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Integration and system level testing for Korean multi-connectivity

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Abstract

This deliverable was created as part of the project Work Package 5 “Prototyping, Validation and Demonstration” activities, and details implementation, integration and testing of Korean multi-connectivity testbed.

Keywords

5G ; Testbed ; Multi-connectivity ; Millimeter Wave; Satellite Access; Cellular Access

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Executive Summary

This document is the output of task 5.3, “implementation, integration and testing of Korean PoC system for multi-connectivity.” The Korean 5G cellular access system and the satellite access system are to be integrated for the multi-connectivity testing and PoC demonstrations. The integrated system is to be utilized in the final task of WP5, task 5.4 as the Korean trial platform in the intercontinental trial PoC platform at a key event.

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List of Abbreviations

5GCN	5G Core Network
AMF	Access and Mobility Management Function
AP	Access Point
API	Application Programming Interface
DASH	Dynamic Adaptive Streaming over HTTP
DRU	Digital plus Radio Unit
eCall	Emergency Call
GEO	Geosynchronous Equatorial Orbit
gNB	next Generation Node
HLS	HTTP Live Streaming
HTTP	Hyper Text Transfer Protocol
ITS	Intelligent Transportation System
JSON	JavaScript Object Notation

KPI	Key Performance Indicator
PoC	Proof-of-Concept
MC	Multi-connectivity
MCT	Multi-connectivity Testbed
OEM	Original Equipment Manufacturer
REST	Representational State Transfer
RRC	Radio Resource Control
RU	Radio Unit
SMF	Session Management Function
TC	Traffic Controller
TB	Testbed
TS	Transport Stream
UE	User Equipment
UPF	User Plane Function

1 Introduction

Global automotive manufacturers are experimenting with the wireless communication systems to provide high-speed Internet environments to customers in moving vehicles for high quality services such as virtual reality, seamless high definition video streaming, and ITS (Intelligent Transportation System) services. However, the existing communication systems have not provided the perfect solutions to meet the technical requirements of the global automotive manufacturers yet. The cellular-based communication systems represented by 2G, 3G, and 4G, need to meet the requirements from the global automotive OEMs (Original Equipment Manufacturers) in terms of speed, coverage and security. In addition, even the commercialized 5G is yet to have shown satisfactory performance. Meanwhile, deploying resilient ITS services regardless of the user location - whether rural or urban – is raising an interesting challenge for providing seamless and continuous connectivity to end-users. Frost and Sullivan forecasts that approximately 27.2% of automotive use cases will use satellite connectivity by 2025 such as autonomous driving, connected services, and safety eCall services [1]. With the help of its global coverage, the multi-connectivity technology representing the convergence of cellular and satellite communication will be a core technology in creating resilient and seamless connectivity for both ITS and automotive related services.

In this regard, this deliverable aims at reporting the integration and system-level testing of the Korean multi-connectivity testbed (TB) developed within the framework of 5G-ALLSTAR. This document consists of four chapters including this introductory chapter as follows:

- Chapter 1 is the introduction to the document.
- Chapter 2 describes the integration of the Korean multi-connectivity system, which includes the architecture of the overall system and component subsystems.
- Chapter 3 explains the system-level testing and corresponding test results of the Korean multi-connectivity testbed.
- Chapter 4 draws conclusions.

1.1 Work objectives and Tasks

WP5 is a work package to fulfill prototyping, validation and demonstration of the laboratory testbeds and trial platforms, and it relates three objectives to be addressed as follows:

- **O5.1**: Provide laboratory technology demonstration showing capability of mmWave-based multiple access network capable of providing reliable broadband 5G services with a perceived low latency for ubiquitous and zero-interruption connection.
- **O5.2**: Demonstrate that the proposed global interoperability intercontinental interoperable architecture implemented through 5G CN (Core Network) can efficiently provide a variety of intercontinental 5G services for validating the interoperability of the system.
- **O5.3**: Provide a Proof-of-Concept based on regional trial platforms interconnected for demonstration at a key event.

Specifically, four tasks are defined as follows:

- Task 5.1 is to implement “European PoC (Proof-of-Concept) testbed.”
- Task 5.2 is to implement “Korean PoC testbeds for 5G cellular and satellite access.”
- Task 5.3 is to implement “Korean PoC system for multi-connectivity.”
- Task 5.4 is to provide “system level testing of Proof-of-Concept phase 1 and phase 2.”

The deliverable, D5.4 is the output of task 5.3, which aims at delivering i) implementation of an interface module for multi-connectivity support, ii) integration of 5G cellular access and satellite access systems, and iii) testing of the integrated PoC system.

1.2 Cooperative Tasks

The WP5 is to deliver the PoC demonstration over the intercontinental test trial platform at a key event. To achieve this goal, the WP5 needs critical interactions with other work packages. **오류! 참조 원본을 찾을 수 없습니다.** depicts some specific cooperative relations among tasks in different work packages. Task 2.3 in the WP2 delivered D2.4 that dealt with use cases and scenarios in the project. This could provide useful inputs to the task 5.3. Meanwhile, task 4.2 suggests various solutions on the load-balancing algorithms and some selected implementation based on those algorithms. The resultant load-balancing algorithm implementation or the traffic controller (TC) in Korean platform will play a key role in the task 5.3. Moreover, the figure illustrates that the output of the task 5.3 will be utilized in the final demonstration at a key event defined in the task 5.4.

