VALIDATION OF INTEGRATED NETWORK CONTROL ARCHITECTURE FOR FIXED, MOBILE AND SATELLITE CONVERGENCE

Ved P. Kafle; Mariko Sekiguchi; Hitoshi Asaeda; Hiroaki Harai

National Institute of Information and Communications Technology, Japan

ABSTRACT

Future network systems, such as beyond-5G or 6G, are expected to integrate non-terrestrial networks (NTN), such as satellite networks, with existing terrestrial networks (TN) to provide global access to high-quality communication services and promote digital transformation for everyone. Various standard development organizations are actively working on standards for TN-NTN convergence, also known as fixed, mobile, and satellite convergence (FMSC). The International Telecommunication Union (ITU) has recently developed several ITU-T Recommendations covering different aspects of FMSC. Notably, ITU-T Recommendation Y.3207 addresses a critical component of the Integrated Network Control Architecture (INCA) of FMSC. This paper describes the implementation of an experimental system designed to demonstrate the feasibility of INCA. It explains the implementation of the individual network controller of the TN and NTN segments, the integrated network controller, and the interfaces connecting them. We experimentally verify that INCA can configure network services with the desired quality of service (QoS) levels over both TN and NTN segments. Additionally, we validate INCA's capability to monitor and dynamically control computing and bandwidth resources in both segments to maintain consistent QoS levels.

Keywords— Integrated network control architecture; terrestrial and non-terrestrial network convergence; fixed, mobile, satellite convergence; digital transformation.

1. INTRODUCTION

Beyond-5G or 6G networks aim to seamlessly integrate non-terrestrial network (NTN) segments, such as satellites, with terrestrial network (TN) systems such as the Internet and mobile networks. This integration is intended to provide universal access to high-quality communication services worldwide and foster equitable opportunities for digital transformation. 5G mobile network systems can seamlessly connect a vast number of handheld devices and Internet of Things (IoT) devices, providing enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC) services over a shared, virtualized infrastructure [1]. However, terrestrial mobile network services primarily serve densely populated urban areas, leaving gaps in global coverage due to economic and geographical challenges. Operators hesitate to deploy 5G base stations in remote or rural regions due to high costs and low revenue per user. Furthermore, deploying 5G infrastructure in deserts, seas, and mountainous areas presents additional challenges.

Hence, for beyond-5G and 6G systems to provide global coverage of high-quality communication services, full integration of NTN segments, such as satellites and high-altitude platform stations, with the Internet and terrestrial mobile networks is imperative [2]. This convergence of TN and NTN is crucial for ensuring uninterrupted communication services during natural disasters such as earthquakes, tsunamis, forest fires, and floods, which may damage terrestrial base stations and interrupt connectivity [3,4].

The research and development of new technologies for integrating terrestrial and non-terrestrial networks, also known as fixed, mobile, and satellite convergence (FMSC), has been progressing rapidly. Standards development organizations (SDOs) such as the International Telecommunication Union (ITU) and the 3rd Generation Partnership Project (3GPP) have begun creating the necessary standards. ITU defines FMSC as the capabilities enabling service and application delivery to end users, irrespective of their location or the fixed, mobile, or satellite access technologies used [5].

In this paper, we review the ITU Telecommunication Standardization Sector (ITU-T) Recommendations of FMSC in the related work section. Among them, Recommendation ITU-T Y.3207 [6] addresses a critical aspect of the integrated network control architecture (INCA) for the convergence of FMSC. To demonstrate the feasibility and functionality of INCA components specified in ITU-T Y.3207, we have developed an experimental system in our lab.

We describe the implementation of the INCA functional components and interfaces, along with the individual controllers for fixed, mobile, and satellite network segments. Our experimental system comprises the data network (DN), 5G core (5GC) network, 5G radio access network (RAN), and NTN segment. The DN is configured using OpenStack and the Open-Source MANO (OSM) platform, while the 5GC and RAN are based on open-source software: Free5GC (https://free5gc.org) and UERANSIM (https://github.com/aligungr/UERANSIM), respectively. The NTN includes a satellite network simulator in the control plane and a bandwidth and latency emulator in the data plane, both developed in our lab.

Through experimentation, we validate the INCA's capability to effectively create network services on both TN and NTN segments with desired levels of quality of service (QoS). Additionally, we validate INCA's capability to continuously monitor computing and bandwidth resource usage on TN and NTN segments. It dynamically adjusts resources to maintain required end-to-end QoS levels, even amidst fluctuations in user numbers or data traffic volume.

The remainder of this paper is organized as follows. Section 2 reviews related standardization efforts, research, and development activities. Section 3 provides an overview of INCA functions and control message flow sequences abstracted from ITU-T Y.3207. Section 4 details the development of the experimental system. Section 5 discusses demonstrations of INCA capabilities for configuring network services and monitoring and controlling resources. Finally, Section 6 concludes the paper and outlines future work.

