NETWORK LAYER

Application	Application
Presentation	
Session	
Transport	Transport
Network	Internet
Data Link	Network Interface
Physical Layer	Physical

Two Network Approaches

- Connection-oriented
  - performs routing at call setup
  - adopted by "big-LEO" architectures
- Connectionless network
  - performs routing hop-by-hop
  - used on the Internet
- Remark: Connection-less protocols can rely upon connection-oriented networks e.g., IP over ATM.

- The Internet Protocol (IP)
  - Network layer protocol (addressing protocol)
  - Integrates heterogeneous networks
  - Each media (satellite, Ethernet, ATM) encapsulates IP datagrams in specific way
  - Routers move IP datagrams between different media according to routing information
  - Allows implementation of standard procedures for security (e.g. IPSec)
  - IPv6 compatible
  - Unreliable datagram delivery, higher layer reliability may be necessary
  - Theoretically no limits on throughput, higher layer congestion control may be needed

Connectionless in Space

Why?

- IP is the base of almost all current networks! Everything-over-IP (even parodies: RFC3251)
- Connectionless IP runs over heterogeneous networks, is a simple protocol with relatively low overhead, no connection setup
- As well as in terrestrial networks, connectionless communications offer some degree of fault tolerance for data delivery
- Seamless integration with IP multicast across the satellite
- Higher coding adopted on satellite can reduce the number of lost packets, increasing IP performance

Why not?

- Some services need granted performance and call setup available in connection-oriented networks
- ATM is already used in several cases, even to tunnel IP (e.g., in DVB-RCS)
- For LEO/MEO (some may be connection oriented)
  - Possibility of full mesh connectivity with intra and inter-plane ISL (e.g., Iridium)
  - Due to high speed in orbit (25,000 km/h) satellite networks topology might be too dynamic for standard IP routing
  - Frequent handovers may require frequent network routing reconfigurability that may not comply with IP standard protocols
  - fixed number of nodes and deterministic routing due to predictable movement and periodic behavior
- Internet-style routers on board require huge processing and memory usually not available
- Multicast problems

Connectionless in Space (2)

- Connectionless remarks
  - The technology is mature enough to launch satellites with full routing capabilities! IP is now suitable to be used over satellite and can be a key driver of the satellite design
  - New higher layer protocols and architecture can allow IP based networks to approach performance of connection oriented networks: MPLS, QoS (DiffServ/IntServ), IMS (IP Multimedia Subsystem), SIP, etc.
  - Newer systems are extending even more the connectionless concept, introducing Delay Tolerant Networks (DTN) protocols to manage long channel interruptions.
  - Most of satellite payloads are transparent, thus the IP paradigm is applied at ground network management level

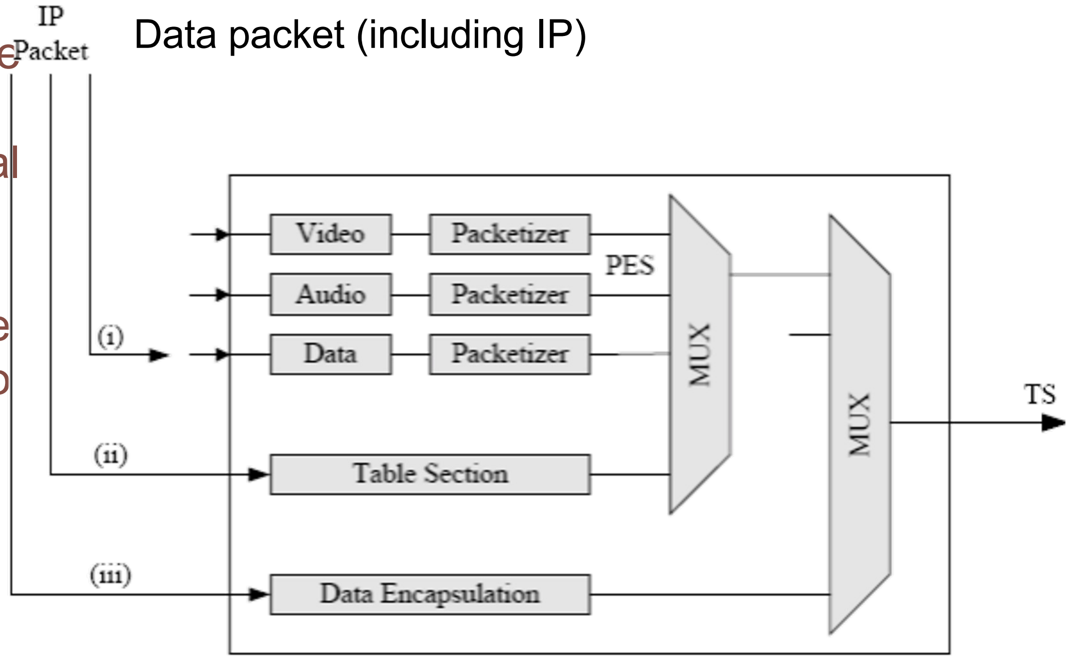
Advanced Topics for IP over Satellite

- Pico/Micro-sats
  - Mega Constellations of several small satellites
    - low power, low weight & small antennas, easy to launch, expendable
  - Commonalities with sensor networks, potentially an high density mesh network
  - High capacity (promised!)
  - Dynamic Routing protocols shall be applicable.
- Interplanetary Internet (IPN) – Deep space protocols
  - DTN and bundle based middleware protocols
- Internetworking with wireless systems
  - Satellite with UAVs, *ad hoc* and wireless access networks
  - Single IP for different access
- Integrated architectures for multimedia services (e.g., IMS based).

