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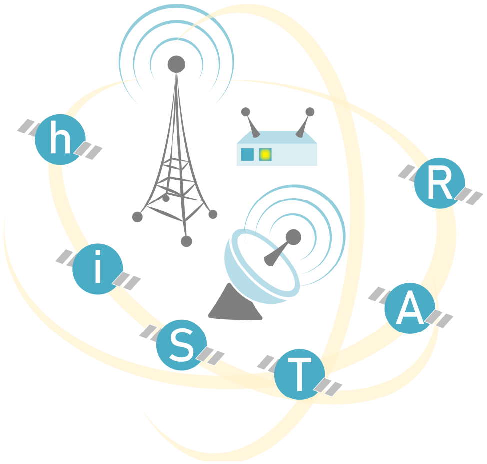

D5.1: Functional network core gateway for PoC

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Authors	Zoran Čiča
Reviewers	Goran Đorđević, Dejan Drajić

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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 WP5 Subactivity T5.1 – Network core functions and gateway design and development. Deliverable D5.1 presents functional gateway that connects to network cores of terrestrial and satellite RATs to enable ATSSS (Access Traffic Steering, Switching and Splitting) functions to users that have possibility on their devices to connect to these two RATs. The purpose of the gateway is to enable persistent, robust and reliable TCP (Transmission Control Protocol) sessions to users prone to handovers and/or loss of connection over one of the RATs. This deliverable also discusses UDP (User Datagram Protocol) traffic from ATSSS and end user points of view. Discussion regarding possible approaches in enabling ATSSS support is given as well.

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ABBREVIATIONS

ATSSS	**Access Traffic Steering, Switching and Splitting**
ATSSS-HL	**Access Traffic Steering, Switching and Splitting - Higher Layer**
ATSSS-LL	**Access Traffic Steering, Switching and Splitting - Lower Layer**
DoS	**Denial of Service**
FEC	**Forward Error Correction**
GW	**Gateway**
HTTP	**Hypertext Transfer Protocol**
HTTPS	**Hypertext Transfer Protocol Secure**
HUT	**Hybrid User Terminal**
IP	**Internet Protocol**
LDPC	**Low-Density Parity Check**
LEO	**Low Earth Orbit**
MA-PDU	**Multiple Access Protocol Data Unit**
MP	**Multi-Path**
MP-TCP	**Multi-Path Transmission Control Protocol**
PoC	**Proof of Concept**
QoE	**Quality of Experience**
QoS	**Quality of Service**
QUIC	**Quick UDP Internet Connections**
RAT	**Radio Access Technology**
RTT	**Round Trip Time**
SCTP	**Stream Control Transmission Protocol**
TCP	**Transmission Control Protocol**
TLS	**Transport Layer Security**

UDP	**User Datagram Protocol**
WP	**Work Package**

SECTION 1 - INTRODUCTION

Deliverable D5.1 represents one of two main key components of WP5 that are necessary for PoC (Proof of Concept) demo design that will show the benefits of having hybrid access to two different RATs. The other one being the network core support. Deliverable D5.1 is the result of the WP5 Subactivity 5.1 – Network core functions and gateway design and development. Scope of this deliverable is to present gateway that will be used in PoC demo. Also, a discussion regarding the possible approaches in ATSSS support is given and reasons for our selection are justified and explained. Finally, open research questions are discussed and our future work directions and focus are given regarding the topic of multipath support that is a key component in enabling ATSSS functions.

This deliverable is structured as follows: Section 2 gives a background information regarding the network architecture for hybrid access that has been defined in deliverable D2.2. In section 3, ATSSS functions are defined along with a list of obvious benefits of using them. Section 4 discusses possibilities of implementation of ATSSS support. Besides, selection of ATSSS support for PoC is justified and explained. Section 5 describes PoC scenarios and interaction between HUT (Hybrid User Terminal) and GW (Gateway).

SECTION 2 – BACKGROUND

A need for efficient use of multiple available network paths has emerged very early because of multiple benefits such approach brings. Inside the network, use of multiple equal-cost paths can more evenly distribute the traffic load across the network and decrease the possibility of congestions [1]. This feature is especially attractive for data centres [1-3]. Users also experience benefits such as higher reliability and availability, and higher throughput for their sessions. Multipath support is very interesting for mobile wireless communications especially given the number of existing smartphones and other similar communication devices. In case of wireless connections, being able to have multipath support would provide additional benefits like easier handovers with smaller probability of breaking an ongoing session and switching from one wireless technology to another in case of moving from the cover range of one of the RATs without session breaking [4]. In another words, service continuation would be supported in wireless communications when having access to multiple RATs and having multipath support. In early research efforts mostly technologies like 3G or 4G were considered along with WiFi as this was typical scenario for users [5-6]. However, due to development of satellite communications and expectations that LEO satellites use in mobile communications will constantly rise, recent researches and standardization organizations are considering integration of satellite and 5G communications [7-8].

