Optical Transport Networks Converging Edge Compute and Central Cloud: An Enabler For 6G Services

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Abstract: Intent-based networking that automates the operation of converged edge compute and central cloud 6G infrastructures through optical transport networks is proposed. GPT AI is used to translate high level intents to optical transport network configurations.

1. Introduction

6G networks are expected to offer ubiquitous and advanced services for next generation sustainable, fair and resilient Information and Communication Technology (ICT) ecosystems. This introduces the need for extended connectivity of a huge number of devices, extreme levels of capacity and varying bandwidth granularity, increased user mobility with strict sustainability, efficiency and autonomy goals. In view of these, 6G involves convergence of a variety of advanced radio access technologies and the associated (edge and central cloud) compute resources, controlled through mobile core networks. In this context, high-capacity optical transport networks play a key role in providing flexible connectivity across technologies and domains. However, to enable seamless operations across a multiplicity of technologies, domains and infrastructures there is a need for solutions offering improved automation with real-time decision-making capabilities. *Network Intelligence* can be used to automate and optimize complex interactions between different sets of network devices and domains in an efficient and practical manner [1]. In this context, *Intent-based networking (IBN)* has been recently proposed to enhance the level of intelligence in communication networks [2]. In contrast to conventional communication systems that rely on manual processes for their configuration, IBN defines a set of fully automated tools for the management and operation of the whole system. Using IBN, network administrators define a set of high-level intents (high level business objectives and service characteristics) and based on these the system identifies how to achieve the requested goals adopting Artificial Intelligence (AI) and Machine Learning (ML) techniques [3]. *IBN* also allows intelligence to be embedded across all layers of the heterogeneous infrastructure enabling each domain to operate autonomously. Therefore, each autonomous domain tries to self-optimize its operation under a specific set of objectives and constraints hiding at the same time the details of the specific domain implementation.

To showcase the feasibility of this approach, the present study proposes and implements an IBN framework that provides coordination, and optimization of a 6G infrastructure integrating multiple individual autonomous domains including Radio Access Networks (RAN), optical transport and core networks so that they can collectively support optimized 6G services. Each domain is managed through intent-driven control loops taking actions at the: a) "infrastructure resource layer" (through the optical transport network) to adjust traffic forwarding policies taking optimal routing and traffic steering decisions, b) "service layer" to dynamically update end-to-end policies, considering measurements that can assist in understanding the environment, and the needs of end-users, and c) "business level" ensuring delivery of services according to the agreed functional and non-functional specifications (e.g. service level availability and guarantee, repair times etc). To implement this concept, conventional northbound and southbound interfaces (NBIs, SBIs) that are used to manage the optical transport network have been enhanced with intent capabilities. These interfaces expose abstracted resource information of the optical/electronic networks to the E2E orchestrator and enable the creation of an autonomous transport network.

2. Intent-based Architecture

The overall platform covering business, service, and infrastructure layer operations is shown in Figure 1. As can be seen each layer functions in a self-operating mode, while the details associated with the domain implementation, operations, and the functions within the domain are not visible to the other domains or layers. At the *business layer*, network operators and service providers define intents to deliver a specific objective (i.e., network, service, slice) with a guaranteed performance (in terms of throughput, latency, coverage, isolation etc.). To implement this functionality, the high-level intents written in natural (human) language defining and describing business objectives are translated into an optimization model written in General Algebraic Modeling System (GAMS)/ A Mathematical Programming Language (AMPL) or any other modeling language. This functionality has been implemented using the "Translator" Module shown in the top-right part of Figure 1. The basic component of the "Translator" is a Natural Language Processing (NLP) module implemented using the "Transformers" AI model [4]. This AI model comprises an encoder part namely *Bidirectional Encoder Representations from Transformers* (BERT) and a decoder namely *Generative Pre-trained Transformer* **(**GPT). The BERT model uses the encoder part of the transformer AI architecture so that it understands high level intents provided by users usually written in natural language. The decoder part based on the

