SUNSET: Sustainable Network Infrastructure Enabling the Future Digital Society

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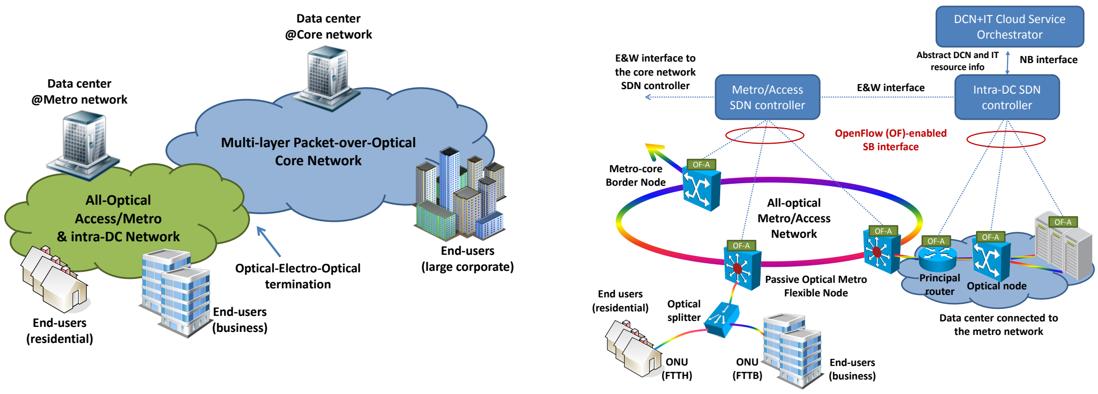
ABSTRACT

The ICT eco-system is constantly growing in traffic demands, with emerging cloud services, mobile and social network technologies to be integrated in 5G networks. New architectural changes at the underlying networks are required to support the traffic volume growth, while providing a high level of dynamic connectivity so that applications are constantly provisioned, released, and moved around. SUNSET project focuses on overcoming the existing bottlenecks of current solutions to provide a successful support of the future Digital Society, paving the way to new-coming cloud ICT services. SUNSET network infrastructure proposes a novel architecture including all network segments (access, metro and core) and data centre network, empowered by advanced optical technologies and SDN, capable of sustaining the growing resource and operational demands of next 5G generation networks.

Keywords: Nyquist Modulation, Faster-Than-Nyquist (FTN), Flexible Optical Network (FON), Passive Optical Network (PON), Software-Defined Network (SDN), Virtualisation

1. INTRODUCTION

During the last 20 years, the Internet data traffic has grown exponentially and is expected to continue this trend, up to the point that over 10,000 million handsets are expected by 2020, fostered by the development of the Internet of the Things (IoT). Such an enormous amount of terminals connected to the Internet, all of them running a wide and heterogeneous set of data applications will push network capacity and flexibility far beyond its limits. Therefore, a new generation of network and IT infrastructures is required, from the access (where users are connected) to the intra-data centre domain (where most applications are hosted), by way of the Access/Metro and Core network segments. The demands not only target ultra-high network, computation and storage capacities, but also unprecedented flexibility and agility in the management of the underlying network and IT resources. To these goals, advanced optical devices, transmission technologies, e.g., optical Orthogonal Frequency Division Multiplexing (optical-OFDM), space division multiplexing (SDM) and switching paradigms (DWDM, FlexGrid) have been proposed, in conjunction with Software-Defined Network (SDN) paradigm, enabling virtualization, user-defined programmable control and management, and innovative Network Function Virtualization (NFV). The SUNSET Project, through the coordination of two multi-disciplinary research teams, focus on investigation, integration and evaluation all these solutions towards the definition of a network infrastructure able to successfully support the future Digital Society.