2. RELATED WORK

Non-terrestrial networks, including satellites, HAPS, and drones, offer widespread access to high-quality communication services due to their global coverage and robust multilink transmission capabilities. High-throughput satellites (HTS) are being deployed to expand the small cell coverage capacity of urban 5G systems to rural and remote areas. The extensive deployment of low-earth orbit (LEO) satellites, positioned approximately 400-2000 kilometers from the Earth's surface, enables the provision of high-bandwidth, low-latency communication services to support various applications of the eMBB, mMTC, and URLLC.

Research, development, and standardization of innovative technologies facilitating the convergence of TN and NTN networks are advancing swiftly. This paper focuses on implementing a testbed system to validate the integrated network control architecture outlined in ITU-T Recommendation Y.3207. To provide context, we offer an overview of related ITU-T and 3GPP standard documents. Further details about related 3GPP activities can be found in [2].

Table 1. FMSC-related ITU-T Recommendations

Rec. No.	Title	Year of approval
ITU-T Y.3200	Fixed, mobile and satellite convergence – Requirements for IMT-2020 networks and beyond	2022
ITU-T Y.3201	Fixed, mobile and satellite convergence – Framework for IMT-2020 networks and beyond	2023
ITU-T Y.3202	Fixed, mobile and satellite convergence – Mobility management for IMT-2020 networks and beyond	2023
ITU-T Y.3203	Fixed, mobile and satellite convergence – Connection management for IMT-2020 networks and beyond	2023
ITU-T Y.3204	Fixed, mobile and satellite convergence – Service continuity for IMT-2020 networks and beyond	2023
ITU-T Y.3205	Fixed, mobile and satellite convergence – Requirements of integrated user-centric service units	2023
ITU-T Y.3206	Fixed, mobile and satellite convergence – Capability exposure for IMT-2020 networks and beyond	2023
ITU-T Y.3207	Fixed, mobile and satellite convergence – Integrated network control architecture framework for IMT-2020 networks and beyond	2024

Table 1 shows the ITU-T Recommendations related to FMSC recently developed by ITU-T Study Group 13. Approved in 2022, ITU-T Y.3200 delineates FMSC requirements, categorizing them into service and network capability requirements. It also outlines FMSC use case scenarios within the context of IMT 2020 (or 5G) networks and beyond. Similarly, ITU-T Y.3201 specifies the comprehensive framework for land-based and satellite-based converged networks. It enumerates enabling technologies, including mobility management, session management, connection management, subscription management, service continuity, traffic scheduling, network slicing, multi-access edge computing, artificial intelligence (AI) and machine learning (ML), distributed ledger technology (DLT), and quantum information technology.

ITU-T Y.3202 describes the scenario and framework for mobility management in FMSC, detailing related requirements, architecture, and service procedures. ITU-T Y.3203 specifies the requirements, scenarios, and functional architecture for connection management in FMSC. Furthermore, ITU-T Y.3204 specifies scenarios, requirements, enablers, network function enhancements, and procedures for service continuity in FMSC, ensuring ongoing services and their states for moving objects.

ITU-T Y.3205 delineates scenarios, general characteristics, requirements, and framework for the Integrated User-centric Service Unit (IUSU), enabling end users to define network and service capability profiles based on their needs. ITU-T Y.3206 specifies scenarios, requirements, reference points, network function enhancements, and procedures for capability exposure in FMSC, allowing network functions to expose their capabilities to third parties such as users or other operators.

Finally, ITU-T Y.3207 delineates the scenarios and architectural frameworks of the integrated network control system and the individual network segment control system. It outlines procedures for designing and orchestrating network services spanning across TN and NTN segments, along with unified performance monitoring and resource control. Further elaboration on its functional components and control message flow sequences is provided in the next section.

3GPP started documentation of TN and NTN integration-related study items from Release 15 for 5G systems, with the consideration on the deployment scenarios, service requirements, satellite propagation models, and related system parameters of satellites and HAPS. Release 16 further added the architectural aspects of the integration of satellite access in the 5G system (TR 23.737 [7]) and management and orchestration aspects (TR 28.808 [8]). TR 23.737 has identified the impact areas and solutions (including procedures) for resolving radio access and core network-related issues. TR 28.808 has listed the service and network management issues of satellite-integrated 5G, presented a reference architecture for management, and listed the associated solutions. From Release 17, normative work on specifying solutions for additional aspects of NTN integration in 5G system architecture with New Radio (NR) and narrow-band IoT (NB-IoT) RAN coverages has begun [9]. Future releases are being planned to enhance the