IP encapsulation over DVB

DVB-S data transmission: MPEG-TS

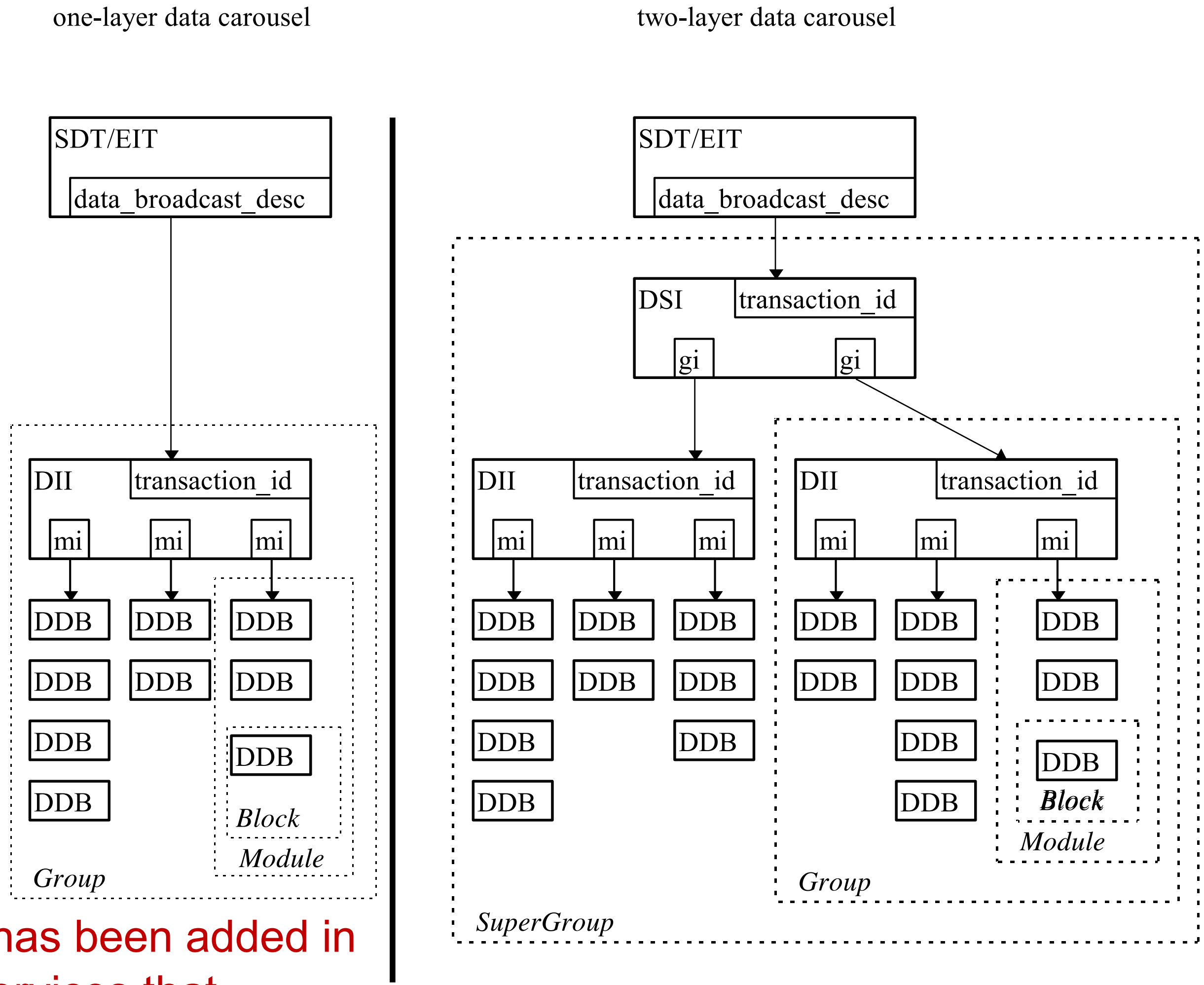
- **MPEG2** standard defines the rules to multiplexing several types of multimedia information into one Transport Stream (TS). The next generations (MPEG4) updated only on compression.
- DVB standard defines 3 modes to "insert" data packets into MPEG-TS:
  i. Data packets can be encapsulated and carried inside the PES packets intended for video and audio streams. This method is referred as **Data Streaming** and used for instance for TeleText.
  ii. Data packets can be carried inside the section packets defined for system control in DSM-CC TS packets (Digital Storage Media Command and Control). This method supports normally **data carousel** for interactive TV (MHP) but it has been extended to support IP packets delivery (ETSI EN 301 192) using e.g. ***Multiprotocol Encapsulation*** **(MPE)**.
  iii. An adaption layer protocol (e.g., AAL5), called ***Data Piping***, can be used to segment data packets directly into a sequence of TS cells.



- (i) and (ii) are provided as standards.
- (iii) requires a suitable adaptation layer.

Data carousel

- The specification of DVB data carousels is based on the DSM-CC data carousel specification (ISO/IEC 13818-6 [5]). The DSM-CC data carousel specification embodies the cyclic transmission of data to receivers. The data transmitted within the data carousel is organized in "modules" which are divided into "blocks". All blocks of all modules within the data carousel are of the same size, except for the last block of each module which may be of a smaller size.