(a) (b)

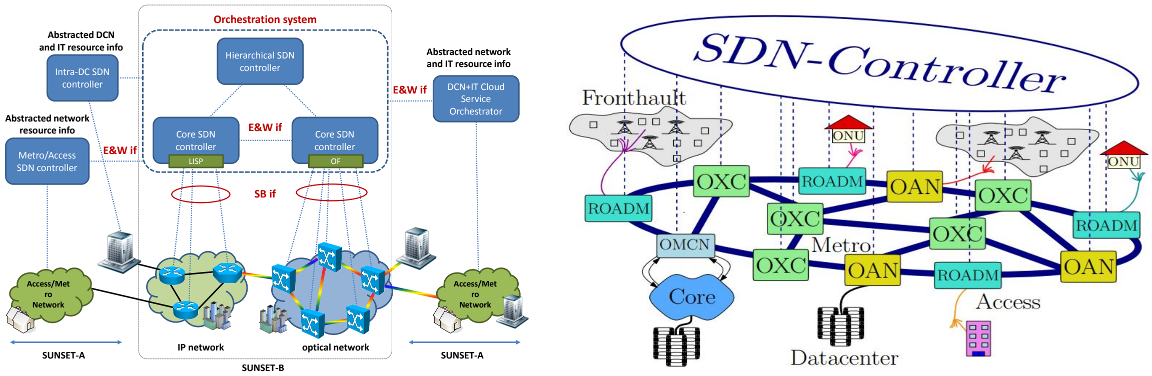
Figure 1. a) Overview of SUNSET project research, containing a general sketch of all-optical access/metro & intra-DC network and multi-layer packet-over-optical core network; b) Detailed sketch of the all-optical access/metro & intra-DC network.

The 5th Generation mobile communication (5G) has been defined in mobile communication context as the natural evolution of currently under deployment Long Term Evolution (LTE), to identify the future needs and requirements in mobile communications by 2020 and beyond and to identify the appropriate radio access technologies and system concepts [1]. Major market and service trends have been identified by 2020. Some of them related with the Internet of Things (IoT) as: multiple personal devices interacting across multiple devices;

entertainment, navigation and traffic information for car, bus, train transportation; remote operation of consumer electronics using personal terminal; use of watch, jewelry or cloths for human interface and healthcare sensors; remote control of facilities for house security; and distributed sensors for smart power grid, agriculture and framing monitoring, factory automation and weather and environment monitoring [1]. Another set of service trends have been identified as a full set of rich content delivery in real-time and to ensure safety, as they are: 4K/8K video resolutions; glasses, tactile internet terminals; remote health check and counseling, distance learning; accidents prevention; robustness and resilience in case of disasters; and in general, all kind of cloud computing services [1]. All those expected services are demanding new challenges for the 5G mobile networks as: an increase by a x1000 factor per km^2, from which it is expected that about more than 70% of this data consumption will occur indoors, that means: homes, offices, malls, train stations, and other public places [2]. Other 5G mobile networks challenges are: an increase of date rate by a factor of x10 to x100; End-2-End latency lower than 5ms; an increase in the number of connections of x10 to x100; and maintaining a sustainable cost and current of better Quality-of-Service [3].

In order to address the 5G mobile networks, technological enablers and design principles have been identify by major companies. Regarding the key expected 1000-fold system capacity increase and the 10- to 100-fold date rate increase, all-optical transmission and switching and all optical networks are pointed out as key technologies [3]. In fact, continuing and increasing the current trend of operators, pico and femto cells and Remote Radio Units (RRUs) are connected to centralized baseband units by optical fibers to improve capacity [3].

In parallel, optical transport networks have continuously evolve during last 20 years, providing an enormous progress in network capacity, topology and functionality, evolving from: the initial 1 to 140 Mbps of Point-to-point links implemented by Plesiochronous Digital Hierarchy (PDH) and Fiber Channel (FC) in 1990s; towards current 4th generation optical networks providing 1 Gbps to 100 Gbps by implementing e.g. Optical Transport Network (OTN), Reconfigurable Optical Add and Drop Multiplexers (ROADM), 100G Ethernet and ring and mesh topologies and fixed grid [4].



(a) (b)

Figure 2. a) SUNSET scenario: Multi-layer Packet-over-Optical Core Network; b) Flexible 5G Metro-Access Network scenario, including: OMCN, OAN, ROADM, OXC, ONU.

Similar to 5G mobile networks, new requirements are driving optical transport networks from static architectures towards more dynamic, flexible, adaptive and energy efficient solutions, referred as 5G optical transport networks [4]. The 5G optical networks are expected to provide trendy services as HD video production, machine-to-machine communication, and 5G mobile networks backhaul [5]. They are challenged to provide capacities in excess of 100 Tbps over single-mode, single-core fibers and even 1 Pbps using Spatial Division Multiplexing (SDM) over few-mode, multi-mode or multi-core fibers [5]; In addition, by deploying network NFV and SDN, the requirements of the cited services can be flexibly provided. Those latest characteristics of 5G optical networks fully answering to the required flexibility for 5G transport networks supporting 5G mobile networks, demanded by companies in the field [6].