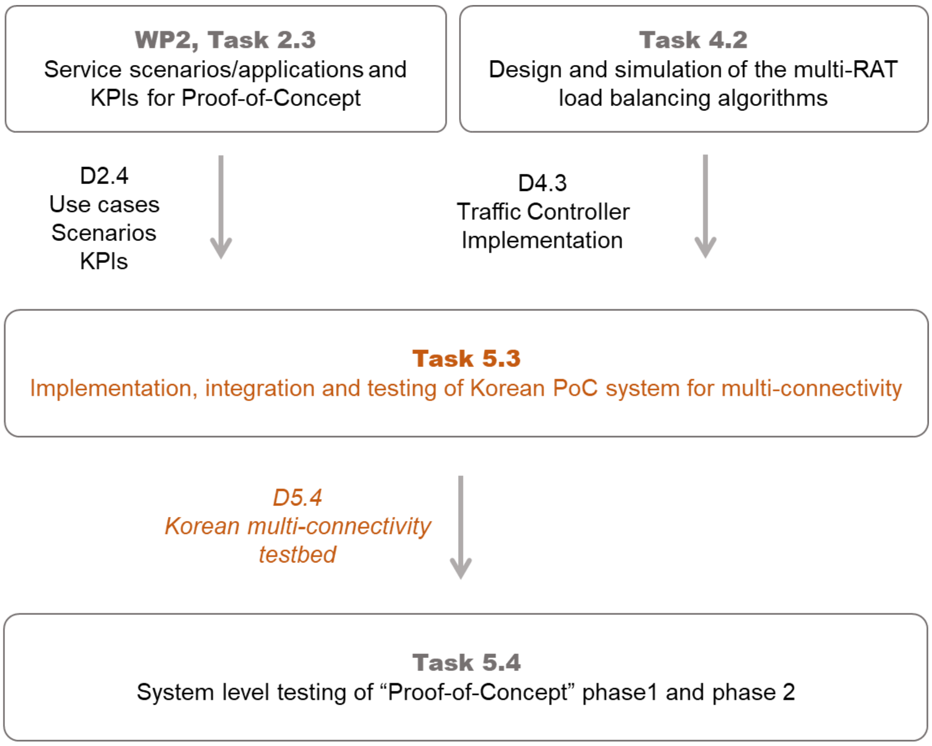

Figure 1: Task flows over different work packages

1.3 Task schedule

Basically, the WP5 is supposed to deliver the PoC demonstration over the intercontinental test trial platform at a key event. In task 5.3, the Korean multi-connectivity testbed need to be prepared by M36 and the system should be adopted at the final demonstration. On the other hand, since the unprecedented COVID-19 situations had caused many obstacles to hold offline events, having appropriate opportunities of holding a key event for the final demonstration within M36 would not be easy. Considering this specific unprecedented case, the period of the 5G-ALLSTAR project had been extended. In consideration of this change of the project schedule, Figure 2 illustrates the original WP5 schedule plus four-month extension.

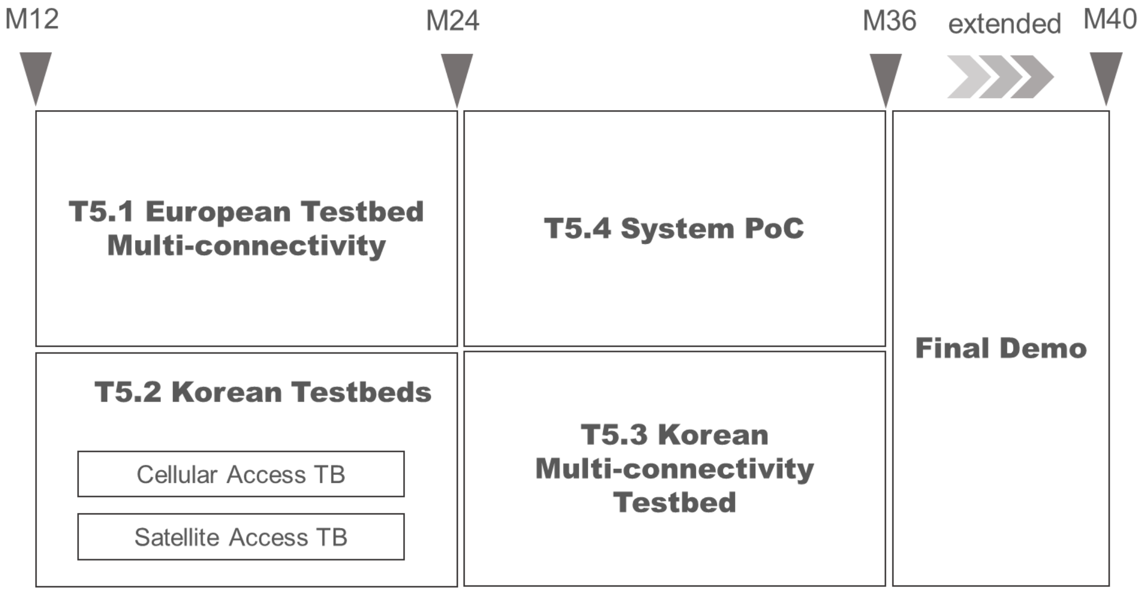

Figure 2: An updated WP5 schedule in consideration of the COVID-19 situations

2 Integration of Korean Multi-connectivity System

D5.3 describes the Korean testbeds for the 5G cellular access and satellite access [2]. On top of that, this document, D5.4, describes the integration of those testbeds for multi-connectivity (MC) usage scenarios. To merge those two different radio access systems, a traffic controller is added. The details on the traffic controller is described in D4.3 [3]. In the following sections, the architecture of Korean multi-connectivity testbed (MCT) is described and the implementation of a video server is described as well.

2.1 Architecture of Korean multi-connectivity testbed

The Korean multi-connectivity testbed consists of the 5G cellular access part and the satellite access part as in Figure 3. A vehicular UE (User Equipment) has the antennas and modems for both of the radio accesses – the satellite access and the cellular access. For the Korean MCT, the satellite access transceiver is based on commercially available products and independent from the 5G frame structures. Meanwhile, the cellular access transceiver is based on the 5G frame structures. Since these two access technologies do not share the frame structure in common, they cannot be aggregated in a protocol stack level. Instead they have been aggregated in the IP (Internet Protocol) layer with the traffic controller.

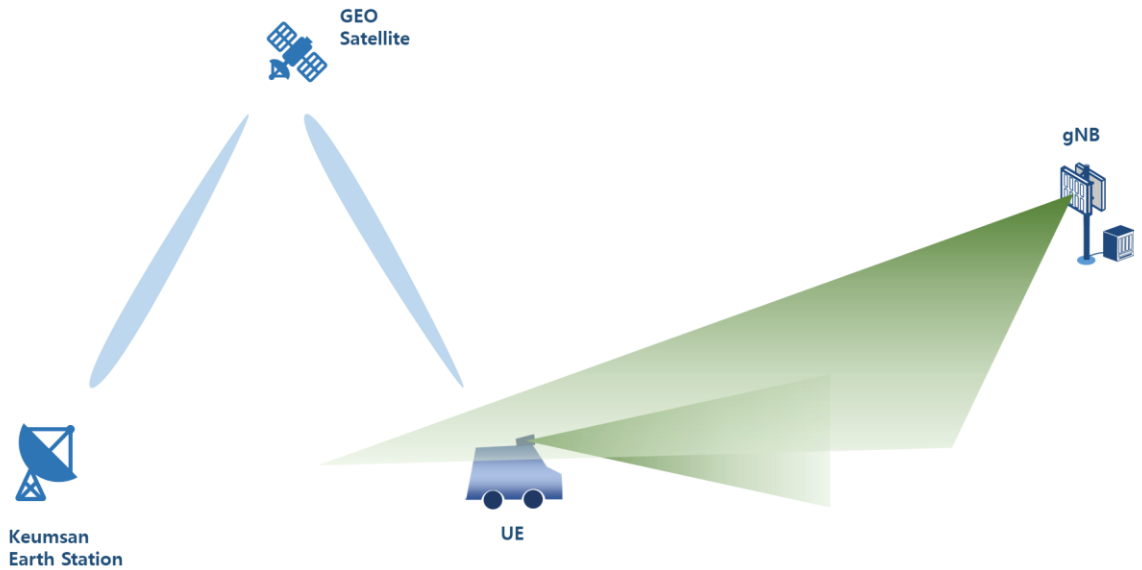

Figure 3: Architecture of Korean multi-connectivity testbed

2.1.1 Korean multi-connectivity testbed connections with the traffic controller

The key components of the Korean MCT including the traffic controller and their connections are illustrated in Figure 4. A video server is connected directly to the cellular network through a 5G core network. As shown in the figure, the satellite network can access the video server through the Internet. The location of the video server can be changed so that it can be accessed from the both networks via the Internet. If it is not connected directly to one of the networks, i.e., the 5G CN or the earth station herb, the data throughput from the server to an end user may be limited by the Internet performance.

