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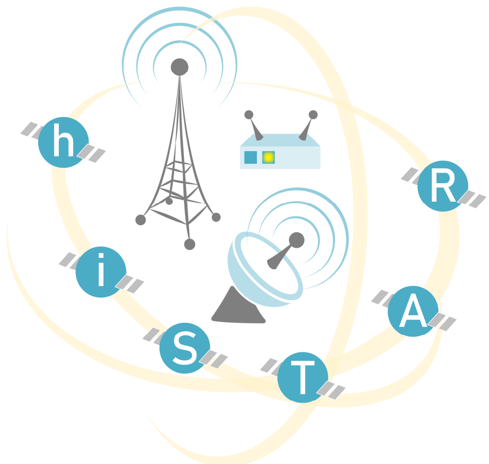
Hybrid Integrated Satellite and Terrestrial Access Network



D2.2: HUT architecture

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EXECUTIVE SUMMARY

The hi-STAR project addresses integration of non-terrestrial networks with terrestrial 5G network which is in focus of the next generation wireless networks. The project's main goal is to develop flexible framework for integrated terrestrial 5G and Low-Earth-Orbit (LEO) satellite networks. One of the first steps toward the framework design and implementation is defining the network architecture of the overall user access to services where user terminal has the ability to access two different RATs (Radio Access Technologies) - terrestrial and satellite.

This deliverable is a result of the work done in WP2 Subactivity T2.1 – System architecture proposal and state of the art overview. Deliverable D2.2 presents hybrid user terminal (HUT) architecture. It relies on the previous deliverable D2.1 and network architecture for hybrid access that was presented in D2.1. Based on that network architecture, HUT system architecture is developed. In this deliverable, overall HUT system architecture is presented and explained. Architecture choices regarding implementation aspects are explained and justified.

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ABBREVIATIONS

ARQ	Automatic repeat request
ATSSS	Access Traffic Steering, Switching and Splitting
CRC	Cyclic Redundancy Check
DVB-RCS	Digital Video Broadcasting Return Channel via Satellite
DVB-S2X	Digital Video Broadcasting Satellite Second Generation Satellite Extensions
HUT	Hybrid User Terminal
IP	Internet Protocol
LEO	Low Earth Orbit
MAC	Medium-Access Control
MA-PDU	Multiple Access Protocol Data Unit
MP-TCP	Multi-Path Transport Control Protocol
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PL	Physical Layer
PLSCODE	Physical Layer Signaling CODE
PoC	Proof of Concept
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RLC	Radio-Link Control
SDAP	Service Data Application Protocol
SDU	Service Data Unit
SNR	Signal-to-noise ratio
SOF	Start of Frame

TCP	**Transmission Control Protocol**
UDP	**User Datagram Protocol**
WP	**Work Package**

SECTION 1 - INTRODUCTION

Deliverable D2.2 represents major part of WP2 Subactivity 2.1 – System architecture proposal and state of the art overview. D2.2 is continuation of D2.1 deliverable results. In D2.1, overall networks architecture of hybrid access is presented. HUT needs to adopt to such architecture which means that HUT system architecture is built to be compliant with network architecture presented in D2.1. There were several implementation approaches and aspects that had to be considered during HUT architecture development. This deliverable provides discussion regarding these approaches and provides justification regarding the made choices. The results of this deliverable are very important for activities in other work packages and final PoC (Proof of Concept) demo.

This deliverable is structured as follows: Section 2 presents the background in terms of network architecture for hybrid access that is selected in deliverable D2.2. HUT main functions that utilize the hybrid access are presented in section 3. These functions have major impact on HUT architecture. Section 4 discusses the implementation approaches for realization of the HUT functions described in section 3. Also, the choice of selected approach is justified in section 4. Section 5 is the main section of this deliverable. In this section, HUT system architecture is presented and explained, on overall level as well as on building blocks level.

