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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 the Korean Testbed.

Keywords

5G ; Testbed ; Multi-Access ; specification ; mmWave

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Executive Summary

This document as the output of task 5.2 is about "Integration and system level testing for Korean testbeds of 5G cellular and satellite access networks." It describes two testbeds: one is a 5G cellular access testbed and another is a satellite access testbed. These will be integrated into a multi-connectivity testbed in task 5.3. Specifically, the 5G cellular access testbed will address one of three WP5 objectives (**O5.1**).

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List of Abbreviations

3GPP	3rd Generation Partnership Project
5GC	5th Generation Core
5GCN	5th Generation Core Network
ADC	Analog-to-Digital Converter
AMF	Access and Mobility Management Function
CATB	Cellular Access Testbed
CN	Core Network
CNS	Core Network Subsystem
CP	Control Plane
CPS	Control Plane Subsystem
CPU	Central Processing Unit
CPUS	Control and User Plane Separation
DAC	Digital-to-Analog Converter
DL	Downlink
DN	Data Network
DPDK	Data Plane Development Kit
DRU	Digital & Radio Unit
DU	Distributed Unit
EPC	Evolved Packet Core
FPGA	Field Programmable Gate Array
GbE	Gigabit Ethernet
GPRS	General Packet Radio Service
GTP	GPRS Tunnelling Protocol
GW-C	Gateway – Control Plane
GW-U	Gateway – User Plane
IF	Intermediate Frequency
MAC	Medium Access Control
MCU	Micro Controller Unit
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MN	Moving Network
MNS	Moving Network System
NAS	Non-Access Stratum
NGAP	Next Generation Application Protocol
OFDM	Orthogonal Frequency Division Multiplexing
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
QFI	QoS Flow Identifier
QoS	Quality of Service
RAS	Radio Assess Subsystem
RF	Radio Frequency
RLC	Radio Link Control
RRC	Radio Resource Control
RTL	Register Transfer Level
SDU	Service Data Unit
SDAP	Service Data Adaptation Protocol
SFP	Small Form-factor Pluggable
SMA	Sub Miniature version A
SMF	Session Management Function
SNR	Signal to Noise Ratio
SSB	Synchronization Signal Block
TDD	Time Division Duplexing
TE	Terminal Equipment
UL	Uplink
UP	User Plane
UPS	User Plane Subsystem
UPF	User Plane Function

1 Introduction

1.1 Background and project context

The 5th generation (5G) networks have been widely expected to provide network related quality of experiences (QoEs) and faster and reliable services. Since the advent of the world first commercial 5G services in 2019, a couple of mobile operators launched their services based on millimeter waves. For example, AT&T and Verizon launched the 5G services based on 39 GHz and 28 GHz, respectively, March 2020 [1-2]. They reported that overall speeds were improved with the new spectrum. Problems, however, arose in coverage. Successful connection to the 5G network were as low as below 3 % depending on the region [3]. These are attributed to certain physical characteristics of the millimeter waves.

Since the coverage impacts the end user experience no less than any other issues, advanced technologies for improving the coverage of millimeter wave networks need to be pursued. Moreover, future 5G will not bound the coverage within terrestrial regions, but expand it into sea and space. Hence, non-terrestrial-networks (NTNs) are also to be researched further. This project concerns the service continuity over very wide coverage. Therefore, multi-connectivity between two heterogeneous networks plays the key role in addressing the coverage issue to improve the service continuity. One of the two networks is the millimeter wave based 5G cellular access network and another is the satellite access network, which will be main issues of this document.

In the subsequent sections, work package (WP) objectives and relation to other WPs are described. Chapter 2 devotes to the millimeter wave 5G cellular access testbed, and chapter 3 to the satellite access testbed. Last, chapter 4 summarizes the main points.

1.2 Work Package objectives and Tasks

WP5 is responsible for prototyping, validation and demonstration. There are three specific objectives to be fulfilled in the WP5:

O5.1: Provide laboratory technology demonstration showing capability of Millimeter wave (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 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.

There are four specific tasks to accomplish the WP objectives. First, task 5.1 is to implement “European Proof of Concept (PoC) testbed.” Second, task 5.2 is to implement “Korean PoC testbeds for 5G cellular and satellite access.” Third, task 5.3 is to implement “Korean PoC system for multi-connectivity.” Last, task 5.4 is to provide “system level testing of Proof-of-Concept phase 1 and phase 2.” This deliverable D5.3 is the output of task 5.2, which aims at delivering i) implementation, integration and testing of components for Korean 5G cellular access PoC system, ii) implementation, integration and testing of components for Korean GEO-based satellite access PoC system. Hence, D5.3 will address the first objective O5.1 of the three WP5 objectives.

1.3 Links with the other Work Packages

The WP5 is supposed to deliver the PoC demonstration over the intercontinental test trial platform at a key event. For this goal, cooperation among different WPs is important. Figure 1 illustrates what input the WPs deliver to WP5 and vice versa. The WP2 helps to setup overall demonstration scenarios and story-telling underneath those, and the WP4 suggests candidate load balancing algorithms to support multi-connectivity and implements the best algorithms with the WP5 feedback.

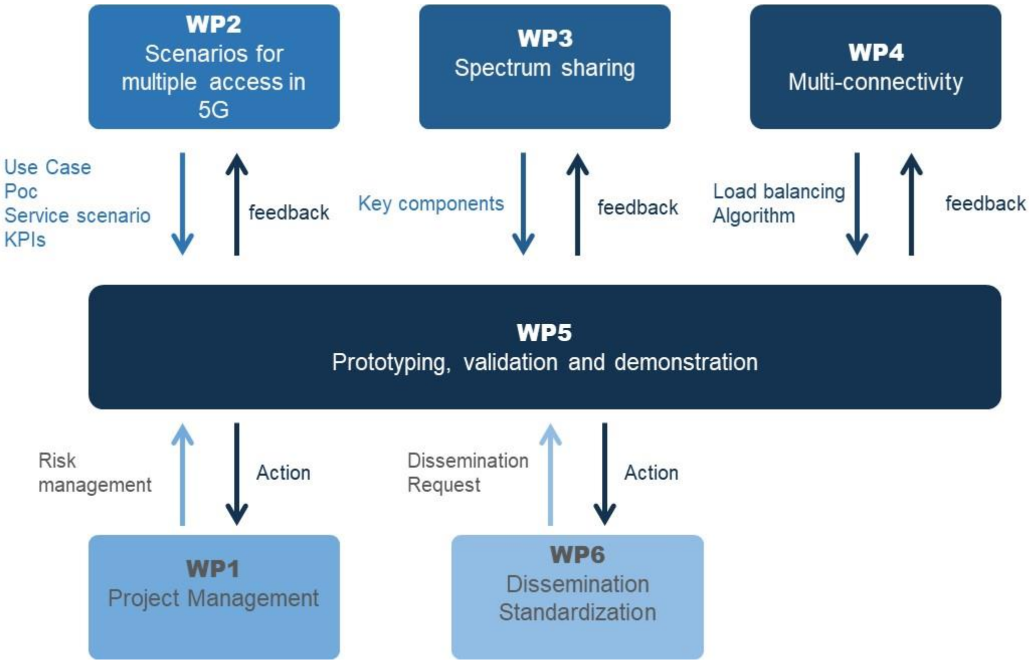


Figure 1: Interaction among WPs

1.4 Task Schedule

Figure 2 illustrates overall task schedule in the WP5. Both of European and Korean testbeds deal with 5G cellular access and satellite access and integrate them into one joint trial platform for the EU-KR joint task and final demonstration.

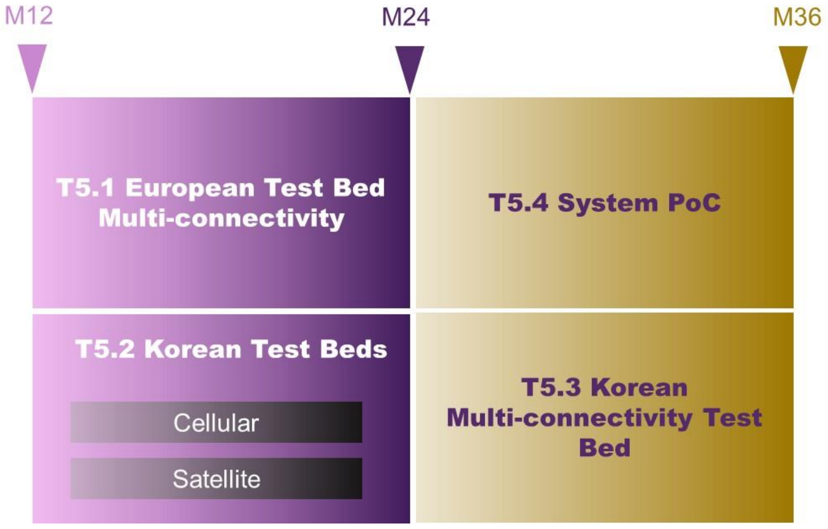


Figure 2: Task Schedule in WP5

2 5G Cellular Access Testbed

This chapter describes a Korean 5G CATB (Cellular Access Testbed) and PoC test results. In the first subsection, the architecture of the 5G CATB is described. Next, the integration of the components is described. In the subsequent sections, the system tests and their results are described.

2.1 Architecture of 5G cellular access testbed

The Korean 5G CATB consists of 5GCN (5th Generation Core Network) and RAN (Radio Access Network) as shown in Figure 3. The 5GCN is responsible for functions not related to the radio access but needed for providing a complete network. This includes, for example, a session management function, an access and mobility management function, and a user-plane function. These functions will be described in detail in the subsequent subsection. The RAN is responsible for all radio-related functionality of the overall network including, for example, radio resource control, ciphering/deciphering of data packets, retransmission protocols, scheduling, coding/decoding, and dealing with multi-antenna transmissions.

The RAN of the CATB has two main points. First, it deals with mmWave of around 22 GHz to exploit the wideband for achieving a large capacity. Second, a terminal equipment of transmitting and receiving the mmWave is for a vehicle. Hence, end users inside the vehicle do not need to transmit/receive mmWave and they connect to a Wi-Fi AP connected to the mmWave terminal equipment.