These heterogeneous networks are connected to the traffic controller before they are connected to a UE, and then, the traffic controller is connected to a Wi-Fi access point (AP). Interfacing these ports, the TC needs IP settings for inputs from the two heterogeneous networks and for output to the Wi-Fi AP. An end user inside a vehicle may be a smartphone user that accesses the video server or Internet via the Wi-Fi AP.

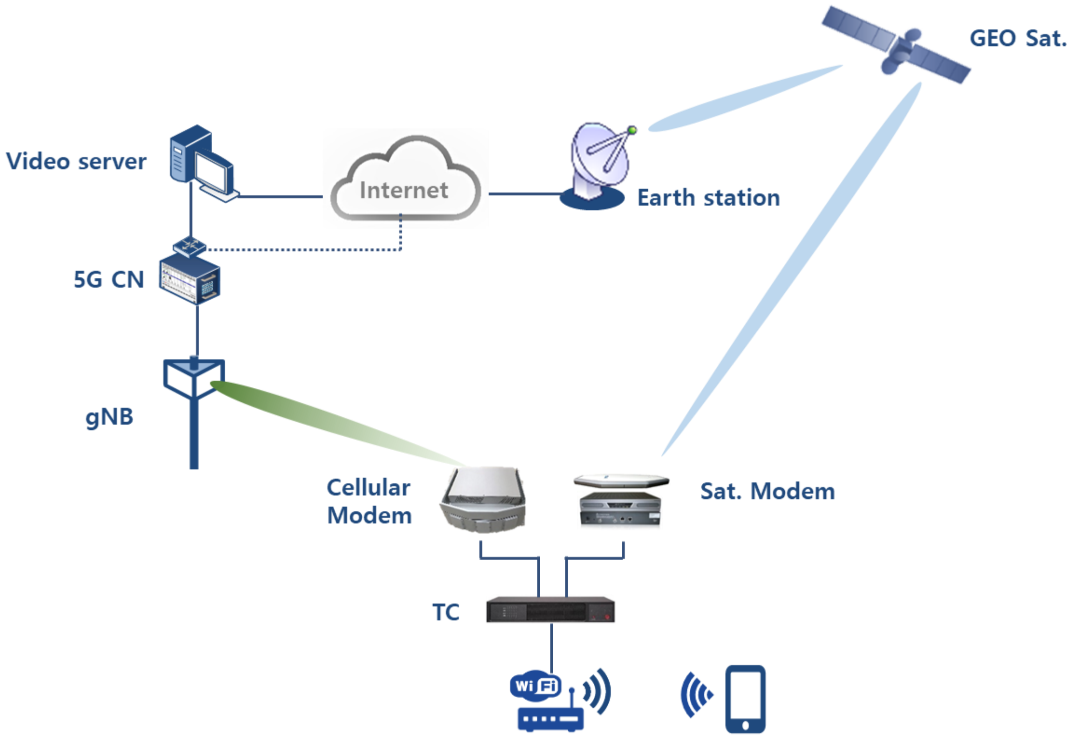

Figure 4: Components of Korean MCT and their connections

2.1.2 Integration of Korean cellular access system

The integration of the Korean cellular access TB is described in D5.3 [2]. In brief, the cellular access TB consists of a base station part and terminal equipment part as shown in Figure 5. The base station is comprised of the protocol stacks for layer 2 and 3, and the physical layer modem, named DRU (Digital and Radio Unit). As in the figure, the higher layers are set in a laboratory whereas the physical layer modem is set on outdoors. The terminal equipment part includes the protocol stacks of layer 1-3 for UE, a Wi-Fi AP, and end user devices, e.g., smartphones.

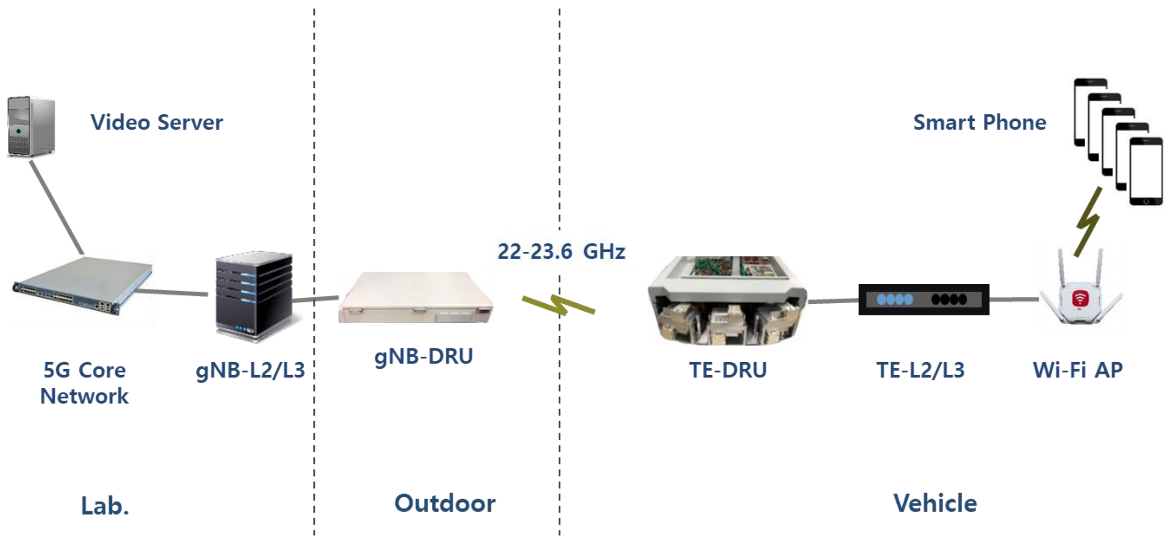

Figure 5: Integration of Korean cellular access system

2.1.3 Integration of Korean satellite access system

The integration of the Korean satellite access TB is described in D5.3 [2]. As in Figure 6, it makes use of the GEO (Geosynchronous Equatorial Orbit) satellite called Koreasat-6, the earth station in Kumsan, Korea and a remote part. The earth station has connections to the public Internet network through the Internet backbone of the Korean service provider's network of KT. The modems in the earth station and remote site are commercial products, and their components are named in the figure.

