# Chapter 11

| | |
|---|---|
| course | Computer Networks |
| Zohaib | rookie |
| Status | Not started |
| Resource | ☐ |

# Notes

## Data Link Control (DLC) Services

The Data Link Control (DLC) layer handles communication between two adjacent nodes, including framing, flow control, and error control. This section summarizes the key concepts and mechanisms used in DLC.

### 11.1 Framing

**Framing** involves organizing bits into frames to distinguish each frame from another.

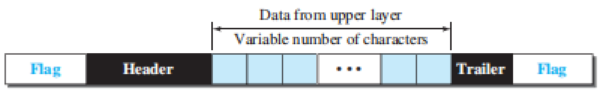
### Types of Framing

1. **Fixed-Size Framing**
    - Uses a predetermined size as a delimiter.
    - Example: ATM WAN uses fixed-size cells.
2. **Variable-Size Framing**
    - Requires mechanisms to define frame boundaries.
    - Two approaches: Character-Oriented and Bit-Oriented.

### Character-Oriented Framing

- Data and control information are in 8-bit characters (e.g., ASCII).
- Frames are delimited by special 8-bit flags at the beginning and end.
- **Byte Stuffing**: Adds an escape character (ESC) to data sections containing flag-like patterns to prevent misinterpretation.
    - Example: If data includes a flag-like byte, ESC is added before it.
    - To differentiate actual ESC characters in the data, an extra ESC is added.

**Figure 11.1** *A frame in a character-oriented protocol*




### Bit-Oriented Framing

- Data is treated as a sequence of bits.
- Frames are delimited by an 8-bit pattern flag `01111110`.
- **Bit Stuffing**: Adds a 0 bit after every sequence of five consecutive 1 bits in the data to prevent flag-like patterns.
    - Ensures the pattern `01111110` does not inadvertently appear within the frame.\

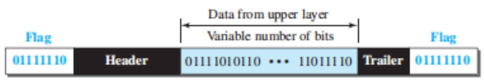



Figure 11.3 *A frame in a bit-oriented protocol*

### 11.1.2 Flow and Error Control

### Flow Control

- Ensures the sender does not overwhelm the receiver.
- **Buffers**: Temporary storage at both sender and receiver helps manage flow.
    - **Communication**: The receiver notifies the sender when its buffer is full or has space.

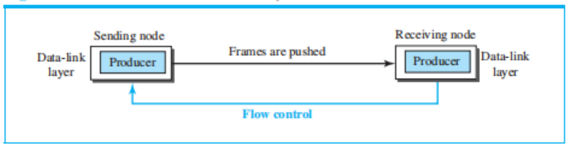



Figure 11.5 *Flow control at the data-link layer*

### Error Control

- Ensures the receiver gets uncorrupted data frames.
- Two methods:
    1. **Silent Discarding**: Corrupted frames are discarded silently.
    2. **Acknowledgment (ACK)**: Uncorrupted frames are acknowledged; corrupted ones are silently discarded.

### Combining Flow and Error Control

- Acknowledgments serve both purposes.
    - ACK indicates frame received uncorrupted.
    - No ACK indicates a problem.

### Summary Table: Framing Types

| Type | Mechanism | Delimiter | Control Mechanism |
| --- | --- | --- | --- |
| **Fixed-Size Framing** | Predetermined size | Frame size | No additional mechanism needed |
| **Character-Oriented** | 8-bit characters (ASCII) | 8-bit flag | Byte Stuffing |
| **Bit-Oriented** | Bit sequence | 8-bit pattern flag | Bit Stuffing |

### Flow Control Diagram

```
+---------------+          +---------------+
| Sending Node  |          | Receiving Node|
| Data-Link Layer|         | Data-Link Layer|
+---------------+          +---------------+
       |                           |
       v                           v
      Frames --------------------> Frames
   (Producer)                  (Consumer)
       |                           |
+---------------+          +---------------+
|    Network    |          |    Network    |
+---------------+          +---------------+
```

### Example: Flow Control with Buffer

- Single-slot buffer system: The receiver informs the sender when it has an empty slot to accept the next frame.

By organizing the information in a structured manner, these notes highlight the essential concepts and mechanisms of DLC services while maintaining clarity and brevity.

## 11.1.3 Connectionless and Connection-Oriented Protocols

**Connectionless Protocols:**

- Frames are sent independently from one node to the next.
- There is no relationship or ordering between frames.
- Common in LAN protocols.