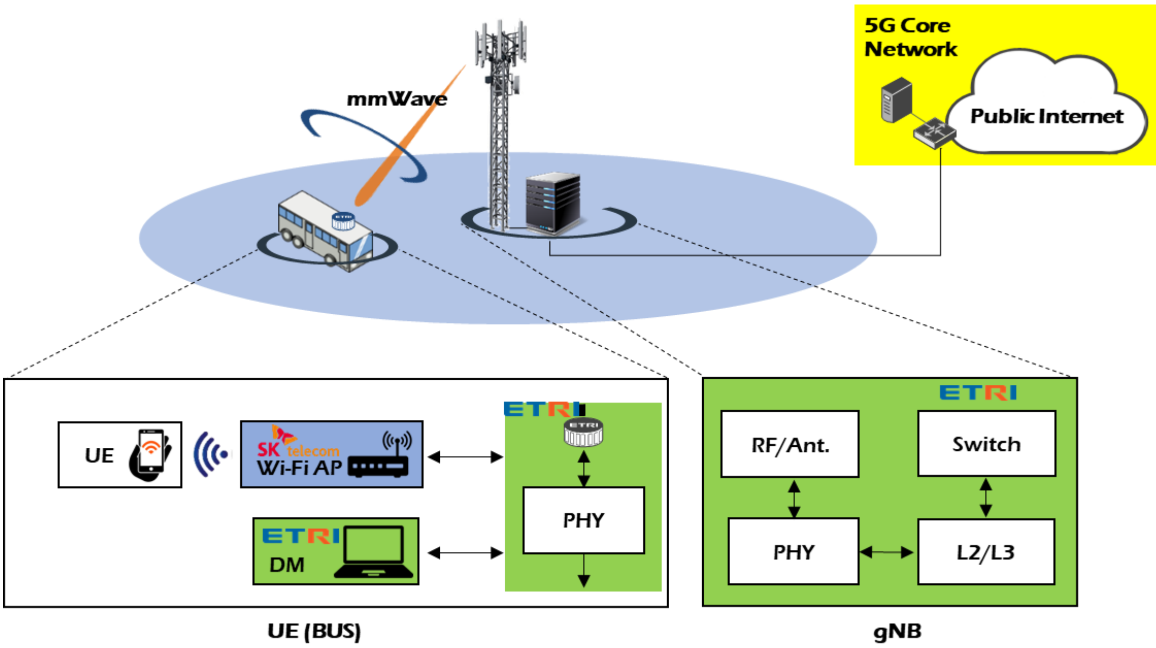


Figure 3: Architecture of Korean 5G cellular access testbed

2.1.1 5G core network

The 5G has been designed to support i) wide bandwidths, ii) large data traffic, iii) low latency and iv) massive device connections. To achieve these goals, the EPC (Evolved Packet Core) of the 4G has been evolved to the 5GCN, while a concept of CUPS (Control and User Plane Separation) was introduced as a key element. Figure 4 shows the CUPS structure of the 5GCN. Upon the control plane (CP), EPC MME (Mobility Management Entity) functions like authentication/authorization for the UE and mobility control have been recombined to the 5GC AMF (Access and Mobility Management Function), and the session management functions of the EPC MME and GW-C (Gateway – Control Plane) have been recombined to the 5GC SMF (Session Management Function). And, upon the user plane, packet processing and policy enhancement functions of the EPC GW-U (Gateway – User Plane) have been recombined to the 5GC UPF (User Plane Function). Interfaces among the 5GC function blocks are also shown in the figure; N11 interface is defined between the AMF and SMF, N4 between the SMF and UPF. N6 interface is defined between the UPF and external DN (Data Network). N2/N3 interfaces are defined between the AMF/UPF and gNB, respectively [4].

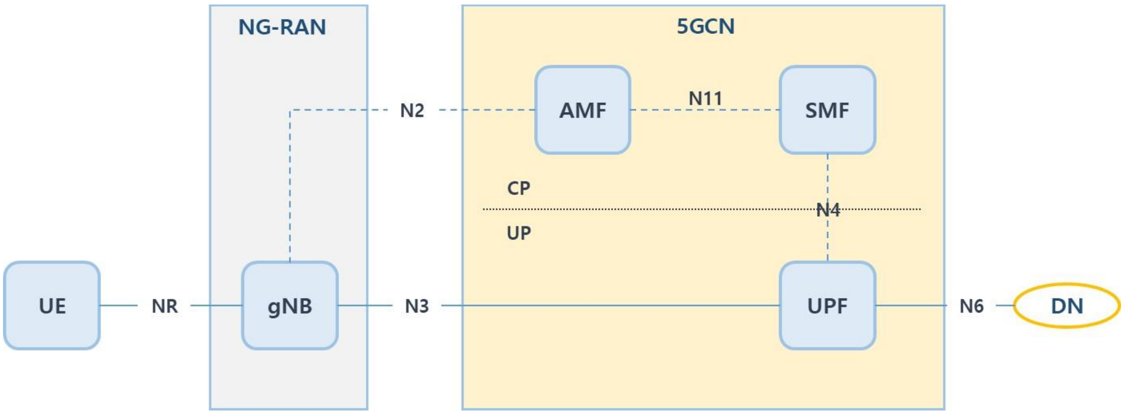


Figure 4: 5GC CUPS structure

Main functional aspects of the 5GCN are described as follows:

- Control Plane
  - NAS (Non-Access Stratum)
    - The NAS functionality operates between the AMF in the 5GC and the device through NGAP, and it deals with authentication, security, and idle mode procedures as paging.
  - IP Allocation
    - The IP allocation functionality manages IP Pool allocating/withdrawing IPs upon the UE request.
  - Mobility Control
    - The mobility control functionality assures efficient data traffic while a device moves out of a cell and into a new cell.
  - Bearer Controller
    - The bearer controller functionality deals with the creation, deletion, and addition of radio bearer.
- User Plane
  - Session Manager

    - The session manager functionality manages gNB session including GTP (GPRS Tunneling Protocol; GPRS: General Packet Radio Service) Tunneling, GTP encapsulation/de-capsulation, GTP packet routing, etc.
- Traffic Controller
    - The traffic controller functionality deals with packet routing/transfer, traffic QoS (Quality-of-Service) control, inter-gNB mobility management point roles.

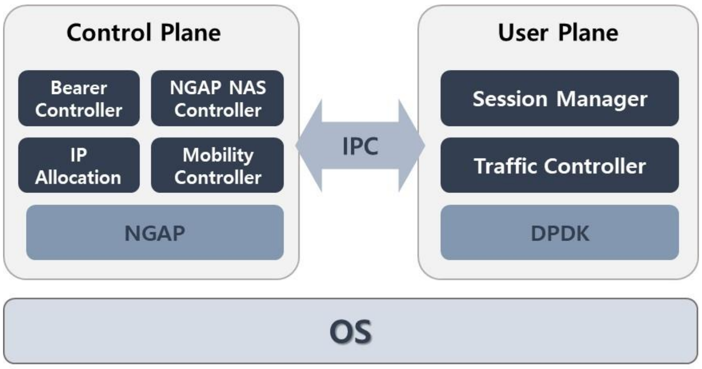


Figure 5: Functional diagram of the 5GCN

2.1.2 5G NR based RAN

The radio access network is responsible for all radio-related functions between the 5GCN and devices (or UE) in the 5G cellular access network. It deals with radio resource management, admission control, connection establishment, routing or user-plane data to the UPF and control-plane information to the AMF, and QoS flow management. Figure 6 shows the RAN architecture of the KR cellular access testbed. There are L2/L3 protocol stacks upon physical layers, i.e., RRC (Radio Resource Control), SDAP (Service Data Adaptation Protocol), PDCP (Packet Data Convergence Protocol), RLC (Radio Link Control), MAC (Medium Access Control) in the gNB and UE sides. Since the gNB is a logical node, not all the protocol functions be necessarily put in the same place, or the locations of split functions can be separated. For example, upper layers (from MAC to RRC) and physical layer can be separated typically up to several kilometers and they can be connected by 10GbE protocol over the optical cable.

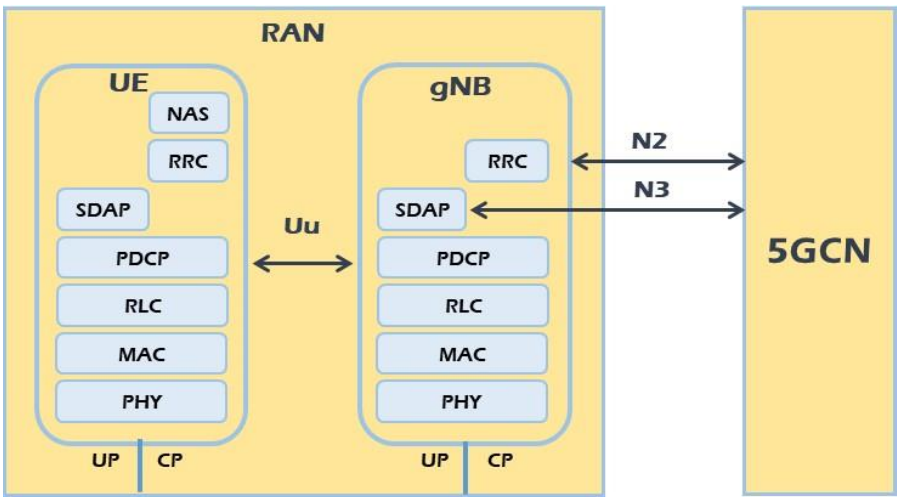


Figure 6: Architecture of the RAN

Main functional aspects of the RAN protocol stacks are described as follows:

- SDAP
  - Mapping QoS flows to radio bearers according to QoS requirements
    - Marking QoS flow ID (QFI) in both DL and UL packets
    - A single protocol entity of SDAP is configured for each individual PDU session except for dual connectivity
- PDCP
  - Performing IP header compression/decompression, ciphering/deciphering, and integrity protection
  - Handling retransmissions and duplicate removal in the case of handover
  - Transfer of user data
  - PDCP PDU routing in case of split bearers
  - In-sequence delivery
    - In-sequence delivery from RLC layer might incur high latency due to deciphering
    - Complete PDCP PDUs (Protocol Data Units) can be delivered out-of-order from RLC to PDCP. RLC delivers PDCP PDUs to PDCP after the PDU reassembling
    - PDCP reordering is always enabled if in sequence delivery to layers above PDCP is needed
- RLC
  - Transfer of upper layer PDUs
  - RLC SDU (Service Data Unit) discard
  - RLC re-establishment
  - Performing segmentation and retransmission handling
    - Sequence numbering independent of the one in PDCP
    - Segmentation and re-segmentation
    - Error correction through ARQ
- MAC
  - Mapping between logical channels and transport channels
  - Multiplexing/de-multiplexing of MAC SDUs belonging to one or different logical channels into/from TB (Transport Block) delivered to/from the PHY
  - Scheduling information reporting
  - Error correction through HARQ
  - Priority handling
    - Priority handling between UEs by means of dynamic scheduling
    - Priority handling between logical channels of one UE by means of logical channel prioritization
- PHY
  - Encoding/decoding transport channels
  - Modulation/demodulation of physical channels and signals