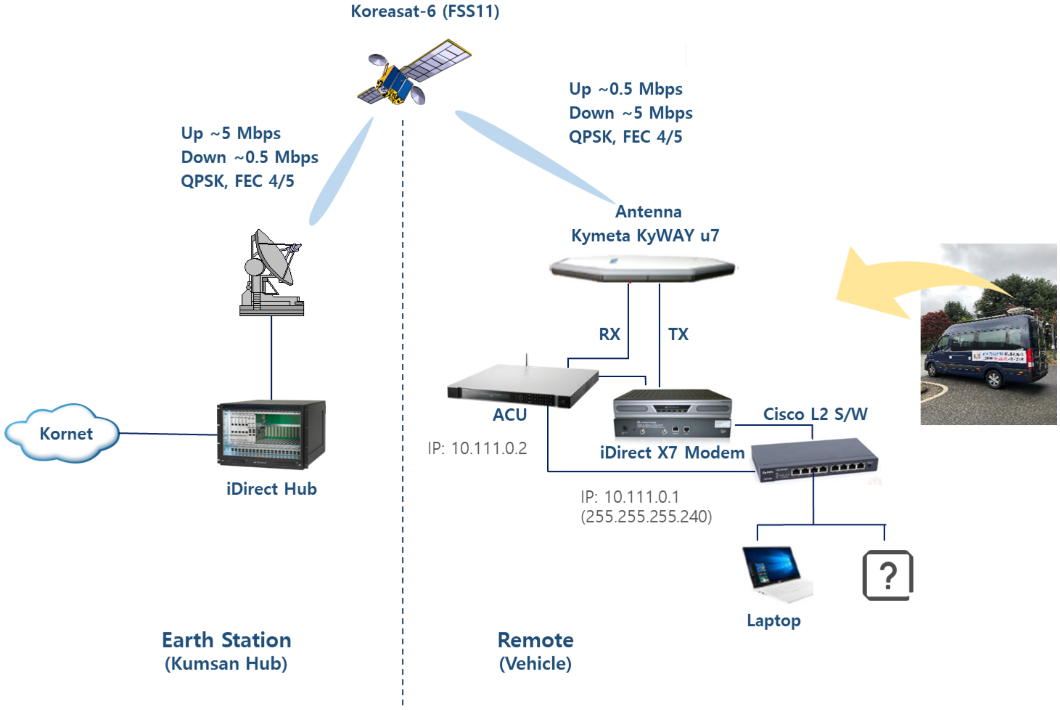

Figure 6: Integration of Korean satellite access system

2.1.4 A vehicle for multi-connectivity testbed

In the Korean MCT, the mobile data services are for the passengers inside a vehicle. In accordance with this concept, the cellular modem and satellite modem are set up on the roof of the test vehicle. In addition, the traffic controller, Wi-Fi AP and more devices are installed in the vehicle. Figure 7 shows the picture of the test vehicle with the modems on top and the 5G-ALLSTAR logo on the side.

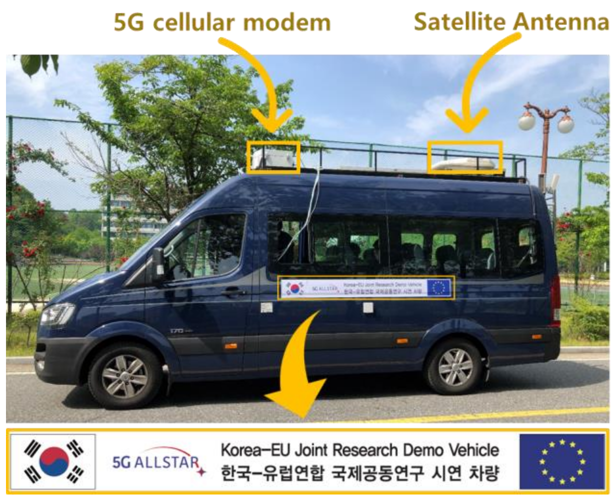

Figure 7: A vehicle for multi-connectivity testbed

2.2 Implementation of a video server

The video streaming services are useful to prove a service continuity concept in the MCT. In particular, YouTube must be the well-known example of the video streaming service, and surely that will be part of the MCT validation. On the other hand, a customized video streaming service is necessary sometimes if we want some special contents with various resolutions, e.g., a demo video of PoC itself. Once the video server is customized, it should have the benefit of flexibility in configuring test environments even without the Internet connection for some trial sites where the Internet cannot be reached.

2.2.1 Design overview

Following the requirements of the final PoC demonstration scenarios defined by WP2, a web-based video streaming server and a media player application for the user devices have been developed. The video server can be accessed either through a browser with its IP address on a laptop or a developed media player application installed on the smartphones.

To demonstrate two PoC service scenarios, use cases 1, 2, and 4 defined in D2.4, a video server and media player application have been designed. They can support resolutions of up to 8K. With the help of that, video contents with 8K resolution can be sent to users through the Korean MCT and/or the European MCT. Further, they allow access of 10 user terminals simultaneously.

2.2.2 Video streaming server design

The video server is based on REST (Representational State Transfer) API (Application Programming Interface) and provides resources such as video list web page and JSON (JavaScript Object Notation) and video m3u8, ts, png. In addition, a player web page for test play is also provided.

The main functionalities implemented on the video server include:

- ❑ Video uploading
  - ■ The video upload function is implemented through the multer module and can be used on a web page. When a video is uploaded, the video is uploaded to the uploads folder. When the upload is completed, a folder with the name of the video file excluding the extension is created in the videos folder.
- ❑ Thumbnail creation
  - ■ Thumbnail creation is operated through FFmpeg, and to use FFmpeg, fluent-ffmpeg module abstracted by node.js module is used.
- ❑ HLS (HTTP Live Streaming) encoding
  - ■ HLS encoding also requires FFmpeg and additionally requires FFprobe to obtain video metadata. When the thumbnail creation is completed, the metadata of the video is read with an implemented function.
  - ■ Then, a function that creates FFmpeg option for HLS encoding based on the metadata of the video is executed, and the quality list is determined based on the height value of the metadata, and the bit rate is determined by the formula, width x height x frames per second x 0.15.
  - ■ When HLS encoding starts, a function that creates a metadata.json file that records the encoding progress and video metadata in real time is executed.
  - ■ For a video that has been HLS encoded, folders are created for each quality, and in each created quality folder, ts files and a playlist.m3u8 files containing the playback section of the ts files are saved.