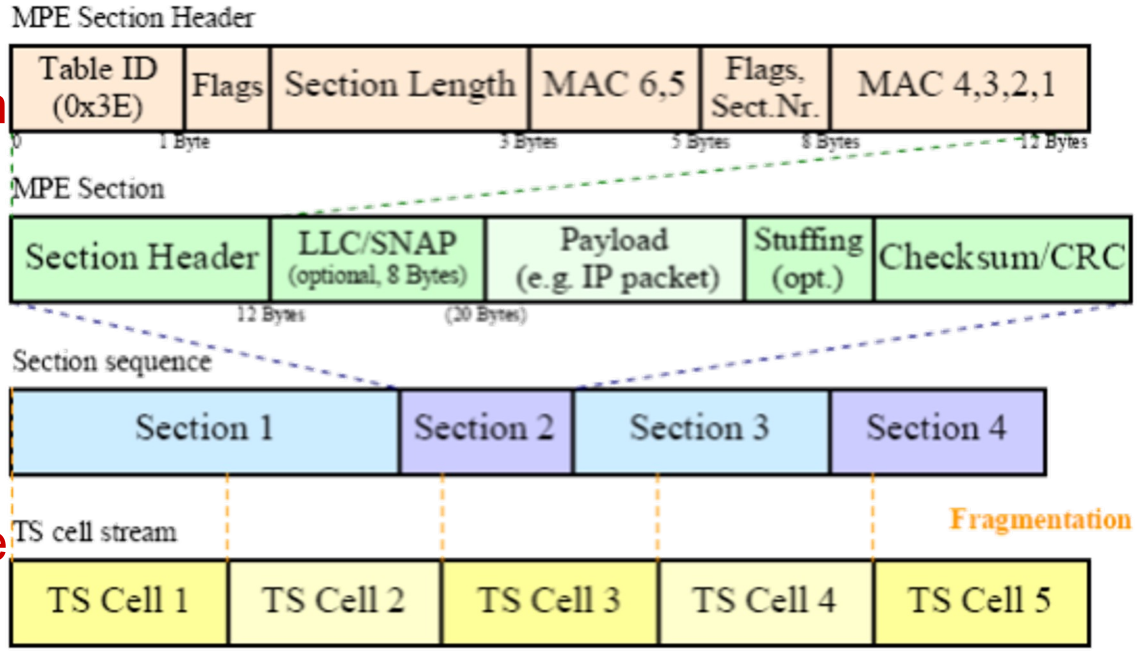
- The object carousel specification has been added in order to support data broadcast services that require the periodic broadcasting of User Objects through DVB compliant broadcast networks, specifically as defined by DVB Systems for Interactive Services (SIS) (ETS 300 802).

DSI: DownloadServerInitiate
gi: GroupInfoBytes
DII: DownloadInfoIndication
mi: ModuleInfoBytes
DDB: DownloadDataBlock
⟶ : Location reference (transactionId, optional componentTag)

DVB-S IP delivery
Multi Protocol Encapsulation (MPE)

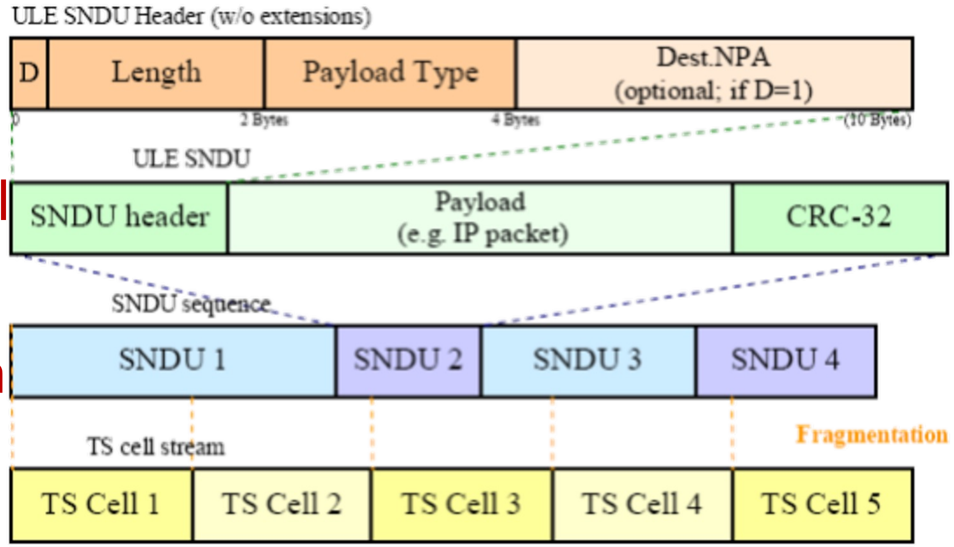
- IP packets are first wrapped into a MPE DSM-CC (Digital Storage Media-Command & Control) section:
  - 12 bytes section header
  - 32 bits (4 bytes) Checksum/CRC (Cyclic Redundancy Check)

- Section header does not contain a payload type field. An additional 8-byte LLC (Logical Link Control)/SNAP (Subnetwork Access Protocol)-header has to be added for non-IP payload types.
- Optionally stuffing bytes can be added.



Ultra (unidirectional) Lightweight Encapsulation (ULE)

- Not originally in DVB standard, RFC4326, now mentioned in DVB standard and allowed to be used (for example in Linux)
- Back compatible, alternative to MPE in DVB-S.
- Like MPE, the payload is first wrapped into a SNDU (Sub-Network Data Unit) with a 4-bytes SNDU header and a CRC-32 at the end.
- Unlike MPE, the destination NPA (Network Point of Attachment) is optional and allocates an additional 6 bytes if enabled.
- The SNDUs may contain extension headers, which are signalled by protocol type value 0x60.



ULE with extension header

- An extension format for the ULE SNDU has also been defined
- New extension headers can be added to the ULE SNDU
- Packet format for an ULE SNDU with one extension header, H1.

ULE Base Header

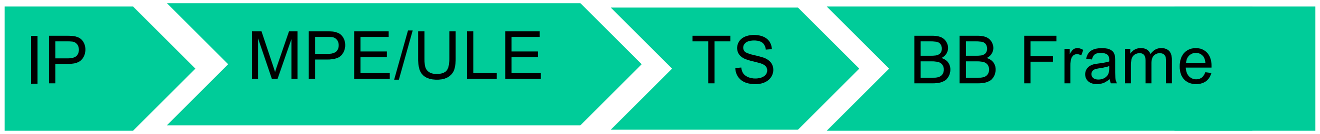
D=0	Length	T1	NPA Address	H1	T2	IP Payload	CRC

ULE Extension Header

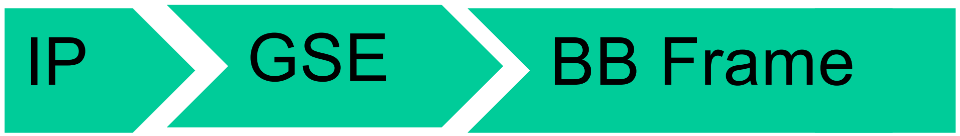
- The type field, T1 in the ULE base header would specify the type of the extension header, while the type T2 in the extension header would specify the type of payload carried by the SNDU.