Current convergence of 5G mobile and 5G optical transport networks is motivating the design of 5G transport networks in a global view analyzing key architectural and technological for the design of a flexible 5G infrastructure, both providing mobile and fixed end-user broadband services [7].

SUNSET network proposes architectures and technologies addressing the challenges of 5G transport networks as: sustainable cost, high capacity, flexible and elastic network subsystems and network flexibility by SDN controller. A general overview is shown in Fig. 1a, containing both: an all-optical access/metro and & intra-DC network, detailed in Fig. 2b; and multi-layer packet-over-optical core network. Next sections provide further details on the main elements integrating the SUNSET network as: SDN controlled physical technologies for Flexible converged Metro-Access networks; Intra-Data Centre Architectures; Spatial Division Multiplexing; Overlay Programmable Networking; Network measuring and monitoring; and Overall Orchestration shown in Fig 2a.

2. SDN controlled physical technologies for Flexible converged Metro-Access networks

SUNSET approach to the convergence of Metro-Access networks allowing for the flexible establishment of connectivity services across a geographically distributed urban and sub-urban area is depicted in Fig. 2b. In this regard, SUNSET envisages the use of novel optical subsystems designed to give the necessary flexibility to establish connectivity services among heterogeneous actors such as 5G-based radio stations, business, home users and Data Centre (DC) infrastructures. An SDN-based control plane is designed to achieve programmatic control over the network devices, allowing for a dynamic and flexible configuration of the whole network fabric, as well as to configure connectivity services in intra-DC ecosystems. A more detailed description of the novel optical subsystems and the SDN-based controller is provided by [8]. Moreover, SUNSET aims to investigate the utilization of SDM technologies to enable the interconnection of multiple Metro-Access networks with high-capacity core networks. More details about the proposed solutions are discussed in the sub-sections below.

2.1 SDN-based Metro-Access Network Infrastructure

The proposed optical network is composed mainly by five different network subsystems: Optical Metro-Core Node (OMCN), Optical Aggregation Node (OAN), Optical Network Unit (ONU), Reconfigurable Optical Add and Drop Multiplexer (ROADM) and Optical Cross-Connect (OXC). Through their collaborative configuration, it is possible to establish optical connections across the whole Metro-Access scenario. Specifically, the OMCN, OAN, ROADM and ONU nodes allow the transfer of information between the metro and core networks, the metro network and DC/5G-based infrastructures, the metro and access networks, and the access networks with the end user, respectively, while the OXC provides extra flexibility to provide connectivity across the metro network [8]. FlexGrid-based transmission technologies are employed in all nodes in order to better exploit the available spectrum of the whole network fabric, adapt the capacity of the optical channels to the user necessities, dynamically add/remove specific channels to/from the networks and perform aggregation and de-aggregation of multiple optical connections.

The configuration of all network devices is performed through a centralized SDN controller. Essentially, all network subsystems are equipped with an OpenFlow (OF) [9] agent, which translates OF commands to the internal set of instructions for the configuration of each node. In this regard, the configuration of the nodes is performed through the southbound interfaces of the SDN controller, which implements the OF protocol. Thanks to the proper modelling of the network subsystems, the SDN controller can trigger the necessary OF instructions that enable the dynamic configuration of the network. Then, higher entities can request connectivity services across the network through the northbound interface of the controller.

2.2 Intra-Data Centre Architectures

DC architectures are a key element on the whole Cloud arena, allowing to access enormous quantities of information as well as advanced services and applications at any time, from anywhere and from any devices. Due to their critical role, and the increase of the traffic they have to handle, electronic-based intra-DC Network (DCN) fabrics are being replaced by optical technologies. In this regard, the DCN is responsible to bring high connectivity services between servers across the DC infrastructure. To allow for the dynamic configuration of the DCN fabric, SUNSET envisions the incorporation of an SDN-based control plane as well as the inclusion of orchestration solutions for the optimization of the resource deployment inside DC, that is, both connectivity services among servers as well as the configuration of IT resources. This allows to dynamically install/deploy applications on top of the DC infrastructure to be offered as services to end user. Then, through the collaborative efforts of the intra-DC control/orchestration platform and the Access-Metro SDN controller, SUNSET will allow for a dynamic and optimized end-to-end service delivery inside metropolitan areas.

