light, emitted by a laser or LED, is directed into the strand, it travels along the fiber (the refractive layer prevents its escape). Each fiber optic strand can accommodate thousands of speech channels and multiple TV channels simultaneously. Fiber optic technology finds use in long-haul telecommunications links, high-speed data communication for computers, and information services like PAY TV for homes.

Advantages of fiber optic cable include:

- High capacity due to laser bandwidth
- Immunity to electromagnetic interference
- Ability to cover long distances with low attenuation

Its disadvantages are:

- High cost
- Difficulty in joining
- Expensive installation requiring skilled labor

An optical fiber transmission system comprises three components: the light source, the transmission medium, and the detector. Traditionally, a pulse of light represents a 1 bit, while the absence of light represents a 0 bit. The transmission medium is an ultra-thin glass fiber. The detector is a photo-detector generating an electrical pulse when exposed to light.

Attaching a light source to one end and a detector to the other creates a unidirectional data transmission system. It accepts an electrical signal, converts and transmits it as light pulses, and then reconverts the output to an electrical signal at the receiving end.

Fibers can be connected in three ways: First, they can terminate in connectors and be plugged into fiber sockets. Connectors result in about 10 to 20 percent light loss but facilitate system reconfiguration.

Second, they can be mechanically spliced. This involves placing carefully cut ends together in a special sleeve and clamping them. Alignment can be optimized by passing light through the junction and making small adjustments for signal maximization. Trained personnel can complete mechanical splicing in 5 minutes, with approximately 10 percent light loss.

Third, two fiber pieces can be fused (melted) to create a solid connection. Fusion splicing is nearly as effective as a single drawn fiber but still incurs slight attenuation. Reflections can occur at splice points for all three methods, potentially interfering with the signal.

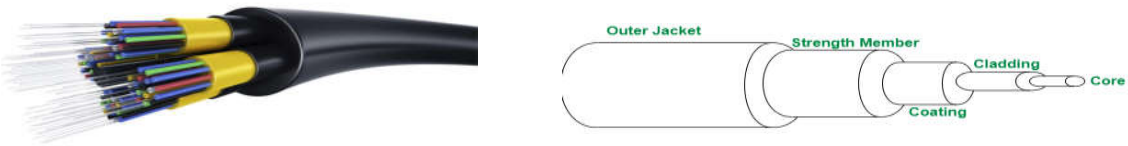


Figure 11. Optical fiber

Comparison between Optical Fiber and Copper Wire

Optical fiber presents numerous advantages over copper wire. These advantages include:

- High Bandwidth: Optical fiber can handle much higher bandwidths than copper wire.
- Low Attenuation: Repeater placement is necessary only about every 30 km on long lines, in contrast to copper wires requiring repeaters every 5 km. This substantial reduction need in repeater leads to cost savings.
- Resilience: Optical fiber is unaffected by power surges, electromagnetic interference, and power failures. Additionally, it remains unharmed by corrosive chemicals in the air, making it suitable for harsh industrial environments.
- Lightweight: Optical fiber is lighter than copper. While one thousand 1-km-long twisted pairs weigh 8000 kg, two fibers with greater capacity weigh only 100 kg. This significant reduction in weight minimizes the demand for expensive mechanical support systems that require maintenance.
- Lower Installation Cost: For new installations, optical fiber incurs a lower installation cost than copper wire.
- Enhanced Security: Optical fibers do not leak light and are challenging to tap, providing robust security against potential wire trappers.

The superiority of optical fiber over copper wire lies in its underlying physics. When electrons move within a wire, they influence each other and are influenced by external electrons. In contrast, photons within a fiber do not interact with each other (due to their lack of electric charge) and remain unaffected by stray photons outside the fiber.

However, optical fiber also has its disadvantages:

- Complex Technology: Optical fiber is a complex technology requiring skills that many engineers may not possess.
- Unidirectional Nature: Inherent unidirectionality of optical transmission necessitates either two fibers or two frequency bands on one fiber for two-way communication.
- Higher Interface Cost: Fiber interfaces are more expensive than electrical interfaces.

9. Data encoding

Encoding is the process of converting data into various formats, including:

- Program compilation and execution
- Data transmission, storage, and compression/decompression
- Application data processing, such as file conversion

Encoding is also utilized to reduce the size of audio and video files. It's important to note that encoding is distinct from encryption, which is used to conceal content.