SECTION 2 – BACKGROUND

Previous deliverable D2.1 discussed the overall network architecture that involves HUT (Hybrid User Terminal) and its connection to two different RATs (Radio Access Technologies), one terrestrial and one satellite [1]. Several options and scenarios have been analyzed, and although the scenario where both RATs are under one telecom operator's control is the most desirable and provides better control and optimal performance, other scenario is selected to be pursued. The selected scenario, shown in Figure 1, considers that there are two different telecom operators and each of them controls different RAT, one operates the terrestrial access network and the other operates the satellite access network. This choice is based on the fact that it is not likely in near future to have telecom operators that have both (terrestrial and satellite) network segments under their control. However, HUT adjusted to this selected scenario will be suitable for other considered network scenarios that are discussed in D2.1. The other scenarios will just add new possibilities that come from the joint control of two different RATs in sense that telecom operator will have better insight in the overall traffic and user behaviour in both RATs. Thus, telecom operator will be able to optimize the network performance and instruct its users with better configuration and control messages. This means, that the HUT will just need to add feature of processing these additional messages without affecting its architecture that is presented in this section.

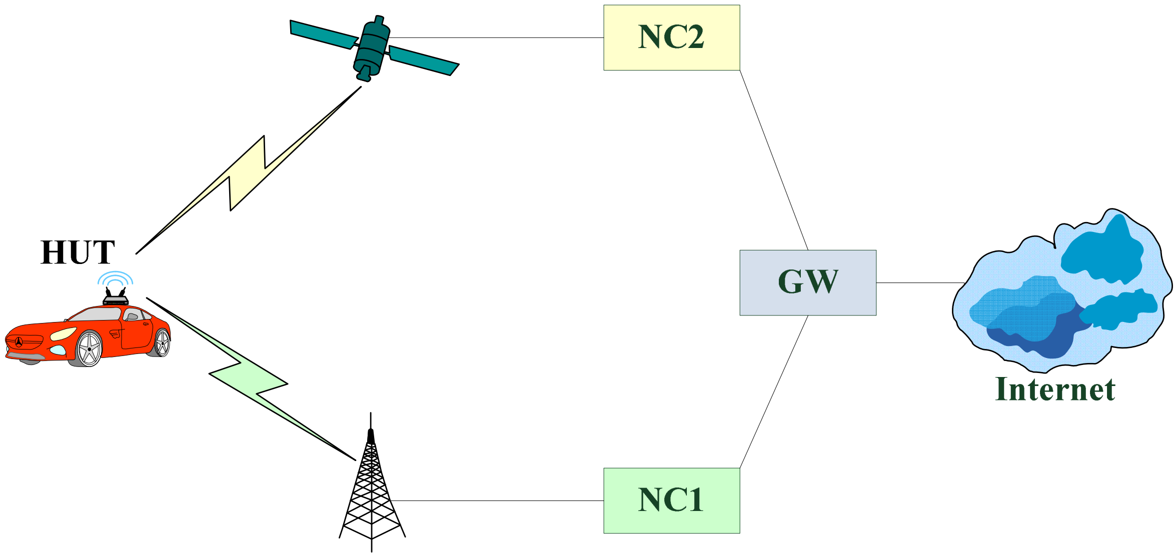

Figure 1: Separated satellite and terrestrial RATs [1].

SECTION 3 – HUT FUNCTIONS

Before explaining the HUT architecture, it is necessary to first understand which functions HUT needs to support. Main HUT feature is the supported access to two RATs, which provides multiple benefits such as:

- better availability - for user to have a network connection, only one available RAT is sufficient;
- continuous connection - if connection to one RAT is lost, user can redirect its service to the other (operating) RAT without interrupting and breaking the established service;
- more bandwidth - user service can utilize both RATs, thus, having more bandwidth at its disposal;
- better Quality of Service (QoS) - user can select RAT that is more suitable for its services, and with better availability this provides better QoS for user.

Obviously, the main HUT advantage is using two RATs like using two network links for better traffic management and increased reliability and availability. In order to utilize this advantage, HUT needs to support the ATSSS (Access Traffic Steering, Switching and Splitting) functions [2-6]:

- **Steering**: This function selects RAT that is more suitable for a new data flow.
- **Switching**: This function switches data flow from one RAT to other, typically in case of lost RAT connection, to preserve continuous data flow i.e. service.
- **Splitting**: This function enables that new data flow can be split across multiple RATs. This means that some portion of data flow's traffic goes via one RAT and remaining traffic goes via other RAT. This function is typically used to achieve increased bandwidth for service.

