UNIT-1
Introductory Concepts

Physical Layer in Computer Networks

1. Digital and Analog Signals

- **Analog Signals**:
  - **Definition**: Continuous signals that vary smoothly over time and can take any value in a given range.
  - **Representation**: Typically represented by sine waves.
  - **Characteristics**:
    - **Amplitude**: The height of the wave, indicating the strength of the signal.
    - **Frequency**: The number of cycles per second, measured in Hertz (Hz).
    - **Phase**: The position of the wave relative to a point in time.
- **Digital Signals**:
  - **Definition**: Discrete signals that have specific values, often represented as binary values (0 and 1).
  - **Representation**: Represented by square waves.
  - **Advantages**: More robust to noise, easier to regenerate, and can be processed by digital systems.

2. Periodic Analog Signals

- **Sine Wave**:
  - Fundamental form of a periodic analog signal.
  - **Equation**: $s(t)=A\sin(2\pi ft+\phi)$
    - A: Amplitude
    - f: Frequency
    - ϕ Phase
- **Characteristics**:
  - **Amplitude (A)**: Indicates the signal's strength or power.
  - **Frequency (f)**: The number of times the signal cycles per second.
  - **Phase (φ)**: The position of the wave at the start of the cycle.

3. Signal Transmission

- **Transmission Types**:
  - **Baseband Transmission**:
    - Uses the entire bandwidth of the medium to send a single signal.
    - Common in Ethernet networks.
  - **Broadband Transmission**:
    - Uses multiple channels to send multiple signals simultaneously.
    - Common in cable TV and broadband internet.
- **Transmission Media**:
  - **Guided Media**:
    - **Twisted Pair Cable**:

        - Pairs of wires twisted together to reduce electromagnetic interference.
        - **Unshielded Twisted Pair (UTP)**: Common in Ethernet networks.
        - **Shielded Twisted Pair (STP)**: Includes shielding to further reduce interference.
    - **Coaxial Cable**:
        - Consists of a central conductor, insulating layer, metallic shield, and outer insulating layer.
        - Used in cable TV and broadband internet.
    - **Fiber Optic Cable**:
        - Uses light to transmit data.
        - Very high bandwidth and low signal loss.
- **Unguided Media**:
    - **Wireless Transmission**:
        - Uses electromagnetic waves (radio waves, microwaves, infrared) to transmit data.
        - Includes technologies like Wi-Fi, Bluetooth, and satellite communication.

4. Limitations of Data Rate

- **Nyquist Theorem**:
    - Describes the maximum data rate for a noiseless channel.
    - **Formula**: $R=2B\log_2 MR$
        - R: Maximum data rate (bits per second)
        - B: Bandwidth (Hz)
        - M: Number of signal levels
- **Shannon's Theorem**:
    - Describes the maximum data rate for a noisy channel.
    - **Formula**: $R=B\log_2(1+SN)R$
        - R= Maximum data rate (bits per second)
        - B=Bandwidth (Hz)
        - S= Signal power
        - N= Noise power

5. Digital Data Transmission

- **Asynchronous Transmission**:
    - Data is sent one byte at a time with start and stop bits.
    - Allows for communication without synchronization between sender and receiver.
- **Synchronous Transmission**:
    - Data is sent in a continuous stream with synchronization bits.
    - Requires synchronization between sender and receiver to ensure accurate transmission.

6. Performance Measures

- **Throughput**:
  - The actual rate at which data is successfully transmitted over a network.
  - Measured in bits per second (bps).
- **Latency**:
  - The time taken for a message to travel from sender to receiver.
  - Composed of propagation delay, transmission delay, processing delay, and queuing delay.
- **Jitter**:
  - The variability in packet arrival times.
  - Important in real-time applications like voice and video communication.
- **Bit Error Rate (BER)**:
  - The number of bits received in error divided by the total number of bits transmitted.
  - A lower BER indicates a more reliable communication channel.

7. Line Coding

In digital communication, data and signals can be categorized as either digital or analog. Line coding is the process used to convert digital data into digital signals. This technique involves transforming a sequence of bits into a digital signal. On the sender's side, digital data is encoded into a digital signal, and on the receiver's side, the digital signal is decoded back into digital data.