- Resource/antenna mapping/de-mapping
- Measurements and report of channel state information

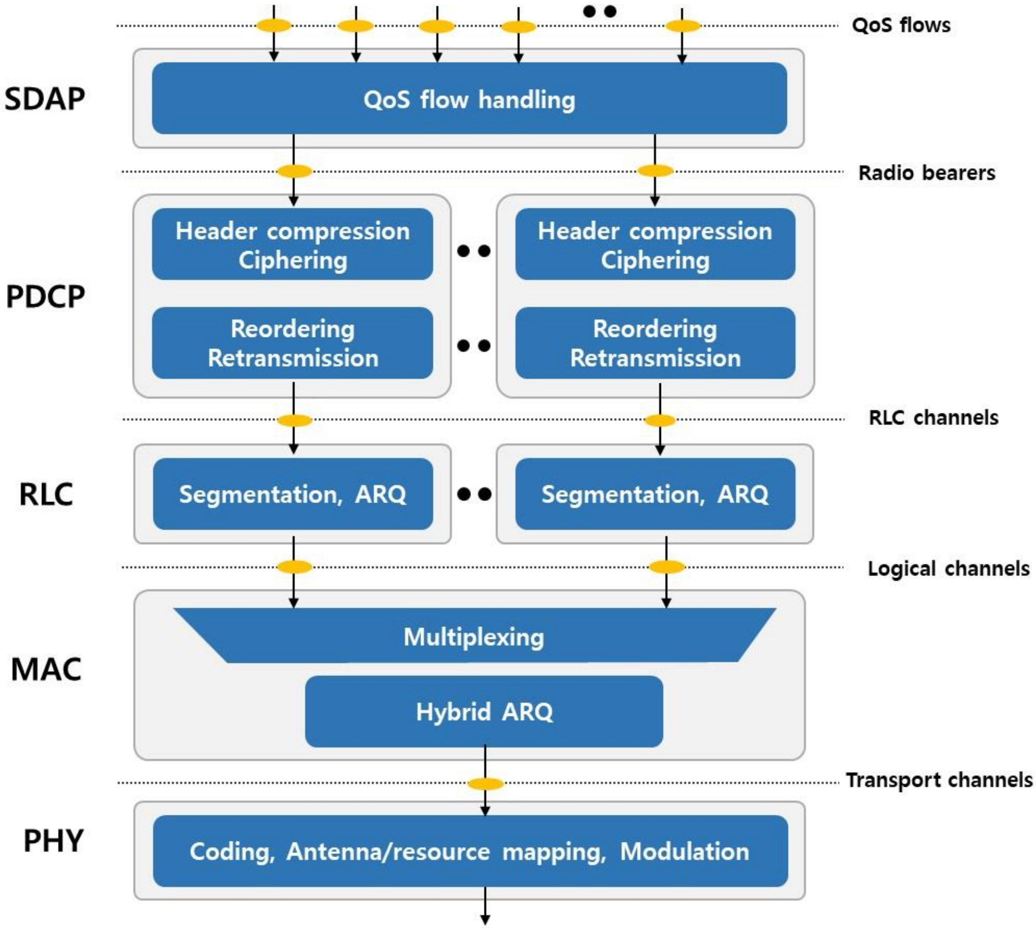


Figure 7: User-plane protocol stacks for downlink

2.2 Integration of 5G cellular access testbed

The 5G CATB includes several hardware platforms to implement each component as shown in Figure 8 where the images or pictures for the hardware devices are illustrated. All the components in the figure are listed in Table 1. Their functions or services and specifications are summarized. The hardware for the video server, 5G Core, gNB, TE (Terminal Equipment)-L2/L3 basically are computers with appropriate performance features such as CPU (Central Processing Unit) speed/number and memory speed/size. To support high data throughput, the 5G Core and L2/L3 require high-performance server PCs with multiple numbers of CPU core. On the other hand, RF equipment needs normally dedicate designs according to frequency, bandwidth, and antenna configuration. Furthermore, in the 5G CATB, RF/antenna and baseband modem are integrated into single equipment: DRU (Digital & Radio Unit) and TE-PHY are RF/antenna/baseband modem integrated equipment for gNB side and UE side, respectively. In the subsequent subsections, the DRU and TE-PHY will be described in detail.

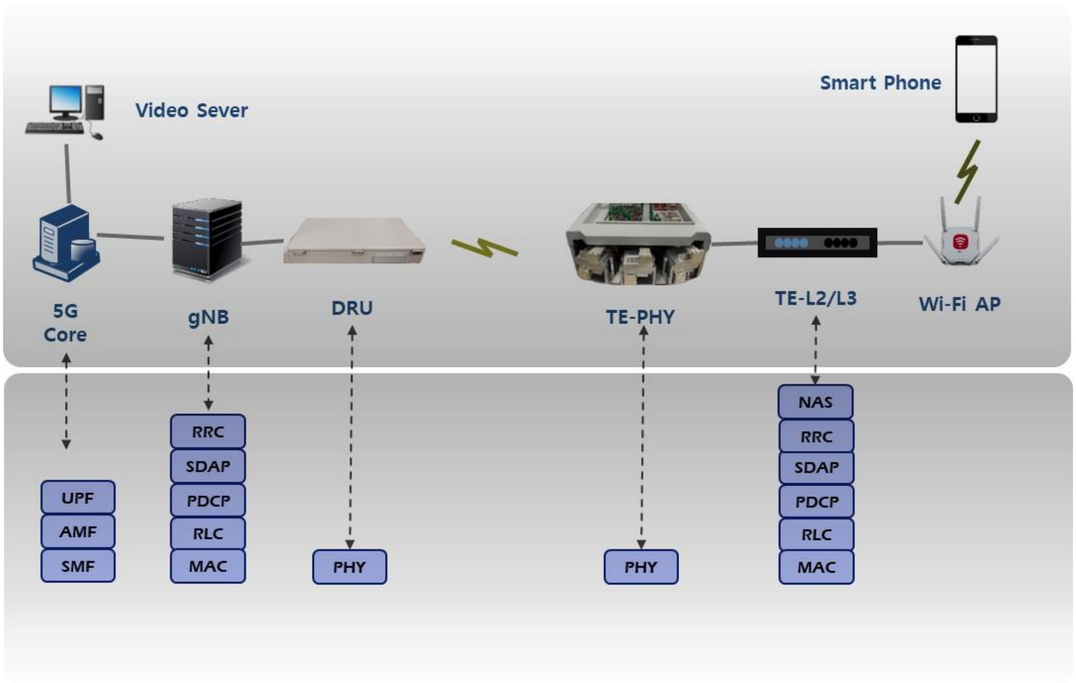


Figure 8: Component HW and protocol stacks of the 5G CATB

Table 1: List of the TB components and characteristics

Component	Function/Service	Specification	Provider
Video server	Video streaming	8K video streaming TCP/IP protocol based VSP, VTP	ETRI
5GCN	UPF, AMF, SMF	Xeon Server, Znyx B series 480G switching capacity with OA4 & Quagga protocol stack	Snet ICT
gNB	5G gNB protocol stack	Xeon Server (16 cores) gNB throughput of 6Gbps (2 cells)	ETRI
DRU	5G gNB baseband/RF	Dedicate designed HW 2T2R antenna configuration 600 MHz bandwidth at 22-23 GHz	ETRI
TE-PHY	5G UE baseband/RF	Dedicate designed HW 2T2R antenna configuration Beam switching capability	ETRI
TE-L2/L3	5G UE protocol stack	Xeon Server (8 cores) UE throughput of 3 Gbps	ETRI
WiFi AP	WiFi Access Point	Netgear AX11000 IEEE 802.11ax compliant 2.5 Gbps of data rate	ETRI, SKT
Smart Phone	Internet access Video streaming App Benchbee App	Samsung Galaxy S20+	ETRI

2.2.1 Digital & Radio Unit

A gNB is a logical node in the 5G and it consists of gNB-CU (Central Unit) and gNB-DU (Distributed Unit). In the Figure 8 the gNB and DRU correspond to gNB-CU and gNB-DU, respectively. In the testbed, the gNB-CU is comprised of higher layer protocols from MAC to RRC, and the gNB-DU covers PHY. As described above, the gNB functionalities have been implemented on a server PC, whereas the DRU functionalities have been implemented on dedicate designed equipment. The DRU consists of a DU (Digital Unit) and a RU (RF Unit). Both the DU and RU are placed in a case. Figure 9 illustrates the case of the DRU attached to a pole.

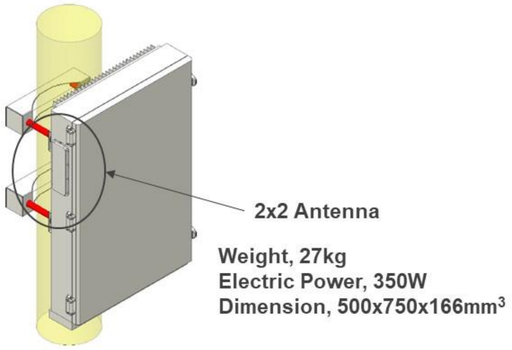


Figure 9: Image of the DRU case

Figure 10 illustrates the DRU exterior and its dimension. It also shows a baseband platform board that installed in the DRU. The baseband board is to implement a baseband modem. There are electronic components such as FPGAs (Field Programmable Gate Array), MCU (Micro Controller Unit), ADC (Analog-to-Digital Converter), DAC (Digital-to-Analog Converter) and SFP (Small Form-factor Pluggable). The ADC and DAC are connected to RF devices. IF (Intermediate frequency) signal flows from the RF to the ADC, and it converts IF to digital. Conversely, digital signal flows from an OFDM (Orthogonal Frequency Division Multiplexing) modulator to the DAC, and it converts digital to IF. The FPGAs are used for RTL implementation of baseband modem functioning encoding, decoding, modulation, demodulation etc. The MCU is to control the baseband modem based on higher layer messages. The SFP+ is used to transmit and receive L2/L3 messages between the MCU and gNB-CU.