From the definitions of ATSSS functions, it can be concluded that these functions control the user traffic route (via which RAT traffic will pass). Thus, the most important parts of HUT are traffic controller and traffic switch. Traffic switch actually implements the ATSSS functions, but the traffic controller is the one that configures the traffic switch operations based on various parameters such as measurements, user preferences, network configuration messages.

SECTION 4 – ATSSS IMPLEMENTATION OPTIONS

ATSSS functions represent the focal point of HUT. Given that IP traffic follows the TCP/IP layered communication, a question arises where is the best place to locate ATSSS functions. There are two main approaches [2, 7]:

- Lower layer implementation
- Higher layer implementation

Lower layer implementation is shown in Figure 2. In this approach, ATSSS functions are implemented in lower layer (data-link layer) and implementation is based on MA-PDUs (Multiple Access Protocol Data Units) that are supported by 5G standards [7, 8]. Prior the data flow starts, it is decided whether the flow will use these PDUs or not. MA-PDUs need to be used in order to have ATSSS support for data flow. User decides will MA-PDUs be used, but network can also enforce the use of MA-PDUs for some services even if the user is not requesting it.

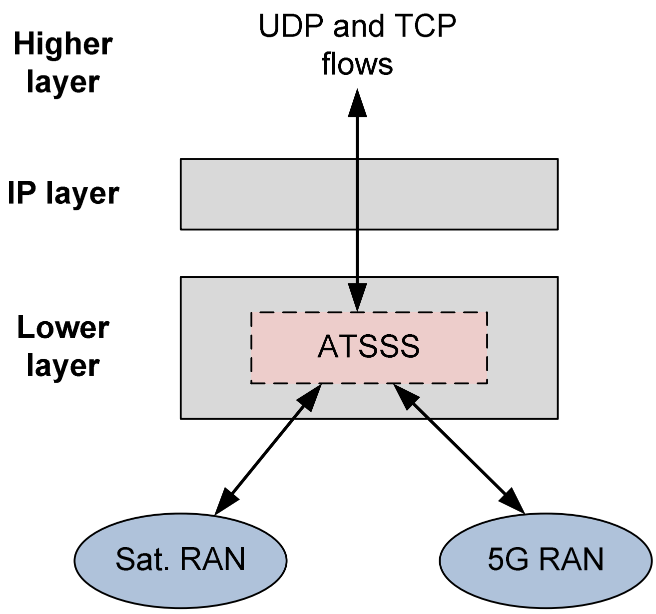

Figure 2: ATSSS lower layer implementation.

Higher layer implementation is shown in Figure 3. In this approach, ATSSS functions are implemented in higher layer (transport layer) and implementation is based on multipath transport protocols like MPTCP (MultiPath TCP) [9, 10] and MPQUIC [11]. Multipath transport protocols enable utilization of multiple links (paths) for data flow, thus, providing increased availability and reliability for continuous service.