Line coding schemes are generally divided into five categories:

1. **Unipolar**: An example of this is the NRZ (Non-Return to Zero) scheme.
2. **Polar**: This category includes schemes like NRZ-L (Non-Return to Zero Level), NRZ-I (Non-Return to Zero Inverted), RZ (Return to Zero), and Biphase (Manchester and Differential Manchester).
3. **Bipolar**: This includes schemes like AMI (Alternate Mark Inversion) and Pseudoternary.
4. **Multilevel**
5. **Multitransition**

Before discussing the differences between the first three schemes, it's important to understand some key characteristics of line coding techniques:

- **Self-synchronization**: The clocks of both the sender and receiver should be synchronized to ensure data integrity.
- **Error detection**: The scheme should have the capability to detect errors.
- **Noise and interference immunity**: The system should resist noise and interference to ensure data is transmitted accurately.
- **Complexity**: The method should be simple and not overly complex.
- **DC Component**: There should be no low-frequency component, as long-distance transfer of low-frequency signals is not feasible.
- **Baseline wandering**: The method should minimize baseline wandering to maintain signal integrity.

Unipolar Scheme

In the unipolar scheme, all signal levels are either entirely above or entirely below the axis. A specific example is:

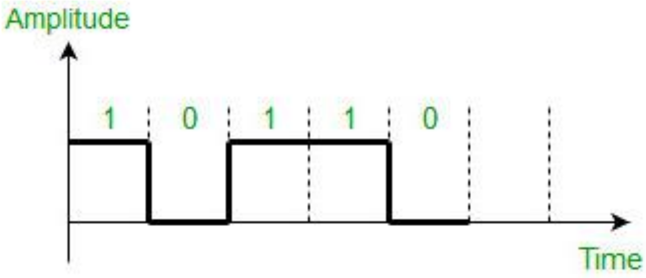
- **Non-Return to Zero (NRZ)**: In this unipolar line coding scheme, a positive voltage represents a bit 1, and zero voltage represents a bit 0. The signal does not return to zero in the middle of the bit, hence the name "Non-Return to Zero."

Example:

For the data sequence 10110, using the NRZ scheme:

- Bit 1 is represented by a positive voltage.
- Bit 0 is represented by zero voltage.

This scheme creates a straightforward way to represent binary data as electrical signals.



But this scheme uses more power as compared to polar scheme to send one bit per unit line resistance. Moreover for continuous set of zeros or ones there will be self-synchronization and base line wandering problem.

In polar schemes, the signal voltages can be both positive and negative, allowing them to span both sides of the axis. This approach uses two levels of voltage, which can represent data more effectively than the unipolar scheme.

Polar Schemes

NRZ-L (Non-Return to Zero Level)

- **Definition**: In the NRZ-L scheme, the voltage level determines the value of the bit. A high voltage level usually represents a binary 1, while a low voltage level represents a binary 0.
- **Operation**: There is no signal transition between bits unless there is a change in the bit value from 0 to 1 or from 1 to 0.

NRZ-I (Non-Return to Zero Invert)

- **Definition**: In NRZ-I, the signal inverts its voltage level (or has a transition) at the boundary of a bit if the bit being transmitted is a logical 1. If the bit is a logical 0, the voltage level remains the same.
- **Operation**: The key feature of NRZ-I is that the transition occurs only when transmitting a 1, allowing the scheme to encode more information about the bit sequence through transitions rather than static voltage levels.

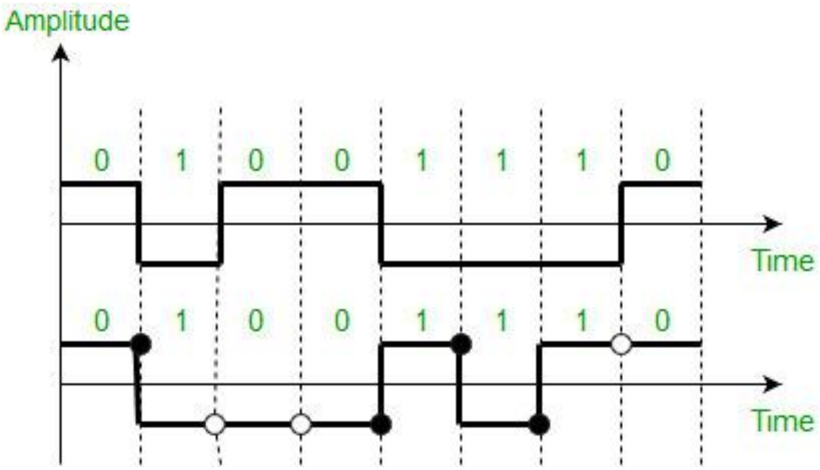
Note: When using NRZ-I, the initial signal level needs to be defined. In this example, we assume the previous signal before the start of the data set "01001110" was positive. Therefore, the first bit "0" starts from a positive voltage, and there is no transition at the beginning.

