**Assignment 1**

**Service Data Adaptation Protocol (SDAP) Architecture in 5G NR**

The Service Data Adaptation Protocol (SDAP) is a key component in the 5G NR protocol stack, designed to handle Quality of Service (QoS) requirements by mapping service data flows to the appropriate Data Radio Bearers (DRBs). Below is a detailed description of the SDAP architecture in 5G NR:

**1. Overall Structure of the SDAP Layer**

The SDAP layer is positioned between the Packet Data Convergence Protocol (PDCP) and the Radio Link Control (RLC) layers in the 5G NR protocol stack. Its primary functions include mapping QoS flows to DRBs and ensuring that the data packets meet their specific QoS requirements. The overall structure can be outlined as follows:

1. Input from PDCP Layer: SDAP receives PDUs (Protocol Data Units) from the PDCP layer, which encapsulates the data from higher layers.
2. QoS Flow Management: SDAP processes these PDUs based on their QoS Flow Identifiers (QFIs), ensuring that each packet is treated according to its QoS requirements.
3. Mapping to DRBs: SDAP maps the QoS flows to appropriate DRBs, which are then managed by the RLC layer for transmission.
4. Output to RLC Layer: The processed PDUs are forwarded to the RLC layer, which handles further segmentation, reassembly, and error correction before transmission over the air interface.

**2. Role of SDAP Entities**

SDAP entities are responsible for managing the QoS flows and ensuring that the data packets adhere to their specific QoS requirements. Each SDAP entity is associated with a single PDU session, which represents a logical connection between the User Equipment (UE) and the core network. Key roles of SDAP entities include:

1. QoS Flow Identification: Each PDU is tagged with a QoS Flow Identifier (QFI) that specifies its QoS requirements.
2. SDAP Header Management: An SDAP header is added to each PDU, which contains the QFI and helps in managing the QoS flow.
3. Uplink and Downlink Handling: In the uplink direction, SDAP entities map PDUs from the PDCP layer to the appropriate QoS flows and DRBs. In the downlink direction, they map incoming packets from the RLC layer back to the PDCP layer.
4. QoS Compliance: SDAP entities ensure that the data packets are transmitted in compliance with their QoS parameters, such as latency, jitter, and throughput.

**3. Process of Mapping QoS Flows to DRBs**

1. The mapping of QoS flows to DRBs is a critical function of the SDAP layer, ensuring that each data packet is transmitted with the appropriate QoS level. The process involves several steps:

2. QoS Flow Identification: Each PDU from the PDCP layer is associated with a QFI, which specifies its QoS requirements.

3. SDAP Header Addition: The SDAP entity adds an SDAP header to the PDU, which includes the QFI and helps in identifying and managing the QoS flow.

4 QoS Flow to DRB Mapping: Based on the QFI, the SDAP entity maps the PDU to the corresponding DRB. Each DRB is characterized by specific QoS parameters that match the requirements of the QoS flow.

1. DRB Management: The RLC layer handles the DRBs,  ensuring that data is transmitted according to the QoS parameters through segmentation, reassembly, and error correction.
2. Transmission: The data is then passed to the MAC layer, which schedules and transmits it over the air interface.
3. This mapping process ensures that the data packets are handled according to their specific QoS requirements, providing efficient and reliable transmission over the 5G network.

**Assignment 2**

**1. Services SDAP Provides to Upper Layers**

The SDAP layer provides several key services to the upper layers, specifically the Packet Data Convergence Protocol (PDCP) and the Radio Resource Control (RRC) layer. These services include:

* **Quality of Service (QoS) Handling**: SDAP maps the QoS flows from the upper layers (such as PDCP) to the appropriate bearers in the data plane. It ensures that each QoS flow receives the correct treatment as per the QoS profile defined.
* **Traffic Management**: SDAP performs traffic management by classifying and scheduling data packets based on QoS requirements. This helps in efficient utilization of network resources and maintaining service quality.
* **Bearer Management**: It handles the establishment and maintenance of bearers. SDAP ensures that the data flows are correctly mapped to bearers, which can be of different types such as default bearer or dedicated bearer.
* **Flow Control**: It manages the flow of data between the user equipment (UE) and the core network, ensuring that data flows are regulated according to the QoS requirements and network policies.

**2. Services SDAP Expects from Lower Layers**

SDAP relies on services provided by lower layers, specifically the User Plane Function (UPF) and the gNodeB (gNB) in the 5G architecture. The services SDAP expects include:

* **Data Forwarding**: SDAP expects the lower layers to forward user data packets efficiently. The lower layers, such as the UPF, handle the actual data transfer over the network, while SDAP manages the adaptation and mapping.
* **Bearer Handling**: SDAP relies on the lower layers to provide bearer resources and handle bearer establishment, modification, and release as needed. The lower layers manage the physical and logical resources required for data transport.
* **Packet Transport**: SDAP expects lower layers to transport packets reliably and with minimal delays. The lower layers, including the gNB, are responsible for the physical transmission and reception of data packets.
* **Error Reporting**: Lower layers need to report any errors or issues encountered during data transmission. This feedback helps SDAP make necessary adjustments and ensure data integrity and QoS compliance.