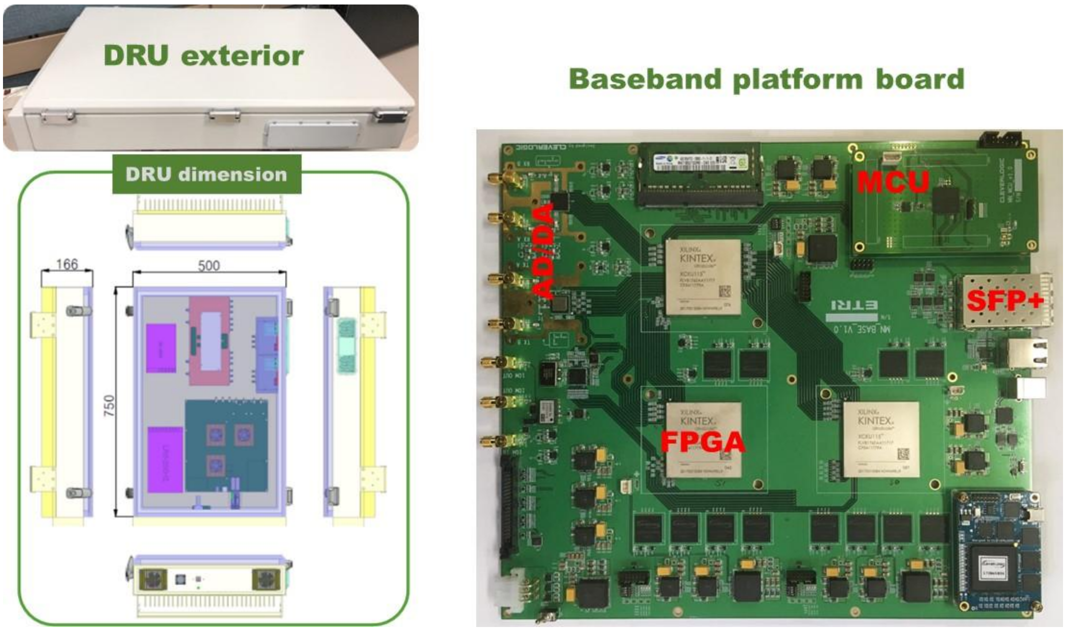


Figure 10: Pictures of a DRU case and DU board

Main electronic components for the DU board are listed in Table 2 and their functions and specifications are summarized as well.

Table 2: List of electric components of baseband modem board

Part	Function	Model/Specification
FPGA	Modulator, Demodulator, Encoder, Decoder	Xilinx FPGA (Kintex UltraScale series), KU115 1.3M CLB Flip-Flops 663K CLB LUTs 76 Mb block RAM
MCU	Modem control, Interface between higher layers and PHY	ARM STM32H743 Frequency of up to 480 MHz 1027 DMPIS
ADC	IF to digital conversion	TI ADS54J60 16-bit resolution, dual-channel, 1-GSPS ADC JESD204B interface
DAC	Digital to IF conversion	TI DAC38RF8x 16/12/8-bit, dual-channel data mode JESD204B interface
SFP+	Optical transceiver for 10GbE interface between higher layer and PHY	Intel SFP+ SR Optics 10GBASE-SR-10GbE

The RU is responsible for RF signal transmission and reception. Up-converted baseband OFDM signals from the DACs of the DU are transmitted to the RU through SMA connectors. Reversely, down-converted baseband OFDM signals from the RU are transmitted to the ADCs of the DU through SMA connectors. Operating RF and IF frequencies are specified in Table 3. In addition, output and input levels at RF or IF sections are listed. TDD (Time-Division Duplexing) switching time is less than 5 μs.

Table 3: RF specification

item	range	comment
RF frequency	22043.2-23043.2 MHz	Center = 22543.2 MHz
IF frequency	1343.2-2343.2 MHz	Center = 1843.2 MHz
TDD switching time	< 5 μs	
TX output power	17 dBm	Maximum output
TX IF power	-15 dBm	Input
RX input power	-20 dBm	Maximum input
RX IF power	-5 dBm	Output

The DU and RU are laid in the DRU case as shown in Figure 11. These are connected by SMA cables for data path and a 2.00 mm pitch, 40-pin connector for control path.

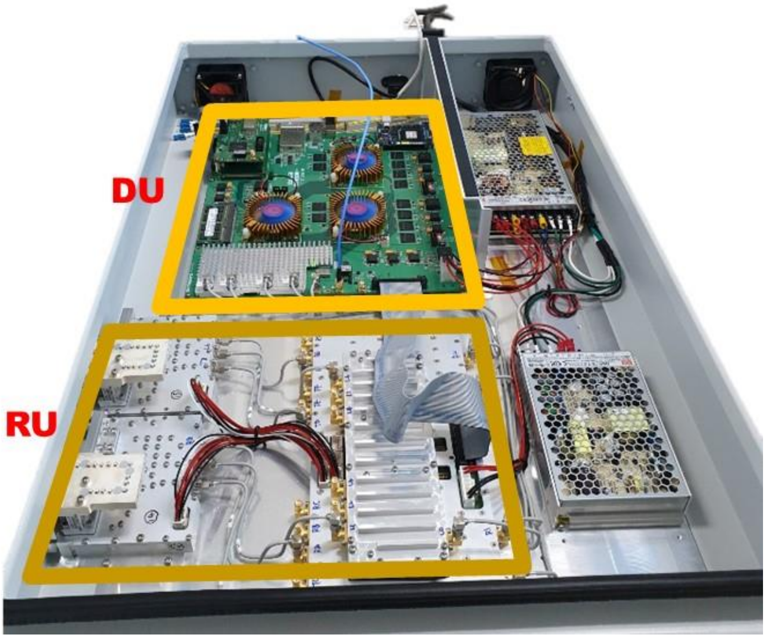


Figure 11: Picture of DRU interior

2.2.2 Terminal Equipment – Physical Layer

A TE-PHY is responsible for physical layer processing and RF transmission and reception in the terminal equipment. Accordingly, the TE-PHY includes a baseband processing board and RF parts as illustrated in Figure 12. Unlike the DRU, however, the TE-PHY has three sets of RF transceiver and antenna – each set covers different directions with around 18 degrees of 3-dB beam width so that the combined beams can cover overall 54 degrees forward.

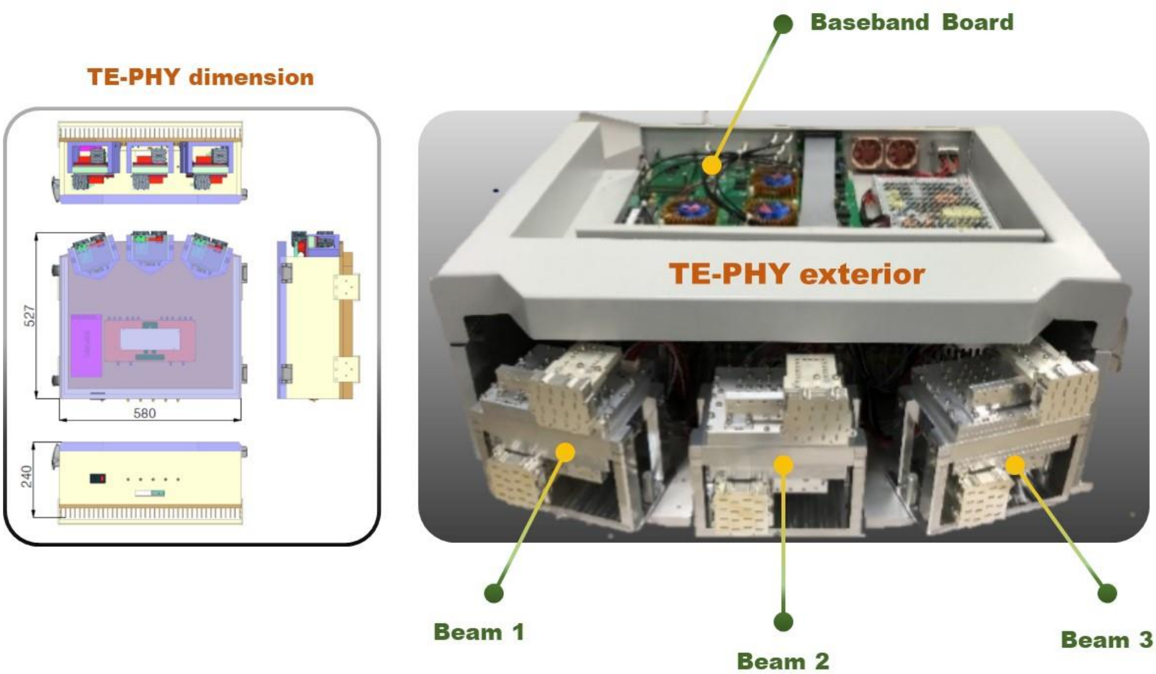


Figure 12: TE-PHY exterior and dimension

Three sets of the antennas in the figure correspond to beam 1-3, respectively. Each set has two polarization antennas as shown in the figure. Those antennas are for downlink MIMO (Multiple Input Multiple Output) reception, and uplink transmit diversity operation. The RF transceivers follow the same specification as the one of the DRU listed in Table 3. The base-band processing board in the TE uses the same hardware as the one in the DRU. Meanwhile, since TE processing is different from DU processing, software programs need to be coded to comply with the TE specifications.
The TE-PHY operates three beams in a switched beam forming manner as in Figure 13. Three RF transceivers are connected to a processing unit via a 3x1 path switch with around 1 μs switching time. The switch connects TRX1 – 3 alternately for short duration periodically, and corresponding received signals are buffered and the processing unit calculates each beam quality. A few algorithms can be applied to select one of three paths to assure best data throughput.

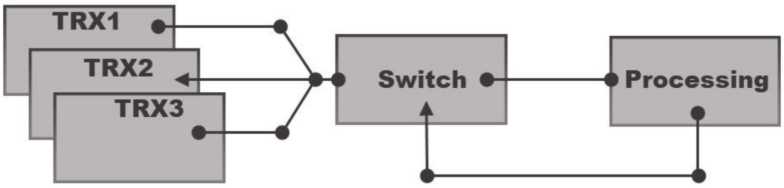


Figure 13: Beam switching process

2.2.2.1 Simulation on beam switching

The mmWave experiences higher path loss compared to sub-6 GHz radio waves, which should have negative impact on the cellular coverages. To overcome the severe path loss problem in the mmWave, advanced antenna technologies have been developed to make use of high antenna gains. The TE and DRU have slotted waveguide antenna array to achieve 19 dB of antenna gain. This high beam forming gain, however, should sacrifice wide beam angle, and this can cause sudden drop of SNR (Signal-to-Noise Ratio), for example, in an overtaking scenario. With a raytracing simulation, the impact of beam switching on this scenario can be observed and analyzed. Figure 14 illustrates beam switching simulation scenarios under urban and expressway channel environments. Table 4 and Table 5 summarize the locations of TX/RX and simulation configuration, respectively.