DVB-S2 encapsulation

- DVB-S2 guarantees the compatibility with DVB-S
  - Mode to encapsulate TS cells in the BBframe (default for video) using either MPE or ULE (nested encapsulation, not efficient for IP packets!)



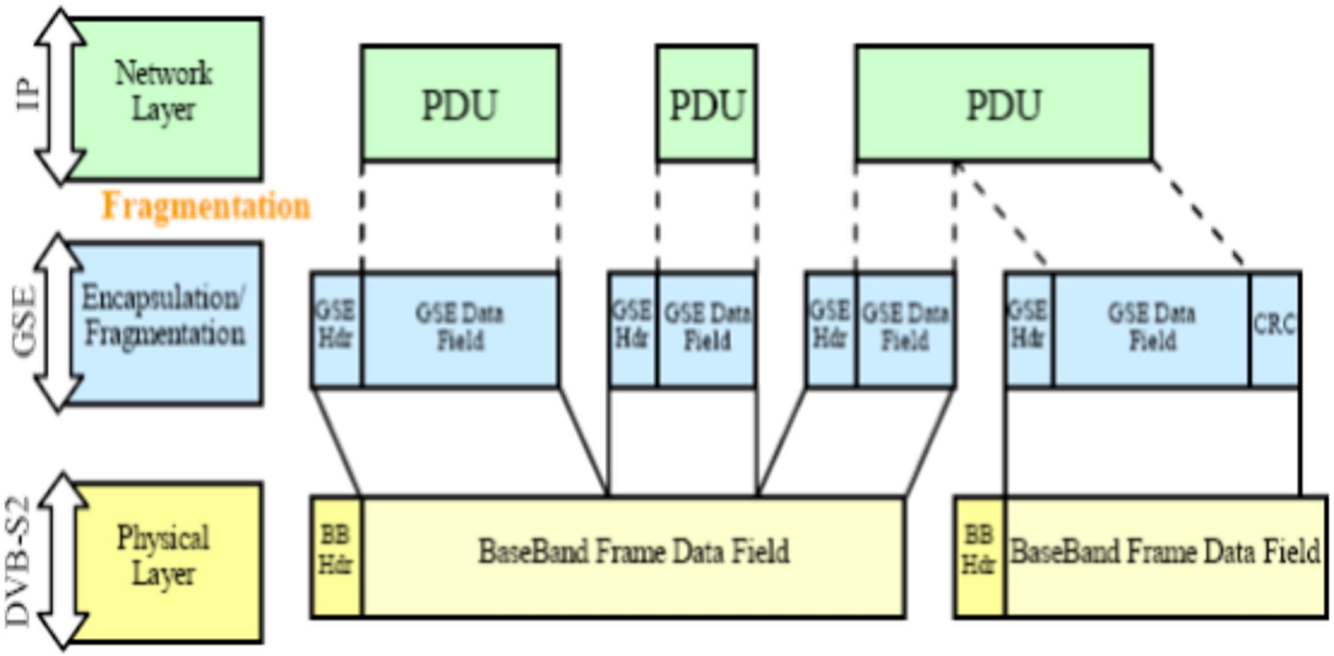
- A new encapsulation protocol is defined to natively encapsulate IP packets directly in the DVB-S2 frame.
  - Generic Stream Encapsulation (GSE) avoids the double encapsulation IP-TS-BBframe (*)



* BBframe = Base Band Frame

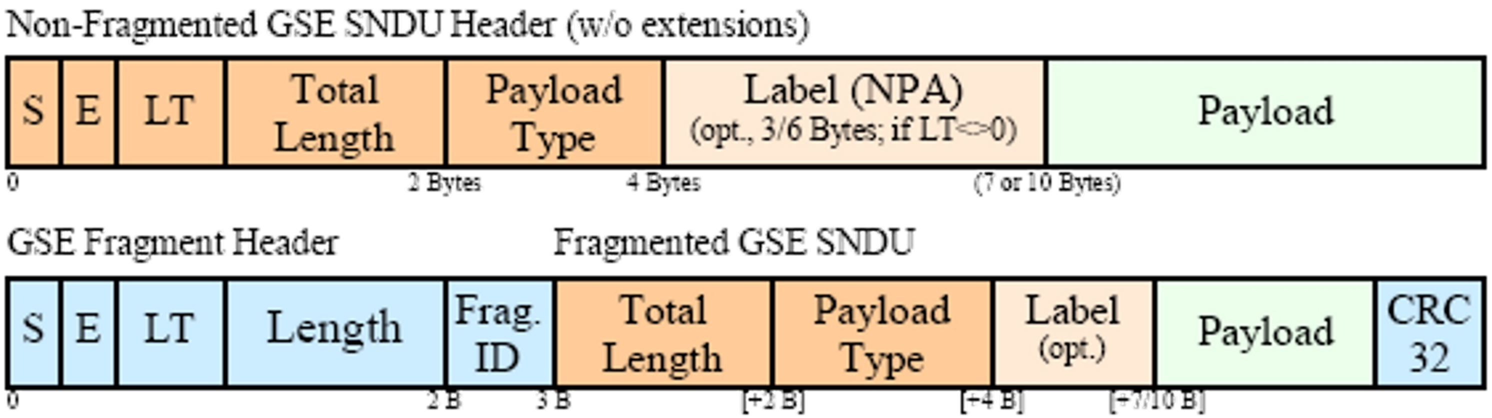
Generic Stream Encapsulation GSE (1/2)

- GSE encapsulates data (IP packets) directly and efficiently into BBframe (saving of overhead!!)
- Like ULE, each packet is wrapped into a GSE SNDU structure with:
  - First/last fragment flag
  - Label type
  - SNDU length
  - Payload type
  - Label
  - Payload fields