**3. Main Functions of the SDAP Layer**

The SDAP layer performs several critical functions, including:

* **QoS Flow Mapping**: SDAP maps the QoS flows to the appropriate bearers. This involves associating each QoS flow with the correct bearer and ensuring that the QoS requirements are met throughout the data transmission process.
* **Traffic Scheduling**: It schedules traffic according to the QoS requirements of each flow. SDAP manages how data is sent and prioritized based on the specified QoS parameters.
* **Bearer Resource Management**: SDAP handles the allocation and management of bearer resources. It ensures that bearers are properly configured and maintained to support the **required QoS levels.**
* **Flow Control and Adaptation: The SDAP layer adapts the data flow according to network conditions and QoS requirements. It adjusts the flow of data to prevent congestion and ensure smooth transmission.**
* **QoS Enforcement: It enforces QoS policies by monitoring and controlling the data flows to comply with the defined QoS profiles. This includes ensuring that each flow meets its performance criteria, such as latency, bandwidth, and packet loss.**

**Assignment 3**

**1. Establishing and Releasing an SDAP Entity**

**UE,'NG-RABI 
QoS flow 
Transmitting 
SOAP entity 
Mapping of QoS now to a DRa 
NG-RAN/IJE 
QoS flow 
Receiving 
SOAP entity 
Removing SOAP header 
Reflective QoSflowto I 
DRa mapping 
SOAP header 
is configured 
Adding SOAP 
header 
SOAP 
header is not 
configu red 
SOAP 
header is 
configu red 
Radio Interface (U u) 
SOAP header 
is not 
configu red **

**Establishing an SDAP Entity:**

Request Initiation: The process begins when the User Equipment (UE) or the network requests the establishment of a Service Data Adaptation Protocol (SDAP) entity. This is typically triggered during the initial attach procedure or during the bearer setup procedure.

SDAP Context Setup Request: The network (e.g., eNodeB/gNodeB) sends an SDAP Context Setup Request to the UE. This request includes parameters like QoS rules and the mapping of QoS flows to bearers.

SDAP Context Setup Response: The UE responds with an SDAP Context Setup Response, acknowledging the request and providing any additional parameters needed.

Context Activation: Upon receiving the response, the network activates the SDAP context. This involves setting up the necessary bearer paths and QoS handling mechanisms.

Releasing an SDAP Entity:

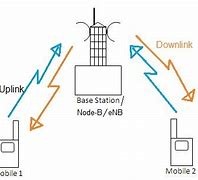
Request Initiation: The release process starts when the network or UE requests the release of an SDAP entity. This could be triggered by changes in the bearer configuration or during detach procedures.

SDAP Context Release Request: The network sends an SDAP Context Release Request to the UE, indicating that the SDAP entity should be released.

SDAP Context Release Response: The UE sends an SDAP Context Release Response, confirming the release and updating any necessary parameters.

Context Deactivation: After receiving the response, the network deactivates the SDAP context, clearing any associated resources and QoS rules.

2. Uplink and Downlink Data Transfer



**Uplink Data Transfer:**

**Data Preparation:** The UE prepares the data for uplink transfer, including associating it with the correct QoS flow.

**Packet Formation:** The data is encapsulated into SDAP PDUs (Protocol Data Units), which include QoS flow identifiers.

**Transmission:** The UE transmits the SDAP PDUs to the network.

**Network Handling:** The network receives the SDAP PDUs, decapsulates them, and forwards them to the appropriate destination within the network.

**Downlink Data Transfer:**

**Data Preparation:** The network prepares downlink data for transmission to the UE, associating it with the correct QoS flow.

**Packet Formation:** The data is encapsulated into SDAP PDUs, including the relevant QoS flow identifiers.

**Transmission:** The network transmits the SDAP PDUs to the UE.

**UE Handling:** The UE receives the SDAP PDUs, decapsulates them, and processes the data accordingly.

3. Reflective QoS Flow to DRB Mapping

Data Radio Bearer 
(ORB) 
Air Interface (uu) 
gNB 
Qos 
PDU Session 
N3 Interface 
UPF 
N3 GTP-U 
Tunnel 

**Reflective QoS Flow to DRB Mapping:**

**Concept Overview:** Reflective QoS flow to DRB (Data Radio Bearer) mapping involves associating QoS flows with specific DRBs to ensure proper data handling and QoS enforcement.

**QoS Flow Identification:** Each QoS flow is identified by a QoS Flow Identifier (QFI). The QoS flow parameters dictate the level of service required for the data being transmitted.

**DRB Mapping:** Each QoS flow is mapped to a  specific DRB. This mapping is based on the QoS requirements and the network's capability to handle different types of traffic.

**Mapping Implementation:** The network applies the mapping rules to ensure that data is transmitted over the appropriate DRB, enforcing the desired QoS levels. This mapping is reflected in the SDAP layer, where QoS flows are managed and mapped to DRBs accordingly.

This mapping ensures that the data traffic adheres to the defined QoS policies and is efficiently handled by the network.