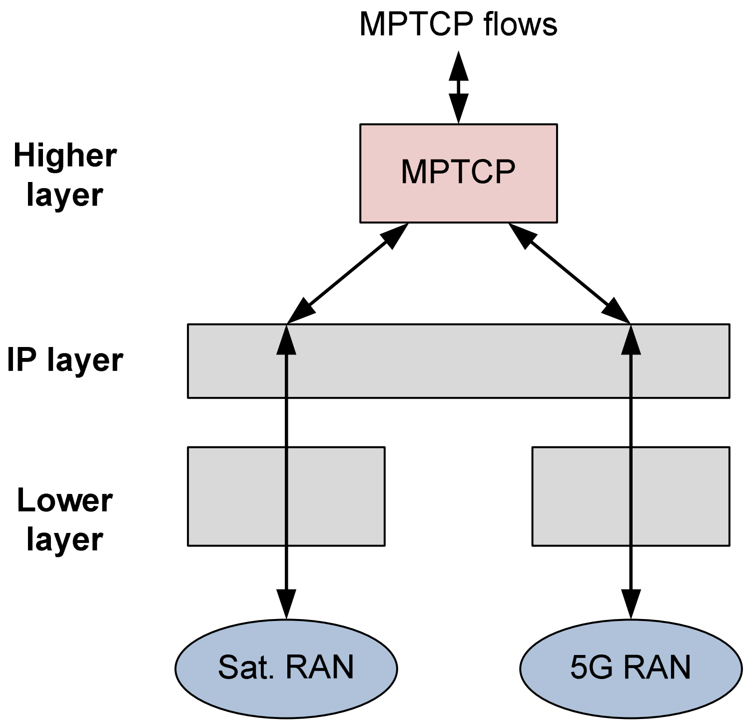

Figure 3: ATSSS higher layer implementation.

By comparing figures 2 and 3, some differences can be immediately spotted between these two approaches. Lower layer approach provides more general support for protocols. It supports any flow - UDP flows, TCP flows, Ethernet flows. On the other hand, higher layer approach provides support only for connection-oriented transport protocols i.e. TCP, but not for connectionless transport protocols i.e. UDP. But, lower layer approach requires ATSSS support from the network side (network core). In case of terrestrial 5G network this is well covered by the standards and one should expect that ATSSS support will be provided by 5G telecom providers. But, satellite network core ATSSS support is questionable, especially in selected scenario shown in Figure 1. In this scenario, there is also a question of compatibility between ATSSS support in different RATs. Higher layer support can avoid this problem by adding the gateway as an end point for multipath transport protocol. In this case, ATSSS functions do not depend on network cores and their ATSSS support, but only on the gateway that is joint exit point to internet for both networks, terrestrial and satellite.

Based on the presented discussion, pros and cons of both approaches, and the selected overall network architecture scenario, our decision is to first add higher layer ATSSS support. Note that, lower layer support can be added later and can work in parallel with higher layer support.

SECTION 5 – HUT SYSTEM ARCHITECTURE

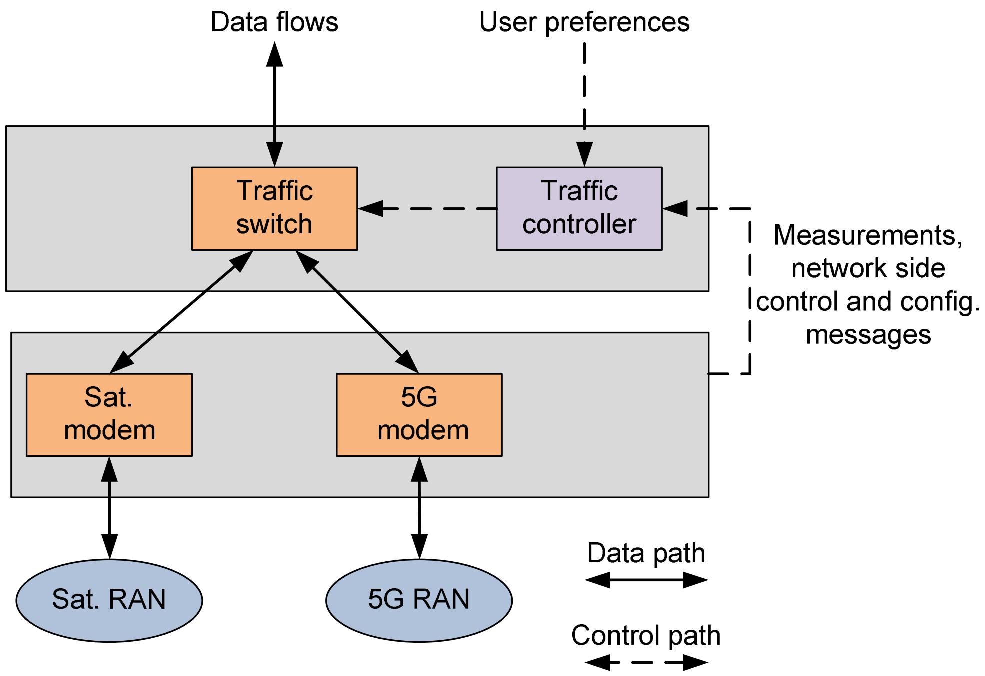

Figure 4: HUT architecture.