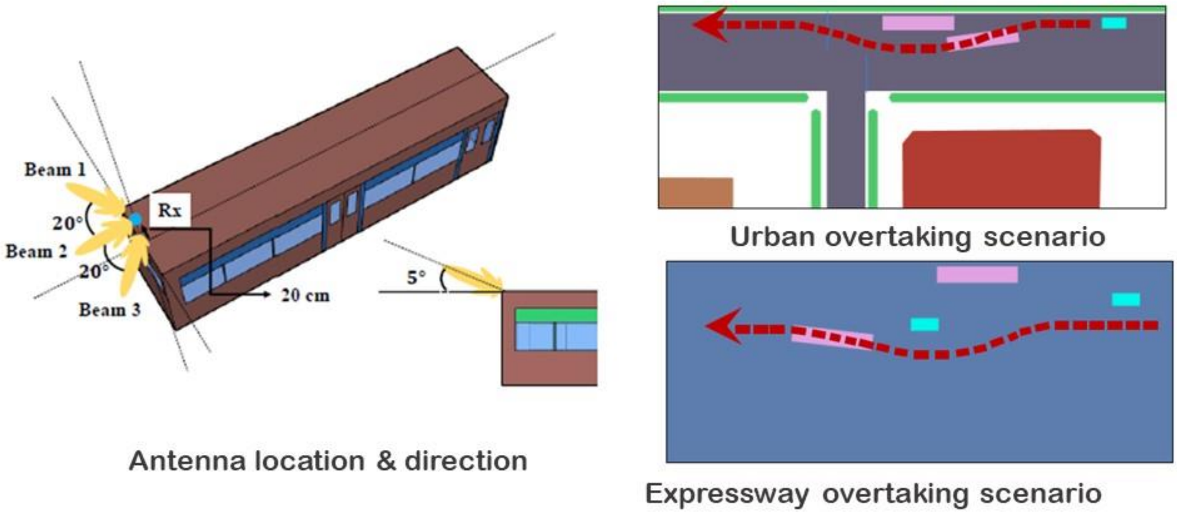


Figure 14: Beam switching simulation scenario

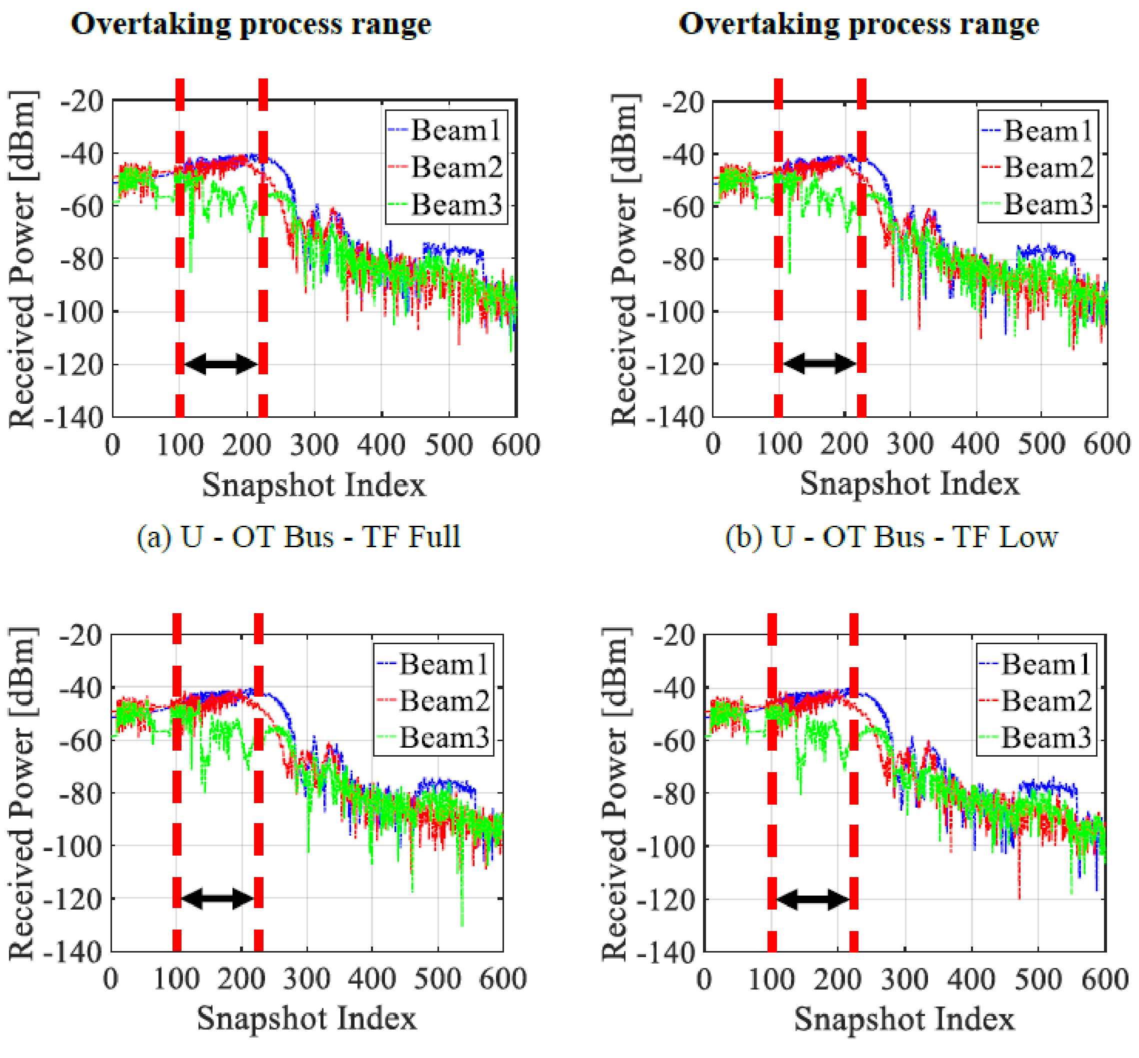
Table 4: The locations of each TX and RX in the simulation

Transceiver	Scenario	
	Urban	Highway
TX	Placed in a building on the roadside (182, 38, 25)	Placed above the traffic light (340, 35, 10)
RX	Placed on the top of the bus with a height of 3.2 m	

Table 5: Simulation configuration

Frequency	22.1 – 23.1 GHz	
Bandwidth	1 GHz	
Antenna	Directional Antenna	
TX	Power	20 dBm
	Maximum antenna gain	16 dBi
	Antenna beam width	20 degrees
RX	Maximum antenna gain	16 dBi
	Angle between the three beams	20 degrees
Vehicle Type	Passenger car	60 % of total vehicle
	Bus	20 % of total vehicle
	Delivery Van	20 % of total vehicle
Propagation	Direct	✓
	Reflection	Up to 2nd order
	Diffraction	Deygout
	Scattering	Directive scattering model
	Transmission	✓
Material	Building	Brick, Marble, Toughened glass
	Urban furniture, Vehicle	Metal
	Tree	Wood
	Ground, Highway fence	Concrete

The simulation results of received powers are depicted in Figure 15, where the overtaking scenario applies for four cases of combinatorial situations of bus or car and low or high traffic. Blue, red, and green dotted lines indicate beam 1, 2, and 3, respectively. In the scenario, the overtaking process takes place after the snapshot 100 and ends after the snapshot 210. For all the cases, the received power of beam 2 is greater than that of beam 1 before the overtaking begins. Once the overtaking begins, the vehicle gradually turns from lane 1 to lane 2. During this process, with the steering of the vehicle, the main lobe of the beam 2 gradually deviates from the main lobe of the base station, meanwhile, the main lobe of the beam 1 gradually align to the main lobe of the base station. Therefore, the received power of beam 1 gradually exceeds beam 2. When the vehicle continues to drive in lane 2 and is close to the base station, since the beam 1 is gradually aligned with the main lobe of the base station, the received power of the beam 1 is greater than that of the beam 2 (maximum of 20 dB). Since the vehicle leaves the main lobe of the base station once the overtaking process ends, the received power of all beams begins to decrease. These simulation results imply that when the base station is at the roadside, the vehicle can achieve more secure and reliable communication by adopting beam switching during overtaking.



(a) U - OT Bus - TF Full
(b) U - OT Bus - TF Low
(c) U - OT Car - TF Full
(d) U - OT Car - TF Low

Figure 15: Received power of the overtaking situation in the urban scenario

2.2.2.2 Vehicle test and results for beam selection

Beam switching functionality has been tested at the road environment. Figure 16 shows a test route with three DRUs deployed along the roadside and a test vehicle with a TE-PHY. The test route includes three straight paths and the DRUs are deployed at junctions between every two paths. Since all the DRUs direct toward the road the beams from the DRUs also see the road directly. While the test vehicle moves along the test route, the TE-PHY receives and transmits with three RF and antenna sets (see Figure 12). Figure 17 shows the measured beam power of the TE-PHY under the road test environment. The red beam corresponds to the center RF and antenna set shows the highest value when the test vehicle isn’t close to the DRUs. If the vehicle approaches the junctions, overall power reception levels drop severely because the DRU and TE connect through the sidelobes. Furthermore, the blue beam gets higher signal strength at the junctions for DRU 2 and 3. The junction for DRU 1 include a dead zone due to signal blockage. Hence a beam selection algorithm must choose the blue beam near the DRU 2 and 3.