Example

For the data sequence 01001110 using NRZ-I:

1. **Initial Signal**: Assume starting from +V (positive voltage).
2. **Bit 0**: No transition, stays at +V.
3. **Bit 1**: Transition occurs, moves to -V.
4. **Bit 0**: No transition, stays at -V.
5. **Bit 0**: No transition, stays at -V.
6. **Bit 1**: Transition occurs, moves to +V.
7. **Bit 1**: Transition occurs, moves to -V.
8. **Bit 1**: Transition occurs, moves to +V.
9. **Bit 0**: No transition, stays at +V.

The NRZ-I scheme, through its use of transitions for logical 1s, can reduce the risk of long sequences of constant voltage levels, which helps in maintaining synchronization between the sender and receiver.



Comparison Between NRZ-L and NRZ-I

- **Baseline Wandering**: This issue occurs when the average voltage drifts over time, making it difficult for receivers to distinguish between high and low voltages. Both

NRZ-L and NRZ-I suffer from baseline wandering, but it's more pronounced in NRZ-L. In NRZ-I, the transitions for logical 1s help mitigate this problem slightly by introducing more frequent changes in voltage levels.

- **Self-Synchronization**: In both schemes, self-synchronization can be problematic, especially with long sequences of 0s, as there are no transitions to help maintain clock synchronization. However, with long sequences of 1s, NRZ-L faces a more severe synchronization problem since NRZ-I will still have transitions due to logical 1s.

Return to Zero (RZ)

The Return to Zero (RZ) scheme addresses some of the issues found in NRZ schemes by using three voltage levels: positive, negative, and zero. This approach introduces a zero voltage level to help reduce baseline wandering and improve synchronization.

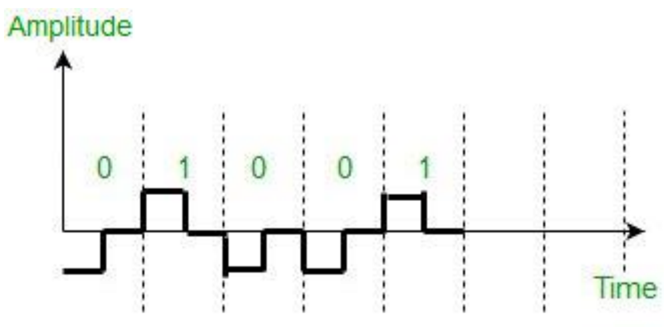
- **Operation**: In the RZ scheme, the signal returns to zero in the middle of each bit period. This means each bit is represented by two voltage levels: a high or low level for the first half of the bit and zero for the second half.
- **Encoding Logic**:
  - For a **bit 1**, the signal is positive (+V) for the first half and zero for the second half.
  - For a **bit 0**, the signal is negative (-V) for the first half and zero for the second half.

Example

For the data sequence 01001 using the RZ scheme:

1. **Bit 0**: The signal is -V for the first half and returns to 0 for the second half.
2. **Bit 1**: The signal is +V for the first half and returns to 0 for the second half.
3. **Bit 0**: The signal is -V for the first half and returns to 0 for the second half.
4. **Bit 0**: The signal is -V for the first half and returns to 0 for the second half.
5. **Bit 1**: The signal is +V for the first half and returns to 0 for the second half.

This RZ scheme helps in maintaining synchronization and reduces baseline wandering by ensuring that the signal regularly returns to zero, providing a clear reference point. However, it requires more bandwidth compared to NRZ schemes due to the additional transitions.



Main disadvantage of RZ encoding is that it requires greater bandwidth. Another problem is the complexity as it uses three levels of voltage. As a result of all these deficiencies, this scheme is not used today. Instead, it has been replaced by the better-performing Manchester and differential Manchester schemes.