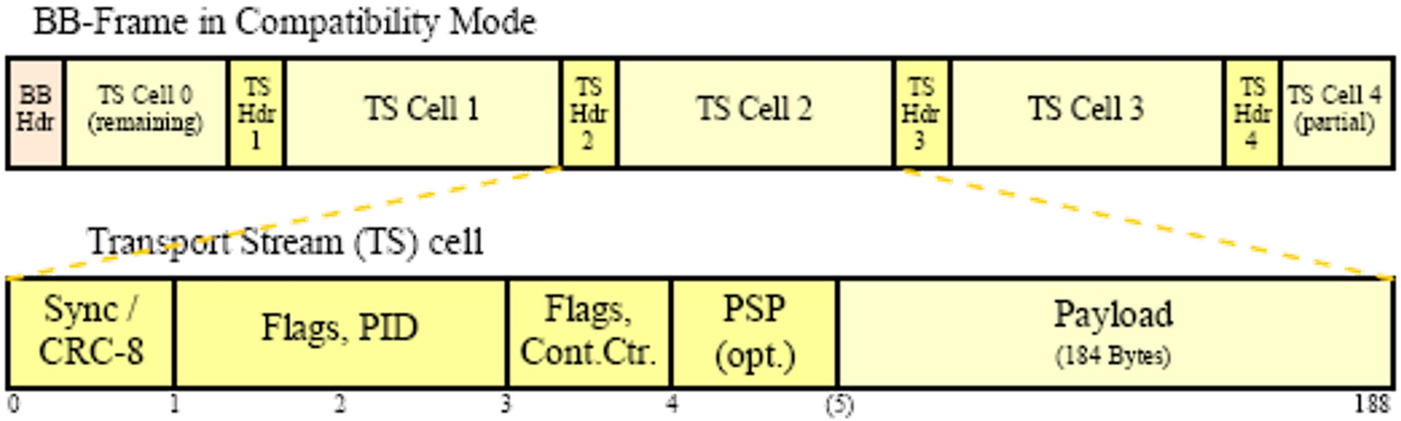
GSE (2/2)

- SNDU can contain an entire PDU (Packet Data Unit) or a fragment of PDU
  - If a SNDU does not fit as a whole, a fragment header is prepended to each fragment and a 4-byte CRC-32 is appended at the end.
- Like ULE, GSE may contain extension headers.
- GSE optionally supports two types of NPA (Network Point of Attachment) of 3 and 6 bytes respectively.



TS over DVB-S2

- TS cells are encapsulated in the BBframe by simply using a concatenation format. Usually done for video and audio, to maintain compatibility with DVB-S demuxing chipsets.
- The "sync" byte is replaced by a CRC-8.
- Length of the BBframe header is 10 bytes
- TS cell can be fragmented over multiple BBframe (in alternative "padding" can be added to fill the spare space)



Encapsulation efficiency

- The encapsulation efficiency is defined as the ratio between the sums of the payload packets (IP) lengths and the lengths of the frames (TS frame in DVB-S or BBframes in DVB-S2)

$$\eta_{encap}(L_{IP}) = \frac{1}{L_{f,total}} \sum L_{IP}$$

Efficiency model for MPE/TS (DVB-S)

- With MPE, IP packets are first wrapped into a section structure (DSM-CC) of length $L_{section}$
  - This consists of a 12 bytes header and a 4 bytes checksum + payload
- In case of non-IP payload, an additional 8-byte LLC-SNAP header is necessary.

$$L_{section}=12+L_{IP}+4$$

$$L_{section,LLC\text{-}SNAP}=12+8+L_{nIP}+4$$

- The total length of the TS frame is:

$$L_{f,total}^{MPE} = \left\lceil \frac{1}{L_{ts}-4} \sum_i L_{section,i} \right\rceil \cdot L_{ts}$$

- L_{TS}=188 bytes for MPEG, with 4 bytes header

Efficiency model for ULE/TS (DVB-S)

- With ULE, the SNDU are wrapped in a 4-byte header and a 4-byte checksum trailer.
- The 6-byte NPA is optional and not constrained in the standard header
- ULE SNDU header contains the "payload type" field and then does not require an additional LLC/SNAP header for non-IP data

$$L_{SNDU}=4+L_{IP}+4$$

$$L_{SNDU,NPA}=4+6+L_{IP}+4$$

- Similar to MPE, the TS frame length is:

$$L_{f,total}^{ULE}=\left\lceil \frac{1}{L_{ts}-4}\sum_i L_{SNDU,i} \right\rceil \cdot L_{ts}$$

Encapsulation efficiency of TS cells in DVB-S2 (to ensure backward compatibility)

- For DVB-S2, the size of the BBframe ($L_{BBframe}$) can range from 384 to 7274 bytes, depending on the ACM mode in use.
- According to source size and either GSE/ULE encapsulation, a given number of TS packets is required, see e.g., $L_{f,total}^{MPE}$
- Each BBframe has a 10 bytes header ($H_{BBframe}$)
- Many TS cells with size L_{ts}=188 bytes are packed into the payload area of the BBframe, with the following overhead (n_{ts}=number of TS cells):

$$OH_{S2-TS}^{+} = \left\lceil \frac{n_{ts} \cdot L_{ts}}{L_{BBframe} - H_{BBframe}} \right\rceil \cdot H_{BBframe}$$

- The overall efficiency over DVB-S2 is reduced due to the nested encapsulation if compared to DVB-S and is equal to:

$$\eta_{encap}^{MPE/ULE} = \frac{\sum L_{ip,total}}{L_{f,total}^{MPE/ULE} + OH_{S2-TS}^{+}}$$

Efficiency model for GSE (DVB-S2)

- The basic SNDU format is very similar to ULE.
- If the SNDU is fragmented, each fragment has a 3-bytes header, and a 4-bytes CRC-32 is appended.
- Optionally, GSE supports two possible NPA (label) length, 3 or 6 bytes.

$$L_{SNDU} = 3 \cdot n^{*}_{frag,p} + 4 + L_P + \delta^{T}_{frag,p}$$
$$L_{SNDU,label} = L_{SNDU} + (3\ OR\ 6)$$

$n^{*}_{frag,p}$ is "0" if SNDU is not fragmented or n=total_fragment_number otherwise

$\delta^{T}_{frag,p}$ is "0" if SNDU is not fragmented, "4" otherwise

$$L^{GSE}_{f,total} = \left\lceil \frac{1}{L_{BBframe} - 10} \sum_{i} L_{SNDU,i} \right\rceil \cdot L_{BBframe} \qquad \eta^{GSE}_{encap} = \frac{\sum L_{ip,total}}{L^{GSE}_{f,total}}$$

