Centre Tecnològic de Telecomunicacions de Catalunya

PACKET OPTICAL NETWORS AND SERVICES

1. Vision

Telecom network operators are required to increase the capacity and dynamicity of their optical networks. The traffic is continuously growing (in terms of volume and variance) over decades, and the current research goal is to deploy 1Pb/s optical transport systems with 10Tb/s optical line interfaces (featuring dynamic adaptation) to meet the future traffic demands. This requirement is based on the native scaling of IP routers and router blades at 45% and 40% per year respectively, to support a compound annual growth rate (CAGRs) in the 60% range of Internet data traffic. Additionally, due to novel services and applications, the increase of the traffic variance results in very high peak data rate to be supported. This situation generates the need for exploiting the additional optical spectrum, as well as new high-capacity and agile optical transmission systems. Additionally, packet technologies need to be integrated with the optical networks to provide a converged transport network with more granular and large-scale management of flows with dedicated QoS in support of Mobile (B5G/6G), IoT/V2X and fixed (enterprise, residential) services.

Another requirement is that the aforementioned demand must be met while keeping a similar network cost, since end-users are not always willing to pay more for additional capacity. Currently, optical network equipment is based on proprietary software and hardware solutions. This closed/aggregated model generates vendor islands. In contrast, data center operators have consolidated a well-recognized strategy to reduce costs and increase efficiency based on the use of open and disaggregated white boxes. This facilitates new providers to enter the market, both at the hardware and software levels. Telecom network operators are looking with great interest to open the optical networks and replace the established aggregated/closed optical systems by open and disaggregated ones. This would allow driving the deployment of optical networks in a more competitive and cost-effective way and less dependent on providers for selected upgrades, yet in relies on the development of open and standard interfaces and interconnections. It will also drive the deployment of edge computing (the concept of deploying computing and storage resources closer to the user, due to service constraints such as latency for mission-critical applications) in the optical networks, in order to support B5G/6G and IoT-oriented services.

Network and service management architectures are also evolving to cope with the increased complexity and security requirements of the open and disaggregated optical networks with edge/cloud computing. On the one hand, all network operational tasks and processes - delivery, deployment, configuration, assurance, and optimization - must be executed automatically, ideally with 100% automation (i.e., without human intervention). Zero-touch network automation will allow to operate the network in a proactive way, using predictive and prescriptive analytics based on machine learning that may anticipate to the problems and events, and propose corrective actions. To this end, it will require large scale telemetry from heterogenous packet and optical systems to support real-time streaming of the data. Another challenge is the introduction of cloud-native control and orchestration architectures in optical networks. This cloudification strategy allows fast service delivery and increased efficiency through agile DevOps & automation using continuous integration (CI) / continuous development (CD).

At the security level, telecom operators are used to rely on the vendor's proprietary complete and integrated solutions (e.g., user authentication, end-to-end encryption, intrusion detection, access control). Open networks will offer a unique opportunity to telecom operators, for the first time, to take advantage of the programmability and flexibility of the open technologies to directly manage the security of their networks, rather than relying on a vendor's proprietary solution. Therefore, telecom operators will deploy smart and secured network services with security policies using software defined security. Similarly, trust management will play a key role in the open telecom networks. Trust is a complicated concept with regard to the confidence, belief, and expectation on the reliability, security, integrity, dependability, ability, and other characters of an entity. Reputation is a measure used to assess the level of trust put into an entity. In closed telecom vendors, with few vendors in play, trust management based on the reputation of the vendors was feasible, but it does not scale in a multi-provider scenario. Therefore, telecom operators will require a trustworthy platform where trust can be measured and evaluated, providing evidence of the deployment of the services. Distributed ledger technology (DLT) will play a key role to create a new basis of trust for telecom services in multi-provider scenarios.

Finally, in the quantum era we are facing, reliable information security mechanisms are crucial as well as their suitable integration in the current network infrastructure for optimal resource usage and for a sustainable transition towards future quantum networks and the quantum Internet. In fact, as the security of current and future networks is threatened by the prospect of the quantum computing, it is particularly relevant to consider quantum technologies and quantum secure communications in preparation for the radical technological advance envisioned for future networks. Identifying and designing suitable cryptographic systems and methods, taking into account the impact on the telecommunications infrastructure, are of paramount importance.