In this project, we consider a scenario where users have access to two different RATs, one terrestrial (5G) and one satellite [9]. User device with access to these RATs is denoted as HUT (Hybrid User Terminal). As discussed in D2.1 [9], there are multiple possibilities of integration of these two RATs and their network cores, and we have selected the one showed in Figure 1 based on our expectation that most likely satellite and terrestrial network operators will not be the same company. The option shown in Figure 1 best matches such expectation as it puts the operators in equal position without giving advantage to one of the operators. In this scenario, GW (Gateway) represents the rendezvous point of terrestrial network and satellite network. HUT would have possibility to make multipath connection to GW by exploiting the fact that it has access to two RATs. This multipath connection would serve as sort of a tunnel between HUT and GW, enabling efficient ATSSS support. Also, in some way user connection is broken in two parts - wireless part (that includes the network cores as well) and wired Internet part. This can also be beneficial for users because mixing wireless and wired technologies along the path can be potentially problematic from TCP point of view - false detection of congestions in network because of packet losses on wireless segment which decreases TCP throughput [10].

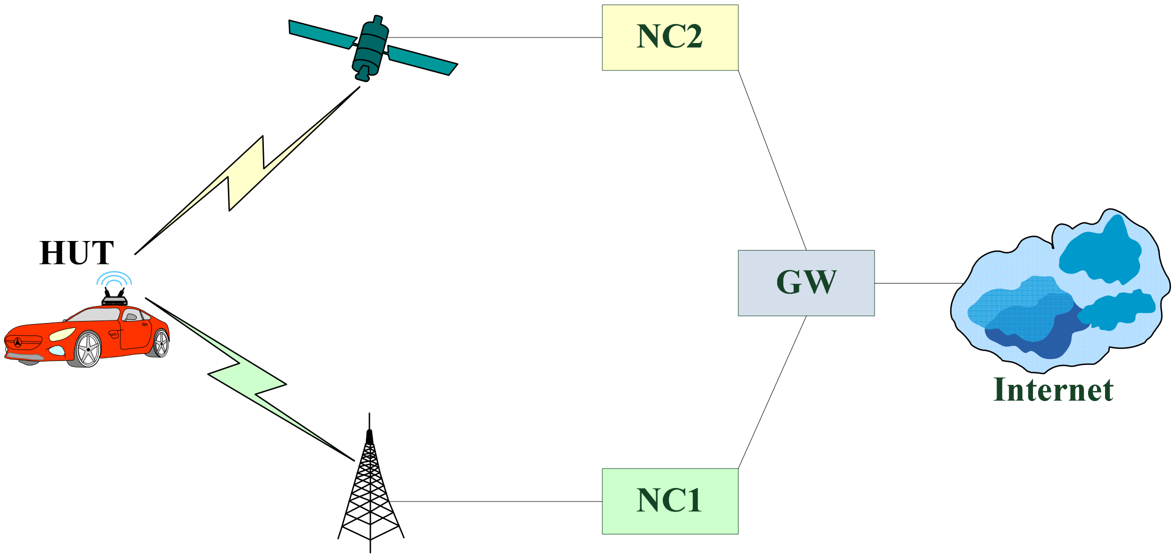

Figure 1: Separated satellite and terrestrial RATs [9].

SECTION 3 – ATSSS FUNCTIONS

Although we have described and defined ATSSS functions in our previous deliverables, given that ATSSS support is one of the key features of HUT, for the sake of completeness of this deliverable we present ATSSS functions in this section.

ATSSS by definition refers to the three following functions for the radio access traffic: Steering, Switching and Splitting [11]. Steering is performed at the beginning of the user (service) session. This function selects RAT that is most appropriate for the initiated service. Figure 2 shows one example of steering. When a new data flow is initiated, steering function in HUT needs to select between available RATs. In the given example satellite RAT is selected.

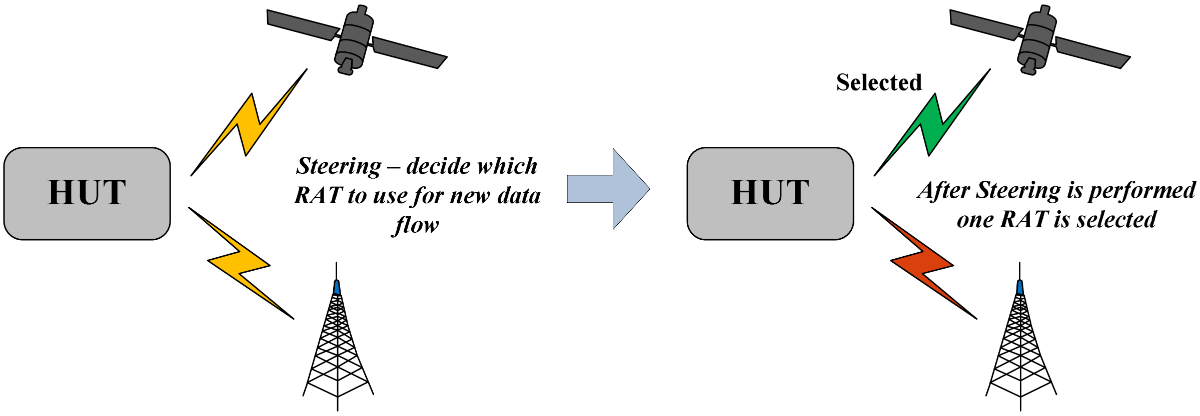

Figure 2: Steering example.

