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# A 6G Transport Network converging THz and Optical network technologies empowered by Federated Learning techniques

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**Abstract** *This paper reports the first experimental demonstration of an autonomously controlled 6G network integrating optical network technologies and THz links in a common transport network. The developed management framework is empowered by Federated Learning to jointly optimize THz and multi-vendor optical networks supporting 6G services.*

## Introduction

The evolution from 5G to 6G is aiming at creating intelligent, ultra-fast, reliable/secure and connected networks that will revolutionize industries and empower digital transformation on a global scale. 6G will integrate multi-technology wired and wireless transport networks operating in new spectrum bands providing enhanced connectivity for the Radio Access Network (RAN) and mobile core elements. In this context, high-capacity optical transport networks combined with THz communication links providing high-bandwidth and flexibility transport connectivity will play a key role. THz links can be installed in indoor or outdoor environments to assist in the deployment of local/private 6G networks. In indoor environments, THz point to point links can provide fully wireless fronthaul/backhaul solutions interconnecting disaggregated RAN and core elements. In outdoor environments THz transceivers can be installed either at rooftops or can be mounted on poles providing point-to-point connectivity for 6G services. However, to enable seamless operations across the multiplicity of 6G technologies, domains and infrastructures these solutions need to be equipped with enhanced automation and real-time decision-making capabilities, through intelligent management and control frameworks.

Although significant research efforts have been dedicated to optical/wireless network integration in support of mobile communication systems, these are mostly limited to communication links operating in sub-6 and 60 GHz bands e.g. [2] and [3]. However, implementations integrating optical and THz technologies are mostly limited to data center networks [7], [8]. On the other hand, management and control of converged wireless and optical 5G transport networks mainly rely on multi-domain Software Defined Networking (SDN) solutions interacting with the core network elements and Management and Orchestration (MANO). The flow management policies are selected adopting either centralized [5] or distributed decision-making frameworks [6], while the flow management decisions are supported using network data collected by the Network Data Analytics Function (NWDAF) that utilizes monitoring data collected from various sources. However, the centralized nature of the NWDAF in 5G systems raises security and trust problems.

This paper proposes a 6G system architecture that utilises a heterogeneous transport network combing together THz links and optical network technologies to interconnect the RAN and the core domains, where optical switching plays a key role. The proposed solution operates in a self-organized manner taking advantage of the SDN control of the optical transport network and an end-to-end (E2E) orchestration layer with intelligence capabilities of-

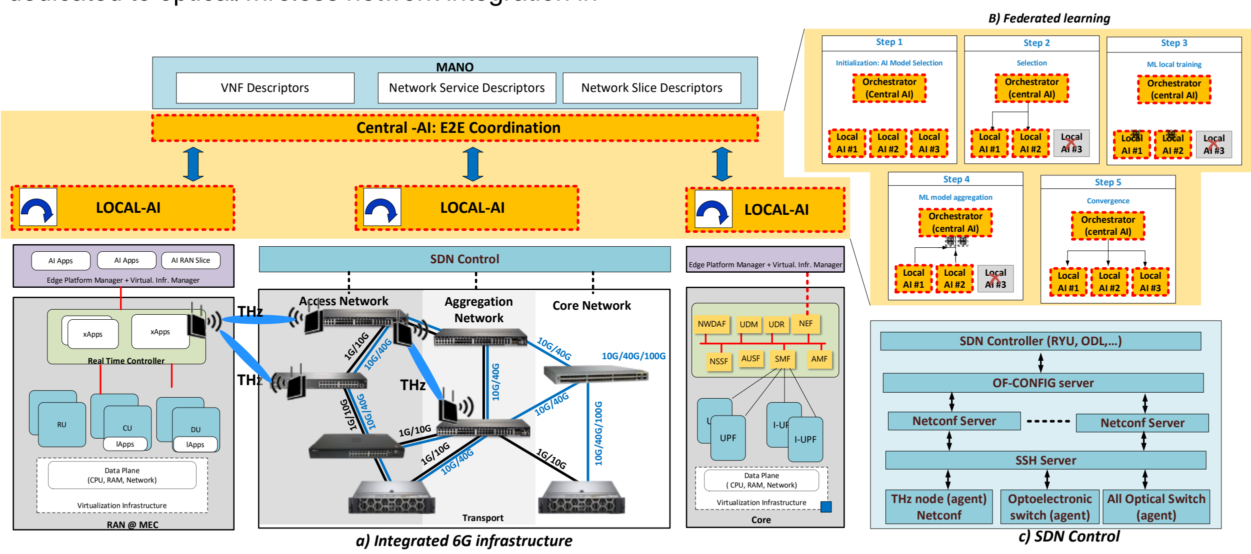


**Fig. 1:** a) AI-based 5G system Architecture: Multiple heterogeneous network segments are managed by local controllers, b) Local data are used per domain to train local AI models adopting FL, c) SDN control for the management of the multi-technology network

fered through the adoption of a Federated Learning (FL) scheme. Based on these, network data are collected and stored locally (within a trusted domain e.g. each Node B) and used to generate a global model applied for E2E service provisioning. To the best of the authors knowledge this is the first experimental demonstration of an autonomously controlled 6G network implementation integrating optical network technologies and THz links in a common transport network. The developed intelligent management framework is empowered by FL to jointly optimize THz and multi-vendor optical networks supporting 6G services

