ENI ISG - PoC Proposal Template

1 PoC Project Details

1.1 PoC Project

PoC Number (assigned by ETSI): PoC#17

PoC Project Name: Intelligent Satellite-Terrestrial Integration Network Architecture

PoC Project Host: China Telecom

Short Description: This PoC identifies how to integrate satellite and terrestrial communication system to provide seamless network coverage and traffic steering, with a special attention to the Artificial Intelligence / Machine Learning (AI/ML) aspects, in the context defined by ENI.

In particular, seamless network coverage and traffic steering are addressed in the specified satellite-terrestrial integration networks. The present document addresses the following topics: system architecture, transport protocol, and intelligent solutions.

Note that we begin with to demonstrate the use case [#1-4: Intelligent Optimization for Transmission Network] and [#2-2: Radio Coverage and capacity optimization] discussed in GS ENI 001 [1]. In general, we aim to achieve these objectives based on a common reference implementation built with open source components. Thus, this ENI system architecture implementation even can be applicable to other user cases.

1.2 PoC Team Members

Table A.1

	Organization name	ISG ENI participant (yes/no)	Contact (Email)	PoC Point of Contact (see note 1)	Role (see note 2)	PoC Components
1	China Telecom	Yes	Yu Zeng (zengyu@chinatelecom.cn) Hongdan Ren, Ziting Zhang, Wenxin Xu	X	Service Provider	- User Stories / Use Cases definition - PoC development - PoC documentation - PoC demos
2	Tsinghua University		jchx@tsinghua.edu.cn gaomeilin@ tsinghua.edu.cn		Academic	-Help with architecture design, protocol design, intelligent solution, and platform verification
3	Asiainfo		Shoufeng Wang wangsf11@asiainfo.com		Vendor	-Help with architecture verification
4	Huawei		Aldo Artigiani aldo.artigiani@huawei.com		Vendor	-Help with concept refinement and use case
5	CAICT		Ziruo Liu liuzhiruo@caict.ac.cn		Academic	-Help with simulation and architecture optimisation
6.	CNIT		Fabrizio Granelli fabrizio.granelli@unitn.it		Academic	-Help with concept proof
7.	CNR ISTI		Pietro Cassarà pietro.cassara@isti.cnr.it		Academic	-Help with concept proof

NOTE 1: Identify the PoC Point of Contact with an X.
NOTE 2: The Role will be network operator/service provider, infrastructure provider, application provider or other as given in the Definitions of ETSI Classes of membership.

All the PoC Team members listed above declare that the information in this proposal is conformant to their plans at this date and commit to inform ETSI timely in case of changes in the PoC Team, scope or timeline.

1.3 PoC Project Scope

1.3.1 PoC Goals

The PoC will demonstrate aspects of various Use Cases that were identified by in GS ENI 001, namely:

Use Case #1-4: Intelligent Optimization for Transmission Network

Use Case #2-2: Radio Coverage and capacity optimization

The PoC will also demonstrate aspects of various requirements that were identified in GS ENI 002, including:

- Service orchestration and management
- Network planning and deployment
- Network optimization
- Resilience and reliability
- Data Collection and Analysis
- Policy Management
- Data Learning

This PoC intends to define and validate the architecture applicable to intelligent satellite-terrestrial integration systems. The detailed goals include:

PoC Project Goal #1: Hand-and-Arm based Architecture. Demonstrate the architecture design with inherent wide-area coverage capability and the unified management of user access with ubiquitous signaling coverage.

PoC Project Goal #2: Intelligent On-demand Coverage. Demonstrate the intelligent on-demand coverage technology to provide dynamic resource allocation for traffic steering to meet diversified user demands.

1.3.2 PoC Topics

PoC Topics identified in this clause need to be taken for the PoC Topic List identified by ISG ENI and publicly available, i.e. the three topics identified in clause 4.5 of the ENI PoC Framework. PoC Teams addressing these topics commit to submit the expected contributions in a timely manner.