Biphase Encoding: Manchester and Differential Manchester

Biphase encoding, which includes Manchester and Differential Manchester schemes, is designed to improve synchronization and reduce the risk of baseline wandering by ensuring frequent transitions within each bit period.

Manchester Encoding

Manchester encoding is a combination of the RZ (Return to Zero) and NRZ-L (Non-Return to Zero Level) schemes. It provides reliable synchronization due to its consistent transition in the middle of each bit.

- **Operation**: Each bit is divided into two halves. There is a transition in the middle of the bit period. This transition serves as a clocking mechanism, aiding in synchronization between the sender and receiver.
- **Encoding Logic**:
  - For **bit 1**, the signal transitions from -V to +V in the middle of the bit.
  - For **bit 0**, the signal transitions from +V to -V in the middle of the bit.

Differential Manchester Encoding

Differential Manchester encoding is a combination of the RZ and NRZ-I (Non-Return to Zero Invert) schemes. It guarantees a transition at the midpoint of each bit but determines bit values based on transitions at the beginning of the bit period.

- **Operation**: There is always a transition in the middle of the bit. The presence or absence of a transition at the beginning of the bit period determines the bit value.
- **Encoding Logic**:
  - For **bit 0**, there is a transition at the beginning of the bit.
  - For **bit 1**, there is no transition at the beginning of the bit.

Note: In the Differential Manchester scheme, the initial signal level before the start of the data sequence can affect how the first bit is encoded. For the example below, we assume the signal was positive before the start of the sequence "010011."

Example

For the data sequence 010011 using both encoding schemes:

Manchester Encoding:

1. **Bit 0**: Transition from +V to -V in the middle of the bit.
2. **Bit 1**: Transition from -V to +V in the middle of the bit.
3. **Bit 0**: Transition from +V to -V in the middle of the bit.
4. **Bit 0**: Transition from +V to -V in the middle of the bit.

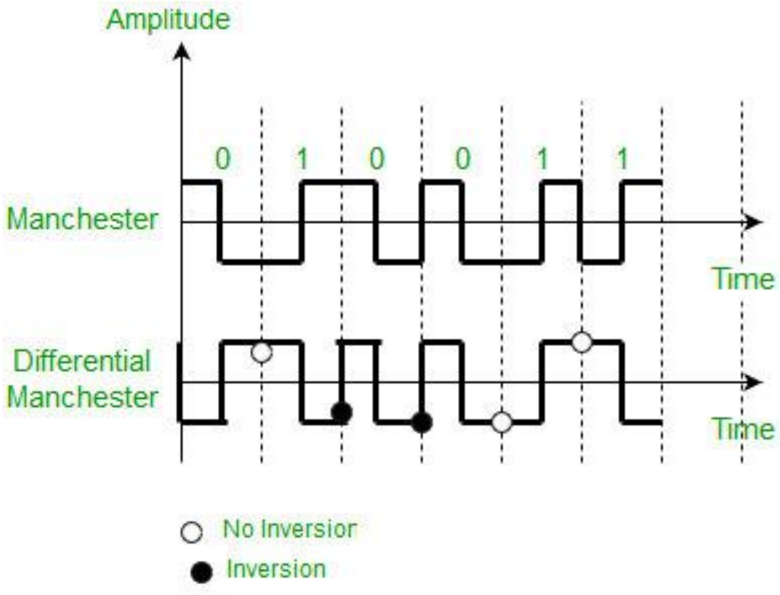
5. **Bit 1**: Transition from -V to +V in the middle of the bit.
6. **Bit 1**: Transition from -V to +V in the middle of the bit.

Differential Manchester Encoding:

Assuming the previous signal before starting the sequence "010011" was positive:

1. **Bit 0**: Transition at the beginning, starting from -V.
2. **Bit 1**: No transition at the beginning, starting from +V.
3. **Bit 0**: Transition at the beginning, starting from -V.
4. **Bit 0**: Transition at the beginning, starting from +V.
5. **Bit 1**: No transition at the beginning, starting from -V.
6. **Bit 1**: No transition at the beginning, starting from +V.