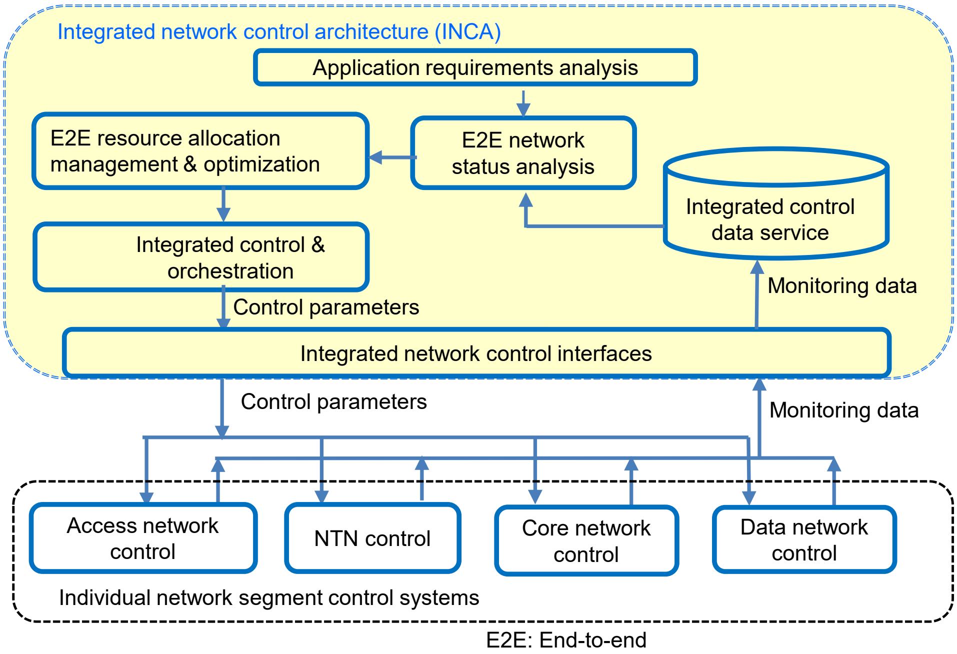


Figure 1 - TN-NTN integrated network control architecture (ITU-T Y.3207).

system with capabilities of direct smartphone connection to satellites, UE location verification for public land mobile network (PLMN) selection (enhancement of TR 24.821 [10]), support for non-continuous coverage with sparse constellation and support of satellite backhauling. Additional information about 3GPP NTN work can be found in [11].

3. TN-NTN INTEGRATED NETWORK CONTROL ARCHITECTURE (INCA)

This section presents an overview of the INCA functional components and the sequence of control message flows.

3.1. Integrated Network Control Architecture

Figure 1 shows the functional architecture of the integrated network control system. The architectural functional components are: (a) integrated control data service, (b) application requirements and user intent analysis, (c) end-to-end (E2E) network status analysis, (d) E2E resource allocation, management and optimization, and (e) integrated control and orchestration functions. The integrated network control system interacts with the network control systems of individual network segments, such as access networks, NTN, core networks, and data networks, via integrated network control interfaces. These interfaces facilitate the collection of control data from individual network controllers and the transmission of control parameters to them.

3.2. Architectural Functional Components

The architectural functional components are briefly described below.

(a) Integrated control data service function: It gathers and manages control (i.e., monitoring) data from individual network segments, storing this data in a database. The system updates the data promptly, ensuring its consistency, and provides it with adjustable levels of granularity to the E2E network status analysis function.

(b) Application requirements analysis function: It encompasses functionalities to interpret the expectations of both users and service providers, which may be articulated in abstract policies known as intents. These intents are then translated into system configuration parameters, which serve as inputs for the E2E network status analysis function.

(c) E2E network state analysis function: This function analyzes control data related to resource utilization, performance metrics, and application requirements to evaluate the status of resource utilization and network service quality. It can identify whether resources are under-utilized, over-utilized, or optimally utilized and whether the service quality meets the required levels. Additionally, by examining trends in resource utilization, the function can predict future resource demands and expected performance quality.

(d) E2E resource allocation, management & optimization function: Based on the status of E2E network resource utilization and performance analysis provided by the E2E network status analysis function, the E2E resource allocation, management, and optimization function formulates optimal decisions for resource control. These decisions involve generating resource control parameters to adjust the resources allocated in various network segments. Different network segments require adjustments to different types of resources. For example, DN configured on virtualized cloud platforms may require more computational resources (e.g., virtual machines, CPUs, GPUs, memory) and storage resources, while NTN may need more radio spectrum bandwidth for feeder and service links or the replacement of radio links with free space optics links due to changes in weather conditions and user traffic demands.

(e) Integrated control & orchestration function: It formulates network control decisions by creating a list or configuration file containing the appropriate resource control parameters for each network segment involved in the E2E network service. These parameter lists are then sent to the control systems of the individual network segments through the integrated network control interfaces.

3.3 Individual Network Segment Control Systems

The TN-NTN integrated network control system architecture assumes that the individual network control systems have functional components similar to those in the integrated network control architecture. The key difference is that the scope of each function is limited to a specific network segment rather than an E2E network service.

Individual network control system has two sets of interfaces: internal and external. Internal interfaces collect monitoring data from physical or functional network elements at varying levels of granularity and time scales. External interfaces connect to the integrated network control interfaces to provide monitoring data and receiving control parameters.

3.4 Control Signaling Message Flow

ITU-T Y.3207 [6] describes the sequence of control signaling message flows to realize the INCA's two key capabilities:

(a) Creating network services that span both TN and NTN segments based on given QoS requirements.

(b) Monitoring performance and controlling resources to maintain QoS, even with fluctuations in network conditions such as changes in user numbers or traffic demands.