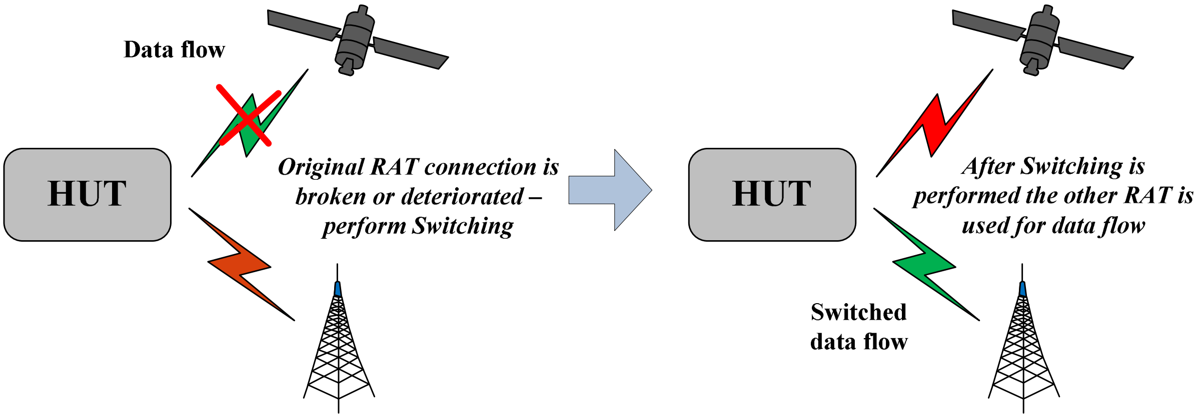

Figure 3: Switching example.

Switching is performed during the session. In case when connection over original (in use) RAT is lost or significantly deteriorated, switching enables moving the session's data flow to the other RAT. Switching is key component for enabling service continuation and preventing session breaking. Figure 3 shows an example of switching. Let us assume data flow established in Figure 2 where steering function selected satellite RAT. For some reason connection to satellite RAT is lost. When HUT detects such situation, HUT needs to perform switching function and switch the ongoing data flow to terrestrial RAT as shown in Figure 3.

Splitting is usually defined at the beginning of the session, and it enables simultaneous use of available RATs. Main purpose is to use available RATs jointly to increase the available bandwidth, and consequently data throughput. Depending on the multipath support implementation and RAT parameters (delay, packet losses), it might not always optimally use the bandwidth of available RATs - actual achieved bandwidth can be below the joint bandwidth value of both RATs [12]. Example of splitting is shown in Figure 4. It is very similar to example given in Figure 2 as splitting in this example shown in Figure 4 is also done at data flow initiation. In the given example, after the splitting is performed, both RATs are used - 30% of data flow goes via satellite RAT, while remaining data flow traffic travels via terrestrial RAT. It is possible to change the splitting ratios between RATs during the session, but typically this would occur as part of the switching when connection to one RAT is lost or unusable due to poor conditions of the link. Also, depending on ATSSS implementation type, splitting ratio value might change dynamically depending on link conditions behaviour without deliberate intervention from the HUT.

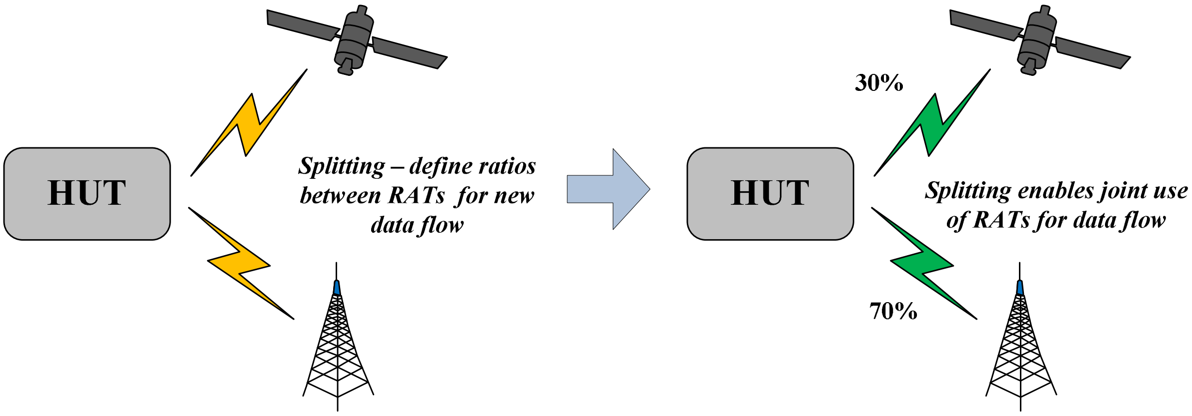

Figure 4: Splitting example.