2.3 Spatial Division Multiplexing

Spatial division multiplexing (SDM) is the only foreseen solution to overcome the nonlinear Shannon limit of standard single-mode fibres [10]. Two different SDM flavours are under intensive investigation. On the one hand multi-mode fibres (MMF), also known as few-mode fibres (FMF), take advantage of the orthogonality among the transversal propagation modes of a waveguide to send independent signals. On the other hand multi-core fibre (MCF) technology uses different cores inside the same cladding instead.

Both MCFs and MMFs present some drawbacks that may limit their feasibility. MMFs suffer severe mode coupling requiring the utilization of expensive multiple input multiple output (MIMO) techniques for its compensation. A 30x30 MIMO has been recently reported [11]. On the other hand, MCFs suffer from inter-core crosstalk (XT) which reduces the transmission reach (TR) of signals. Recent research has demonstrated very low levels of inter-core XT for up to 19 cores in long-haul distances [12]. Both concepts can also be implemented simultaneously, i.e., using several multimode cores. This is known as multi-core few-mode fibres (MC-FMF) and some recent experiments have shown up to 114 spatial channels (19 cores x 6 modes) [13].

3. Multilayer Packet over Optical Core Networks

3.1 Overlay Programmable Networking

Overlay networking aims to provide flexible and programmable communications over optical or IP-cores underlays where the main advantage is that underlay networks are unaware of the overlay features, such technologies work very well with legacy networks. Protocols such as VXLAN (RFC7348) or LISP (RFC6830) are becoming increasingly popular for this. For instance LISP operates deploying border routers at the edge of the underlay –commonly referred as xTRs in LISP's terminology- that exchange encapsulated packets over the underlay. LISP also provides a centralized database (referred as Mapping System) where LISP routers pull state information to operate the network. As such, the LISP Mapping System offers a centralized programmable interface to manage and control the network.

In such scenario in the SUNSET project we aim to push the OpenOverlayRouter (OOR) [14] open-source implementation to support rich SDN/NFV scenarios over optical and IP-core network. OOR is a programmable overlay router open-source implementation for the Linux, Android and OpenWRT platforms. For this we need to address the following research challenges:

1) LISP is built around the design principle of a pull-based control-plane, the data-plane elements pull only the required state from the Mapping System to forward packets. However SDN environments require more flexible communication models where the data-plane subscribes to state and it is notified when such state is updated (Pub/Sub). For instance an SDN controller may update the path of a service chain to deflect traffic towards less loaded network functions. In this context we will research how to design and implement Pub/Sub support. The main challenge is that the performance of data-plane heavily depends on that of the operational control plane, as a result the solution must have low latency and, at the same time, be scalable and distributed to support a very large set of data-plane nodes. For this we will study state-of-the-art software approaches designed to provide low-latency real-time data feeds, such as Apache Kafka and analyze its applicability to networking scenarios.
2) LISP forwards packets based on the destination address, as a consequence it has designed hierarchical databases to store mappings (the Mapping System). However typical SDN scenarios operate with non-hierarchical forwarding state, a notable example are source-destination forwarding in VPN. There is a need to research integration of overlay technologies with flat databases that, as mentioned before, provide low-latency, scalability and can be distributed. We will research the applicability of CAP (Consistency Models in Non-Relational Databases) such as Apache Cassandra, and we will explore how they must be adapted to this scenario (e.g., how to incorporate longest-prefix match).
3) OOR currently uses NETCONF/YANG for managing and LCAF for control. The main issue with such approach is that while XML provides a well-defined and flexible language to design and deploy new services, it is too verbose and hence, slow for operational control requirements. On the other hand LCAF offers a compact and low-latency approach, but too rigid to deploy new services. At the time of this writing the LCAF draft defines a few types of mappings but does not provide design guidelines for developers to define new ones. We will research data-modelling language that are well-defined and provide the flexibility and speed required by the operational control-plane.