## System Architecture

The overall architecture and the main system blocks are shown in Fig. 1a. The system architecture comprises RAN, transport and core networks. More specifically, an optoelectronic transport network that interconnects the RAN with the MEC elements where core functions are placed is employed. This is organized in a hierarchical manner offering RAN connectivity (access network), collecting and aggregating transport traffic (aggregation network) from various cells to a central location. Both the access and aggregation transport network segments are implemented through multi-vendor SDN-controlled optoelectronic switches with different capabilities (number of ports, capacity per port and latency). The access network is equipped with low energy consuming switching nodes having limited number of input ports and relatively small capacity (1/10GbE/port, with SFP, SFP+ and RJ45 transceivers). The aggregation network segment comprises high-end switches with higher capacity and density (10G/40G/100GbE/ports) offering much higher energy efficiency (lower bit/Joule) under high utilization compared to low-end switches. The optical network is complemented with THz nodes used to provide high-speed connectivity between the gNBs and transport network nodes or between transport nodes. For the RAN segment, the open source 5G platform OpenAirInterface (OAI https://openairinterface.org/) has been deployed. For the compute domain, we consider edge servers attached to the access switches and central cloud servers connected to the aggregation/core switches. To integrate the THz nodes with the optical transport network, the OpenFlow (OF) Configuration Protocol has been used allowing centralized SDN controllers (RYU and OpenDaylight), to manage the whole transport network. A management framework empowered by FL to jointly optimize THz and multi-vendor optical networks has been also developed and demonstrated. This framework relied on the NETCONF Orchestration Application Programming Interface (API), appropriately extended to support the THz nodes. The FL-based optimization framework is used to support optimized E2E service provisioning by identifying the optimal match action rules applied to the transport network. Specifically, using actual mobile network traffic statistics (provided by OTE), prediction of per domain resource requirements is performed through FL. The predicted values are sent to the central orchestrator responsible to calculate optimal E2E optimization policies.

## FL-based management

Each segment is managed autonomously

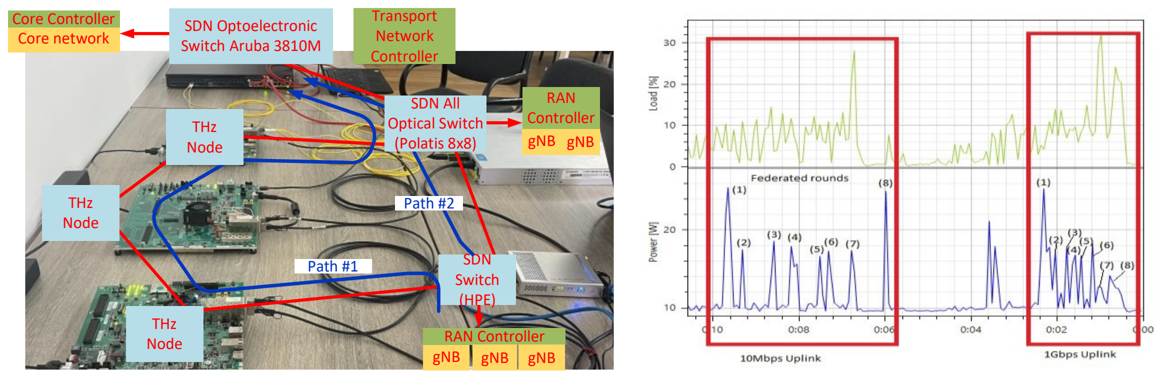


**Fig. 2:** a) Experimental demonstration of multi-technology transport network interconnecting core and gNB, b) Time needed for a FL process to complete for uplink channels with different bandwidth allocation (time in minutes).

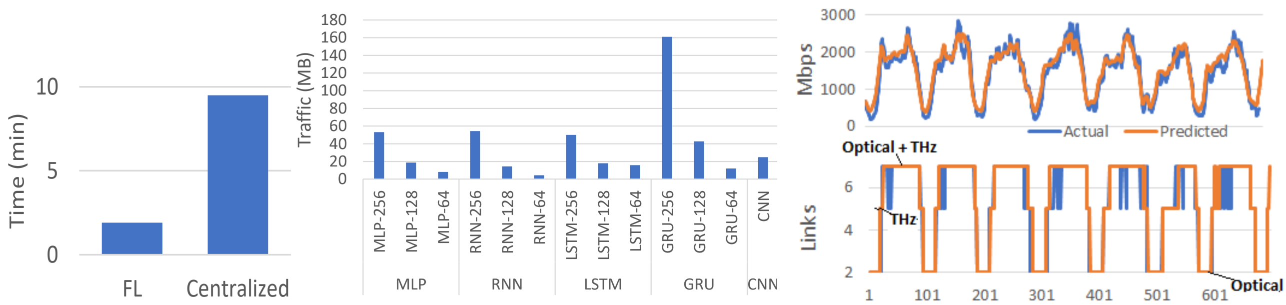


**Fig. 3:** a) Training time for FL vs centralized (MLP, 64) AI, b) Total volume of exchanged information for 10 federation rounds, c) (top) Total Predicted traffic using FL, (bottom) Number of active transport links