**Connection-Oriented Protocols:**

- A logical connection is established before transmitting frames.
- Frames are numbered and sent in order.
- Used in some point-to-point, wireless LAN, and WAN protocols.

# Data Link Control (DLC) Protocols

- **States:** The system can be in one of a limited number of defined states (e.g., State I, State II).
- **Events:** An event (like a signal received) triggers a change in the system's behavior.
- **Actions:** When an event occurs in a specific state, the system performs certain actions (like sending data).
- **Transitions:** Based on the event and current state, the system transitions to a new state (may stay in the same state).
- **Initial State:** The system starts in a specific designated state (e.g., State I).

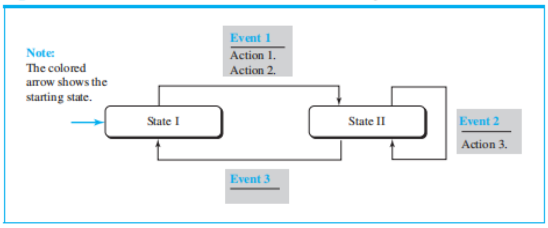
## 11.2 Data-Link Layer Protocols

**Traditional Data-Link Layer Protocols:**

1. **Simple Protocol**
2. **Stop-and-Wait Protocol**

3. Go-Back-N (discussed in Chapter 23)
4. Selective-Repeat (discussed in Chapter 23)

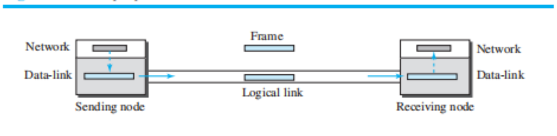
Figure 11.6 *Connectionless and connection-oriented service represented as FSMs*




## Simple Protocol

- No flow or error control.
- Assumes the receiver can handle frames immediately.

Figure 11.7 *Simple protocol*




**Finite State Machine (FSM) for Simple Protocol:**

- **Sending FSM:**
  - State: Ready
  - Event: Packet from the network layer
  - Action: Encapsulate message in a frame and send it.
- **Receiving FSM:**
  - State: Ready
  - Event: Frame arrival
  - Action: Decapsulate message and deliver to network layer.

**Example:**

- Sender sends frames without considering the receiver's state.

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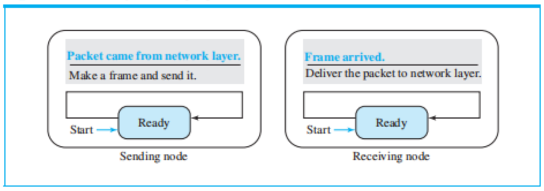
Figure 11.8 *FSMs for the simple protocol*




## Stop-and-Wait Protocol

- Implements both flow and error control.
- Sender waits for an acknowledgment before sending the next frame.

- Uses Cyclic Redundancy Check (CRC) for error detection.

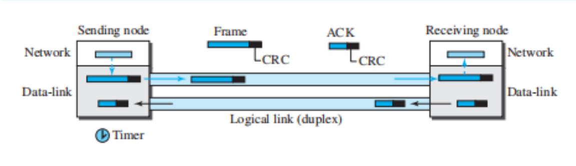


**Figure 11.10** *Stop-and-Wait protocol*

**FSM for Stop-and-Wait Protocol:**

**Sender States:**

1. **Ready State:**
    - Waits for a packet from the network layer.
    - Creates a frame, saves a copy, starts a timer, and sends the frame.
    - Moves to Blocking State.
2. **Blocking State:**
    - **Timeout:** Resends saved frame, restarts timer.
    - **Corrupted ACK:** Discards it.
    - **Error-free ACK:** Stops timer, discards saved frame, moves to Ready State.

**Receiver:**

- Always in Ready State.
    - **Error-free frame:** Delivers message to network layer, sends ACK.
    - **Corrupted frame:** Discards it.

**Example:**

- Handles corrupted frames by resending after timeout.
- Addresses duplicate frame issue using sequence and acknowledgment numbers.