Figure 4 shows our proposed HUT architecture. The main components are traffic switch module, traffic controller module, and two modems - one for terrestrial (5G) connection and one for satellite connection. User traffic source can be user applications or can be traffic from other devices. This means that proposed HUT architecture can support both HUT implementation scenarios, HUT as a part of user device, or HUT as a standalone device (access point) for multiple user devices as shown in Figure 5. In our demo that is one of the main goals of this project, HUT will be demonstrated as a part of user device. User traffic passes through traffic switch that routes the traffic to proper modem according to routing rules set by traffic controller unit. Traffic controller unit based on user preferences, measurements, network control and configuration messages sets routing rules for different services. Modems implement functions necessary for transmission of data across the RAT to which they connect.

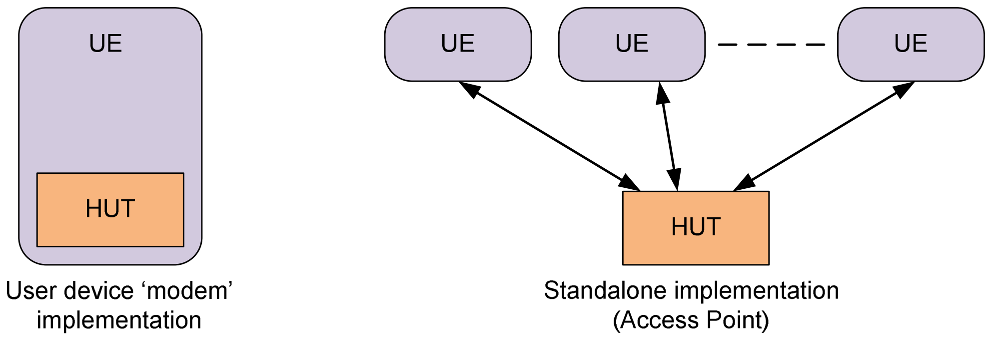

Figure 5: HUT implementation scenarios.

Figure 6 shows the more detailed general architecture of traffic switch module. This module comprises the traffic discrimination unit, traffic distribution unit, policy table, and forwarding table. Traffic discrimination unit performs deep packet inspection and based on its results it classifies the packets. Traffic distribution unit performs routing (switching) of packets to proper modems i.e. RANs (Radio Access Networks). Both modules use corresponding table entries for their operation. Traffic discrimination unit uses policy table entries to discriminate (classify) packets. For example, some of the packets might belong to data flows that do not use ATSSS functions. Traffic distribution unit supports packet routing (distribution among RANs), ATSSS functions, and multipath transport protocol operation. This unit uses forwarding table to route the traffic to proper modem (5G or satellite).

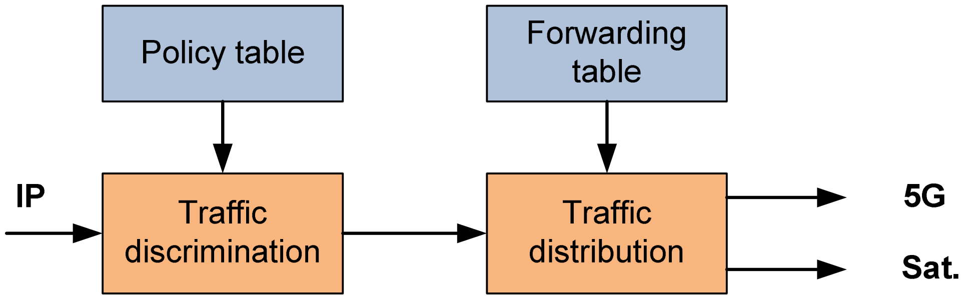

Figure 6: Traffic switch module.

Policy table and forwarding table contain entries that define routing policies and forwarding information needed for proper traffic steering to RANs to which HUT connects. These entries are added, deleted and updated by the traffic controller module. Traffic controller module receives information from the network side (network configuration and control messages), from user preferences settings (for example, which RAN user prefers), and from measurements (both, on user and network side). Based on the received information, traffic controller sets routing policies and forwarding entries for each service class. These policies and forwarding entries are written to policy and forwarding table, and in that way ATSSS functions can properly operate for all service classes, thus, HUT can operate in desired way and utilize optimally its connection to multiple RANs. Table 1 shows some of the recognized services and their default requirements and RAN preferences.