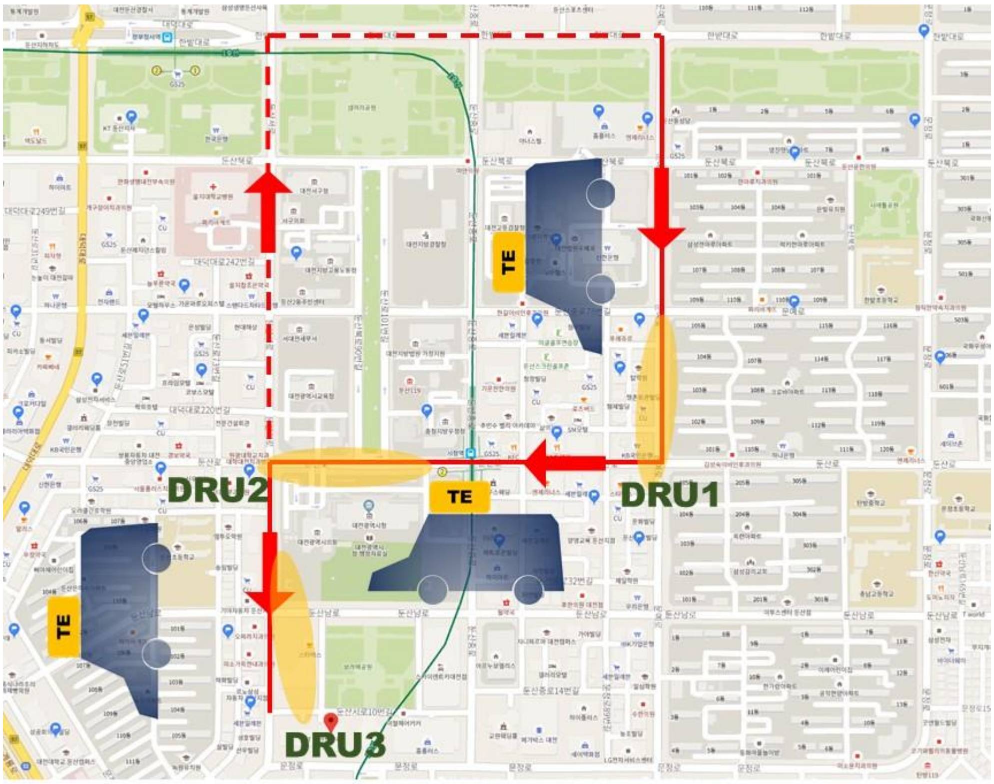


Figure 16: Beam switching test route

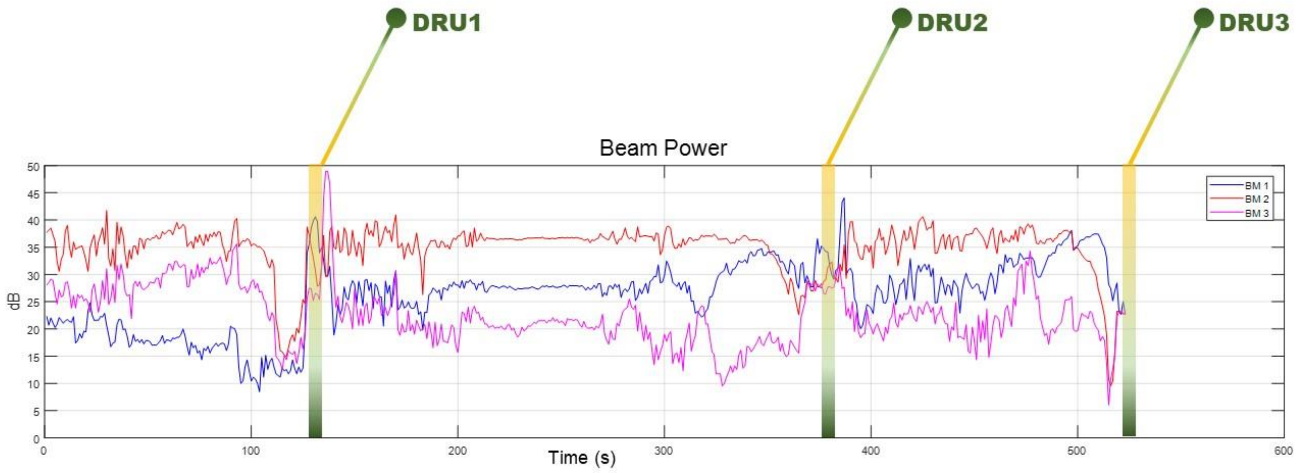


Figure 17: Received power for TE beam 1, 2, 3

2.3 Validation

Once the component hardware, software and technologies are integrated to a system or sub-system, tests are followed to verify the functionalities and performance of the system. To ease debugging process in the system integration, a step-wise approach has been adopted. In the first step, the higher layers and physical layer are tested separately. After this parallel validation, the whole integrated system is tested.

2.3.1 Physical Layer Subsystem Test

Functionalities and performance of radio links have been investigated without a higher-layer integration. Figure 18 illustrates a physical layer test setup where both the physical layers for a gNB side and device side are used.

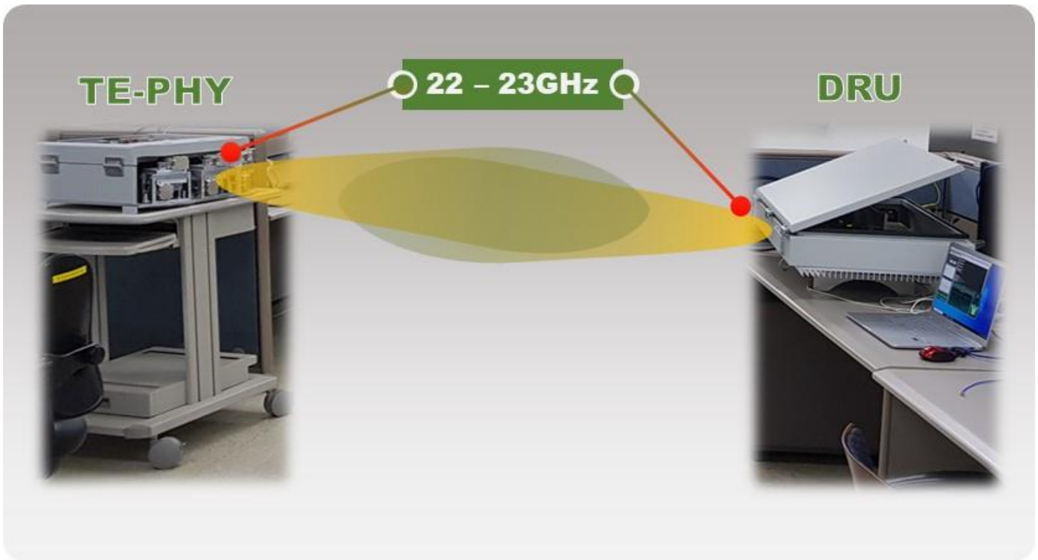


Figure 18: Physical layer subsystem test setup

The first step of the physical layer test is to synchronize the TE-PHY according to the SSB (Synchronization Signal Block) transmission from the DRU. Figure 19 illustrates a SSB frame structure and typical synchronization process or cell search in the TE-PHY. The DRU transmits the SSB signal every 10 ms. The TE-PHY detects the SSB signal step by step until it gets the cell identification number and time/frequency synchronization.

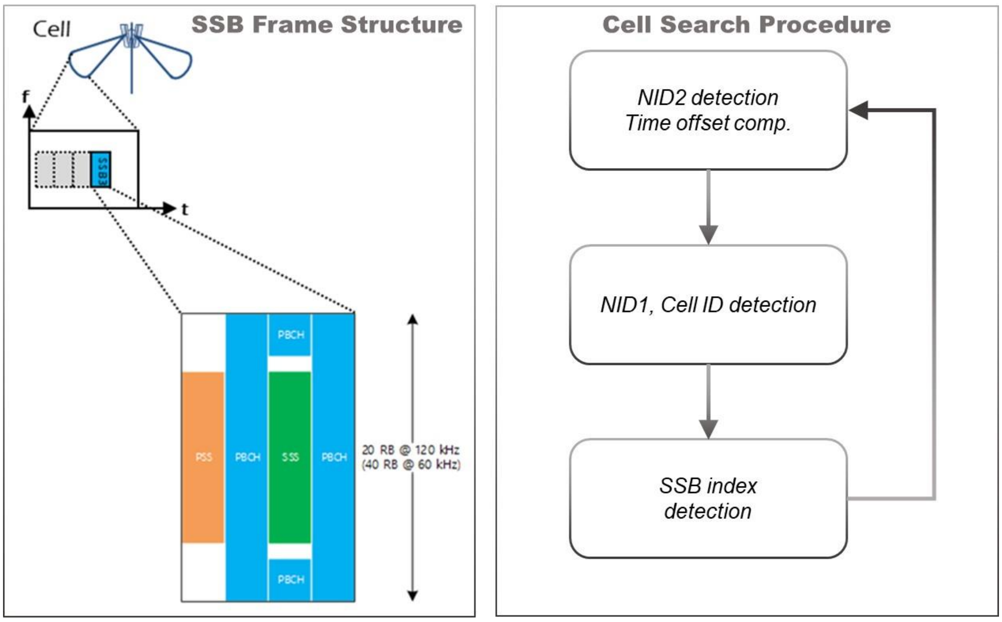


Figure 19: SSB frame structure and cell search procedure

Once the TE-PHY acquires the cell identification number and gets time and frequency synchronization, it begins to demodulate and decode control channel information and shared data channel successively and continually. Test results are monitored by a customized software program or diagnostic monitor. Figure 20 shows a screen capture of the downlink test. 64QAM constellation, frequency/time-domain channel impulse response, SNRs and additional information are drawn periodically. 3.11 Gbps of data throughput is seen.

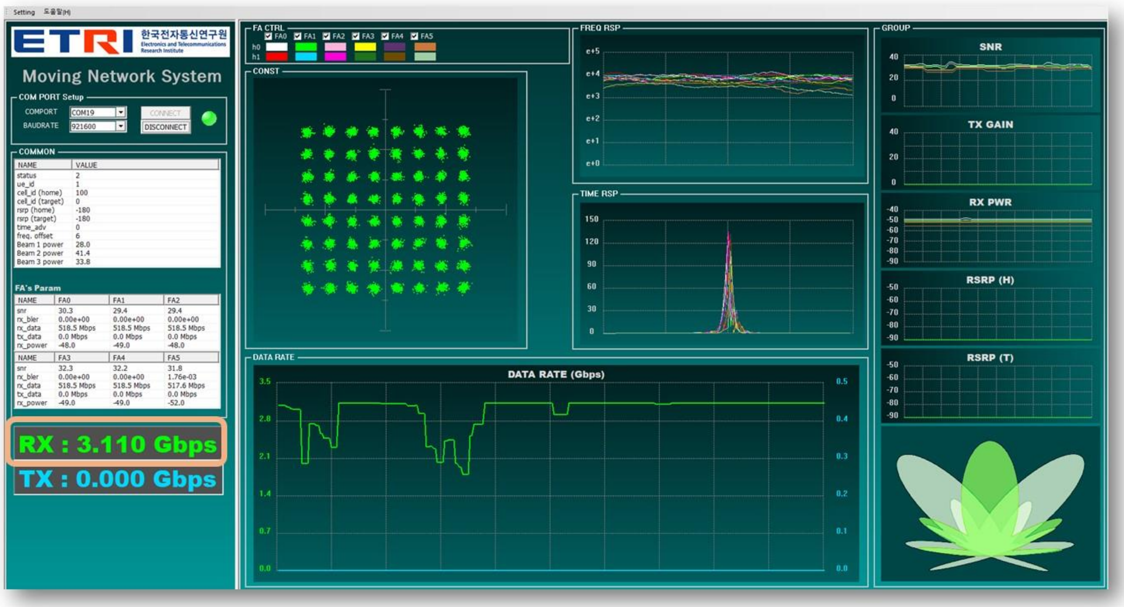


Figure 20: Screen captured image of the TE-PHY diagnostic monitor

2.3.2 Higher Layer Subsystem Test

A subsystem of the 5G core, gNB-L2/L3 and TE-L2/L3 can be tested with a PHY emulator. Since the PHY emulator plays the role of physical layer links, this test can be performed before the physical layer modems are fully available. Figure 21 illustrates a higher layer subsystem test setup. If a video server and end user equipment like a smart phone are connected to the higher layer subsystem, a service level validation can be performed.