Other features of the developed video streaming server also include:

- ❑ It is developed as a web video server to provide video streaming based on HLS communication.
- ❑ Upload progress is displayed in real-time while uploading a video file.
- ❑ Adaptive bitrate streaming, which selects and plays content with an appropriate quality according to the network speed of the user, is supported.
- ❑ After an uploaded video file is encoded in various qualities, a number of segmented video TS (Transport Stream) files and m3u8 files in which the indices of the TS files are recorded are created through the stream segmenter.
- ❑ A GUI (Graphic User Interface) that enables deletion, status check and trial playback of a video is provided.

Figure 8 shows the screen capture of the video server main page with function buttons and status indications.

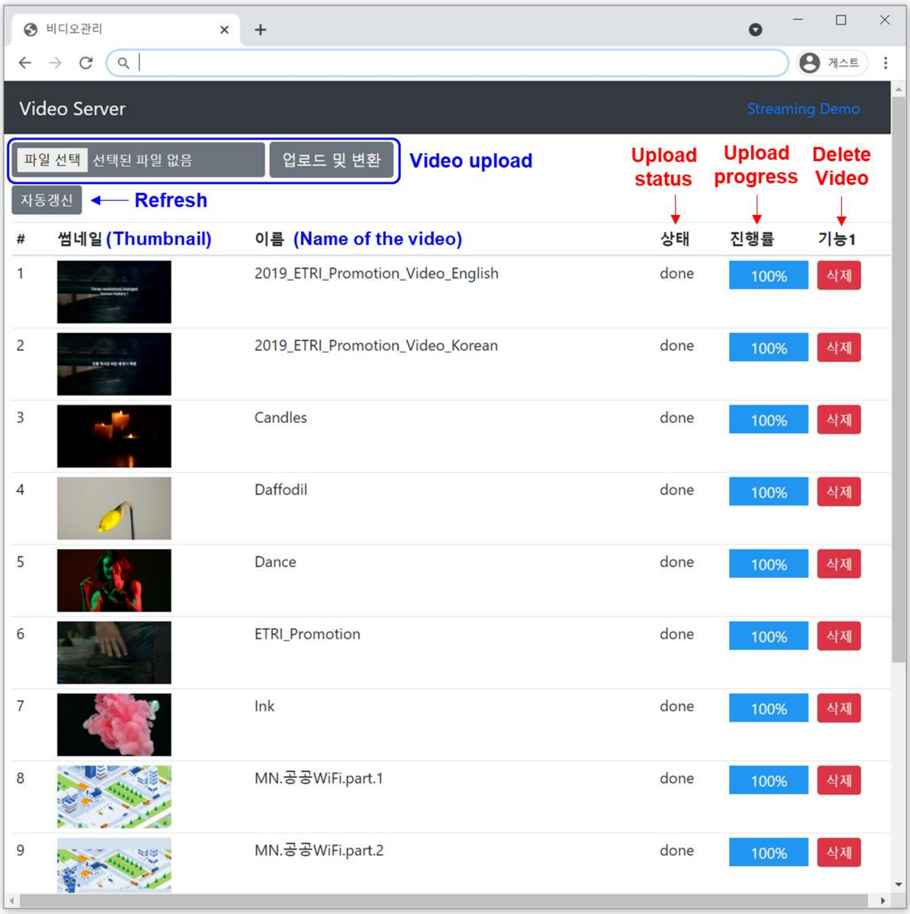

Figure 8: Video contents management in the video server

2.2.3 Media player application design

The main functionalities of the media player application include HTTP (Hyper Text Transfer Protocol) communication, video list, and video player.

- ❑ HTTP communication
  - ■ HTTP communication, which requests video lists, thumbnail, m3u8, TS, etc., is implemented with OkHTTP library.

- Video list
  - The view of the video list uses RecyclerView, which is highly reusable and expandable, and the detailed function includes a detailed view of video metadata. Figure 9 shows two screenshots for the video list.

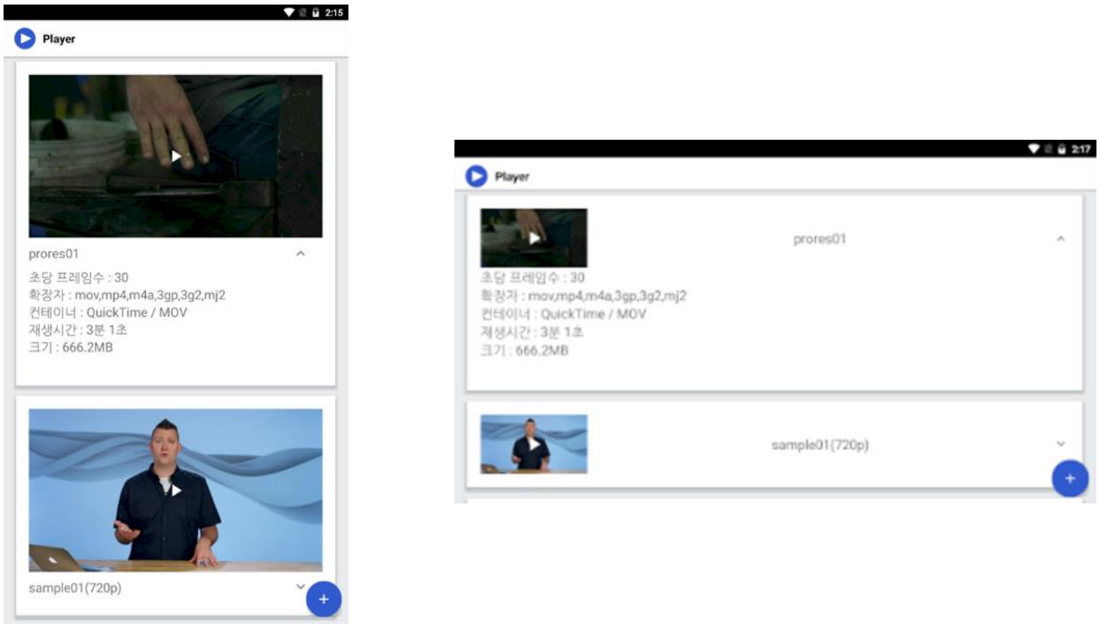

Figure 9: Screenshots of the video list.

- Video player
  - The video player is implemented based on Exoplayer, which is an open-source project that does not belong to the Android framework and is distributed separately from the Android SDK. The standard audio and video components are based on the Android MediaCodec API released in Android 4.1 (API level 16), and the main difference from the MediaPlayer provided as standard by Android is that it supports dynamic streaming such as SmmothingStreaming, DASH (Dynamic Adaptive Streaming over HTTP), and HLS.
  - The detailed functions of the video player include play/pause the video, skip 10 seconds forward/back in a video, quality selection, and screen rotation. Figure 10 shows an example of the playing screen.