Some of the benefits that are expected by deploying the ATSSS support are:

- continuous service - as long as there is connection over one of the RATs (assuming it supports service requirements) service will operate without interruptions;
- increased reliability and availability - only one available RAT is sufficient for services, it is lower probability that all RATs are unavailable when multiple RATs are supported by the user device than in case when user device supports only one RAT;
- better Quality of Service (QoS) and Quality of Experience (QoE) - better reliability and availability increase QoS and QoE, but also users can select more appropriate RAT for their services which also increases user QoS and QoE;
- more bandwidth - by using splitting function users can access the bandwidth offered by available RATs and use these resources jointly.

In the next section, a discussion regarding ATSSS support implementation is given.

SECTION 4 – ATSSS SUPPORT IMPLEMENTATION DISCUSSION

ATSSS functions are at the core of HUT benefits for users. As stated in our previous deliverable D2.2, communication follows TCP/IP layered model and there are two main possibilities to place ATSSS support [4, 13]:

- Lower layer implementation (ATSSS-LL) - placed at data-link layer
- Higher layer implementation (ATSSS-HL) - placed at transport layer

In ATSSS-LL approach, ATSSS functions are implemented at data-link layer (lower layer). MA-PDUs (Multiple Access Protocol Data Units) are used for data flows that require multipath support. MA-PDUs are supported by 5G standards [4, 14]. During the data flow establishing phase, decision regarding use of multipath support is made and this decision defines whether MA-PDUs are going to be used or not. MA-PDUs are required for ATSSS support i.e. multipath support. User decides about multipath support i.e. MA-PDUs use, but standard allows network to enforce a use of MA-PDUs for some services without user requesting such support. However, ATSSS-LL approach requires joint network core for proper multipath support which does not match our scenario shown in Figure 1. For this reason, we are not pursuing ATSSS-LL approach in this project. However, ATSSS-LL and ATSSS-HL can co-exist, which means that ATSSS-LL support can be added later without interrupting results and solutions obtained in this project.

ATSSS-HL is placed at transport layer because this layer is logical choice given its functions - flow multiplexing, flow control, error control etc. Also, application layer can be used but it would not be a good approach because each application would then have to implement same set of multipath support functions, while adding this support at transport layer would enable applications to use same set of functions offered by one entity. There are multiple existing options for adding the multipath support at transport layer: SCTP (Stream Control Transmission Protocol) [15], MP-TCP (Multi-Path TCP) [16, 17] and MP-QUIC [18]. Discussion about these options is given in the following paragraphs.

SCTP was developed to cope with problems of TCP use for some applications. Typical example is transport of signalization messages inside telecom operator networks. Such transport requires reliable transport of enormous amount of typically short messages. Since TCP provides byte oriented delivery, a situation can occur where complete message has been received but cannot be delivered to application layer because the required amount of bytes has not been accumulated and TCP does not recognize message boundaries, thus, it does not recognize such situations. Also, many signalling messages belong to different conversations and are mutually unrelated so retransmission of one message can stall the delivery of other (unrelated) messages. For all these reasons SCTP was developed. SCTP is message oriented and supports parallel streams. But, multihome support is also added to SCTP which means that multipath support is possible in SCTP. In practice, this multipath support is usually considered as backup, so SCTP would be suitable for ATSSS switch and steer functions. However, the main problem of SCTP is that is not well supported by the end user applications and devices, it is mainly used in niches like transport of signalling messages in telecom operator networks. SCTP communication initialization is shown in Figure 5. SCTP uses four-way handshake to establish the session. This process is similar to three-way handshake used in TCP, but with a difference of cookies. Cookie exchange is done to provide defence from DoS (Denial of Service) attacks. In TCP after the first (SYN) packet is received, host answers with SYN ACK packet and reserves resources for the connection. But if attacker only sends SYN packets it can very easily occupy resources of the attacked host and severely decrease its performance. Cookies in SCTP prevents this as the host reserves resources only after cookies are exchanged or in other words other side has shown that it actually wants to setup a connection. Also, during session initialization both sides exchange a list of IP addresses that can be used in session (multihome support). In the given example in Figure 5, HUT starts connection setup to GW. After the session is set up, exchange of data can start.

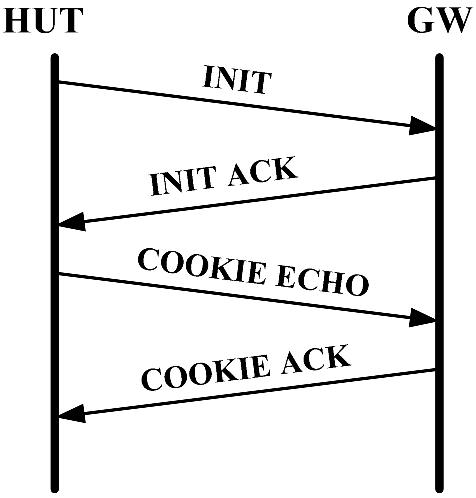

Figure 5: SCTP session initialization.

