1. Management Plane

The Management Plane handles tasks related to network configuration, association, and maintenance. These functionalities are primarily implemented through Management Frames in 802.11, which are used to establish and maintain network connectivity.

MAC Layer Functionalities in the Management Plane:

1. Network Discovery:
    - **Beaconing:** Access Points (APs) periodically broadcast Beacon frames to announce their presence, SSID, supported rates, channel, and other network parameters.
    - **Probing:** Stations send Probe Request frames to discover nearby APs and receive Probe Response frames with network details.
2. Association and Disassociation:
    - Association: Stations send Association Request frames to join a network, specifying capabilities (e.g., supported rates, QoS). APs respond with Association Response frames to confirm or deny the association.
    - Reassociation: Stations send Reassociation Request frames to switch APs within the same ESS (Extended Service Set), maintaining connectivity during roaming.
    - Disassociation: Either the station or AP sends Disassociation frames to terminate an association gracefully.
3. Authentication and Deauthentication:
    - Authentication: Stations exchange Authentication frames to verify identity (e.g., Open System or Shared Key authentication in legacy Wi-Fi).
    - Deauthentication: Stations or APs send Deauthentication frames to terminate an authenticated session, often for security or network management.
4. Power Management:
    - Power Save Mode (PSM): Stations inform APs of their power-saving state via the Power Management bit in the Frame Control field. APs buffer frames for sleeping stations and indicate buffered data via the TIM (Traffic Indication Map) in Beacon frames.
    - PS-Poll: Stations send PS-Poll frames to retrieve buffered frames from the AP.
    - APSD (Automatic Power Save Delivery): Supports scheduled or unscheduled delivery of frames for QoS-enabled stations.
5. Spectrum Management:
    - **Channel Switching:** APs use Channel Switch Announcement frames to instruct stations to move to a different channel for better performance or regulatory compliance.
    - **Measurement Requests/Reports:** Stations respond to Measurement Request frames with Measurement Report frames to provide information on channel conditions, interference, or neighbor APs.

6. Security Management:
    - **Key Management:** The MAC layer supports the exchange of encryption keys (e.g., via EAPOL frames in WPA2/WPA3) during the association process.
    - **Protected Management Frames (PMF):** Implements security for management frames (e.g., deauthentication, disassociation) to prevent spoofing attacks.
7. BSS (Basic Service Set) Management:
    - BSSID Assignment: The MAC layer assigns and manages the BSSID (AP's MAC address) to uniquely identify a BSS.
    - ESS (Extended Service Set) Coordination: Supports roaming and seamless transitions between APs in an ESS using Reassociation frames.

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2. Control Plane

The Control Plane manages access to the shared wireless medium and coordinates transmission to avoid collisions and ensure reliable communication. These functionalities are implemented through Control Frames in 802.11, which facilitate medium access and acknowledgment.

MAC Layer Functionalities in the Control Plane:

1. Medium Access Control (CSMA/CA):
    - Carrier Sense Multiple Access with Collision Avoidance: Stations listen to the medium before transmitting (physical and virtual carrier sensing). If the medium is busy, they defer transmission using a backoff mechanism.
    - NAV (Network Allocation Vector): Stations set the NAV based on the Duration/ID field in received frames to reserve the medium and avoid collisions.
2. Request to Send/Clear to Send (RTS/CTS):
    - Stations send RTS frames to request medium access and receive CTS frames from the AP or recipient to confirm clearance. This mechanism is used to mitigate the hidden node problem.
3. Acknowledgment (ACK):
    - Recipients send ACK frames to confirm successful receipt of data or management frames. Block ACKs are used for multiple frames in QoS environments.
4. Contention-Free Access:
    - PCF (Point Coordination Function): A legacy mechanism where the AP controls medium access using CF-Poll frames to grant transmission opportunities (rarely used).
    - HCF (Hybrid Coordination Function): Supports QoS through Controlled Access Periods (CAPs) and TXOP (Transmission Opportunities) in IEEE 802.11e.
5. Frame Protection and Retransmission:
    - Retry Mechanism: The MAC layer retransmits frames if no ACK is received, using the Retry bit in the Frame Control field to indicate retransmissions.

6. Backoff and Interframe Spacing:
    - Stations wait for specific interframe spaces (e.g., SIFS, DIFS) and perform random backoff to reduce contention.
7. Block Acknowledgment:
    - Block ACK frames acknowledge multiple frames in a single transmission, improving efficiency in QoS-enabled networks.

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3. Data Plane

The Data Plane is responsible for the actual transfer of user data across the network. These functionalities are implemented through Data Frames in 802.11, which carry the payload between stations and APs.

MAC Layer Functionalities in the Data Plane:

1. Data Framing:
    - The MAC layer encapsulates higher-layer data (e.g., IP packets) into 802.11 Data frames, adding headers (MAC addresses, Frame Control, etc.) and trailers (FCS for error checking).
2. Addressing:
    - Uses up to four MAC addresses (Address 1–4) to specify the Recipient Address (RA), Transmitter Address (TA), Source Address (SA), and Destination Address (DA), depending on the network topology (e.g., infrastructure, ad-hoc, WDS).
3. Error Detection:
    - Appends a Frame Check Sequence (FCS) (32-bit CRC) to each frame to detect transmission errors.
4. Fragmentation and Reassembly:
    - Large data frames are divided into smaller fragments to improve reliability in noisy environments, with each fragment tracked via the Sequence Control field.
5. Multicast and Broadcast Handling:
    - Supports transmission of multicast and broadcast frames to multiple or all stations in a BSS, using group MAC addresses.
6. Frame Aggregation:
    - Implements A-MPDU (Aggregate MAC Protocol Data Unit) and A-MSDU (Aggregate MAC Service Data Unit) to combine multiple frames into a single transmission, reducing overhead.
7. Data Forwarding in WDS:
    - Supports frame forwarding in Wireless Distribution System (WDS) networks using the fourth address field (Address 4) for mesh or bridge scenarios