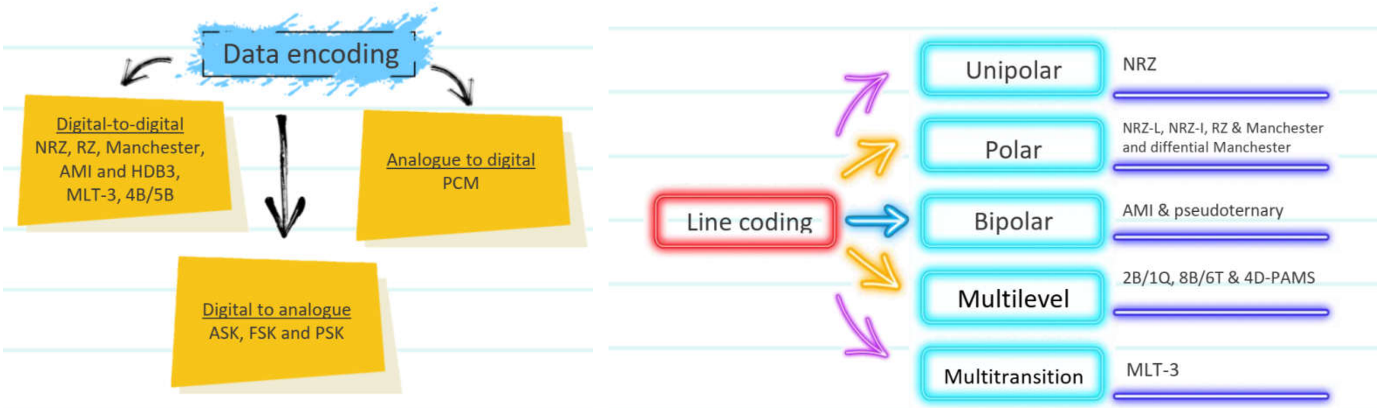


Figure 12. Line & data Encoding techniques

What is Line Coding?

Line coding is a technique that involves representing digital data as digital signals. Through this coding technique, it becomes possible to map a sequence of bits onto a digital signal.

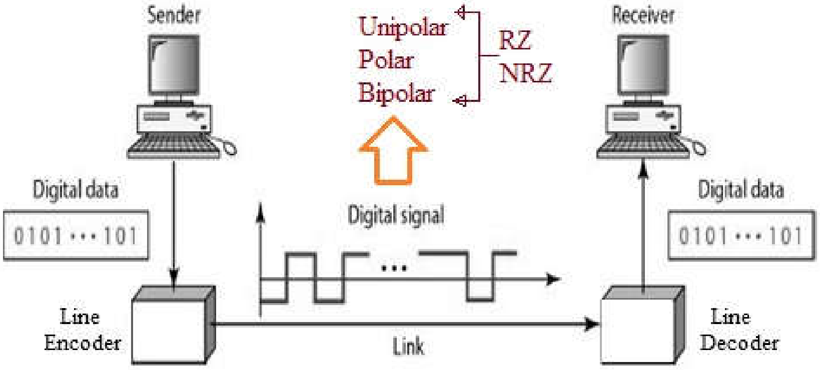


Figure 13. Line Encoding and Decoding

Digital-to-Digital Encoding (Converting Digital Data to Digital Signals through Digital Encoding)

Digital-to-Digital Encoding involves the process of converting digital data, which is represented in discrete binary form (consisting of 0s and 1s), into digital signals using specific encoding techniques. These encoding techniques are employed to ensure reliable and accurate transmission of the digital data over communication channels.

Unipolar Non-Return-to-Zero (NRZ)

In this encoding method, the signal does not return to zero in the middle of a bit. The figure illustrates a unipolar NRZ scheme.

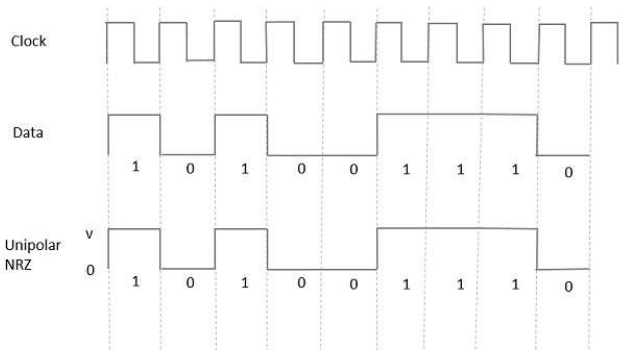


Figure 14. Unipolar Non-Return-to-Zero (NRZ)

Polar NRZ NRZ-L (Non-Return-to-Zero-Level):

In this scheme, the voltage level determines the value of the bit.

- 1 is represented by a negative voltage (low level).
- 0 is represented by a positive voltage (high level).

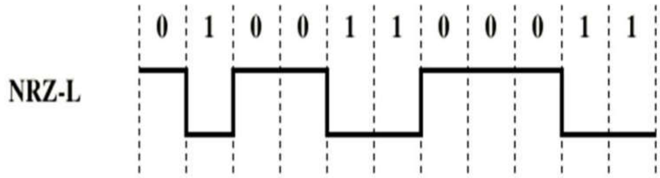


Figure 15. Polar NRZ NRZ-L (Non-Return-to-Zero-Level)

NRZ-I (Non-Return-to-Zero Invert):

In this encoding scheme, a bit is 0 if there is no change, and it is 1 if there is a change.