We have incorporated these message sequences into our experimental system. However, due to space constraints, we will not provide the details here and instead refer readers to [5] for further information.

4. EXPERIMENTAL SYSTEM DEVELOPMENT

Figure 2 shows the layout of the experimental system that we have developed in our lab. It consists of three blocks: 1) INCA functions and integrated network control interfaces, 2) TN-NTN integrated network environment, and 3) Control operation visualization tools.

4.1 INCA Functions and Interfaces

The INCA functions implement the integrated network control architecture functions, interfaces and control message flows as explained in the previous section. The INCA functions and integrated network control interfaces are implemented in Python programming language. The integrated network control interfaces use RESTful Application Program Interfaces (APIs) to communicate with the controllers of individual network segments. The control parameters are exchanged in the JSON format.

4.2 TN-NTN Integrated Network Environment

The TN-NTN integrated network environment includes the 5G RAN functions, 5GC functions, NTN simulator/emulator, and DN. The 5G RAN is based on UERANSIM (https://github.com/aligungr/UERANSIM), and the 5GC network functions are based on free5GC (https://free5gc.org). The 5GC network functions include several functions such as Access and Mobility Management Function (AMF), Session Management Function (SMF), Policy Control Function (PCF), Network Exposure Function (NEF), and Network Repository Function (NRF) in the control plane and the User Plane Function (UPF) in the data plane. The 5GC functions are deployed in standalone mode. More details about the 5GC network functions can be found in [12].

The NTN is composed of a satellite network's detail simulator in the control plane and an emulator of NTN bandwidth, latency, jitter, and loss rates in the data plane, both developed in our lab. In this experimental system, the 5GC network functions are split into two groups: 5GC (central) and 5GC (edge), and the NTN is inserted between them. The AMF and SMF are in the 5GC (edge) while the remaining control plane network functions are in the 5GC (central). The UPFs are in both the 5GC (edge) and 5GC (central).

The DN is configured in the OpenStack platform, whose components are managed by Open-Source MANO (OSM -- https://osm.etsi.org/). The DN contains video application server configured with MPEG-DASH module installed in virtual machines (VMs) for streaming three different quality video files. The video client program or player is installed in the user equipment (UE). Laptop computers are used to operate as UEs by installing the UE module of

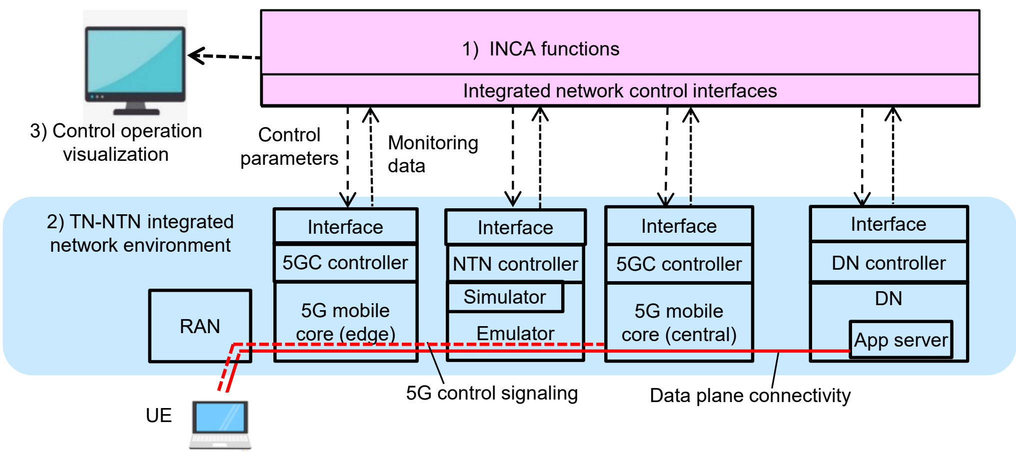
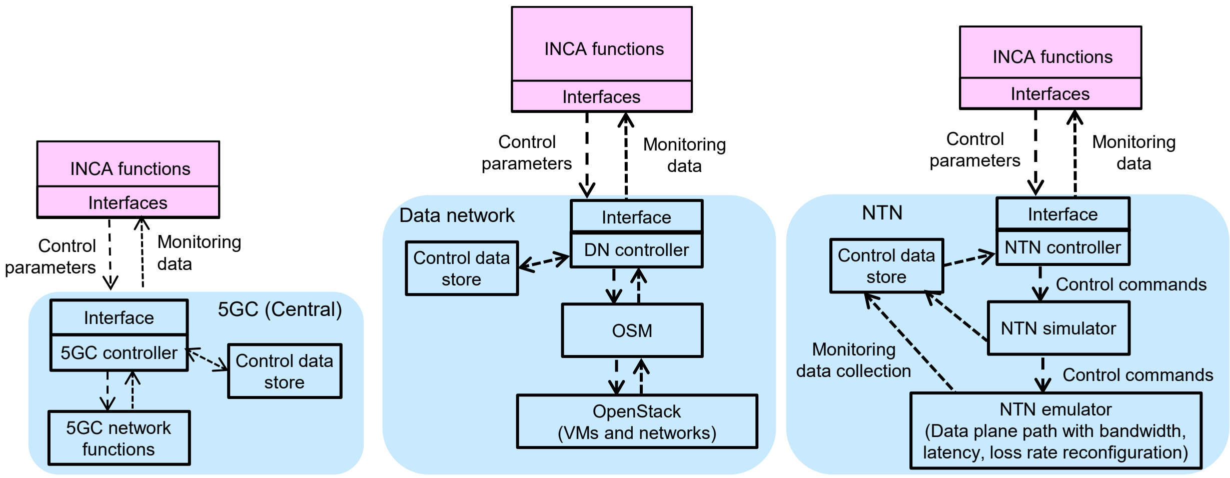


Figure 2 - Experimental system layout.