MP-TCP can be observed as an extension of TCP. Resilient and robust communications are always desired. Given that many devices and servers have multiple network interfaces and possibly access to different network technologies, this provides a possibility to exploit such fact to achieve high availability and reliability from communication point of view. This has lead to development of MP-TCP that extends TCP by adding the multipath support. Very positive is that MP-TCP is backward compatible with TCP in sense that if MP-TCP is not supported by either side in the communication, it falls back to regular TCP communication. Goal of MP-TCP is that it achieves performance no worse than regular TCP, so MP-TCP achieves same or better performance than regular TCP. Also, MP-TCP is designed to be transparent as much as possible, so existence of middleboxes in communication path is not affecting MP-TCP communication in most of the cases. MP-TCP support is added to Linux [19, 20], but also to Apple iPhones [21] which means that MP-TCP is recognized as a promising solution for multipath support. Furthermore, MP-TCP is considered by 3GPP specifications as the main approach for ATSSS-HL support. It is ideal for ATSSS steering and switching functions. It can also perform well for splitting function, but it would require that paths are similar in performance (delay, bandwidth, packet losses). Otherwise, MP-TCP performance regarding the splitting might fall back to best single path performance. MP-TCP communication initialization is shown in Figure 6 that shows example of setting up a MP-TCP session between HUT and GW. Over one RAT (for example, let it be terrestrial) HUT would initiate MP-TCP session. This message exchange is done by using ordinary TCP but with added MP (Multi-Path) option MP_CAPABLE that signals that HUT supports MP-TCP. If GW supports MP-TCP it will also send MP_CAPABLE option so MP-TCP session can be established. If either of sides does not support MP-TCP, then the connection would roll back to ordinary TCP connection. Once MP-TCP session has started, path over the other RAT (in our example, let it be satellite RAT) can be added to session. This is the second half of Figure 6. Now, MP_JOIN option is used. Note that each path is actually a TCP flow, and these TCP flows are observed as subflows of MP-TCP session. During the initial MP-TCP session setup, both sides advertise information about their IP addresses, thus, using these advertised addresses other paths besides the original can be added to session as shown in Figure 6. Either side can initiate path addition to a session, but usually it would be the side that started (initiated) a session as shown in Figure 6.

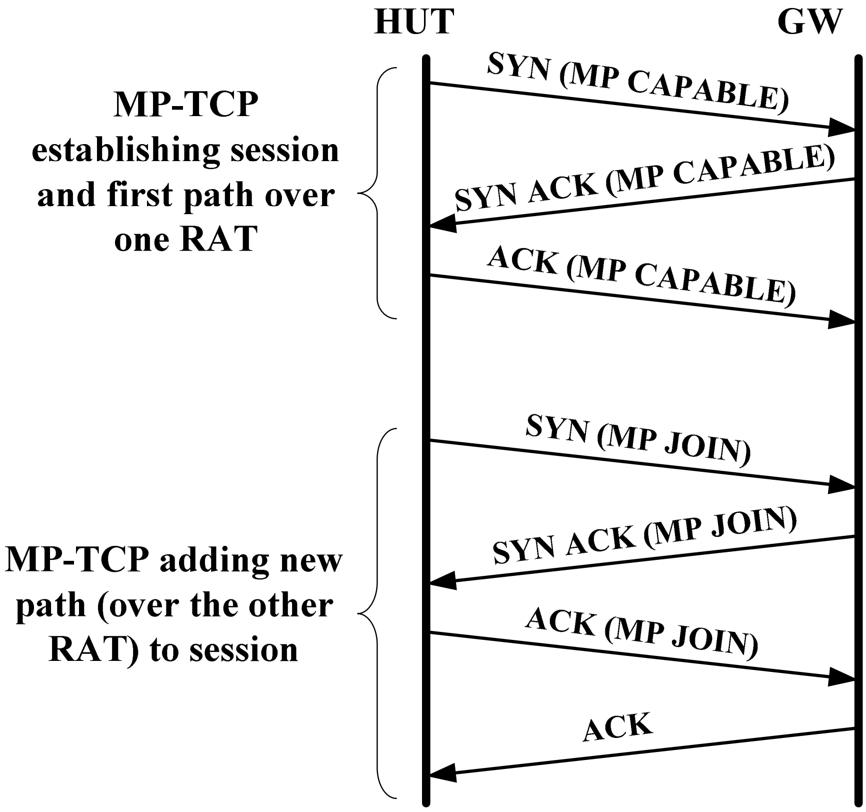

Figure 6: MP-TCP session initialization.

Finally, MP-QUIC represents extension of QUIC protocol. Similarly to SCTP, QUIC was also designed to cope with some of the noticed downsides of TCP protocol. TCP requires three-way handshake to establish a connection. But many communication sessions require security, especially HTTP (Hypertext Transfer Protocol) connections - HTTPS (HTTP Secure). HTTPS, for example, requires TLS (Transport Layer Security) setup over the TCP connection. This means that after TCP connection is open via TCP three-way handshake, additional exchange of messages for TLS setup is required prior actual user data transmission can start. To avoid this, QUIC enables integration of TLS setup along with session start message exchange which significantly reduce the number of exchanged messages prior the user data transmission. Also, QUIC is not standalone transport protocol like TCP and SCTP, but requires UDP. UDP is selected because it is a lightweight protocol and error control is performed at QUIC level.