Table A.2

PoC Topic Description (see note)	Related WI	Expected Contribution	Target Date
Network Operations -> Intelligent Network application	ENI-007 GS ENI 002 Requirements) ENI-008 (GS ENI 001 Use Cases)	1 Functional blocks for this PoC. 3. The feasibility of network intelligent organization and optimization for transmission network 4. Radio Coverage and capacity optimization 5. Framework for intelligent organization and required capacity. 6. The feasibility of intelligent optimization for transmission network.	31/12/2023
NOTE: This column should be filled according to the contents of table 1.			

1.3.3 Other topics in scope

List here any additional topic for which the PoC plans to provide input/feedback to the ISG ENI.

Table A.3

PoC Topic Description	Related WI	Expected Contribution	Target Date

1.4 PoC Project Stages/Milestones

Table A.4

PoC Milestone	Stages/Milestone description	Target Date	Additional Info
P.S	PoC Project Start	03/2023	Presentation during #ENI 25
P.D1	PoC Demo 1	04/2023	Venue, F2F / Webinar
P.D1	PoC Demo 1	06/2023	Venue, F2F / Webinar
…	…		
P.C1	PoC Expected Contribution 1	08/2023	contributions to ENI requirements.
P.C2	PoC Expected Contribution 2	08/2023	contributions to ENI use case.
…	…		
P.R	PoC Report	10/2023	PoC-Project-End Feedback
P.E	PoC Project End	12/2023	Presented to ISG ENI for information
NOTE: Milestones need to be entered in chronological order.			

1.5 Additional Details

For example, URL, planned publications, conferences, etc.

2 PoC Technical Details

2.1 PoC Overview

With the increasing global communication demands, the scale of the information services gradually expands and the demand for aerial, maritime, and mountain services sharply surges, which leads to pressing needs for ultra-high-volume wide-area communication networks. Considering the inherent wide-area coverage capability of satellite communications, space-ground integrated networks become a promising solution. Current global connectivity is generally provided by large-scale low-orbit mega-constellations with inefficient resource utilization and individual network performance optimization, leading to low network efficiency. The space-ground integrated networks get trapped in simple mergers without resources and networking integration.

To break the bottleneck and improve resource efficiency, this PoC investigates intelligent satellite-terrestrial integration networks based on a hand-and-arm architecture, and manages the unified management of user access by using ubiquitous coverage. This PoC provides intelligent on-demand coverage solution for wide-area connectivity and dynamic resource allocation for diversified user demands.

This PoC is proposed to demonstrate the feasibility of the integrated satellite-terrestrial network and the efficiency of the solutions using AI/ML algorithms.

2.2 PoC Architecture

2.2.1 Integrated Satellite-Terrestrial Architecture

We first specify the integrated satellite-terrestrial architecture, as illustrated in Figure 1. The integration of Medium Earth Orbit (MEO) satellite network and the terrestrial network constructs the wide-area information backbone network, connects 5G and B5G micro-base stations globally, and supports seamless cooperative space-ground coverage and mobile deployment of infrastructure. In particular, the terrestrial and satellite base stations provide global access to ground users with individual requirements. In normal conditions, terrestrial networks are preferred for broadband services, while satellite networks act as the complementary for enhanced transmission. When terrestrial networks are unavailable in emergency cases, such as earthquakes and hurricanes, satellite networks turn to be the dominant network for emergency communication. With the information routing capabilities of ISL and satellite-ground links, global seamless coverage is provided.