(a) 5GC controller (b) Data network controller (c) NTN controller

Figure 3 - Layout of 5GC, data network and NTN controllers.

UERANSIM software. The video client program of UEs plays the video on the screen after accessing it from the application server located in DN and receiving the data transmitted through the 5GC (central), NTN, 5GC (edge), and 5G RAN.

All segments (except the RAN) have their respective controllers that collect control data containing resource utilization and performance metrics and execute resource control commands. These controllers are described next.

(a) 5GC controller

The same implementation of the 5GC controller, shown in Fig. 3(a), operates on both the 5GC (edge) and 5GC (central) networks. The 5GC controller collects monitoring data from 5GC network functions using platform-specific virtualization tools and stores this data in InfluxDB, an open-source time-series database. We used Docker Compose to configure, deploy, and manage the 5GC network functions within a Docker container-based resource virtualization platform. Docker tools are utilized to collect monitoring data and send control commands to adjust the CPU and bandwidth resources allocated to each network function. The monitoring data is sent in JSON format to the INCA functions via Web-based APIs. Similarly, the controller receives resource control parameters for the network functions through HTTP requests from the INCA functions. It then formulates resource control commands using Docker tools and executes them on the network function containers.

(b) DN controller

DN controller programs are installed in a Docker container. As shown in Fig. 3(b), the controller sends monitoring data to INCA functions and receives resource control parameters in return. It utilizes OSM for the deployment and management of virtual network resources (e.g., CPU, memory, bandwidth) on VMs and virtual networks within the OpenStack platform. The controller collects monitoring data related to resource utilization and performance metrics (e.g., throughput and latency) from the application server and other network functions, such as load balancers, and stores this data in an InfluxDB. Monitoring data is sent to INCA functions via a web-based API, and resource control parameters are received from them. The controller then converts these parameters into OSM commands and executes them in the OpenStack-based DN.

(c) NTN controller

The NTN controller operation sequence is shown in Fig. 3(c). It receives an HTTP request from INCA functions containing the NTN resource requirement-related parameters such as service type, number of UEs and their locations, traffic rate (uplink, downlink), total traffic rate (uplink, downlink), feeder link gateway locations, NTN segment latency, jitter, etc. are provided to the NTN controller. The NTN controller converts the parameters into a list of NTN simulation parameters and sends the list in a control command to the NTN simulator. The NTN simulator executes simulation codes to configure NTN paths by selecting relevant ground stations and satellites (LEO, GEO) from the satellite constellation topology preconfigured in the simulator. The NTN simulator stores the simulation input and output data in the control data store configured in InfluxDB. The NTN simulator sends a control command containing the values of NTN segment's bandwidth and latency to the NTN emulator. The NTN emulator configures a data plane path with the given capacity by using a platform-specific command such as the Linux *tc* command. NTN emulator stores the traffic control parameters in the data store. The NTN controller retrieves the control data from the data store and sends the data to the INCA functions.

4.3 Control Operation Visualization Tools

Four types of visualization tools are developed for the demonstration of the following system operations: a) E2E network topology and message flows, b) 5GC, NTN, and DN resource monitoring graphs, c) NTN paths, and d) application quality of service parameters.

a) End-to-end network topology and message flows

Figure 4 shows the E2E network topology and control message flow displayed on the web browser of the control

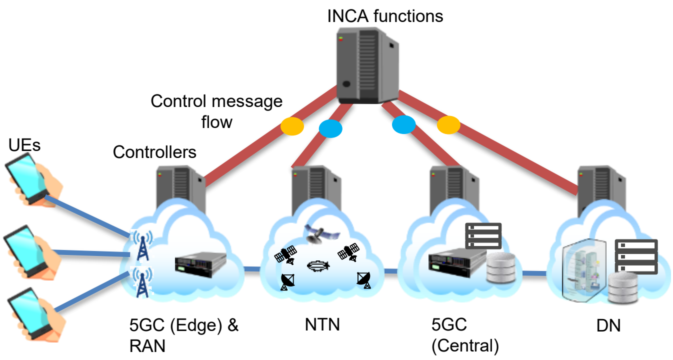


Figure 4 - End-to-end network topology and control message flow.