QoS Definition

- Quality of Service can be referred and defined either at network level or at user level.
- **QoS refers to the capability of a network to provide the best service to the selected users over various interconnected networks according to agreed contract.**
- The primary goal of QoS ⇒ to assign service parameters
  - dedicated bandwidth,
  - controlled jitter and latency (required by some real-time and interactive services)
  - to improve loss characteristics (required by file transfer services).
- It is also important to ensure that the priority assignment to some of the services doesn't decrease overall quality of the others.
- Suitable protocols need to be implemented in every node of the network.
- ***QoS provisioning ⇒ a set of procedures aiming at handling congestion through a more efficient use of the resources rather than just adding capacity.***

QoS Methodologies

- At the moment two main methodologies have been proposed and implemented for IP based networks:
  - **Integrated Services**
  - **Differentiated Services**.
- They have been introduced and implemented in different terrestrial network architectures.
- Now applicable to architectures including a satellite link!

The Integrated Services (IntServ)

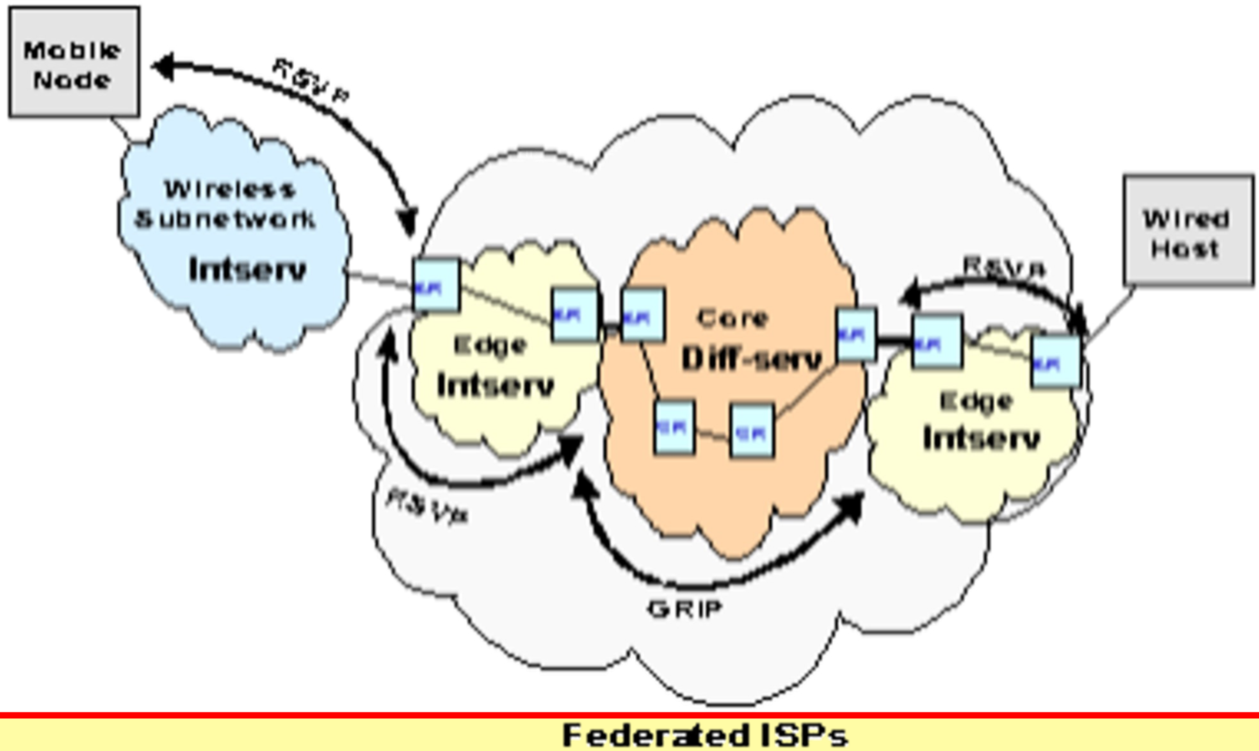
- It defines two services,
  - **guaranteed services and**
  - **controlled load,**
- Pre-allocate the resources necessary to the connection,
  - negotiating with every network node included in the route from the source to the destination.
- Different end-to-end signaling protocols for the negotiation are defined (ST2, ST2+, RSVP)
- Resource reservation Protocol is the most typically used.
  - It consists in sending a message through the network to reserve in each node the resources needed to a particular information flow. After a successful reservation all nodes will store the necessary information to recognize the packets of the reserved flow. This may cause problems when there are too many flows to manage.

The Differentiated Services (DiffServ)

- Per Hop Behavior (PHB) approach, each hop treats the traffic of the same class with a pre-defined priority.
- Traffic needs to be classified when entering a DiffServ domain according to static/dynamic rules (e.g., protocol, source port etc.). Packets are marked using the DSCP (Differentiated Services Code Point) field, former ToS (Type of Service) field
- Each administrative domain enforcing DiffServ might require to re-classify the packets according to its own rules.
- Each domain (set of routers adopting the same QoS rules) can manage the QoS of the traffic in the most suitable way for its local network.
- The end-to-end QoS is not strictly guaranteed, but it is distinct and predictable for each segment of the network.
- The DiffServ procedure is based on the concept that flows are grouped into classes of traffic
- Statistical approach: Probing packets might be used to control the performance of each class of service end-to-end