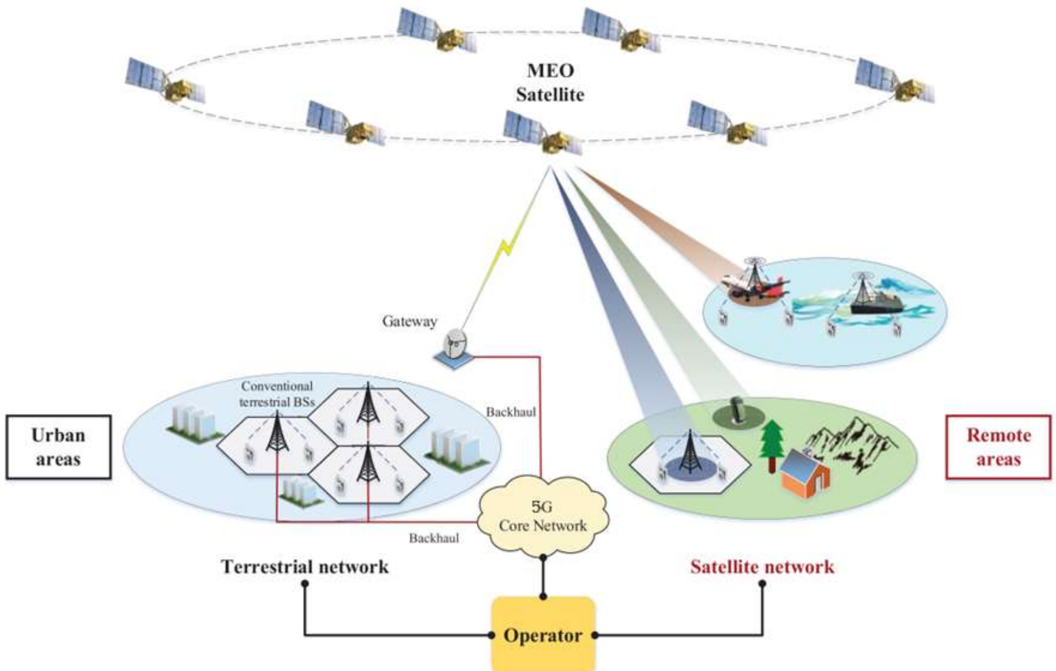

Figure 1: The integrated satellite-terrestrial network architecture.

2.2.2 Transport Layer Protocol

This PoC specifies the transport layer protocol in the presented network architecture, as shown in Figure 2. The satellite MAC sublayer is defined, and the satellite terminal can encapsulate the upper-layer network packets into MAC frames according to the data flow, to ensure the end-to-end service quality. Different upper-layer network protocols are compatible such as IP and CCSDS. Decapsulation and packet processing at the satellite can greatly improve the network flexibility and compatibility. The application sublayer carries data above the defined SMAC sublayer. Note that SMAC packet exchange between network elements is executed at the SLC layer and then packet restoration to application data is executed at the data transceiver ends. For general services, the satellite only forwards data transmission at the SMAC layer. For special services, part of services can be transferred to the network layer and the system filters and forwards packets with the flow table adaptation capability.

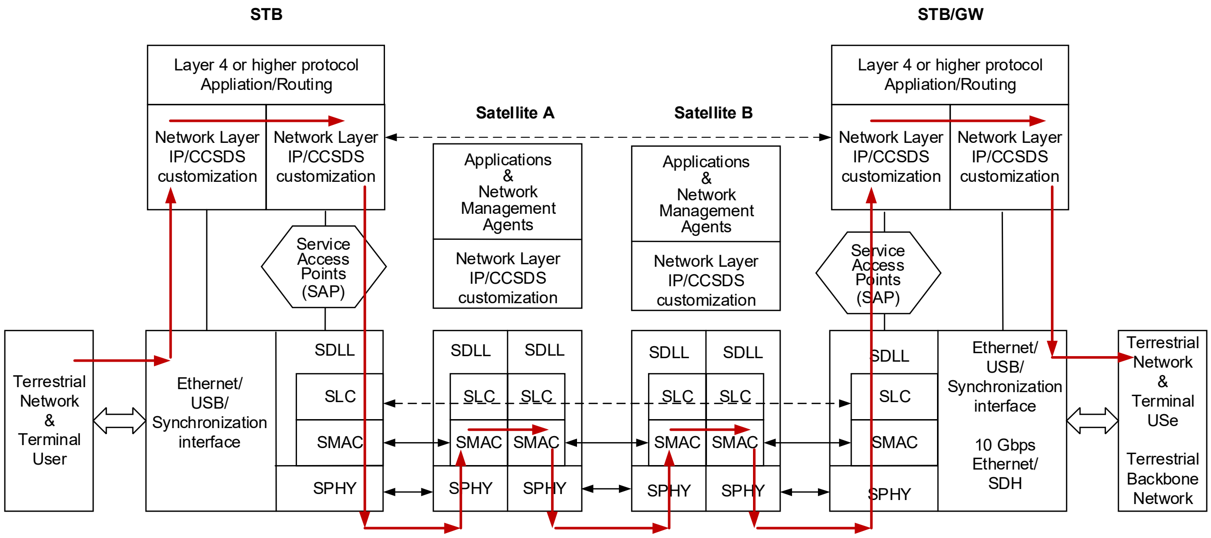

Figure 2: Data transmission transport layer protocol.