To achieve this vision, the Packet Optical Networks and Services Research Unit focuses on three main research lines:

- RL1: Photonic and quantum communication technologies
- RL2: Control and Telemetry of Autonomous Packet/Optical Networks
- RL3: Zero-touch management and secured network service orchestration

2. RL1: Photonic and quantum communication technologies

The research line focuses on the investigation and innovation in photonic technologies and optical communication networks, including quantum communications, to address a sustainable capacity scaling and the need of future optical networks in terms of high-performance, flexibility, agility, cost/power efficiency and security requirements, as well as to face the quantum era, promoting an optimal resource usage and a smooth integration of these innovations in the network infrastructure.

In support of the sustainable capacity scaling and high-performance requirements, it focuses on spectrally (ultrawideband) and spatially multiplexed transmission systems for next-generation open and disaggregated optical networks, covering different network segments. It also includes optical performance monitoring techniques, systems and subsystems (probes) for network telemetry and margin reduction.

To address the demand for bandwidth, flexibility, programmability, as well as the requirements for advanced functionalities, low-cost, low-power consumption, high-integration and small footprint, it focuses on photonic technologies and transceivers for multi-Tb/s capacity adaptation, and photonic solutions for (inter-/intra-) data-center interconnection.

To address security aspects and face the quantum era (in view of quantum networks and future quantum Internet), future projection of the research line is to cover aspects related to optical quantum communications and related technologies (such as the adoption of QKD and quantum cryptography in optical networks) in coexistence with the actual deployed network infrastructure.

High-performance optical transmission and network telemetry systems

- Programmable multi-dimensional transmission systems to support network capacity and bandwidth scaling while efficiently utilizing the available resources and network infrastructure. This includes multi-carrier, wavelength division multiplexing (WDM), considering also ultrawide band (UWB) WDM, polarization division multiplexing (PDM) and space division multiplexing (SDM) systems
- Optical white-boxes and interfaces for future open and disaggregated optical networks.
- High-performance, non-intrusive, flexible and cost-effective monitoring subsystems (optical and opto-electronic probes); AI-assisted monitoring techniques for network telemetry.

Photonic technologies and transceiver solutions

- Suitable combination of photonic technologies (such as novel devices and photonic integrated circuits) and advanced/programmable features addressing the demand for multi-Tb/s capacities and dynamic adaptation.
- Point-to-point and point-to-multipoint, sliceable and (bandwidth/bitrate) adaptive/variable photonic transceivers, and datacenter interconnects, integrating low-cost and power-efficient technologies with reduced footprint.

Quantum communications

- Optical quantum communications with special focus on quantum key distribution (QKD) in optical networks aiming to provide secure network communications (particularly relevant in a disaggregated environment) in coexistence with classical/conventional channels and face the quantum era to promote an efficient use of the available network resources and infrastructure.

3. RL2: Control and Telemetry of Autonomous Packet/Optical Networks

This line addresses research and development on the evolution of packet/optical access, aggregation, metropolitan, and core networks, as well as inter/intra-data center architectures and networking, with special focus on control, orchestration, and telemetry aspects, towards convergent, multi-domain and multi-layer closed-loop and zero-touch autonomous networks.

The research line includes aspects related to traffic engineering and network planning, encompassing analytical methods, experimental (testbed) research as well as algorithms and design methodologies, driven by recent advances such as programmable data plane elements, transmission and switching technologies and technologies in support of B5G/6G emerging services, applications of Machine Learning to network operation.

The line covers a wide range of topics: from low level aspects related to device and pipeline programmability to high level networking such as intent-based, zero-touch and autonomous networking, including new network-oriented connectivity services such as transport network slicing and multi-tenancy.

Functional, Protocol and Physical Architectures for Network Control and (Streaming) Telemetry

- Design, implementation, and validation of Functional, Protocol and Physical Architectures for Network Control and (Streaming) Telemetry for multi-layer, multi-domain and time sensitive/deterministic networks, addressing use cases related to 6G services, and spanning the access, aggregation, metro and long-haul network segments.
- Evolution of Software Defined Networking (SDN), address increasing Security requirements and Traffic Engineering (TE) for Open and Disaggregated Networks enabling the integration of Packet/optical networks into joint orchestration of networking, computing, and storage resources.
- New business models such as multitenancy, transport network slicing or coexistence of classical optical networks and quantum communications.