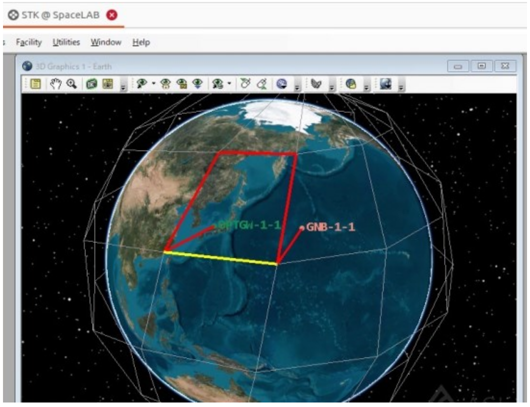


Figure 5 - NTN path visualization

operation visualization monitor. It shows a linear topology containing the UEs, 5GC (edge) & RAN, NTN, 5GC (central), and DN segments. The control message flows are visualized by moving dots in animation. The dots moving from the individual network controllers to the INCA functions represent the flow of monitoring data, while the dots flowing in the reverse directions represent the control parameters flow. The dots flowing in these two directions can be shown in two different colors.

b) 5GC, NTN, and DN resource monitoring graphs

The 5GC, NTN, and DN resource utilization graphs are also displayed on the web browser of the control operation visualization monitor by using Grafana, an open-source analytics and monitoring platform software. Related with the 5GC network functions, the graphs of CPU, memory and bandwidth allocation and utilization can be displayed. The bandwidth allocation and utilization as well as latency and number of satellite hops of the NTN path can also be displayed. Similarly, the CPU and memory allocation and utilization as well as the throughput of the application server in DN can also be displayed in the form of monitoring graphs.

c) NTN paths

The NTN paths are visualized in Fig. 5 using output data from the NTN simulator on Ansys Systems Tool Kit (STK). This figure shows the locations of ground stations connected to the 5GC (edge) (indicated by GNB-1-1 on the right) and 5GC (central) (indicated by OPTGW-1-1 on the left). The vertical lines represent intra-orbital communication links, while the horizontal lines indicate inter-orbital communication links. Each satellite can communicate in five directions: with two satellites of the same orbit, two satellites of the left and right neighboring orbits, and one ground station. The yellow and red lines represent two NTN paths configured by the simulator in response to service creation requests provided by the NTN controller. NTN sets forward and reverse paths separately, which may pass through the same or different sets of satellites. The figure shows only the reverse paths (i.e., paths for transferring data from the application server to UEs).

d) Application QoS graphs

The application QoS graphs are displayed on the UE screen next to the application video. These graphs depict the curves for application throughput, latency, and jitter. These curves are derived from QoS data collected every 10 seconds by a probe program installed on the UE.

5. VALIDATION OF SYSTEM CAPABILITIES

The experimental system validates two key capabilities of INCA as specified in ITU-T Y.3207: the creation of network services across TN and NTN segments, and the monitoring and control of resources to maintain the desired QoS despite fluctuations in network conditions such as varying user numbers or traffic demands.

To demonstrate these capabilities, the system components are initialized as follows:

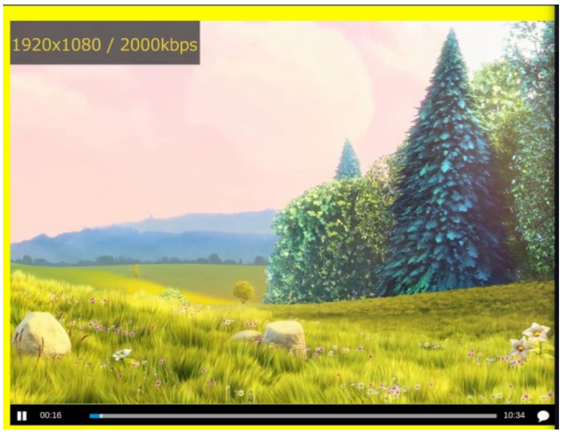
Data network: The application server located in DN is configured to stream three different quality videos using MPEG-DASH: high definition (HD), standard definition (SD), and low definition (LD), with data rates of 3 Mbps, 1 Mbps, and 500 kbps, respectively. The DN controller is activated to monitor and control DN resources (CPU, memory, and bandwidth allocated to the virtual machine hosting the MPEG-DASH application server).

5GC (central): Two UPFs of the user plane and other network functions of control plane are initialized in standalone 5GC deployment mode. Additionally, the 5GC controller is initialized to monitor and control resources allocated to 5GC network functions, especially the UPFs.

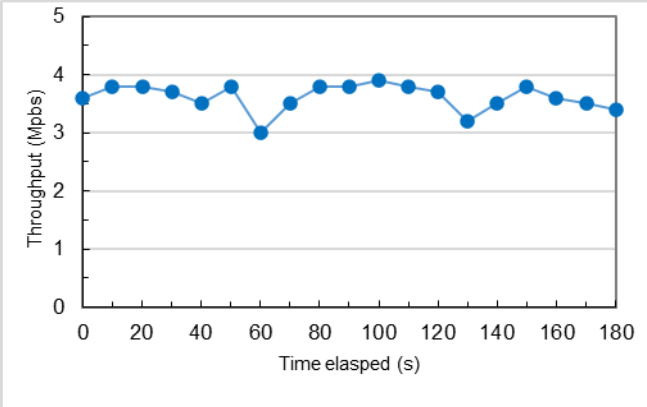
5GC (edge) & RAN: Two UPFs in the user plane and AMF and SMF in the control plane are initialized in the 5GC (edge). The 5GC (edge) controller is also initialized. UERANSIM simulator is configured for gNodeB functions.