through AI-assisted domains. These are responsible to take decisions for a variety of tasks including management of radio and compute resources, prediction of mobile network traffic, etc. Information from local domain managers is combined in a network-wide context and is used by MANO to globally optimize the system performance. To implement "network intelligence" functionality, we adopt a distributed approach (Fig. 1b), where the main decisions are taken in a hierarchical manner. The main parameters of interest for each domain (i.e., resource utilization, energy consumption) are monitored through node exporters while the collected measurements are stored in local databases (DBs). Information stored at each local DB is accessible only by the local (domain) controllers. Based on the local datasets, each domain controller individually trains a Machine Learning (ML) model that for this study performs network traffic prediction. Then the locally trained ML models in the form of prescriptive analytics are transmitted to a centralized server that aggregates the received models creating a new global ML model. The global model is transmitted back to the domain controllers which based on their local datasets create an updated ML model that is transmitted back to the centralized server. The process is repeated for several rounds until certain prediction accuracy is achieved. The predicted network traffic is used as a system resource requirements estimate.

**SDN Control and Management**

To integrate the THz node with the overall system architecture a set of Northbound and Southbound Interfaces (NBIs & SBIs) have been developed. These provide the necessary abstraction required for the integration with the optical network controllers and MANO. The overall architecture of the SDN controller developed is shown in Fig. 1c. The SDN-capable THz controller is able to expose to the orchestrator a set of actions and notifications including: a) its availability for the provisioning of connectivity services, b) details of the internal PHY layer configuration parameters, c) the option to reconfigure the system and change its parameters, d) termination of connectivity services, etc. The system is also able to expose the THz nodes actual network topology graph through the NBI of the SDN Controller. To implement the corresponding functions, the NETCONF Orchestration API has been extended to support the THz nodes (developed by IHP). The implemented NETCONF agent for the THz nodes provides a small set of low-level operations to manage device configurations and retrieve device state information. In the current implementation, the basic operations supported are related to retrieval, change, copy, and deletion of the THz node configuration parameters. This allows to control a variety of THz node parameters (modulation format, frame length, guard length, etc). The NETCONF agent is also able to set up a secure connection with the NETCONF server exposing/receiving all physical parameters of the node in a standardized XML scheme. The THz node has been programmed to operate as an OF "Capable-Switch" and, therefore, being compatible with standard OF controllers.

**Experimental Validation**

To experimentally validate the FL empowered 6G Transport Network we have considered a testbed (Fig. 2a), comprising THz and multi-vendor optical nodes. For the THz nodes, only the data link layer processing units implemented in FPGAs are shown (for more information see [9]). For the optical nodes, both high and low port count optoelectronic switches have been used. The testbed comprised an 8x8 all-optical switch supporting the SCPI) control interface extended to support the OF protocol. gNBs are interconnected with the core network using either THz (with 1.6 Gbps capacity) or optical links (1 Gbps and 10 Gbps capacity).

gNBs generate traffic based on real measurements provided by OTE. In accordance to the proposed FL scheme, data traffic statistics from each gNB are stored locally. These statistics are then used to train local ML models that are aggregated by a centralized controller, creating a new global model that is then sent back to the domain controllers. The whole process runs for several federation rounds until convergence is achieved. Fig. 2b compares the time needed for the FL process to complete. The system has been configured to terminate after 8 federated rounds. For low channel bandwidth (10 Mbps uplink) the interarrival time of the trained ML models reaching the gNBs increases, causing also increase in the time needed to execute the whole process (approx. 4 mins). As the bandwidth increases, the total time to complete the process reduces by 50%. In Fig. 3a, the FL model is compared with the centralized learning model. In both cases, the ML models are offloaded to GPUs. Due to that, FL models split the processing workload in multiple devices, lower training times are required. Fig. 3b shows the total volume of data (metadata) exchanged for different ML implementations and 10 FL rounds. Finally, Fig. 3c shows the total predicted traffic in the network and the resources used (in terms of number of active links) by the system to accommodate gNB connectivity requirements. The optimization scheme used by the orchestrator tries to minimize the total number of active links. Under low demands, traffic is redirected through the optical path (path # 2, active links=2). As the traffic increases above 1 Gbps, the controller forwards traffic through the THz path (path #1, active links = 5). When the traffic exceeds the capacity of the THz links (1.6 Gbps), both paths are utilized to support network demands.

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