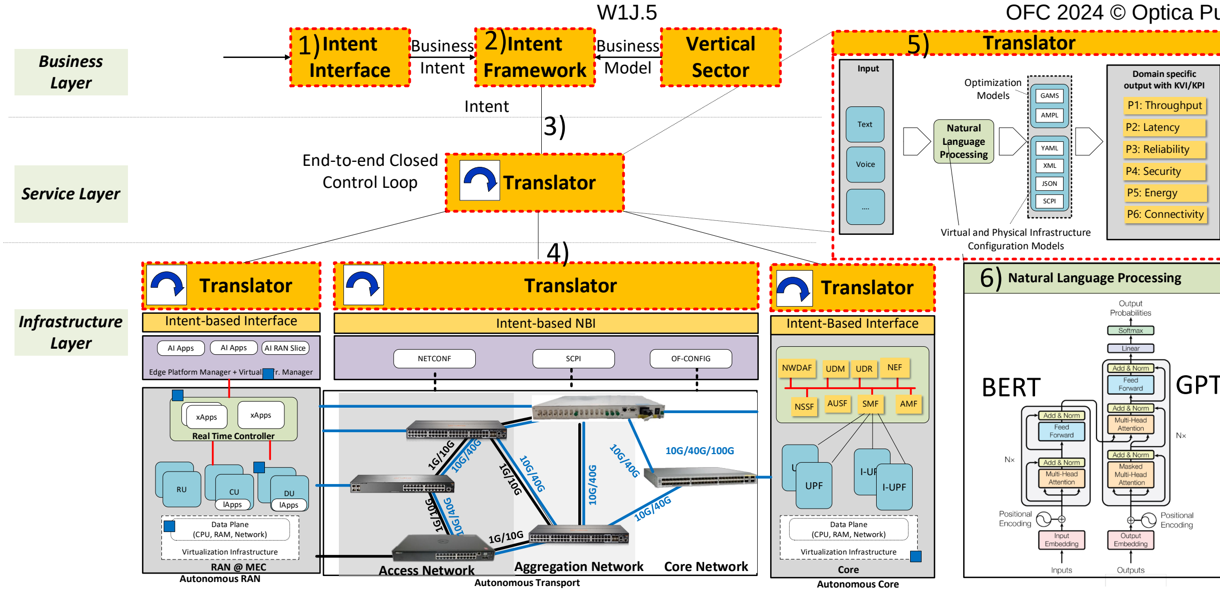

Figure 1: Intent-Based Architecture: *A) Business Layer*: 1) The vertical industry manager use this interface to input business intent, 2) Collect the intent. *B) Service Layer*: 3) Translate the high-level intent into network-specific requirements, *C) Infrastructure Layer*: 4) Send the intent into the network controller. 5) Translator: Translate from the human inputs to domain specific understandable parameters. 6) NLP implementation using GPT

GPT model is used to generate the response. At the business layer, the GPT has been trained to generate as a response the optimization problem to be solved by the orchestrator at the "*Services layer*". At the "Services Layer", the output of the auto-generated optimization problem is used to create the: (a) Network Slice Templates (NST), (b) network service descriptors (NSD), and (c) Virtual Network Function Descriptors (VNFD) required by Open Source Management and Orchestration (MANO) (OSM) [5]. VNFDs define the specifications of the Virtual Machines (VMs) that will host the main entities of the mobile communication platform (i.e. virtualized Core and RAN elements), and the actions that need to be performed to ensure that they function appropriately. The NSD contains the network interfaces for the Virtualized Network Function (VNF) and the NSTs are used to create the virtual links between the various NSDs, chaining and combining multiple VNFs. Once, all resources and configuration files are available, the OSM can create a Network Slice Instance (NSI) providing the required service. At the "Infrastructure Layer", the translator takes as input the virtual link connectivity requirements and generates the appropriate configuration files for the underlying optical transport network.

3. Implementation Example

The intent-based management framework described above has been validated in a lab environment for the topology shown in Figure 2, extending the experimental set-up demonstrated in the context of the EU project 5G-COMPLETE [6]. Our implementation included integration of RAN and core domains through an optical transport network that operated in a self-organized manner adopting the IBN concept. For the transport network segment, we relied on multi-vendor SDN-controlled optical and optoelectronic switches with different capabilities (in terms of number of ports, capacity per port, latency) interconnecting the RAN with the Multi-access Edge Compute (MEC) elements and the central cloud where 6G Core functions were placed. The transport network was organized in a hierarchical manner (Figure 2) offering RAN connectivity, collecting and aggregating transport traffic from various cells to a central location. The access network was equipped with switching nodes having limited number of input ports and relatively small capacity (capacity 1/10GbE per port, with SFP, SFP+ and RJ 45 transceivers). A combination of high-end optoelectronic switches with higher capacity and density (10G/40G/100GbE/ports) and an all-optical (Polatis) switch were used to facilitate aggregation and offer connectivity with the core network segment. For the RAN segment, we relied on the open source 5G platform OAI (https://openairinterface.org/). For the compute domain, we considered edge servers attached to the access switches and central cloud servers connected to the aggregation/core switches.