Table 1 - Requirements for the identified services

Use Case	Preferred RAN?	Throughput	Latency
Telemetry with critical latency	Yes - 5G	$\sim 10^2$-10^4 kbps	critical
Telemetry with non-critical latency	No	$\sim 3 \cdot 10^2$ kbps	not critical
Voice and video communication	Yes - 5G	$\sim 10^2$-10^4 kbps	critical
Cloud services	No, except for latency critical services (5G)	$\sim 10^2$-10^4 kbps	typically not critical

Content access	No	best effort	not critical
Devices updates	No, except for broadcast delivery (Sat.)	$\sim 3\cdot 10^2$ kbps	not critical
Multimedia delivery	No, except for broadcast delivery (Sat.)	$\sim$1-25 Mbps	not-critical expect for live event, jitter is more critical

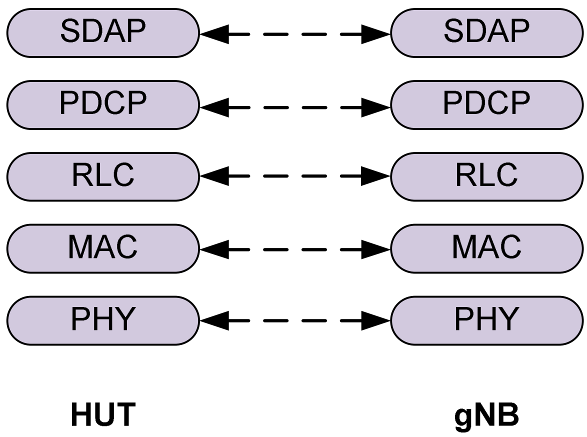

Figure 7: 5G protocol stack.

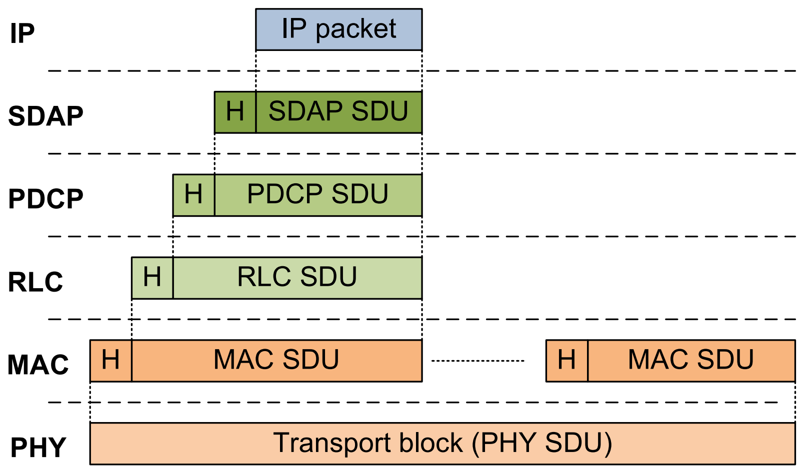

Figure 8: IP packet encapsulation in 5G.

HUT connects to two RANs - satellite and terrestrial. Terrestrial RAN is considered to be 5G. Thus, one modem is 5G modem that enables connection to 5G RAN. Figure 7 shows simplified 5G modem protocol stack for user data flows that must be supported. Figure 8 shows the IP packet encapsulation across the layers of 5G protocol stack. Brief description of layers in 5G protocol stack [12]:

- Service Data Application Protocol (SDAP) layer maps QoS bearers to radio bearers according to their QoS requirements.

- Packet Data Convergence Protocol (PDCP) layer is responsible for IP header compression, ciphering, integrity protection, retransmissions, in-sequence delivery, and duplicate removal in the case of handover.
- Radio-Link Control (RLC) layer does segmentation and retransmission handling. RLC layer provides RLC channels to PDCP layer.
- Medium-Access Control (MAC) layer performs multiplexing of logical channels, hybrid-ARQ retransmissions, and scheduling and scheduling-related functions. Scheduling is located in gNB for both uplink and downlink. MAC layer provides logical channels to RLC layer.
- Physical Layer (PHY) performs coding/decoding, modulation/demodulation, multi-antenna mapping, etc. Physical layer provides transport channels to MAC layer.