UEs: Three UEs are configured to connect to the gNodeB simulator, and their subscription information is added to the Unified Data Management (UDM) component in the 5GC (central). Their browsers are configured to play the streaming videos. Additionally, the QoS parameter probe tool is initialized to monitor the data rate, latency, and jitter, while Grafana is set up to display monitoring graphs.

NTN simulator and emulator: Simulation script files are prepared to establish NTN paths upon receiving control commands from the INCA control function. The STK visualization tool is launched, and NTN emulator paths are



(a) Screenshot of HD video played on UE screen



(b) HD video application data throughput (Mbps) versus time

Figure 6 - UE's video replay screenshot and application throughput graph.

preconfigured with basic setup parameters, including IP addresses and namespaces.

INCA functions and interfaces: INCA function modules are executed, and integrated control interfaces are initialized to communicate through Web-based APIs with individual network segment controllers.

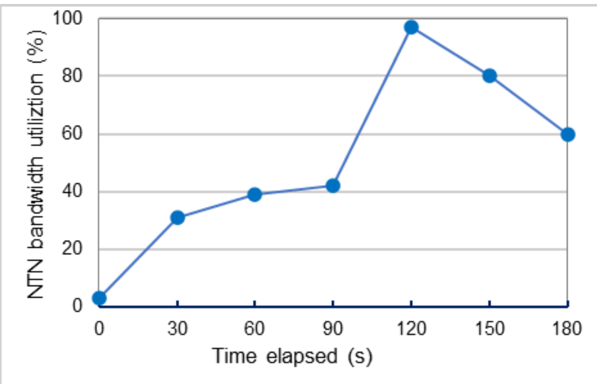
Control operation visualization monitor: Grafana tools are initialized to display resource utilization monitoring graphs drawn with the monitoring data retrieved from INCA functions.

5.1 Validation 1: Network service creation

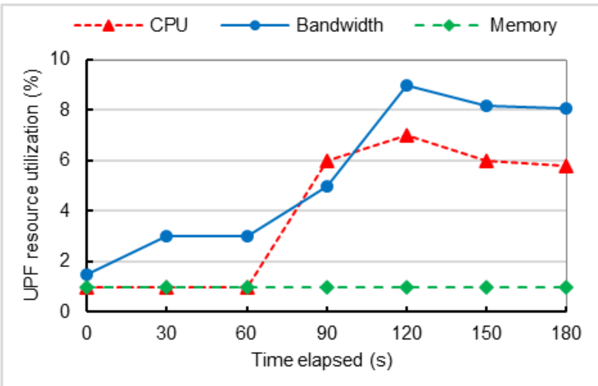
This demonstration confirms that INCA can create three network services, each tailored for HD, SD, and LD video applications when service creation requests are orchestrated from INCA functions to the controllers of the 5GC, NTN, and DN. UEs, having associated with their respective network services, initiate downloading and playing the HD, SD, and LD videos on their screens. The QoS graphs, including data rate, round-trip time, and jitter, are displayed alongside the video content. Additionally, the control operation visualization monitor displays graphs of CPU, memory, bandwidth utilization of the 5GC network functions, and the bandwidth utilization of the NTN. Similarly, the NTN topology visualization window illustrates the three NTN paths. As an illustration of the demo visualization, Fig. 6 shows a screenshot of the HD video played on UE's screen and the monitoring graph of the HD video application data throughput.

5.2 Validation 2: Network monitoring & control

This demonstration confirms that the INCA can monitor and control the resource utilization of NTN, 5GC, and DN continuously, and maintain the required level of QoS consistently. In this scenario, we create a single network service by allocating 25 Mbps bandwidth to the NTN segment, emphasizing the adjustment of NTN bandwidth due to its scarcity compared to TN bandwidths. Three UEs connect to the same network service to download and play the HD video content. Resource utilization graphs for 5GC



(a) NTN bandwidth utilization versus experiment time. When network congestion is created by injecting background traffic from around 60 seconds, the NTN bandwidth utilization surges to nearly 100%. The utilization decreases after increasing the NTN bandwidth by the control decision made by the INCA controller.



(b) UPF's resource utilization versus experiment time. The bandwidth and CPU utilization of the UPF increase from 60 seconds due to the background noise traffic. However, as the utilization is still very nominal, the INCA controller decides nothing to do with the control of CPU, bandwidth, and memory resources.

Figure 7 - NTN path bandwidth utilization and 5GC (central) UPF bandwidth, CPU, and memory utilization when network service is congested by background traffic.

UPFs, NTN, and DN are displayed on the control operation visualization monitor, whereas the HD video and throughput graphs are shown on each UE (similar to those shown in Fig. 6).