Biphase encoding schemes like Manchester and Differential Manchester are widely used because they ensure consistent transitions that help in maintaining synchronization and are less affected by baseline wandering, although they require more bandwidth compared to other encoding schemes like NRZ.



Advantages of Manchester and Differential Manchester Schemes

Manchester and Differential Manchester encoding schemes offer significant advantages over NRZ-L and NRZ-I by addressing some of their inherent problems:

- **No Baseline Wandering**: Both Manchester and Differential Manchester schemes avoid baseline wandering because each bit contains both positive and negative voltage contributions, ensuring the average voltage level remains constant over time.
- **No DC Component**: The absence of a DC component helps in the reliable transmission of signals over long distances without the need for DC-coupling techniques.
- **Synchronization**: These schemes provide excellent synchronization due to the consistent transitions in the middle of each bit period.

- **Bandwidth**: The primary limitation of these schemes is that their minimum bandwidth requirement is twice that of NRZ schemes, as each bit is represented by two transitions.

Bipolar Schemes

Bipolar schemes use three voltage levels: positive, negative, and zero. This approach allows for encoding data in a way that helps mitigate baseline wandering and maintain signal integrity over long distances.

Alternate Mark Inversion (AMI)

AMI encoding uses a neutral zero voltage to represent binary 0. Binary 1s are represented by alternating between positive and negative voltages.

- **Encoding Logic**:
  - **Bit 0**: Represented by a zero voltage.
  - **Bit 1**: Alternates between +V and -V for consecutive 1s.

Pseudoternary

Pseudoternary encoding is essentially the opposite of AMI. In this scheme, bit 1 is represented by a zero voltage, while bit 0 is represented by alternating positive and negative voltages.

- **Encoding Logic**:
  - **Bit 1**: Represented by a zero voltage.
  - **Bit 0**: Alternates between +V and -V for consecutive 0s.

Example

For the data sequence 010010:

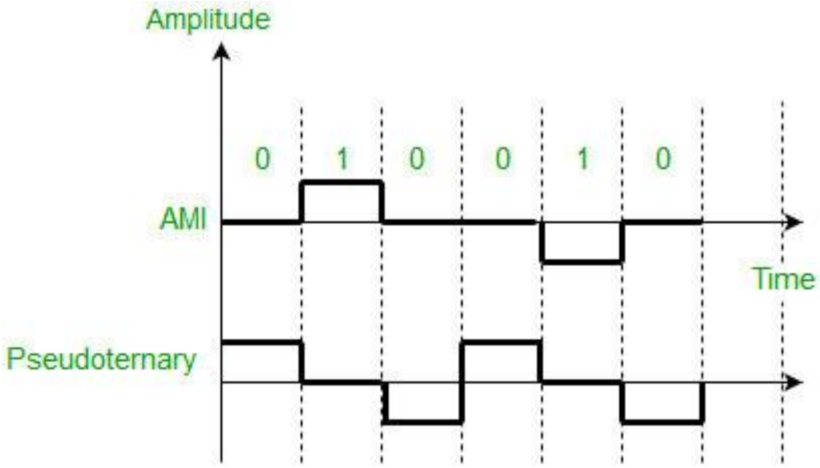
Alternate Mark Inversion (AMI):

1. **Bit 0**: Zero voltage (0).
2. **Bit 1**: Positive voltage (+V).
3. **Bit 0**: Zero voltage (0).
4. **Bit 0**: Zero voltage (0).
5. **Bit 1**: Negative voltage (-V).
6. **Bit 0**: Zero voltage (0).

Pseudoternary:

1. **Bit 0**: Positive voltage (+V).
2. **Bit 1**: Zero voltage (0).
3. **Bit 0**: Negative voltage (-V).
4. **Bit 0**: Positive voltage (+V).
5. **Bit 1**: Zero voltage (0).
6. **Bit 0**: Negative voltage (-V).

Bipolar schemes like AMI and Pseudoternary offer advantages such as reduced baseline wandering and the absence of a DC component. These features make them suitable for long-distance communication, although they do require careful handling of alternating voltage levels to maintain signal integrity.



The bipolar scheme is an alternative to NRZ.This scheme has the same signal rate as NRZ,but there is no DC component as one bit is represented by voltage zero and other alternates every time.