3.2 Network measurement and monitoring

The main objective of the SUNSET network monitoring element (NME) is to provide continuous information about the global status of the network. This information includes the number of user petitions, their characteristics and the performance exhibited by the network when serving them. Ultimately, the Quality of Experience (QoE) perceived by the end users is the main metric that should drive the decisions in the SUNSET architecture. Due to the lack of a standard approach for network monitoring in the core design of Internet protocols, providing effective network measurement functions is very challenging. Fortunately, SDN opens an opportunity to solve this problem, as it provides a vendor agnostic interface to interact with the network devices and to integrate monitoring functions inside the control plane.

Estimating the QoE from network measurements requires information from the application layer, since different users and applications have different QoE expectations. However, the SDN controller operates at the network layer and can only derive this information from network measurements. The state-of-the-art technology to identify applications from the network traffic (i.e., traffic classification) is based on Deep Packet Inspection (DPI) [15]. DPI technology is expensive and requires access to the full packet stream, including the payload. DPI would thus introduce an excessive overhead in the SDN controller, in terms of processing and bandwidth required between the controller and the network devices.

The most challenging aspect in the design of the NME for the SUNSET architecture is the need to operate under heavy resource constraints due to the ever-increasing traffic demands, network-based services and devices, with little time to process incoming packets. The overhead of such measurement functions in the SDN controller should be minimal in terms of processing and bandwidth requirements. The SUNSET project will investigate much more efficient and lightweight traffic classification techniques, leveraging previous proposals based on Machine Learning for traditional networks [16], and combine them with probabilistic, specialized streaming algorithms and data structures (e.g., sketches, bitmaps, filters) for traffic measurement [17], which have a small memory footprint and CPU requirements. In order to minimize the communication between the network devices and the SDN controller, these algorithms must also be resilient to sampling and operate at the flow level without requiring access to the full packet stream. On the contrary, existing methods for performance measurement are based on active techniques, which require traffic injection and cannot be integrated in the SDN controller. In addition, they do not provide metrics at the connection level, but only averages of the path between the source and the destination, which is shared by multiple users and applications. An early design of the NME of the SUNSET architecture was recently described in [18].

4. Overall Orchestration

The top desire of operators for their infrastructures is 'Service Agility'. That is the ability to support automation across the full service life-cycle for network services that span multiple domains and vendors. Today's networks are able to provide an existing service in more than a week, three months to upgrade or replace network devices, and more than a year to introduce a new service [19]. This is mainly due to 1) the lack of an accurate and global service and resource inventory, 2) an insufficient abstraction and modeling of services and resources, and 3) the use of multiple software systems each with its own model and API's.

To achieve the desired service agility and overcome the above issues, the SUNSET orchestration solution will be in charge of translating external service requests into concrete orchestrated process like end-to-end connectivity provisioning, multi-domain path computations, inter-domain configurations, function provisioning, etc. This automation will lower both the cost and time frames to provide existing and new services.

This orchestration system will operate over the network following the SDN paradigm, through SDN controllers, which expose a given view of the network and IT resources. Such view depends on the relationship between the different actors (network operator, infrastructure operator, service provider, cloud provider, etc.) under the orchestration umbrella. Therefore, the orchestration system may involve both peer-to-peer relationship between SDN controllers for corporate segments and hierarchical structure with a parent controller (see Fig. 2a). The SDN controllers of this orchestration system will be coupled with a monitoring element able to identify the number of user petitions (i.e., connections), their characteristics and the performance exhibited by the network when serving them. Such inputs, that in an abstracted environment cannot be known in advance, will be used to maintain a real-time, centralized, shared inventory system that combines the ability to discover and reconcile all information and drives the decisions of the orchestration system. These decisions will involve both the provisioning of given services when new request arrives and the new paradigm of self-organization. Indeed, SDN provides an unprecedented level of centralization and control over the network since, at its most fundamental level, becomes software. This allows re-thinking the traditional deterministic algorithms targeted in future SDN deployments and taking advantage of artificial intelligence techniques to deploy, operate, monitor and troubleshoot networks.

5. CONCLUSIONS

The paper introduces the overall architecture and optical technologies envisioned in the SUNSET project to provide end-to-end network solutions, to fully support the requirements imposed by emerging 5G-related applications and services. In particular, the SUNSET technological view covers all the network segments and it relies on the cooperation between the novel optical devices and the control and orchestration layer to deploy a programmable infrastructure for the provision of flexible and optimal cloud-based services.

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