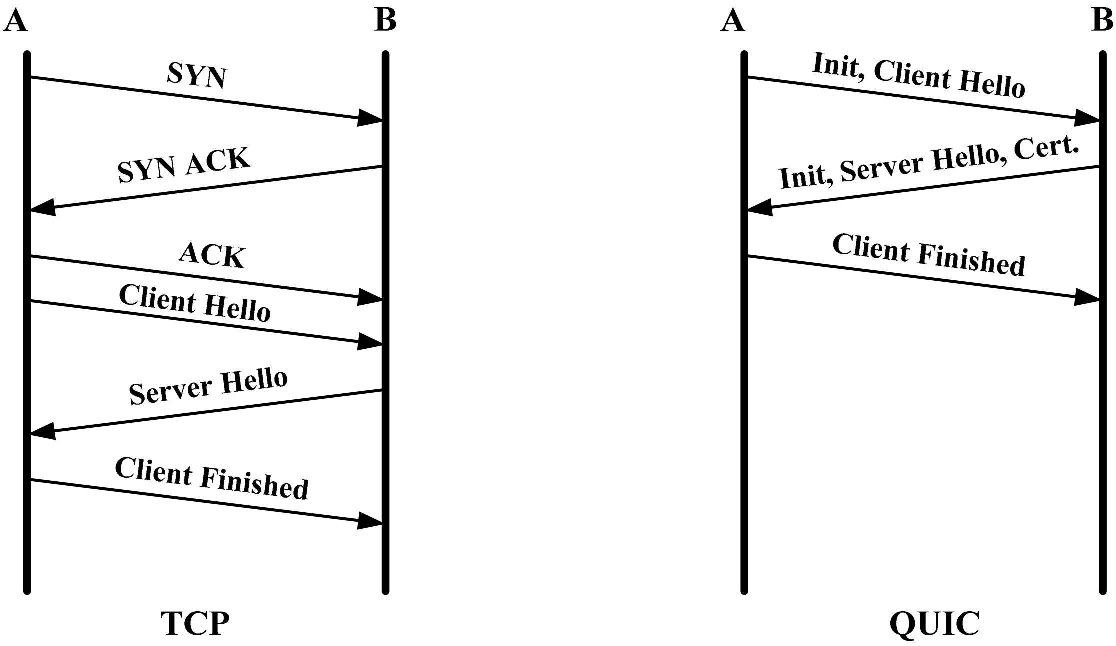

Figure 7: TCP+TLS vs QUIC+TLS.

Figure 7 shows the comparison of session start of TCP with TLS and QUIC with TLS. It is obvious that QUIC uses significantly less messages to establish the connection because TLS support is integrated in QUIC. In case of TCP, two setups need to be performed. First, TCP session via three-way handshake and then TLS session. MP-QUIC is extension of QUIC to add multipath support. Actually, MP-QUIC starts as a single QUIC connection where multipath support is signalled and negotiated. Later, additional paths can be added to a session (before they are added the paths are validated that they are functional). MP-QUIC is also considered as potential solution by 3GPP [22], although MP-TCP currently still remains as the main approach. Potential downside of QUIC and MP-QUIC is the use of UDP because some middleboxes can be restrictive to UDP traffic.

Based on the analysis of potential ATSSS-HL approaches described above, we have decided to choose MP-TCP solution. SCTP is eliminated because it is not widely adopted and not considered by 3GPP and multipath approach for ATSSS-HL. MP-QUIC is a promising approach that uses UDP and can avoid some of the problems that congestion control might make since congestion would probably not be an issue in HUT-GW communication - since session needs to be approved by the network core and it can reject session if it would lead to congestion. However, MP-TCP is more mature protocol that is well covered in literature. There are papers that add link parameters info to MP-TCP decisions [6] which is our goal as well. Also, in case of similar paths, ATSSS splitting would be well supported my MP-TCP. Since LEO satellites induce RTT (Round Trip Time) comparable to 5G values [23] (if not considering low-latency services that would not use multipath support since LEO satellites fail to support very low-latency requirements) and if offered bandwidths are similar, splitting function would perform optimally or at least nearly optimal. Thus, our selection is MP-TCP for PoC demo and HUT/GW design. However, we will continue to investigate and include MP-QUIC similar approach in sense of using UDP as transport tunnel to optimize ATSSS splitting function and response to connection losses (ATSSS switching) for different combination of access link parameters on terrestrial and satellite connections.

The previous analysis is given for connection-oriented sessions. But, there is a question of UDP based applications. In general, we can observe two types of UDP applications. There are UDP applications that send very small number of messages (one, maybe two messages). In such cases, there is no need to establish reliable session because it is more practical and efficient to just send a message. In this case, ATSSS switching and splitting functions make no sense because there is no ongoing session. Here, only steering should be performed on packet basis without using multipath protocols. But, in case of UDP ongoing sessions (for example, streaming that uses RTP on top of UDP), switching and splitting are of interest. In this case, MP-TCP can be used as a tunnel between HUT and GW. This might negatively affect UDP flows in sense of increased latency given the potential retransmissions but in general probability of packet losses should not be high [23] for both 5G and LEO satellite networks, especially if good performance FEC (Forward Error Correction) codes are used (like LDPC (Low-Density Parity Check) in 5G), so this should not be significant issue in most of the cases. Also, urgent delivery might be used for UDP payloads in MP-TCP connection to avoid waiting of UDP stream data to wait in buffer. However, urgent delivery is usually not recommended to be used. Nevertheless, we are going to inspect this approach as well. Initially, we are going to use MP-TCP as a tunnel for UDP stream data flows, but as we already stated we are going to investigate and include use of UDP as underlying transport protocol for multipath support similarly to MP-QUIC.