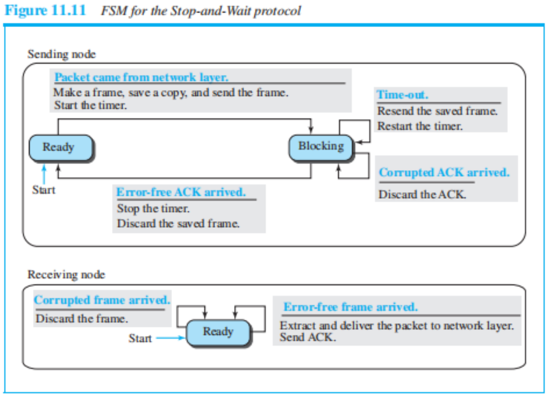


**Figure 11.11** *FSM for the Stop-and-Wait protocol*

## Piggybacking

- Allows bidirectional data flow with acknowledgments included in data frames.
- Not commonly used due to complexity.

**Table: Key Differences Between Protocols**

| Protocol | Flow Control | Error Control | Frame Dependency | Usage |
|---|---|---|---|---|
| Simple | No | No | Independent | Basic, minimal use |
| Stop-and-Wait | Yes | Yes | Ordered | Reliable links |
| Piggybacking | Yes | Yes | Ordered, Bidirectional | Advanced, less common |

### Summary

- **Connectionless protocols** are simpler, sending independent frames without order.
- **Connection-oriented protocols** require an established connection and maintain frame order.
- **Simple Protocol** offers minimal control, suitable for non-complex data transmission.
- **Stop-and-Wait Protocol** ensures reliability through flow and error control, using sequence numbers to prevent duplicates.
- **Piggybacking** enhances bidirectional communication by combining data and acknowledgments, though it is more complex.

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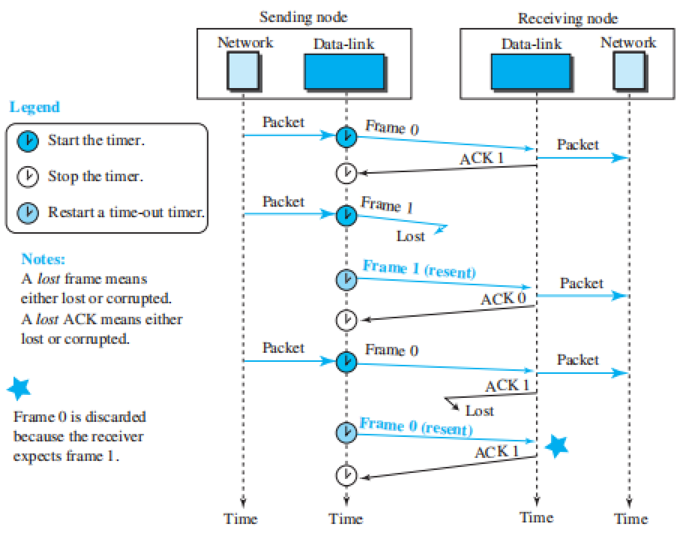
## HDLC (High-level Data Link Control)

### Overview

HDLC is a bit-oriented protocol for communication over point-to-point and multipoint links. It provides foundational concepts used in other practical protocols like PPP and Ethernet.

Figure 11.13 *Flow diagram for Example 11.4*




### Configurations and Transfer Modes

### Normal Response Mode (NRM)

- **Unbalanced configuration**: One primary station and multiple secondary stations.
- **Primary station**: Sends commands.
- **Secondary stations**: Respond only.
- **Usage**: Both point-to-point and multipoint links.

## Asynchronous Balanced Mode (ABM)

- **Balanced configuration**: Point-to-point link with both stations functioning as primary and secondary.
- **Usage**: Common mode today.

## Framing

HDLC frames are categorized into three types: I-frames, S-frames, and U-frames.

Figure 11.14 *Normal response mode*

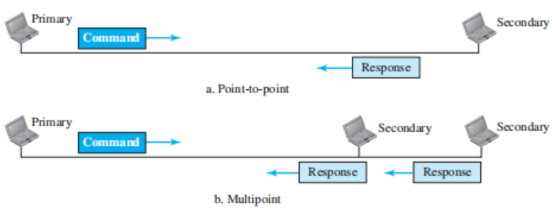


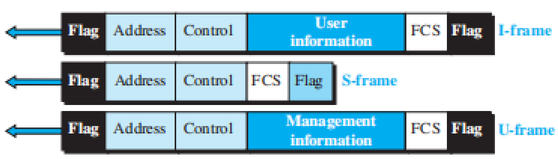

Figure 11.15 *Asynchronous balanced mode*


## Frame Structure

Each frame consists of up to six fields:

1. **Flag field**: Synchronization pattern (01111110) at the beginning and end.
2. **Address field**: Contains the address of the secondary station.
3. **Control field**: Used for flow and error control.
4. **Information field**: Contains user data or management information.
5. **FCS (Frame Check Sequence) field**: Error detection field (2- or 4-byte CRC).
6. **Ending flag field**: Identifies the end of the frame.