- Research on hybrid deployment approaches combining hierarchical and distributed solutions, including cloud-native deployments and the usage of DLTs for multi-actor scenarios.
- Joint control of UWB WDM and SDM technologies, leveraging the programmability exposed by data plane technology advances, with functions such as topology discovery, connectivity service management, path calculation and provisioning.

Remote Configuration and Control of Programmable Forwarding Pipelines and Open Devices

- Research on whitebox-based nodes (e.g., ROADMS, BVTs, Packet Switches, etc.) architecture, focusing on the nodes' Network Operating Systems (NOS), and interfaces towards the control plane.
- Development of data models, protocols, and interfaces for device and system configuration, control and monitoring, accounting for technology specific extensions and including the development of prototypes for the corresponding SDN agents.

Design, evaluation and implementation of Generalized Resource Allocation algorithms and heuristics

- Algorithms and heuristics in support of path computation and generalized resource allocation in multi-layer and multi-domain networks, accounting for technology specific constraints such as frequency slot contiguity / continuity, physical impairments, or the integration of new switching technologies and paradigms such as SDM.
- Performance evaluation of the aforementioned algorithms, combining experimental (e.g., testbed based) as well as simulation-based research.

Autonomous Networks

- Development of use cases related to autonomous networks with emphasis on network operation and aligned with industry trends and standard architectures.
- Development and integration of network orchestration, network telemetry and control systems for autonomous networks exploiting hierarchical closed loops.
- Design and validation of Zero-touch network operations with Intent-based networking, data analytics and machine learning models in support of network operation, transport Network slicing and network multi-tenancy.

4. RL3: Zero-touch management and secured network service orchestration

This RL focuses on the zero-touch life-cycle management of secured network services on top of disaggregated packet/optical networks. The RL considers the integration of distributed edge/cloud computing resources, as well as the integration of current Network Function Virtualization (NFV) and Multi-access Edge Computing (MEC) architectures with network slices. Moreover, this RL also incorporates the autonomous end-to-end zero-touch management of network services. Finally, security mechanisms for network service operations will be explored, including the definition of Security SLA, ML-based security services, as well as the usage of Permissioned Distributed Ledgers (PDLs).

Cloud-Edge Continuum integration

- Multi-access edge/cloud computing integration with disaggregated packet/optical network. This shall include the integration of Machine Learning dedicated resources to Edge/Cloud, considering the inclusion of novel computation paradigms such as GPU and TPU, as well as the integration of compute virtualization techniques using Container or virtual machine orchestration
- Transport Network Slicing integration with Edge and Cloud computing, enabling a continuum of resources in a highly distributed network location. Resource allocation mechanisms for this continuum will also be considered.

End-to-end zero-touch management of network services

- Study and analysis of autonomous network mechanisms for providing Zero-touch service management. This includes the definition of novel data models and novel workflows. Including, cloud-native life-cycle management of the multiple network services in support of mobile, IoT, and V2X.
- Multi-tenancy support of the network, with the introduction of a clear set of APIs that support vertical customer's programmability control of network functions and connectivity.
- Digital Twin Networks deployment and operation, using virtualization techniques, with the objective of safely exercise the enforcement of network planning policies, deployment procedures, without jeopardizing the daily operation of the physical network. This research shall include the usage of multiple Machine Learning models.

Centre Tecnològic de
Telecomunicacions de Catalunya

Security and Trust mechanisms for network service operations

- Security Service Level Agreements (SSLAs) provide the means to specify the security requirements or policies and assessing or enforcing their fulfillment to obtain the desired Quality of Service (QoS) from a security point of view. The application of selected SSLAs will provide the required security properties of the network slices that will be deployed.
- Research on Machine Learning based security mechanisms for the enforcement of dynamic physical layer security assessment and mitigation procedures. This also includes the analysis of the necessary platform requirements in terms of distributed monitoring and intelligence placement as well as considering the necessary scalability and reliability related issues.
- Analysis of the applicability and feasibility of trust mechanisms such as Distributed Ledger Technologies (DLT), e.g., blockchain, for multiple network scenarios, including marketplaces, remote attestation, and traceability of the allocated resources. Permissioned Distributed Ledgers (PDLs) will also be explored, allowing for only pre-selected participants to record and validate transactions.