The control plane information includes non-access stratum (NAS) information, network control (CTRL) information and wireless resource control information, as shown in Figure 3. In particular, NAS information includes mobility management and session management and so on, and is in the network operation control center (NOCC) core network control center related management entity to exchange with STB and GW. CTRL information includes the status reporting information and flow table delivery information of the control plane, and is in NOCC's core network controller to exchange with the switches in all nodes of the system. RRC wireless resource control information is related to the establishment, modification and release of wireless resources and is in the NOCC's core network control center related management entity to exchange with STB and GW. The control plane information is processed by network element management agents. At present, it is considered to encapsulate network control information on the IP layer.

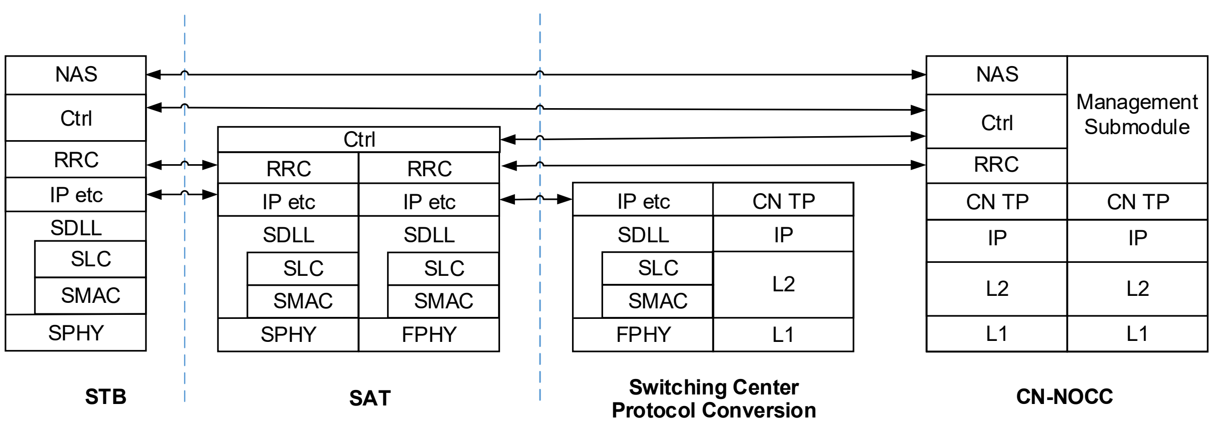

Figure 3: Control plane transport layer protocol.

2.2.3 Adaptive Coding and Modulation

Low-density Parity-check (LDPC) code is a linear error-correcting block code and can be specified by a non-systematic parity-check matrix, which is a super sparse random matrix with the number of random element “1” in each row or column very small.

This PoC specifies the variable bit rate and variable packet length scheme as follows:

1. Determine the code structure and rules according to the requirements such as the minimum bit error rate.

2. Optimize the distribution of degrees of freedom (DoF) by the density evolution (DE) algorithm according to the performance requirements.

3. Based on the DoF distribution, the improved PEG+ACE algorithm is used to design the basis matrix.

4. Design the cyclic shift matrix using the previously patented PSG algorithm.

5. LDPC codes of various code lengths can be generated by using the obtained basis matrix and cyclic shift matrix.

This PoC further specifies the design of quasi-continuous code rate varying LDPC code with variable code length, which adapts to the adaptive transmission requirements of satellite communication. The design of LDPC codes can adapt to the rate and packet length transformation, and shows very good performance with low encoder and decoder complexity. It is very easy to implement partially parallel decoder structure to reduce the need for decoder memory.

2.2.4 Intelligent On-Demand Coverage

Due to the non-uniform geographic distribution and time-varying characteristics of the ground traffic request, how to make full use of the limited satellite resources to match the traffic demands efficiently is a big challenge for satellite systems. The multi-beam satellites (MBS) play an important role to solve this problem, which can generate a large number of beams and flexibly allocate these beam resources to improve communication coverage and transmission capacity. Traffic steering allows to optimize the dynamic beam hopping and resource utilization, users' service perception and the system throughput are jointly optimized by directing the traffic to the beam that provides the best performance. However, this has to be tied closely together with mobility management, which assures optimized mobility performance, for example a reasonable complexity of the algorithm and high efficiency in terms of time-varying traffic requests. This PoC proposes a dynamic beam pattern and bandwidth allocation scheme based on deep reinforcement learning (DRL), which can fully exploit three degrees of freedom (i.e. time, space and frequency) of the beam.