Figure 9 shows the order of functions in downlink direction that 5G modem needs to implement across the layers of 5G protocol stack.

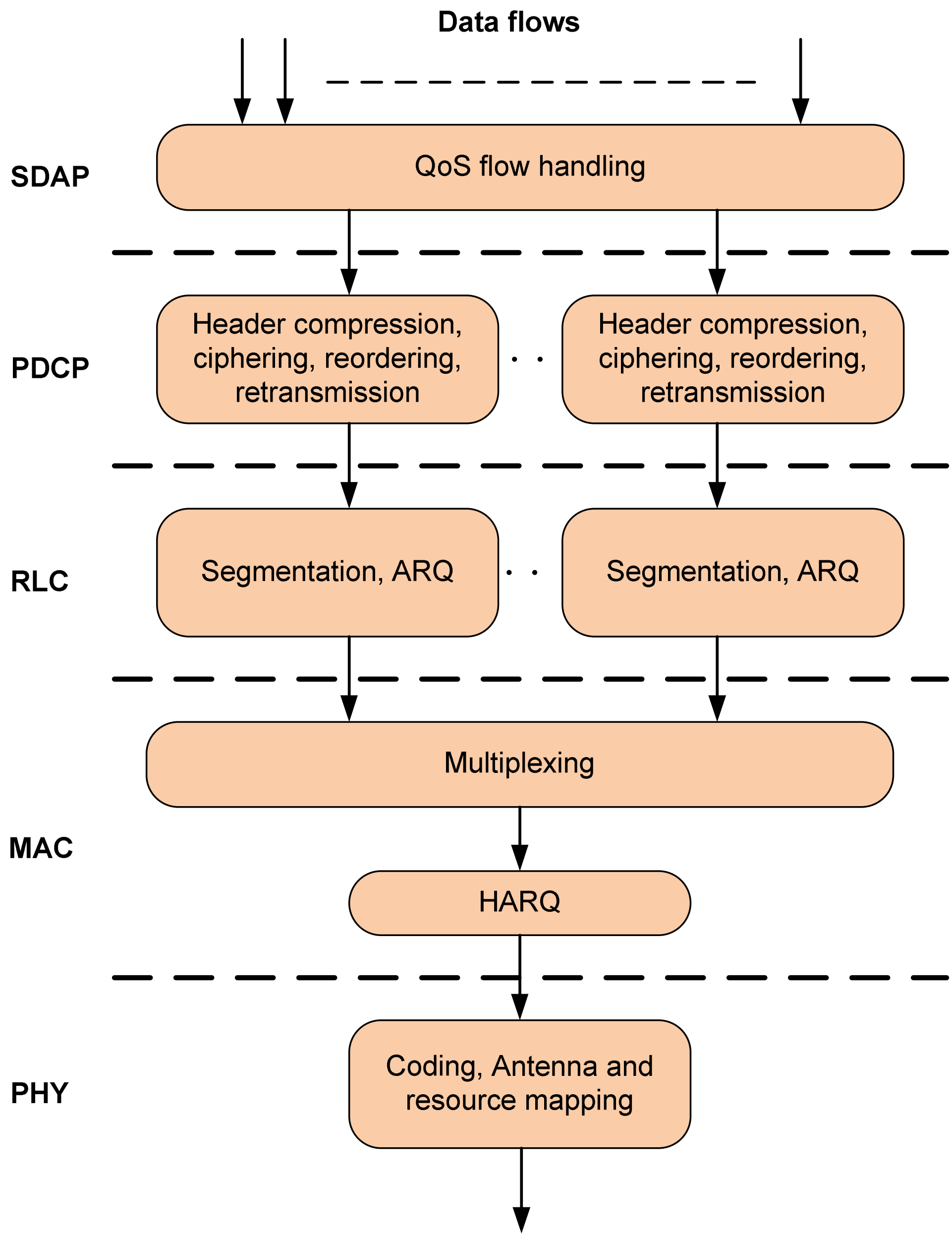

Figure 9: Functions across the 5G protocol stack layers.