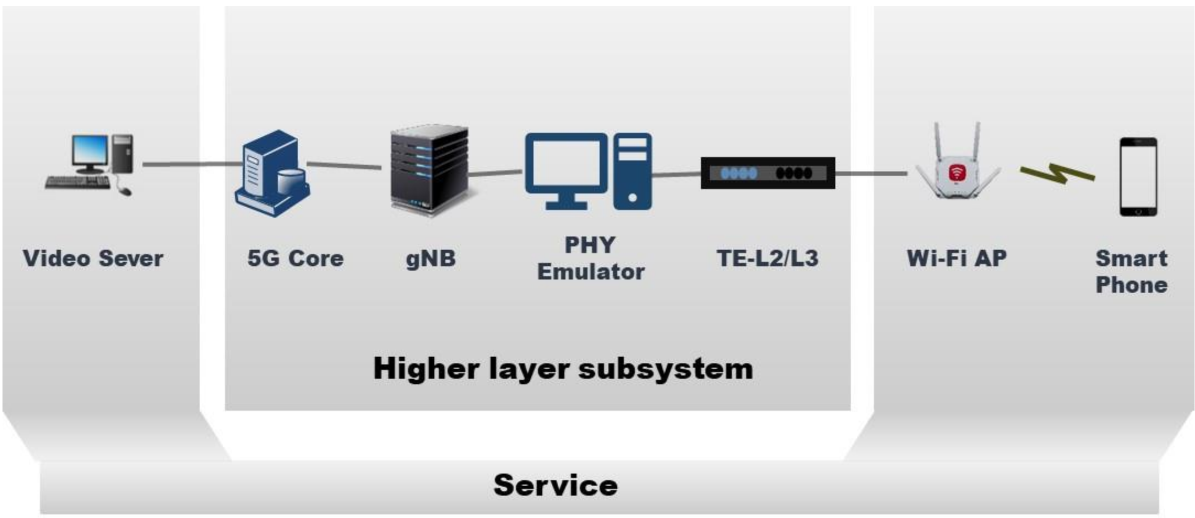


Figure 21: Higher layer subsystem test setup

In this subsystem test, CP and UP functionalities are checked. The CP mainly deals with an RRC connection setup, mobility management and security. In the early stage of the 5G CATB preparation, the RRC connection setup has been mainly tested. Figure 22 illustrates a signal flow to establish the RRC connection setup. In this validation process, state transitions between RRC_IDLE and RRC_CONNECTED are repeated until a certain number of successful events are accomplished successively.

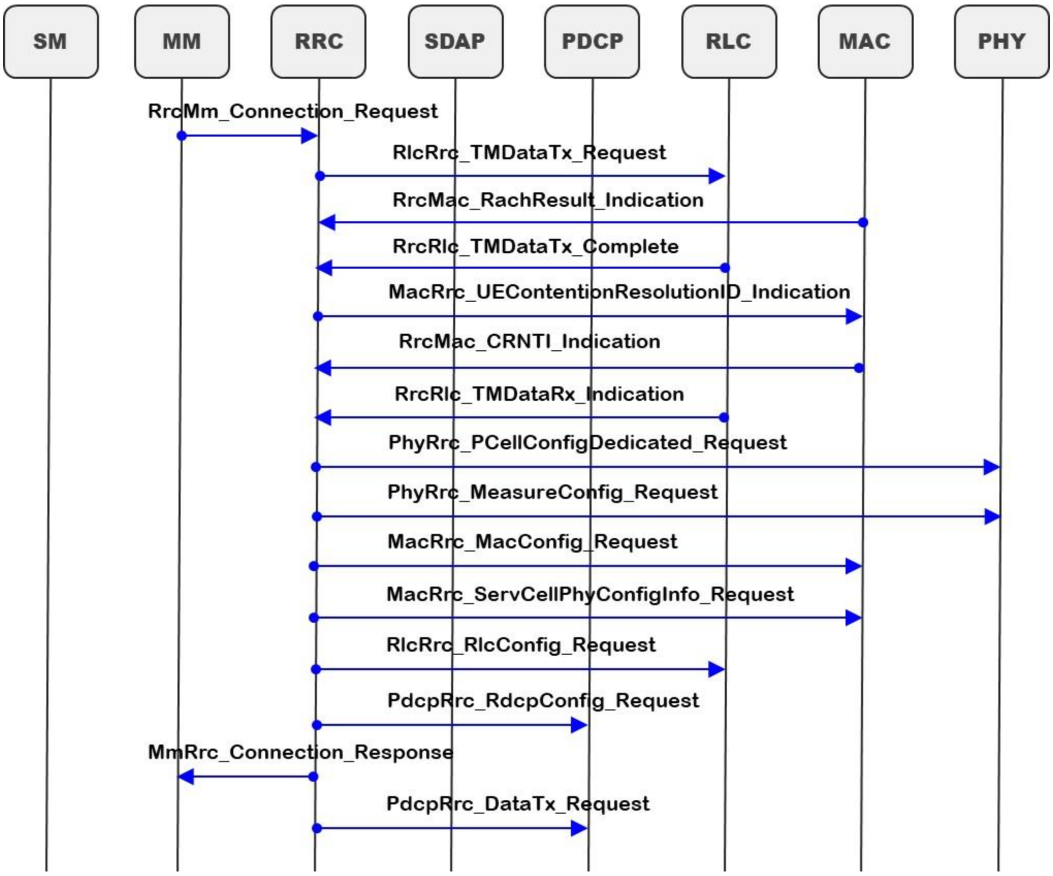


Figure 22: flow chart for an RRC connection setup

Once the RRC connection setup is established, downlink and uplink data transmission and reception are tested in the UP. Downlink data rate of up to 1.7 Gbps has been successfully received and uplink data rate of up to 150 Mbps has been successfully received at the UP test. After the successful UP test, the 5G Core was connected to the Internet, and the TE-L2/L3 was connected to a laptop as shown in Figure 23. With this test configuration, the laptop connects to the Internet via the subsystem, which proves the complete UP connection state even if the data rate does not reach the maximum system capacity.

Figure 23: Example of video streaming service

2.3.3 System Test

A full system test was conducted after the separate tests for the physical layer and higher layers. The overall procedure was the same as the higher layer test process but for the replacement of the PHY emulator with the real physical layer device and equipment. First, control plane was tested and then data plane was tested. Second, the video stream services were tested using the setup in Figure 21. Total seven smart phones were used in the test as shown in Figure 24. Each end-user equipment has a "PLAYER" application – once executed it connects to the video server and shows a play list. In the test, seven devices were used at the same time and they all were connected to the video server, and played smoothly selected contents.
This full system was tested in the laboratory environment at this early stage. Next step will be performing an outdoor test under different channel environments including an expressway and urban roadway. In addition, the functionality of handover and data rate measurement by "Benchbee" application will be included in the future test.

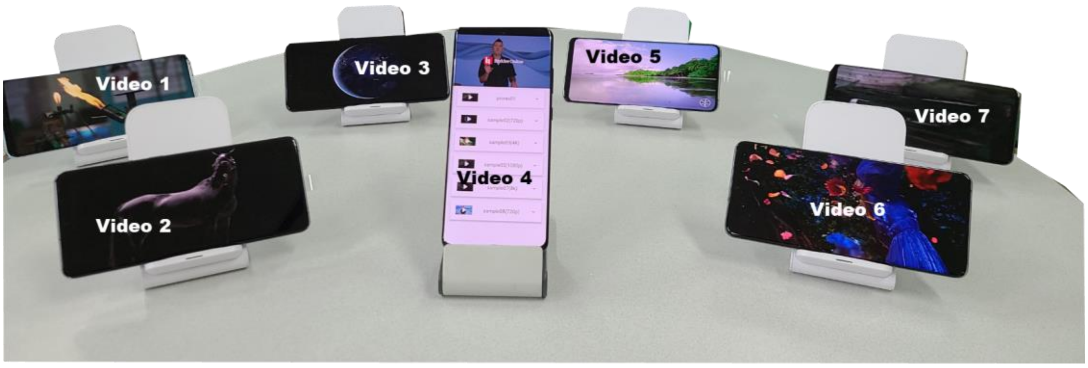


Figure 24: Video streaming service using smart phones

3 Satellite Access Testbed

3.1 Architecture of Satellite Access Testbed

The Korean Testbed will be used to demonstrate multi-connectivity functionalities and traffic aggregation between cellular and satellite network as shown in Figure 25. For transmitting data from the satellite network side to a traffic aggregation (TA) module in the remote side, the Korean Satellite Access Testbed (KSAT) have installed commercial products for on-the-move antenna and network equipment on the remote side connected to a hub system via a traditional Geostationary (GEO) satellite.