- 1 is indicated by the presence of a signal transition at the start of the bit time.
- 0 is indicated by the absence of a signal transition at the start of the bit time.

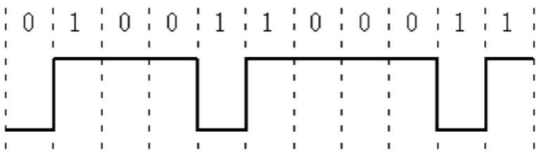


Figure 16.NRZ-I (Non-Return-to-Zero Invert)

Return-to-Zero (RZ) Encoding

In this encoding method, the signal state is determined by the voltage during the first half of each binary digit. The signal returns to a baseline state, often referred to as zero, during the second half of each bit. This baseline state is typically set to zero volts, although it can be different if needed.

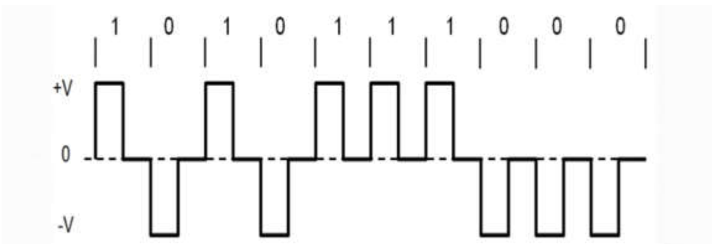


Figure 17. Return-to-Zero (RZ) Encoding

Manchester Encoding

- 1 : Low-to-high transition
- 0 : High-to-low transition

In Manchester encoding, there is always a mid-bit transition, which serves as a clocking mechanism. The direction of this mid-bit transition represents the digital data being encoded.

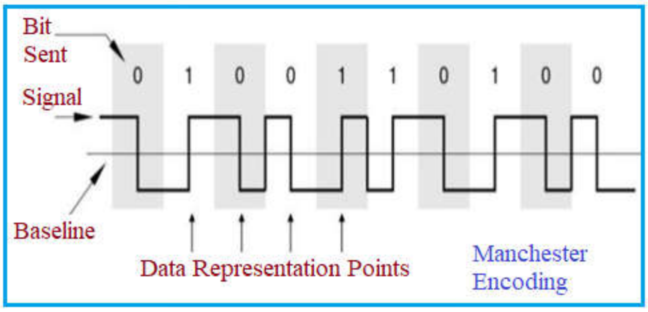


Figure 17. Manchester Encoding

Manchester Differential Encoding

- 1 : Transition from a high level to a low level
- 0 : Transition from a low level to a high level

Manchester Differential Encoding, also known as Differential Manchester Encoding, utilizes transitions for encoding digital data. Each bit is encoded by observing the transition between two consecutive bits. A transition at the beginning of the bit period represents a 1 and the absence of a transition indicates a 0. This encoding scheme ensures constant transitions, facilitating clock recovery and data synchronization.

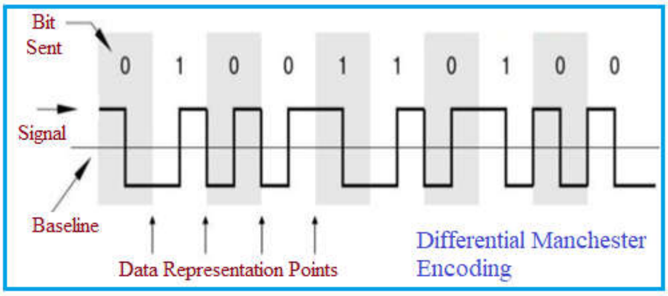


Figure 18. Manchester Differential Encoding

Alternate Mark Inversion (AMI)

In the AMI scheme, a binary 0 is represented by no line signal, while a binary 1 is represented by a positive or negative pulse. It's important to note that the binary 1pulses must alternate in polarity.

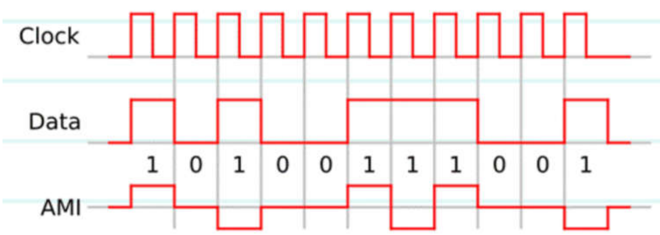


Figure 19. Alternate Mark Inversion (AMI)

> “There is no science without patience”