We induce network congestion by injecting background noise traffic using *iperf*, a widely used network testing tool. This traffic is injected into 5GC (central) UPF, routed through the NTN path, and terminated in the 5GC (edge) UPF. We do not induce congestion in the RAN because its resources are not controlled by INCA. Therefore, the noise traffic is added only to the 5GC UPFs and NTN segments, which are monitored and controlled.

After creating congestion, the resource utilization monitoring graphs show a surge in NTN path bandwidth utilization reaching nearly 100% (as shown in Fig. 7(a)), with a slight increase in 5GC (central) UPF bandwidth and CPU utilizations (as shown in Fig. 7(b)). Insufficient bandwidth in the NTN segment causes the HD video stream to downgrade to LD video due to dynamic adjustment of data rates by MPEG-DASH.

By analyzing the network status monitoring data using machine learning modules such as linear regression, INCA can forecast resource demands. Accordingly, it determines a new bandwidth allocation value and sends this value to the NTN controller. The NTN controller provides this value to the NTN simulator for NTN path re-computation.

The NTN emulator adjusts the path capacity based on received bandwidth and latency values from the simulator. Once sufficient NTN bandwidth is available, video quality reverts to HD automatically. Subsequently, background traffic is stopped to simulate a congestion-free environment. With the removal of background traffic, INCA detects low bandwidth utilization (e.g., less than 40%) from the monitoring data analysis. It then sends a lower bandwidth allocation value to the NTN controller to release the unused portion of bandwidth. After releasing the surplus bandwidth, the NTN bandwidth utilization slightly increases to about 60%, without negatively impacting the HD video application service.

Through the above two demonstrations, we effectively validated the capabilities of INCA to create a network service with specified QoS parameters, as well as to consistently monitor and control resources, ensuring QoS maintenance even during fluctuations in network traffic. Additionally, INCA supports optimal resource utilization by dynamically adding resources when necessary and releasing them when they are redundant.

6. CONCLUSION AND FUTURE WORK

This paper presented the implementation of functional components and interfaces of the integrated network control architecture specified in ITU-T Recommendation Y.3207. It also described the individual network controllers for the data network, 5G core network, and NTN segments. Through experimentation, we demonstrated INCA's capabilities to create network services on both TN and NTN segments with required QoS levels. Additionally, we showed INCA's capability to monitor computing and bandwidth resource utilization continuously and adjust resources to maintain the required end-to-end QoS levels dynamically, even amidst fluctuating network conditions.

In future work, we will enhance INCA functions to incorporate various machine learning and AI algorithms for predicting network and computing resource demands, allowing proactive adjustments before the QoS degrades. Additionally, we will develop tools and user interfaces to simplify the process of the system operation.

REFERENCES

[1] V.P. Kafle, Y. Fukushima, P. Martinez-Julia, and T. Miyazawa, "Consideration on automation of 5G network slicing with machine learning," ITU Kaleidoscope Academic Conference: Machine Learning for a 5G Future, Santa Fe, Argentina, Nov. 2018.

[2] K. Liolis et al., "Use cases and scenarios of 5G integrated satellite - terrestrial networks for enhanced mobile broadband: The SaT5G approach," International Journal of Satellite Communications and Networking, Vol. 21, Issue 4, Nov. 2017, pp. 1 - 22.

[3] V.P. Kafle, M. Sekiguchi, H. Asaeda, and H. Harai, "Integrated network control architecture for terrestrial and non-terrestrial network convergence in beyond 5G systems," ITU Kaleidoscope Academic Conference: Extended reality– How to boost quality of experience and interoperability, Accra, Ghana, Dec. 2022.

[4] V.P. Kafle, M. Sekiguchi, H. Asaeda, and H. Harai, "Integrated network control architecture for terrestrial and non-terrestrial network convergence," IEEE Commun. Standards Mag., Vol. 8, No. 1, pp. 12-19, Mar. 2024.

[5] Recommendation ITU-T Y.3200 (2022), Fixed, mobile and satellite convergence – Requirements for IMT-2020 networks and beyond.

[6] Recommendation ITU-T Y.3207 (2024), Fixed, mobile and satellite convergence – Integrated network control architecture framework for IMT-2020 networks and beyond.

[7] 3GPP TR 23.737 (V17.2.0), Study on architecture aspects for using satellite access in 5G, Mar. 2021.

[8] 3GPP TR 28.808 (V17.0.0), Study on management and orchestration aspects of integrated satellite components in a 5G network, Mar. 2021.

[9] 3GPP TS 23.261 (V17.11.0), Service requirements for the 5G system, Oct. 2022.

[10] 3GPP TR 24.821 (V17.0.0), Study on PLMN selection for satellite access, Sep. 2021.

[11] X. Lin, S. Rommer, S. Euler, E.A. Yavuz, and R.S. Karlsson, "5G from space: An overview of 3GPP non-terrestrial networks," IEEE Commun. Standards Mag., Vol. 5, No. 4, pp. 147-153, Dec. 2021.

[12] 3GPP TS 23.501 (V18.5.0), System architecture for the 5G system (5GS), Mar. 2024.