Figure 11.16 *HDLC frames*




## Information Frames (I-frames)

- **Purpose**: Carry user data and control information (piggybacking).
- **Control field**:
  - First bit = 0 (identifies I-frame).
  - Next 3 bits: Sequence number (N(S)).
  - Middle bit: P/F bit (Poll/Final).
  - Last 3 bits: Acknowledgment number (N(R)).

### Supervisory Frames (S-frames)

- **Purpose**: Flow and error control without piggybacking.
- **Control field**:
  - First 2 bits = 10 (identifies S-frame).
  - Last 3 bits: Acknowledgment number (N(R)).
  - Middle 2 bits: Code subfield (defines S-frame type).

**Types of S-frames**:

1. **Receive Ready (RR)**: Code = 00, acknowledges receipt.
2. **Receive Not Ready (RNR)**: Code = 10, acknowledges receipt and indicates receiver is busy.
3. **Reject (REJ)**: Code = 01, negative acknowledgment for Go-Back-N ARQ.
4. **Selective Reject (SREJ)**: Code = 11, negative acknowledgment for Selective Repeat ARQ.

### Unnumbered Frames (U-frames)

- **Purpose**: Exchange session management and control information.
- **Control field**: Contains codes divided into a 2-bit prefix and a 3-bit suffix (total 5 bits).

### Example Uses of Frames

- **Connection Establishment and Release**:
  - SABM (Set Asynchronous Balanced Mode) for connection establishment.
  - UA (Unnumbered Acknowledgment) for response.
  - DISC (Disconnect) for disconnection.
  - UA for confirmation of disconnection.
- **Piggybacking**:
  - Frames carry both data and acknowledgment information.

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## Point-to-Point Protocol (PPP)

### Overview

PPP is a widely-used protocol for point-to-point access, especially for Internet connections via telephone lines.

### Services Provided by PPP

- **Frame Format Definition**: Defines the structure of frames exchanged between devices.
- **Link Establishment and Data Exchange**: Negotiates the link and data transfer.
- **Payload Acceptance**: Accepts payloads from multiple network layers.
- **Optional Authentication**: Provides an optional authentication mechanism.
- **Multilink PPP**: Supports connections over multiple links.
- **Network Address Configuration**: Provides temporary network addresses, useful for home users connecting to the Internet.

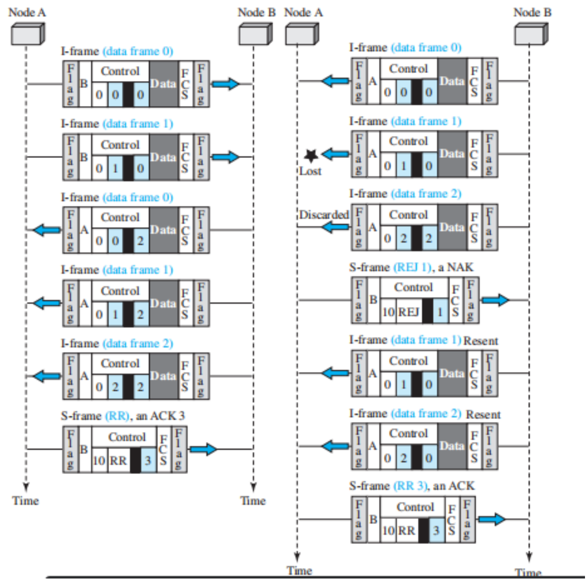
### Connection and Disconnection Example

- **Node A** requests connection using a U-frame (SABM).
- **Node B** responds with a U-frame (UA).
- Data transfer occurs.
- **Node A** sends a U-frame (DISC) to disconnect.
- **Node B** confirms with a U-frame (UA).

### Piggybacking Example

- Frames are exchanged with acknowledgment numbers included to indicate successful receipt or errors.