SECTION 5 – NETWORK CORE GATEWAY FOR POC DEMO

Network core GW for PoC demo should enable support for demonstration of HUT capabilities and benefits of hybrid access and ATSSS support that exploits this hybrid access possibility. Also, GW design should be functional for practical use in real networks with minimal adjustments. Since MP-TCP is selected as ATSSS-HL layer approach, we use Linux MP-TCP implementation and support [19, 20]. This implementation is open-source and can be modified according to needs, for example, to add information from lower layers for better decision making like in [6]. This property is especially important for HUT side in our PoC demo. Figure 8 shows the network core GW principle design for MP-TCP support. As shown in Figure 8 there are two cases. One case assumes that there are two network (in our case Ethernet) interfaces, one to satellite network core and the other to 5G network core. TCP and IP are shown separate for both interfaces to emphasize the fact that two interfaces are used and two IP addresses are used for GW (one associated to 5G part and one associated to satellite part). The other case assumes that both GW use only one network interface (again Ethernet in our case) to connect to both network cores and one IP address. This still works since HUT would have two IP addresses and two paths (each over different RAT) can be utilized. In this case only TCP layer is shown separately to emphasize fact that there are still two subflows in MP-TCP session. Initially, in PoC we are going to use case with two network interfaces, but we also plan to test the case with one network interface as well since it should not require significant modifications to initial test setup. In the remainder of the section, PoC scenarios are described from GW perspective.

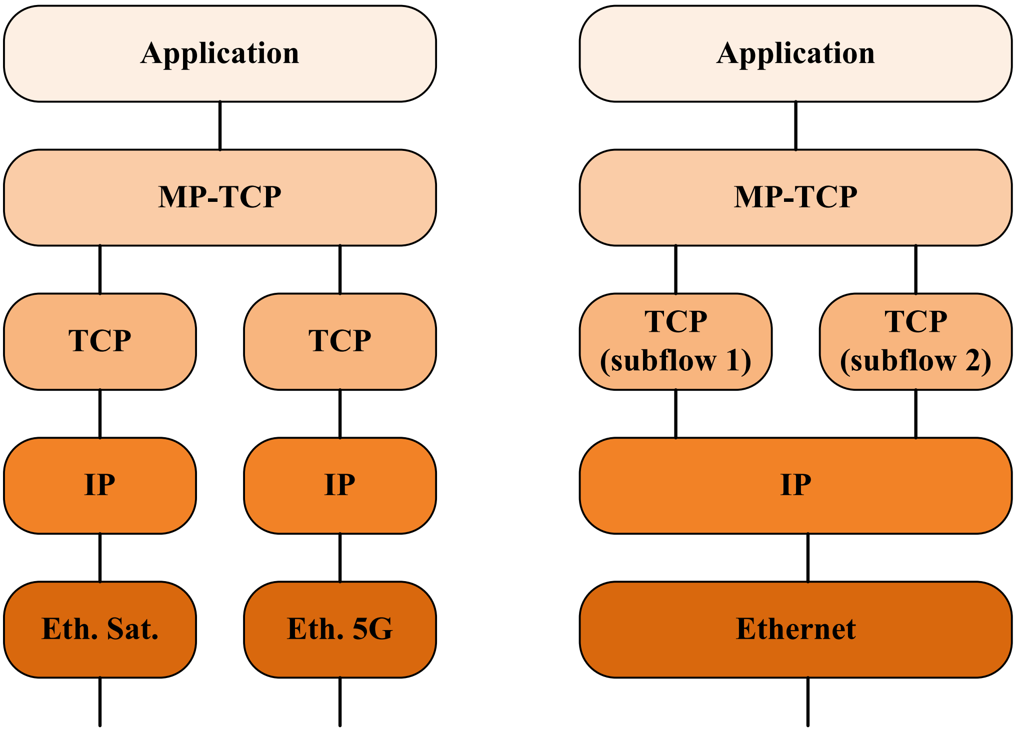

Figure 8: GW principle architecture.

The first PoC scenarios will involve GW in a role of server as end point of communication for HUT. This allows basic testing and demonstration of HUT capabilities and ATSSS functions support. It allows easy testing of steering and switching capabilities as well as the splitting. Communication at GW side can be easily tracked by using Wireshark tool, so it will be very easy to monitor a whole communication session and observe the use of both paths (RATs) and measure the responsiveness of switching function and splitting ratios. Two applications are going to be tested using the principle shown in Figure 9. HUT will play the role of client, thus, on HUT side client application will be used. GW will play the role of the server, thus, server application will be used at GW side. Two applications will be used in PoC: web application which is suitable for more appealing visual demonstration to the audience; and automated ping 'like' application which is more suitable for initial tests, measurements and verification of PoC. As we already said, Wireshark will also be used to capture the traffic and these captures will be used for traffic analysis and measurements.