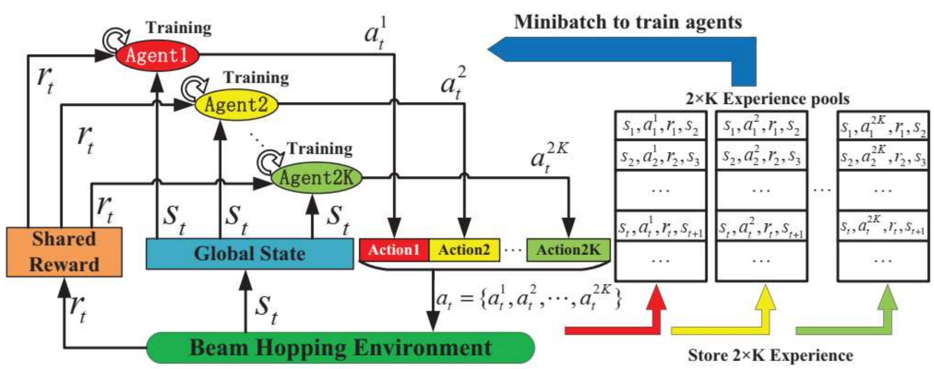

Figure 4: The multi-agent DRL architecture.

As shown in Figure 4, in the multi-agent framework, each beam is regarded as two independent agents. One is responsible for the illumination direction decision and the other allocates the bandwidth of the beam. As a result, each agent has a small action space. Although each agent makes the decision in a distributed way, they can share the global state and reward because all of them are in the same satellite, which will motivate them to cooperate with each other. Since the dynamics of the environment are usually unknown, the model-free DRL method (e.g. deep Q-learning) is adopted, which can learn the policy by offline training. After training, the smart multi-agent model can be deployed in the ground NOCC or the satellite with on-board processing capabilities for dynamic beam hopping. Since all agents are actually located in one node (i.e. NOCC or the satellite), they can observe the same state and potentially achieve cooperation through shared rewards.

Details of the cooperative multi-agent DRL are as follows:

1. Global State: At each time slot, the system can observe the whole traffic demand as the global state and each agent can obtain this state.

2. Action Space: In the proposed multi-agent architecture, there are 2K agents to make decisions on the BH pattern and bandwidth allocation for K beams.

3. Reward: The agents will receive the immediate reward after taking the action. To maximize the long-term optimization target, the data throughput and delay fairness is adopted as the immediate reward. Besides, in order

to encourage the agents to cooperate, all agents share a global reward which can evaluate the global performance and promote collaboration.

4. Double Deep Q-Learning Based DRL: Since the action spaces are discrete, the well-performed Double Deep Q-Learning (DDQN) method is adopted for the agent to learn the policy. Meanwhile, considering that all agents can observe the global environment state, the independent Q-learning can be adopted in the multi-agent framework. In other words, each agent has an independent deep neural networks (DNN) that is used as an approximation function to generate the Q-value function corresponding to the state and the action.

2.3 PoC Success Criteria

Explain how the proposal intends to verify that the goals are presented in clause A.1.2 have been met.

EXAMPLE: Functional (demonstration shown transmission network of PoC proposal worked), Performance (comparing to current application, the terrestrial and satellite base can adapt according to application, etc earthquake situation switch), Availability(can be improved by radio coverage optimization).

2.4 Additional information

[1] RGS/ENI-008 (GS ENI 001), "Experiential Networked Intelligence (ENI); ENI use cases", v3.1.1, Sec 5.2
[2] RGS/ENI-007 (GS ENI 002), "Experiential Networked Intelligence (ENI); ENI requirements", v3.1.1.
[3] DGS/ENI-005 (GS ENI 005), "Experiential Networked Intelligence (ENI); System Architecture", v2.1.1.