Regarding the satellite RAN and modem, currently there are multiple standards on the market and most of them are proprietary, especially in case of LEO (Low Earth Orbit) satellites. It is not clear which standard will prevail in mutual 5G and LEO satellite RAN collaboration. For this reason, satellite modem will be built to support DVB-S2X standard [13] for the downlink (forward direction), and DVB-RCS2 based standard [14] for the uplink (return direction). Figure 10 shows IP packet encapsulation for satellite uplink direction. and formats we assume for satellite RAN. Burst payload structure is also shown in Figure 10 - all fields are optional except RLE packets. In case of downlink (forward direction), we assume that data are sent in frames according to DVB-S2X standard. Frame structure is shown in Figure 11. SOF (Start of Frame) field denotes the beginning of the frame, while the PLSCODE (Physical Layer Signaling CODE) field contains information like modulation scheme, code rate, etc. These two fields are called jointly as PLHEADER. Data are sent in slots and after every sixteen slots pilot symbols needed for synchronization are sent as shown in Figure 11.

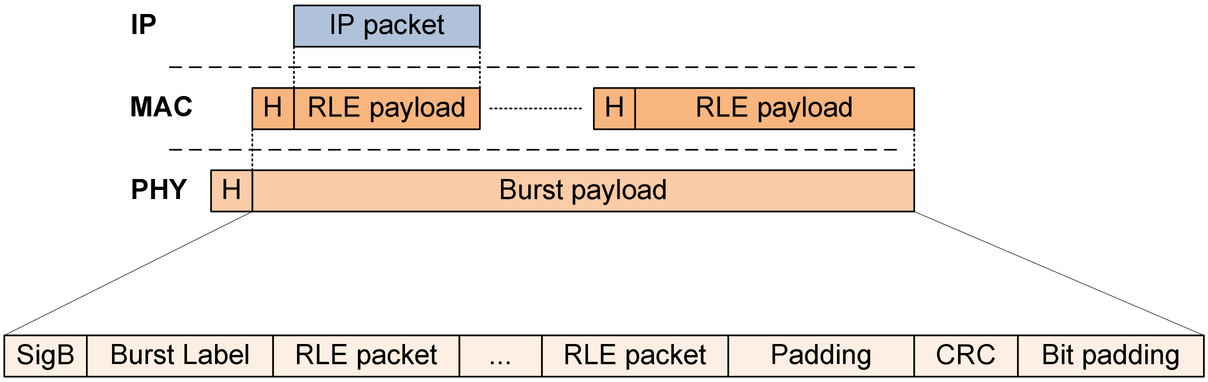

Figure 10: IP packet encapsulation on satellite return direction.

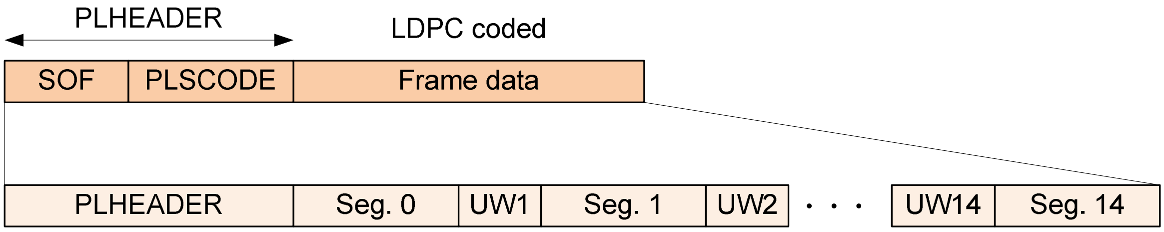

Figure 11: Frame structure on satellite forward direction.

CONCLUSIONS

This deliverable D2.2 presents HUT system architecture that enables HUT to utilize the hybrid access and support so called ATSSS functions. There have been several implementation choices that had to be made. For example, the selection at which communication layer ATSSS support will be added and implemented. All these choices have been made and justified to be optimally compliant to network architecture presented and assumed in deliverable D2.1. The presented HUT system architecture is foundation for HUT PoC demo implementation.

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