Joint implementation

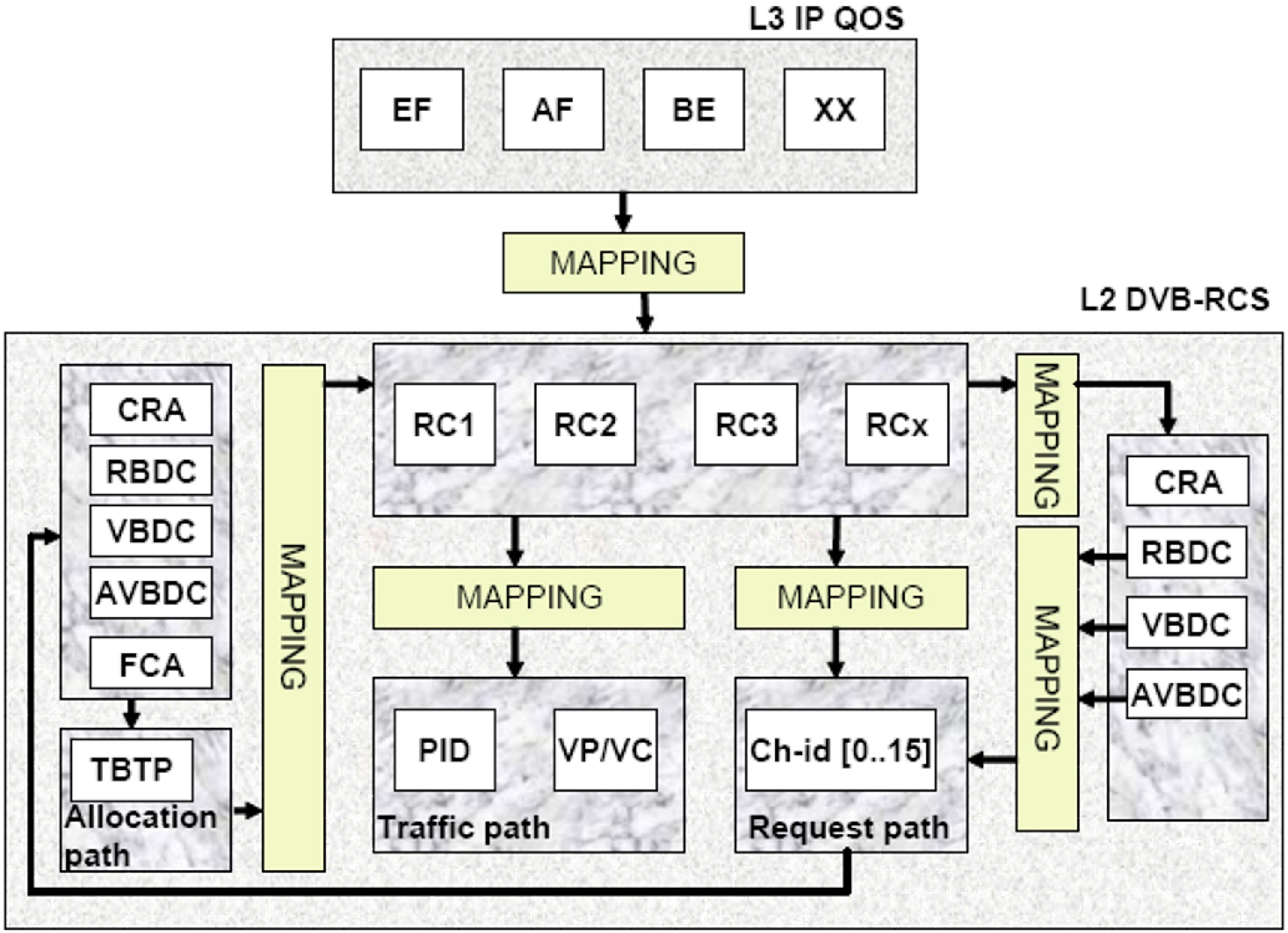
- The two different approaches (IntServ and DiffServ) can be jointly used in a complex network, implementing different scheme in different portions of the network,
  - **IntServ** in the access network
  - **DiffServ** in the core network



QoS in DVB-RCS

- QoS can be implemented in a static way, or using C2P (Connection Control Protocol) dynamic messages for QoS handling on connection basis.
- Static QoS:
  - Supported by Management functions (static configuration of PHB)
  - DiffServ based PHB model
  - Support at MAC layer with re-configurable RC queues mapped to DAMA requests classes.