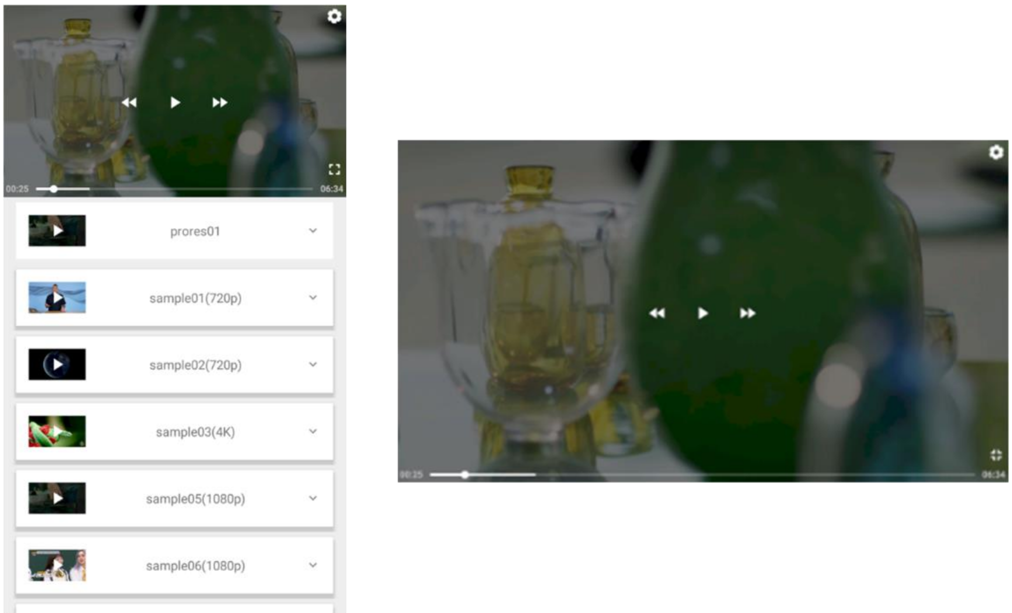

Figure 10: Screenshot of the video player.

Other features of the developed media player application on user devices also include:

- It is developed for Android user devices.
- It is capable of playing HLS container format video.
- It can receive playlists and thumbnails through HTTP communication with the video server.
- When rotating the screen, the views of the horizontal and vertical screens can be distinguished.
- A separate view for showing the metadata of the video is provided.
- A list of changed videos can be displayed by refreshing.

3 System Level Testing of the Korean Multi-connectivity System

D2.4 describes possible use cases and scenarios for the PoCs in 5G-ALLSTAR, of which use case 1 is relevant to the Korean trial systems, i.e., KR-Trial0 and KR-Trial1 [4]. Further, since the Korean multi-connectivity system is akin to the KR-Trial1, the system level testing will follow the context described in section 2.2 of D2.4.

3.1 Test scenario

The test scenario for testing with the Korean MCT comes basically from D2.4, but it needs slight modification considering the real test environments. First and last, keeping the idea of the link switching functionality under a signal loss situation is essential. There is underlying assumption that millimeter wave signals for the cellular access may be lost in some blockage situations but the satellite signals are still good to secure a service continuity. We may get these channel conditions with an appropriate channel emulator for convenience. However, the real testing ground was too limited to set up these channel conditions. In the end, this required some modification of test methodology. In the following subsections, we describe some details on the test environment and methodology.

3.1.1 Test environment

The testing ground to practice the multi-connectivity is in ETRI as shown in Figure 11. The server and switch of the 5G CN is set up inside a laboratory. The 5G CN is connected to the video server which can provide various video contents to clients. The video server is accessible through the Internet from Kumsan Earth Station for satellite. Test roads and the DRU location are indicated. With the configuration, a test vehicle can get line-of-sight channel environments for the millimeter wave based cellular access so that more than Gbps data rates can be achieved. From the satellite perspective, however, the satellite antenna and modem cannot achieve best performance on the front test road and left test road due to the lack of line of sight. The satellite access in the test can use some limited bandwidth of the commercially available whole bandwidths, downlink data rates were less than 5 Mbps. Hence, we need to move the vehicle to some place where we can fully utilize the satellite performance. The figure shows a test point that can get satisfactory channel environments for both networks.

Figure 11: Picture of the testing ground in ETRI

3.1.2 Test methodology

Inside the test vehicle, input/output connections for the traffic controller are setup. General testing with the traffic controller is described in section 7.2 of D4.3. A conceptual test setup is shown in Figure 12. An input port is for a cellular modem and another is for a satellite modem, and the only output port is connected to a Wi-Fi AP. Appropriate IP settings for the TC interface is necessary as well as the physical connections. We can check video streaming services by smartphone applications. Section 2.2 of D2.4 refers to some cases like urban or rural highway scenarios where the cellular blockage occurs while the satellite signal is still good. In the experiments under the test environment, however, we need to simulate cellular blockage situations by switching on/off to the traffic controller input as illustrated in Figure 12.

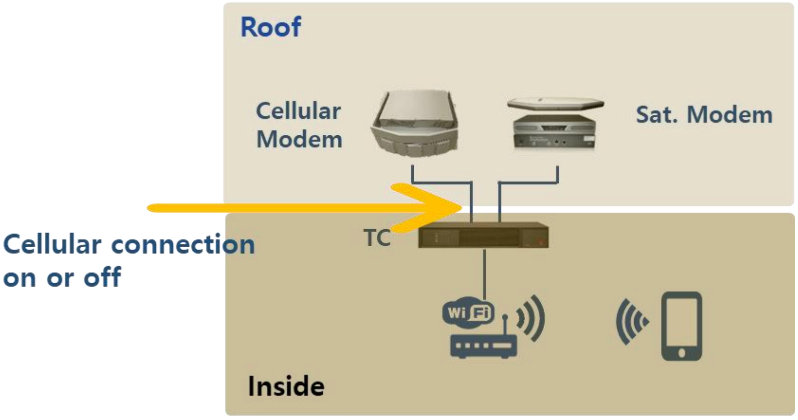

Figure 12: Traffic controller connections

3.1.3 Target KPI

5 KPIs are described in section 2.2.3 of D2.4 and recall in Table 1. Most KPIs but "service continuity" can be addressed with the 5G cellular access testbed and the satellite access testbed, separately. Section 2.3 of D5.3 deals with KPI0-KR2 and section 3.3 of D5.3 deals with KPI0-KR3. The "service continuity" KPI is to be proven with the MCT presented here.

Table 1. Target KPI and mean of demonstration for PoC scenario 1.2

KPI label	Target KPI description
KPI0-KR2	Average PHY data rate of cellular access link to a bus (downlink)
KPI0-KR3	Average PHY data rate of satellite access link to a bus (downlink)
KPI3-KR0	Reliability of cellular link: Block Error Rate (BLER)
KPI3-KR1	Reliability of satellite link: E_b/N_0 for Quasi Error Free (QEF)
KPI4-KR1	Service continuity

3.2 Testing and results

3.2.1 Setup for testing

The video streaming service requires an application server and a client at least. In this testing scenario, the video server is implemented as described in section 2.2, and it is set in the laboratory as shown in Figure 13. The figure also shows the 5G CN for the cellular access network to the left of the video server. The 5G CN includes key function blocks such as SMF (Session Management Function), AMF (Access and Mobility Management Function) and UPF (User Plane Function). It normally provides the cellular terminals with gateway to the Internet as well as the connection to the video server.