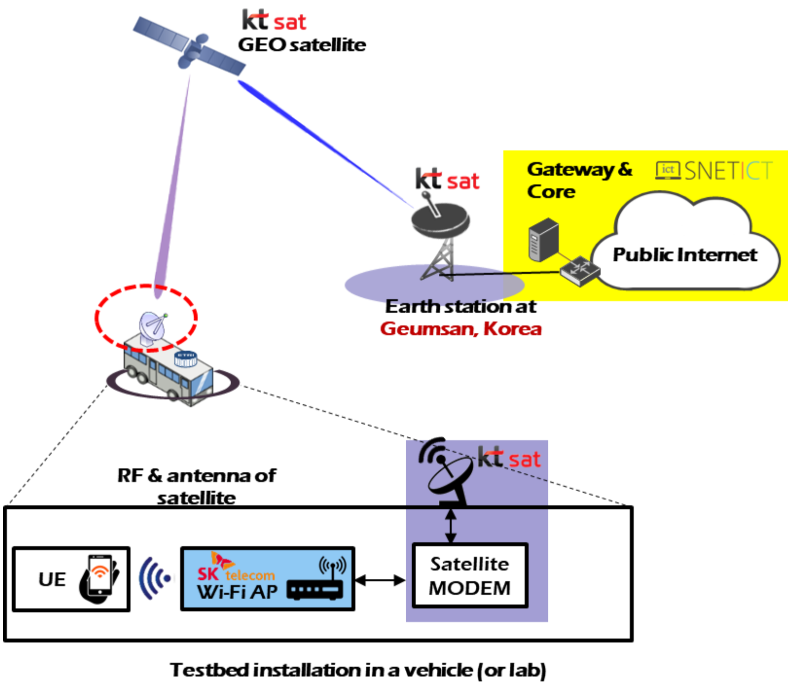


Figure 25: Conceptual diagram of the Korean satellite access testbed

3.2 Component technologies

The KSAT consists of the Koreasat-6, a traditional Geostationary (GEO) satellite and a Hub system located in Kumsan. A Remote side in a moving vehicle includes a commercial antenna system of iDirect Hub. It needs to be noted that the Koreasat-6 uses the waveform of digital video broadcasting (DVB), which is a non-3GPP waveform. The DVB waveform has been widely used for many of the commercial satellite services. Figure 26 shows the main components of the KSAT.

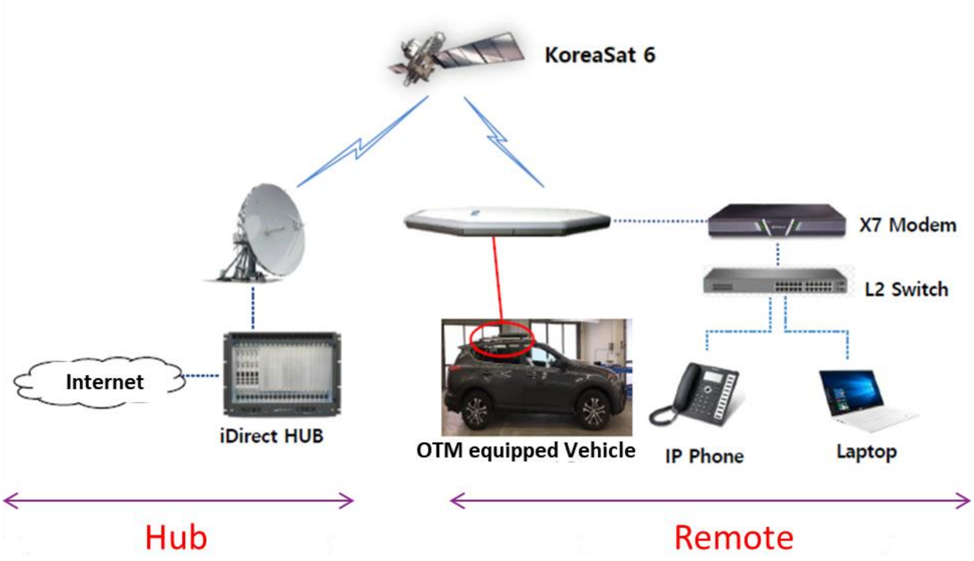


Figure 26: The components of the KSAT consisting of the hub and remote sides

3.2.1 Satellite Hub System

The hub system of the KSAT operates the commercial iDirect Evolution platform. The platform can be used to improve bandwidth efficiency when it is applied to DVB-S2 (DVB second generation), ACM (Adaptive Coding and Modulation) and ATDMA (Advanced Time Division Multiple Access). The hub can connect to any frequency bands of many kinds of satellite architecture and it also automatically adjusts to dynamic traffic demands depending on the changing network conditions.

3.2.2 Satellite Remote Terminal

On the remote side, a vehicle is equipped with a iDirect modem and Kymeta On-the-Move (OTM) antenna as shown in Figure 26. The Kymeta antenna has a different design with phased array from those of other traditional parabolic antennas and it does not require phase shifters and amplifiers to adjust the phase and/or amplitude of each antenna elements.

A key component of the KyWay terminal is called Kymeta mTenna Antenna Subsystem Module (ASM), which includes a combined transmit and receive-capable aperture, control electronics assembly, mechanical enclosure system and software. Table 6 summarizes the specification of the Kymeta ASM.

Table 6: Specification of Kymeta ASM

Parameter	Specification
Rx frequency range	11.4 – 12.4 GHz
Rx gain	33.0 dB
Rx G/T	9.5 dB/K
Rx scan roll-off @ 60° (H-pol)	1.2
Rx scan roll-off @ 60° (V-pol)	1.1
Rx instantaneous bandwidth	>100 MHz
Tx frequency range	14.0 – 1.5 GHz
Tx gain	32.5 dB

Tx instantaneous bandwidth	>100 MHz
Tx scan roll-off @ 60° (H-pol)	1.4
Tx scan roll-off @ 60° (V-pol)	1.2
Tracking rate	>20 °/second
Mobile tracking accuracy	FCC compliant for 25.222 and 25.226
Support BUC	Pre-engineered for 8 W and 16 W BUC
Temperature range	-25 °C to +55 °C (operational), -40 °C to +75 °C (storage)
ASM dimension	L 82.3cm x W 82.3 cm x D 7.1 cm
Input power (ASM only)	100/240 VAC, 50/60
Ingress protection	Outdoor unit (ODU): IP:66 to protect against weather and environmental conditions expected during operation and storage Indoor unit (IDU): Rated for use indoors
ASM mounting interface	5/16” x 18 threaded holes, 95 cm deep on 34.1 cm centers.

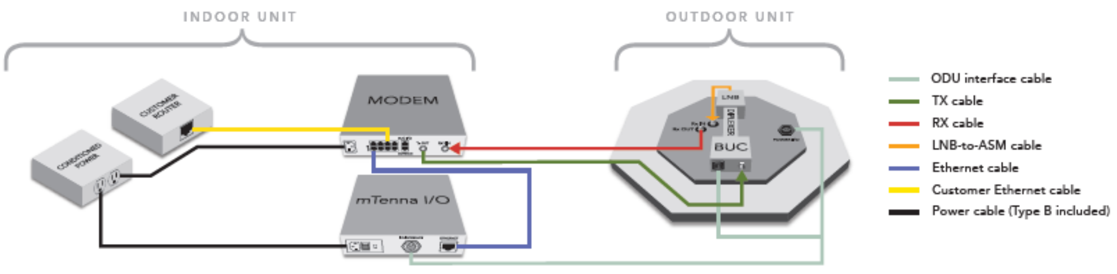


Figure 27: Components of the Kymeta ASM

3.3 System test results

After installing all of satellite network equipment including the OTM antenna and modem, the KSAT have tested diverse applications based on demonstration scenarios such as Internet access, VoIP, and Video Conference.

- ❑ Internet Access
  - ■ Testing the status of internet connection and quality that connected laptop on moving vehicle
  - ■ Process: IP Core → Satellite Hub → Koreasat-6(Sat.) → OTM/Vehicle → Laptop
- ❑ VoIP
  - ■ Testing the quality of voice calling by IP Phone
  - ■ Process: IP Core → Satellite Hub → Koreasat-6(Sat.) → OTM/Vehicle → IP Phone
- ❑ VoIP:
  - ■ Testing the quality of video calling and image quality by chat program on a laptop
  - ■ Process: IP Core → Satellite Hub → Koreasat-6(Sat.) → OTM/Vehicle → Laptop (Video Chat Application)

During the demonstration, the setup configured 3 Mbps of downlink and 0.5 Mbps of uplink in the moving vehicle. And the vehicle equipped satellite antenna and modem has been driven by 60~100 km/h around the Geumsan hub site.

Overall, all the demonstration scenarios have been resulted with good performance. First, the Internet access was good enough to connect stably to the Youtube while the vehicle has been moving. However, the Youtube video was stopped intermittently when the vehicle passed by some obstacles. The other tests of the VoIP and Video conference have been proven to be appropriate services with the KSAT. The results are summarized in the Table 7.

Table 7: Results of the KSAT services

Division	Checklists	Result
Internet Access	Quality measurement (Download/Upload Speed)	Good Download: 3.11 Mbps Upload: 656.99 kbps
VoIP	Self-testing by IP phone in vehicle	Good
Video Con-ference	Self-testing by chat application in vehicle	Good

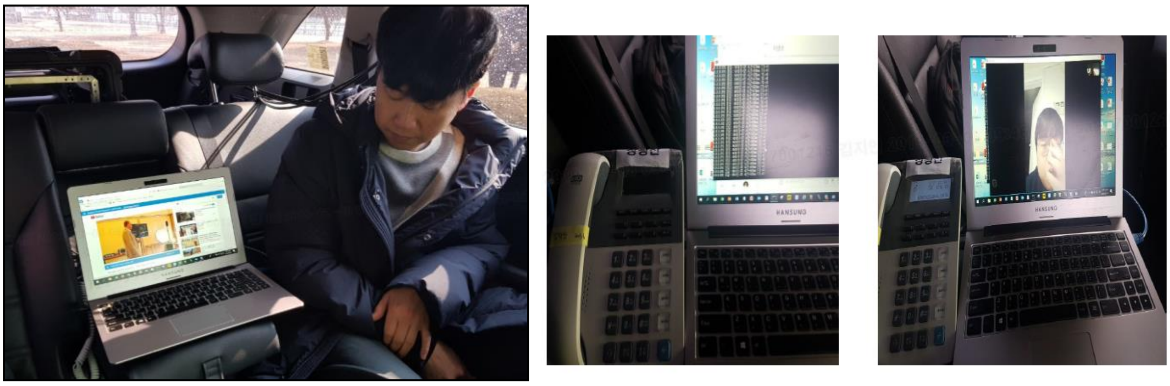


Figure 28: Demonstration Tests

4 Conclusion

This document deals with the Korean 5G cellular access testbed and satellite access testbed. The 5G CATB is comprised of PHY, Layer 2/3, 5GCN and these components have been integrated. The subsystems have been validated with step-wise test approaches. The fully integrated system was proved to function properly with the video streaming service setup. The satellite access testbed is comprised of KTsat earth station and the vehicle equipped with commercial modem and antenna system. This system was also proven to function properly by VoIP, Youtube video and video conferencing services.

In T5.2, these two testbeds were stand-alone. In T5.3, however, they will be used as component TBs for a multi-connectivity TB. D5.4 will be the relevant deliverable. Furthermore, the multi-connectivity TB will be used in T5.4 as inter-continental trial platform for Korea side. D5.6 will be the relevant deliverable.

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