During the initialization phase, the user expresses an intent in free text e.g. "Set up an Energy Aware URLLC slice". The transformer AI model "generates" the appropriate optimization code that can be used to identify the corresponding URLLC slice as shown in Figure 2 step (1)-(2). This AI model uses as a training set the available optimization code libraries developed in previous works [7]. The generated code corresponds to the function "*def*

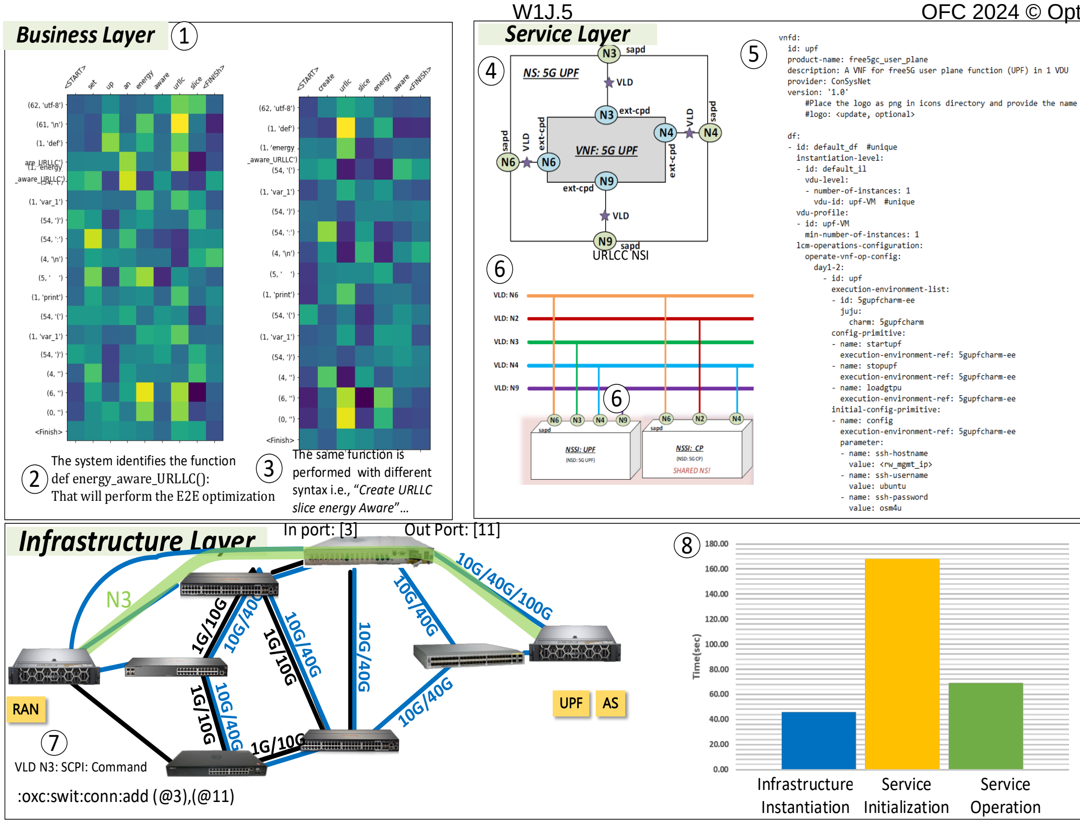

Figure 2: IBN Lab implementation workflow: (1)-(3) High level intent is translated into an optimization framework. (4)-(6): Generation of the corresponding OSM descriptors instantiating the URLLC slice, (7) Auto-generation of the SCPI command in a Polatis all optical switch redirecting input traffic from port 3 to the output port [11]. 8) uRLLC slice instantiation time

energy_aware_URLLC()" which is responsible to identify the optimal size and location of User Plane Function (UPF) nodes along with the corresponding transport network capacity to minimize the energy consumption providing URLLC services. From step (3) (Figure 2) it is also observed that the same function is called even if a different syntax is applied by the user. The optimization output in its turn is used by the service layer to auto generate the relevant configuration files (NSD, VNFD, NST) for the UPF nodes, along with the necessary interfaces ((4), Figure 2). An example of the auto generated descriptor for the UPF VNF is shown in step (5) whereas in (6), the uRLLC slice in instantiated. In step (7), the infrastructure layer translator generates the commands and config files to establish transport network connectivity. In the current IBN implementation, the *Translator* has been trained to create the appropriate input for the SBIs used by the SDN based optoelectronic and all optical switches. Specifically, for the optoelectronic switches (HP ARUBA, CISCO) the Translator creates the necessary OpenFlow Configuration and Management Protocol (OF-CONFIG) and Network Configuration Protocol (NECONF) compliant configuration files providing the physical connectivity for the virtual links defined in the upper layer. For the all-optical switch (Polatis OST) the Translator creates the appropriate set of "Standard Commands for Programmable Instruments" (SCPI) commands to enable/disable specific input/output ports or map an input to an output port. In the current example, the virtual link descriptor (VLD N3) interconnecting the RAN with the UPF through the all-optical switch is implemented by simply generating a SCPI command adding an input/output port connection. Finally, we measured the time it takes for OSM to instantiate and configure a 5G VNF (e.g. UPF) based IBN. This procedure includes three intermediate steps i.e. a) the Infrastructure Instantiation: The VMs hosting VNFs are launched with the appropriate network connections, b) the Service Initialization: The VM gets configured for providing the required function, and c) Service Operations: Specific actions that the operator can perform dynamically (monitoring, reconfigurations etc). The switch configuration time is negligible compared to the compute resources configuration and therefore omitted.

Acknowledgements

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