**Figure 11.19** *Example of piggybacking with and without error*




# Point-to-Point Protocol (PPP)

## Overview

The Point-to-Point Protocol (PPP) is widely used to connect home computers to the servers of Internet service providers (ISPs). It provides necessary services for data transfer over a telephone line (physical layer) and manages data link layer tasks.

## Services

### Provided Services

- **Frame Format Definition**: Defines the format of frames exchanged between devices.
- **Link Establishment and Data Exchange**: Allows negotiation and management of links.
- **Payload Acceptance**: Supports multiple network layer protocols (e.g., IP).
- **Optional Authentication**: Includes optional authentication mechanisms.
- **Network Address Configuration**: Useful for assigning temporary network addresses (e.g., for home users).
- **Multilink PPP**: Supports connections over multiple links.

### Omitted Services

- **Flow Control**: Lacks mechanisms to prevent sender from overwhelming the receiver.
- **Advanced Error Control**: Uses simple CRC for error detection; corrupt frames are discarded without sophisticated error recovery.
- **Sophisticated Addressing**: Does not handle frames in multipoint configurations.

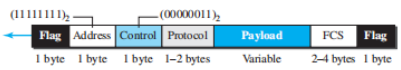
## Framing

### Frame Structure

A PPP frame is character-oriented and includes the following fields:

- **Flag**: 1-byte with the bit pattern 01111110, marking the start and end of the frame.
- **Address**: Constant value 11111111 (broadcast address).
- **Control**: Constant value 00000011.
- **Protocol**: Defines the type of payload (user data or control information); default is 2 bytes.
- **Payload**: Carries user data or control information; maximum of 1500 bytes, subject to negotiation.
- **Frame Check Sequence (FCS)**: 2-byte or 4-byte CRC for error detection.

Figure 11.20 *PPP frame format*




### Byte Stuffing

To prevent confusion with the flag byte, an escape byte (01111101) is used whenever the flag-like pattern appears in the data section.

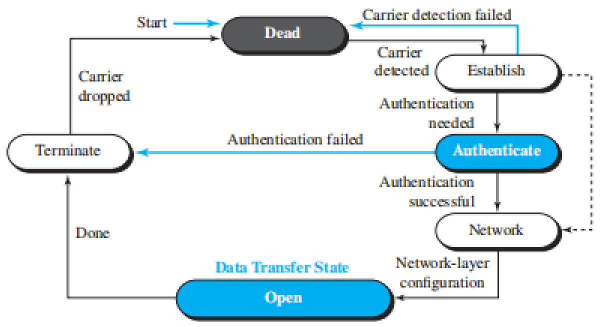
## Transition Phases

### State Diagram

PPP connection phases include:

1. **Dead**: No active carrier, line is quiet.
2. **Establish**: Negotiation of options between nodes.
3. **Authenticate**: Optional step if authentication is required.
4. **Open**: Data transfer state.
5. **Terminate**: Connection termination and return to the dead state.

Figure 11.21 *Transition phases*




# Multiplexing

## Protocols Involved

PPP uses multiple protocols for different functions:

- **Link Control Protocol (LCP)**: Manages link establishment, maintenance, and termination.
- **Authentication Protocols (AP)**: Validates user identity.
- **Network Control Protocols (NCP)**: Configures the link for carrying network-layer data.

## Link Control Protocol (LCP)

- **Packet Types**: Configuration, termination, and link monitoring/debugging packets.
- **Options**: Includes maximum receive unit, authentication protocol, protocol field compression, and address/control field compression.

## Authentication Protocols

- **Password Authentication Protocol (PAP)**: Simple, sends user name and password in plaintext.
- **Challenge Handshake Authentication Protocol (CHAP)**: More secure, uses a challenge-response mechanism without sending passwords directly.

## Network Control Protocols (NCP)

Each network-layer protocol has a specific NCP, e.g., IPCP for IP data. NCPs configure the link but do not carry network-layer data.

# Multilink PPP

## Concept

Multilink PPP divides a logical PPP frame into several smaller PPP frames, each carrying a segment of the logical frame. The protocol field for these frames is set to 003D in hexadecimal.

## Example

A sequence of PPP frames can encapsulate various stages:

1. **Link Establishment**: Using LCP.
2. **Authentication**: Using PAP or CHAP.
3. **Network Layer Configuration**: Using IPCP.