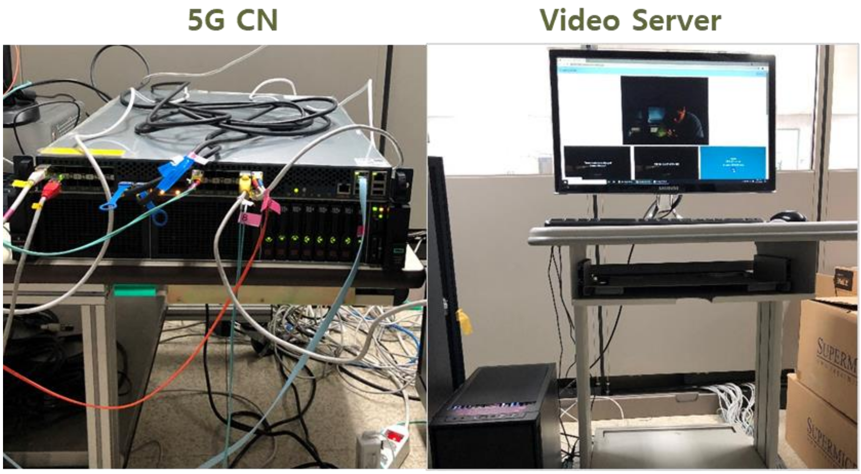

Figure 13: The 5G CN and video server in the laboratory

Since the video server is directly connected to the 5G CN through a switch, the download speed for the video contents through the 5G cellular access network can be as high as the maximum speed of the 5G cellular network itself. On the other hand, the satellite access network needs to route, in this case, through the Internet to reach the video server, which possibly limits the download speed from the server. However, in this testing, the download speed from the server through the satellite access is limited not only by the Internet but also by the bandwidth allocation.

Meanwhile, optical cables from the laboratory to the testing site are used to make a connection between the 5G CN and the gNB. Figure 14 shows the location of the gNB-DRU and its setup.

Figure 14: Outdoor setup for a gNB-DRU

3.2.2 Test procedure

Once the outdoor test setup is established, the test vehicle moves to some place in the route where both the cellular and the satellite channels are good enough for the video streaming service. Table 2 lists a typical exemplary test procedure for the multi-connectivity. An RRC (Radio Resource Control) connection setup for the cellular access and the satellite connection are prerequisites, and then the traffic controller needs to be monitored to check if it functions correctly. After all set, with a laptop or smartphone we can play the video contents in the video server, which is followed by checking the video quality and the service continuity depending on some channel changes or on the traffic switching over.

Table 2: A typical exemplary test procedure

Step	Operation	Comments
1	RRC connection[NOTE1]	5G cellular network
2	satellite connection[NOTE2]	satellite network
3	traffic controller setup[NOTE3]	input/output
4	web browsing with a smartphone	video server IP[NOTE4]
5	selection and play	smartphone
6	monitoring traffic controller	cell path and/or satellite path
7	moving the vehicle to a cellular blockage area while keep watching the video	or switching cellular path off
8	monitoring traffic controller input	checking the service continuity

NOTE1: See figure 22 of D5.3

NOTE2: See section 3 of D5.3

NOTE3: See section 7.3 of D4.3

NOTE4: In this test, an IP in ETRI is issued and the IP can be accessed from the Internet by opening the firewall.

3.2.3 Video streaming services in the vehicle

In the first trial, we access the customized video server by a smartphone as in Figure 15. For convenience, the mirroring of the smartphone to a 15-inch screen was used. A laptop was to monitor the traffic controller status. It can monitor some important status information such as RTT (Round Trip Time), traffic loss, and 'Pending/Online' indication, etc. It can also indicate which input traffic is selected and forwarded to the output port. If any meaningful changes in channel occurs, the TC, sensing the changes, should try to change the traffic selection accordingly. With this functionality, the video streaming maintains from the end user perspective. In the Korean MCT, the download speed of the cellular path is larger than 500 Mbps, and most video contents on the server have been played without buffering. However, the satellite path with its limited bandwidth allocation for test, could provide around 5 Mbps of maximum data rate, and most video contents should experience severe buffering during the contents downloading. If we accept the constraint and some buffering from the satellite path, we could conclude that the MCT had supported a service continuity.

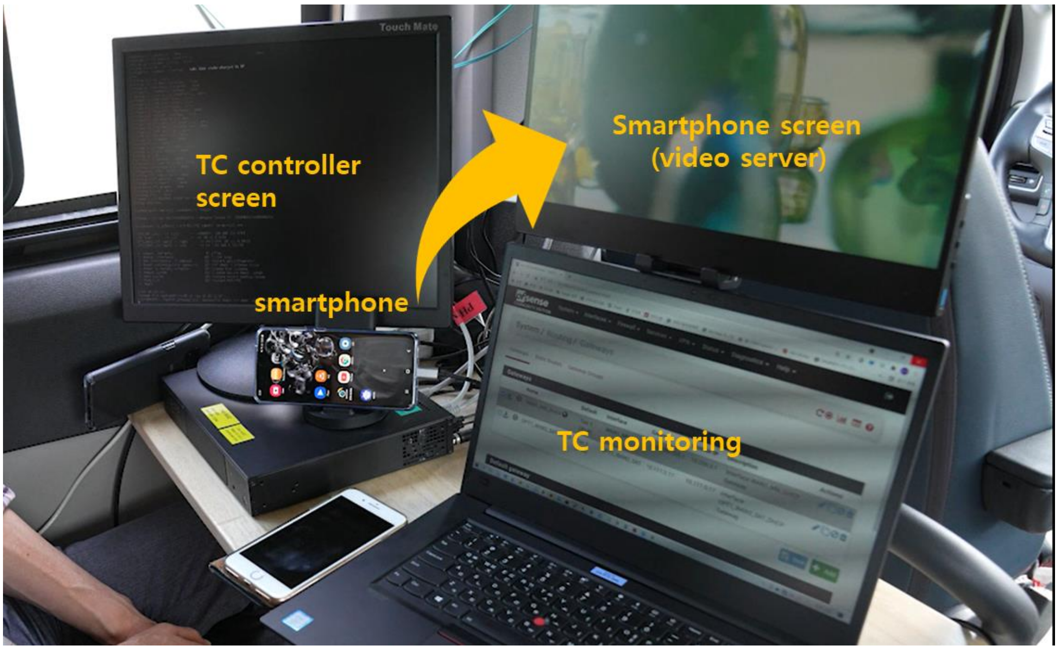

Figure 15: A video streaming service in the vehicle

As the second trial, YouTube, instead of the customized video server, has been tried with the MCT. The smartphone, laptop, and TC have been configured same as above, and shown in Figure 16. The figure shows a BBC live clip. The video could be played with only short buffering even for the satellite path. With this configuration, a few turns of the test procedure showed the service continuity while the TC was functioning well under the cellular access channel blockage. Figure 17 shows the TC status monitoring on the data traffic selection – the left capture indicates the cellular path is selected whereas the right screen indicates the satellite path is forwarded to the output port.