QoS architecture



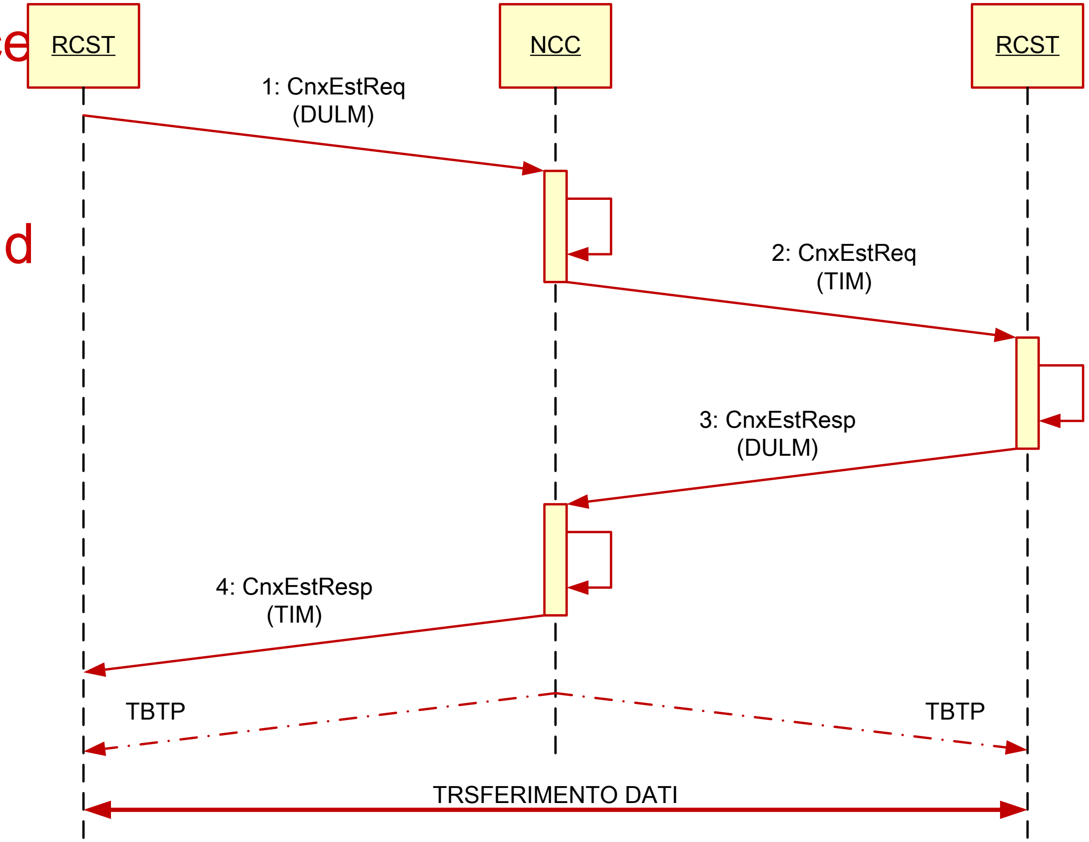
C2P – Connection Control Protocol

- Introduced to establish a connection between two terminals (or terminal and gateway, or multicast relations) for connection setup of critical services with dynamic QoS support. Some of the C2P applications are:
  - When a user needs certain bandwidth to run an application for a limited time, it performs a request using the C2P channel. It is similar to VoIP signalling for call setup.
  - C2P protocol messages are used to grant resources and QoS. The Network Control Center may perform Access Control (Call Admission Control - CAC) functionalities.
  - When the service is allowed, the resources are granted to offer the performance needed by the application (e.g. low jitter for voice calls)

C2P based QoS

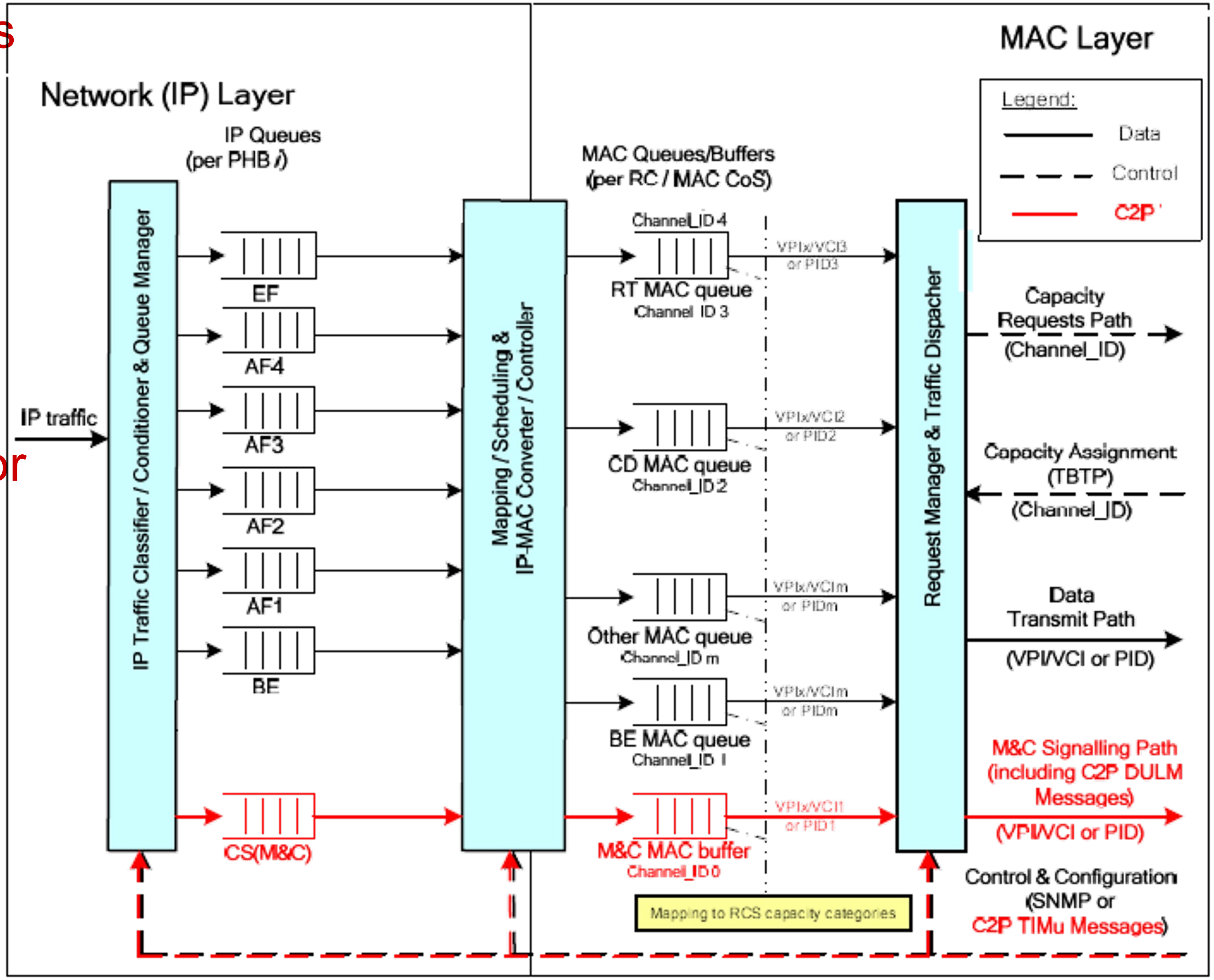
- Dynamic C2P messages adjust the QoS of the RCS nodes according to explicit signaling of new connection entering/leaving the system.

- Each new connection trigger a request for a given type of service (RT – Real Time, CD – Critical Delivery, BE – Best Effort), a Sustainable Data Rate (SDR) and a Peak Data Rate (PDR).
- If the PDR/SDR request is available, the nodes involved in the connection receive a dedicated channel for data transfer.



C2P – QoS queues

- The response includes an association between the connection and a specific Class Of Service (CoS), mapped to a MAC queue. This reflects the different queues for DiffServ services and the specific PHB for that kind of traffic
- Connections of the same kind (e.g., RT) are mapped to the same CoS



C2P – Connection Control Protocol

- Active research topics: Relation with SIP and IMS.