**Assignment 4**

**1. Difference Between Data PDUs and Control PDUs**

**Data PDUs**:

* **Purpose**: Primarily used to carry user data from one end to another. They encapsulate the actual payload that needs to be transmitted.
* **Content**: Data PDUs generally consist of the SDAP header (if applicable) followed by the user data payload.
* **Usage**: They are used in regular data transmission operations, allowing the SDAP to handle the user data that is being sent over the network.

**Control PDUs**:

* **Purpose**: Used to manage the transmission and control the flow of data. They provide signaling and control information rather than user data.
* **Content**: Control PDUs include various types of control information such as session management, flow control, and error signaling. They do not typically carry the actual user data.
* **Usage**: They help in establishing, maintaining, and terminating connections, as well as managing errors and other control functions within the SDAP layer.

**2. Format of a Data PDU with and without an SDAP Header**

1. **Data PDU with SDAP Header**:

* **SDAP Header**: Contains protocol-specific information that helps in managing and identifying the data being transmitted.
  + **SDAP Header Fields**: May include fields like:
    - **Service Data Unit (SDU) Identifier**: Identifies the data unit.
    - **Sequence Number**: Helps in ordering and identifying data segments.
    - **Length**: Indicates the length of the data payload.
* **Data Payload**: The actual user data or application data that is being transmitted.

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SDAP Header             // Protocol-specific information   
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Data Payload            // User data   
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1. **Data PDU without SDAP Header**:

* **Format**:
  + **Payload**: Contains only the user data directly without any additional protocol-specific header information.

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Data Payload        // User data   
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**3. Illustrate the Use of End-Marker Control PDU in SDAP**

**End-Marker Control PDU**:

* **Purpose**: Used to signal the end of a data transmission session or stream. It indicates that no more data will be sent, helping in proper session closure and resource management.
* **Usage**:
  + **Session Termination**: Marks the end of a data session, signaling that the session can be closed or cleaned up.
  + **Stream Conclusion**: Indicates that a particular data stream has finished, ensuring that the receiver knows it has received all intended data.

**Format**:

* **Control Header**: Contains fields specific to control signaling, such as the End-Marker indication.
* **End-Marker Payload**: Often minimal, just indicating the end of the data stream or session.

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Control Header                     // Contains end-marker indication   
-------------------------------------   
End-Marker Payload              // Minimal information to signify end   
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Basically, Data PDUs and Control PDUs serve distinct roles within the SDAP protocol: Data PDUs for transporting user data and Control PDUs for managing data transmission. The SDAP header in Data PDUs provides necessary protocol-specific information, while an End-Marker Control PDU helps in indicating the conclusion of data transmission, ensuring proper session and resource management.

**Assignment 5**

**1. Key SDAP Parameters**

**QFI (QoS Flow Identifier):**

* **Purpose:** QFI is a crucial parameter used to identify and distinguish different QoS flows within a PDU Session (Packet Data Unit Session). It ranges from 1 to 9 and is used to enforce specific QoS policies for each flow.

**D/C (Direction/Control Indicator):**

* **Purpose:** D/C indicates the direction of the data flow and the type of PDU (Packet Data Unit). It distinguishes between user data and control data. For example, D/C = 0 indicates user plane data, while D/C = 1 indicates control plane data.

**RQI (Request Type Indicator):**

* **Purpose:** RQI specifies whether a QoS flow is requested by the UE (User Equipment) or if it is an established flow. This helps in managing the initiation and modification of QoS flows dynamically.

**RDI (Reflective QoS Indicator):**

* **Purpose:** RDI provides feedback about whether the requested QoS parameters have been successfully applied or if there have been modifications due to network conditions or policies.

**2. Use of SDAP Parameters in QoS Flow to DRB Mapping**

In 5G NR (New Radio), the mapping of QoS flows to Data Radio Bearers (DRBs) involves using these parameters as follows:

**QFI:** Determines the specific QoS characteristics (such as latency, priority, and reliability) associated with each QoS flow.

**D/C:** Helps in segregating user data from control data, ensuring different treatment for each type of traffic.

**RQI:** Facilitates the establishment and modification of QoS flows dynamically based on UE requests or network requirements.

**RDI:** Provides feedback to the UE about the QoS parameters applied, ensuring that the expected QoS levels are maintained or adjusted as needed.

 These parameters collectively enable efficient mapping of QoS flows to appropriate DRBs, ensuring that different types of traffic receive the required quality of service based on network conditions and UE requirements.

**3. Importance of QoS Flow Management in 5G NR**

QoS flow management in 5G NR is crucial for several reasons:

**Enhanced User Experience:** It ensures that applications requiring specific QoS parameters, such as low latency for real-time communication or high throughput for multimedia streaming, receive optimal performance.

**Network Efficiency:** By prioritizing and managing QoS flows, operators can efficiently utilize network resources, minimizing congestion and improving overall network performance.

**Service Differentiation:** Different QoS levels allow operators to offer tiered service plans, catering to diverse user needs and applications.

**Future-Proofing Networks:** As 5G evolves and supports diverse use cases (e.g., IoT, industrial automation), robust QoS management becomes essential for meeting stringent reliability, latency, and bandwidth requirements.