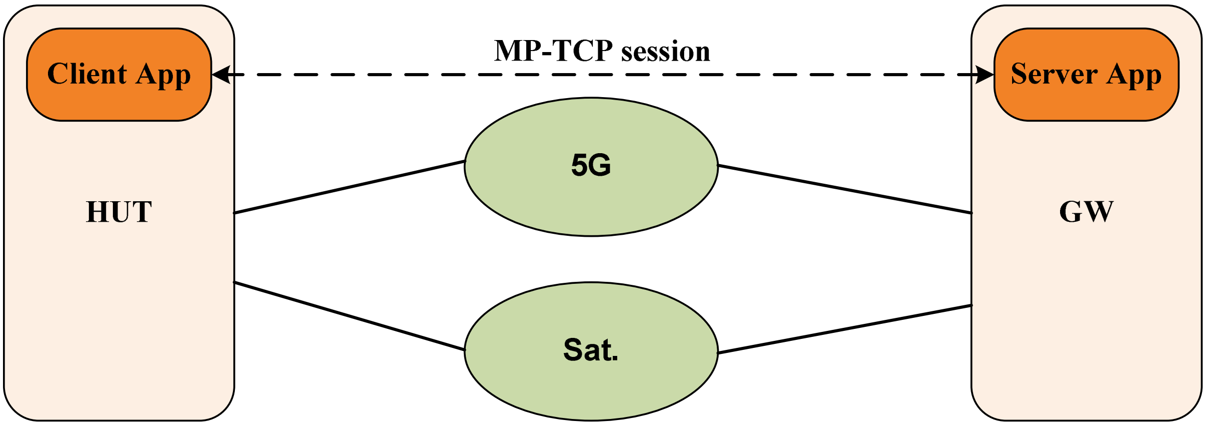

Figure 9: PoC initial test scenarios.

In the latter stages of PoC, GW will be expanded to its real role where GW only takes off MP-TCP information and relays the packets towards Internet, and adds MP-TCP information and relays packets towards HUT in vice versa direction. In this case application layer shown in Figure 8 plays role of a relay between the HUT and internet (i.e. rest of the world). Basically, same tests will be the same as initial tests shown in Figure 9 with a difference that GW now only plays the role of a relay, which is actual GW role which matches to actual real life scenarios. This is shown in Figure 10. As presented in Figure 10, we will add another host in PoC demo. This host will play the server role that GW was playing in scenarios shown in Figure 9. Connection between GW and server will be via Ethernet network since complete test environment setup will be in the same laboratory room but since IP connection is between GW and server, server in general can be setup anywhere remotely.

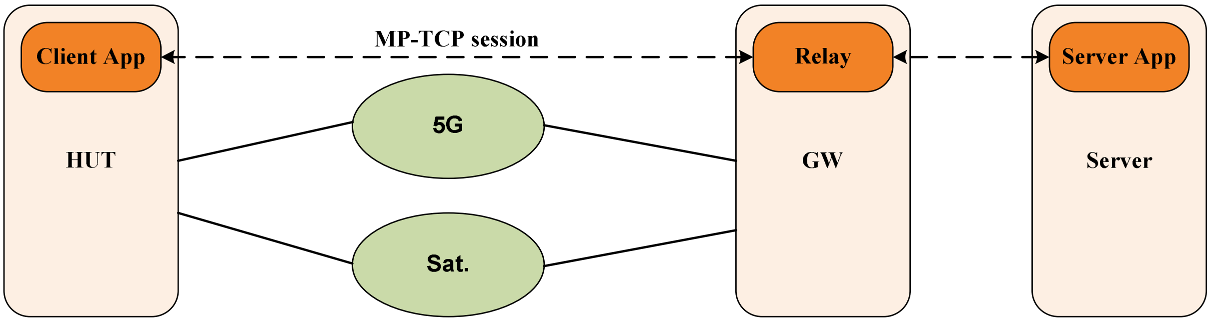

Figure 10: PoC next stage test scenarios.

Lastly, our goal is to inspect use of UDP as underlying multipath transport protocol as in MP-QUIC. Thus, we are going to devise application that utilizes UDP for multipath sessions, and this application will play the role of multipath agent at HUT and GW side. After measurements for different parameter values (packet loss, latency, bandwidth) we should devise optimal setups for different combinations of RAT parameter values along with dynamic measurements and adjustments during the active sessions. Test setup is practically the same as in Figures 9 and 10, only important difference that other multipath protocol is used instead of MP-TCP.

CONCLUSIONS

This deliverable D5.1 has presented GW design along with its use in PoC demo. We have explored several approaches for multipath protocol support and selected MP-TCP as primary choice given the considerations by 3GPP for its use as ATSSS-HL implementation. Also, we have dedicated to explore UDP as underlying transport protocol for multipath support as well. Finally, PoC test scenarios are given and explained.

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