Advantages and disadvantages of Unipolar Line Coding Scheme:

Advantages:

- **Simple receiver circuit:** The receiver circuit for unipolar line coding is simple, as it only needs to detect the presence or absence of a voltage.
- **Low DC component:** The unipolar line coding scheme has a low DC component, which is desirable for some communication systems.
- **Low cost:** Unipolar line coding scheme uses only a single voltage level, so it is easy to implement and requires fewer components, making it a cost-effective solution.

Disadvantages:

- **Poor noise immunity:** The unipolar line coding scheme has poor noise immunity and is susceptible to errors, as it does not have a differential signal.
- **Limited dynamic range:** The unipolar line coding scheme has a limited dynamic range, as it only uses positive voltage levels.

Advantages and disadvantages of Polar Line Coding Scheme:

Advantages:

- **High noise immunity:** The polar line coding scheme has a high noise immunity, as it uses a differential signal.
- **Error resistance:** The polar line coding scheme is less susceptible to errors, as it uses a differential signal.

Disadvantages:

- **Complex receiver circuit:** The receiver circuit for polar line coding is complex, as it needs to detect the positive and negative voltage levels.
- **Limited data rate:** The polar line coding scheme has a limited data rate, as it requires a larger number of bits to represent the same information as the unipolar or bipolar line coding schemes.

Advantages and disadvantages of Bipolar Line Coding Scheme:

Advantages:

- **High data rate:** The bipolar line coding scheme has a high data rate, as it uses positive and negative voltage levels to represent the digital signal.
- **Differential signal**: The bipolar line coding scheme uses a differential signal, which improves noise immunity and error resistance.

Disadvantages:

- **Complex receiver circuit:** The receiver circuit for bipolar line coding is complex, as it needs to detect the positive and negative voltage levels.
- **Limited dynamic range:** The bipolar line coding scheme has a limited dynamic range, as it uses positive and negative voltage levels to represent the digital signal.

- **NRZ (Non-Return to Zero)**:
  - No change in signal level for a binary 0 or 1.
  - **NRZ-L**: Level indicates binary value.
  - **NRZ-I**: Inversion indicates binary value change.
- **Manchester Coding**:
  - Combines clock and data signals.
  - Transition in the middle of the bit period represents binary value.
  - **Manchester**: Transition from low to high indicates 0, high to low indicates 1.
  - **Differential Manchester**: Transition at the beginning of the bit period represents 0; no transition represents 1.

8. Digital Modulation

- **ASK (Amplitude Shift Keying)**:
  - Varies the amplitude of the carrier wave to represent binary data.
  - Simple but susceptible to noise.
- **FSK (Frequency Shift Keying)**:
  - Varies the frequency of the carrier wave to represent binary data.
  - More robust to noise compared to ASK.
- **PSK (Phase Shift Keying)**:
  - Varies the phase of the carrier wave to represent binary data.
  - More efficient and robust compared to ASK and FSK.
- **QAM (Quadrature Amplitude Modulation)**:
  - Combines ASK and PSK to increase the number of signal states.

- Used in high-bandwidth applications like cable modems and Wi-Fi.

9. Media and Digital Transmission Systems

- **Twisted Pair Cable**:
  - **UTP (Unshielded Twisted Pair)**: Common in Ethernet networks, susceptible to electromagnetic interference.
  - **STP (Shielded Twisted Pair)**: Includes shielding to reduce interference, used in environments with high interference.
- **Coaxial Cable**:
  - Consists of a central conductor, insulating layer, metallic shield, and outer insulating layer.
  - Provides higher bandwidth than twisted pair.
  - Used in cable TV and broadband internet.
- **Fiber Optic Cable**:
  - Uses light to transmit data through glass or plastic fibers.
  - Very high bandwidth and low signal loss.
  - Used in long-distance communication and high-speed data networks.
- **Wireless Media**:
  - Uses electromagnetic waves for transmission.
  - **Radio Waves**: Used in Wi-Fi, Bluetooth, and AM/FM radio.
  - **Microwaves**: Used in satellite communication and microwave links.
  - **Infrared**: Used in remote controls and short-range communication.

Conclusion

The Physical Layer is crucial in computer networks, responsible for the actual transmission of data over physical media. Understanding the various aspects such as signal types, transmission media, data rate limitations, digital modulation techniques, and performance measures is essential for designing and maintaining efficient and reliable network communication systems.