4. **Data Transfer**: Encapsulating IP packets.
5. **Termination**: Using LCP termination packets.

## Example Workflow

1. **Establish Connection**: Configure-request and Configure-ack frames.
2. **Authenticate**: PAP frames for user credentials.
3. **Network Configuration**: IPCP frames for IP configuration.
4. **Data Transfer**: IP packets encapsulated in PPP frames.
5. **Terminate Connection**: Terminate-request and Terminate-ack frames.

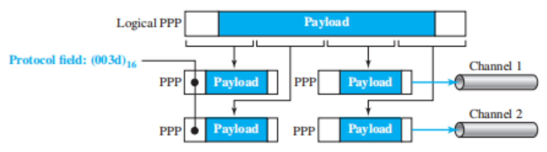



Figure 11.28 *Multilink PPP*

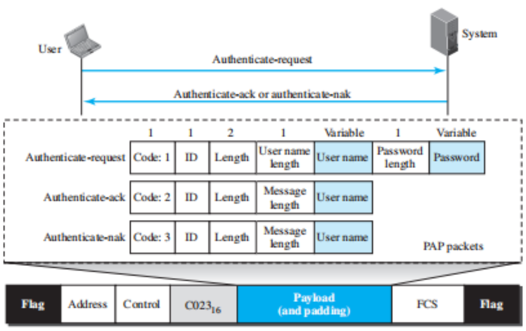



Figure 11.24 *PAP packets encapsulated in a PPP frame*

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## Key concepts:

**1. Framing:**

- Divides data into manageable pieces (frames) for transmission on the network.
- Adds header (sender/receiver addresses) and trailer (error detection) for frame identification.
- There are two main framing types:
  - **Character-oriented:** Uses special characters (flags) to mark frame boundaries. (Less common due to limitations with modern character coding systems)
  - **Bit-oriented:** Uses a special bit pattern (flag) to mark frame boundaries. (More common and flexible)
- Both methods employ techniques to prevent data patterns from mimicking the flag sequence:
  - **Character-oriented:** Byte stuffing (adding an escape character before flag-like patterns).
  - **Bit-oriented:** Bit stuffing (adding a 0 bit after every five consecutive 1s).

**2. Flow Control:**

- Manages the data transmission rate to prevent overwhelming the receiver.
- Achieved through buffers and communication between sender and receiver.
- The receiver informs the sender to stop sending frames when its buffer is full.

**3. Error Control:**

- Ensures data arrives without errors due to physical layer imperfections.
- Employs Cyclic Redundancy Check (CRC) for error detection.
    - Sender calculates CRC and adds it to the frame header.
    - Receiver calculates its own CRC and compares it to the received value.
- Two methods for handling errors:
    - **Silent Discarding:** Corrupted frames are discarded without notification (common in wired LANs).
    - **Positive Acknowledgement (ACK):** Receiver sends an ACK for correct frames, prompting retransmission for corrupted ones.

**4. Combining Flow and Error Control:**

- Acknowledgements serve both purposes:
    - ACK indicates frame received uncorrupted.
    - No ACK indicates a problem (missing or corrupted frame).

**5. Data Link Control Protocols:**

- Protocols define the rules for communication between devices at the data link layer.
- There are two main categories:
    - **Connectionless protocols:** Frames are sent independently without a pre-established connection (common in LANs).
    - **Connection-oriented protocols:** A logical connection is established before transmitting frames, ensuring order and reliability (used in some point-to-point, wireless LAN, and WAN protocols).

**6. Specific DLC Protocols:**

- The notes cover two specific protocols:
    - **Stop-and-Wait Protocol:** Implements flow and error control using sequence numbers and acknowledgements. Simple but less efficient.
    - **HDLC (High-Level Data Link Control):** A bit-oriented protocol with various frame types (I-frames, S-frames, U-frames) for data transfer, flow control, and link management. Used as a foundation for other protocols like PPP.

**7. Point-to-Point Protocol (PPP):**

- Widely used protocol for establishing connections over point-to-point links, especially for dial-up internet access.
- Provides services for framing, link management, data transfer, and optional authentication.
- Lacks advanced flow and error control mechanisms and is not suitable for multipoint configurations.
- Uses multiple protocols for different functions: LCP (link control), Authentication protocols (PAP, CHAP), and NCPs (network control protocols).