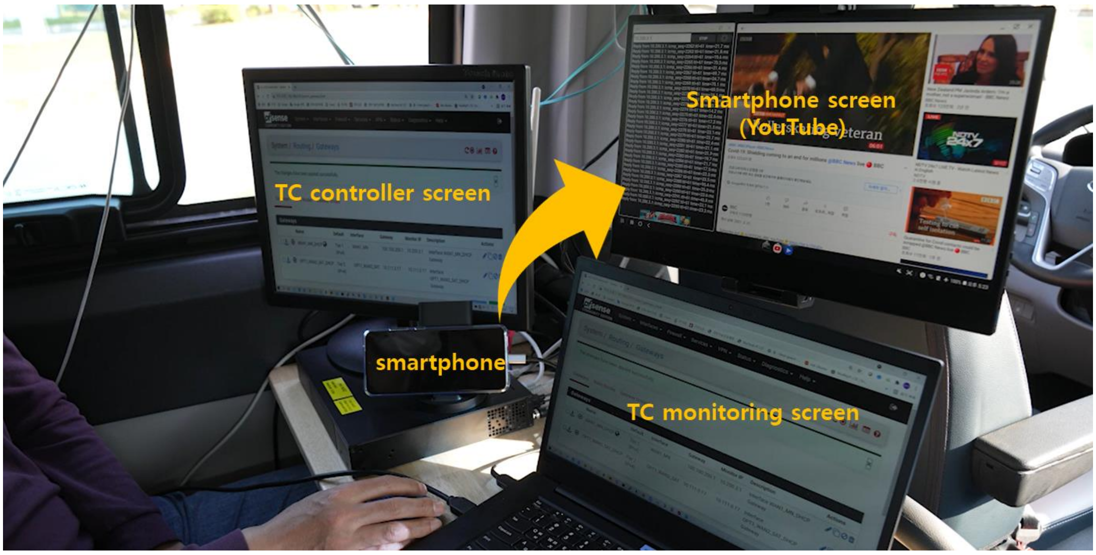

Figure 16: YouTube service in the vehicle

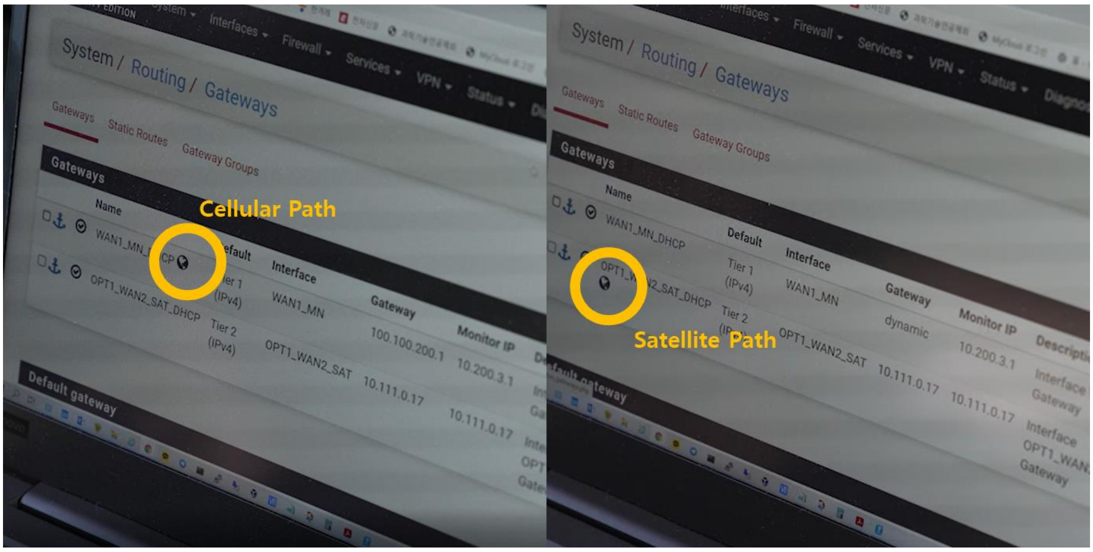

Figure 17: TC path monitoring

Still, there are some issues to be considered for the future study. First point is that the TC was implemented based on the IP traffic aggregation. If the satellite access system evolves to accommodate the 5G frame structures, it can be aggregated with the cellular access system on a protocol layer as in the EU case. Second point is that the TC location may be reconsidered for better efficiency. With the present MCT configuration, both of the cellular path and satellite path always allocate their resources, and only one of them is selectively forwarded to an end user. This inefficiency can be improved if the TC is to be placed closer to the 5G CN. If the TC location changes, the TC will have one input port to an application server through the 5G CN and two output ports to each heterogeneous radio access paths. Any further issues including this different port configuration needs to be studied in the future works.

4 Conclusion

In the task 5.3, we integrated the cellular access TB and satellite access TB into the multi-connectivity TB. The integration of the MCT needs to define appropriate interfaces between the traffic controller and the two different access networks. In the Korean MCT, the integration was based on the IP layer, which necessitates the IP settings for inputs from the two access networks and for output to the Wi-Fi AP. No further issues were observed about the interfaces.

The service continuity is one of five target KPIs to be verified in the 5G-ALLSTAR. To meet the goal from Korea side, the integrated MCT provides the PoC platform for the system level testing. We chose the video streaming services to verify the concept of the service continuity. The customized video streaming server had been implemented for it, and the details had been disclosed. In addition, the YouTube live streaming had been utilized for the PoC as well.

The system level testing with the Korean MCT has been conducted at the ETRI test site according to the predefined procedures listed in the Table 2. Throughout the PoC demonstration, the concept of the service continuity was well defined and proved for the video streaming services using both of the customized video service and the commercial YouTube service. We also discussed that some enhancements should be pursued to improve the efficient resource usage. As in the EU side approach, applying the 5G based air interface to the satellite access is one direction. Keeping the current TC concept while placing the TC closer to the 5G CN is another. These might be future works for further improvement of the service continuity performance and the efficient radio resource usage.

Reference

[1] Frost and Sullivan, “Disruptive satellite communication in the automotive industry”, Sep., 2016.

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[4] D2.4, “Final document of service scenarios/applications for PoC,” delivered in 29 Feb., 2020.

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