Research Trends on ICT Convergence from the CaON Cluster

Sergi Figuerola*, Dimitra Simeonidou, Juan F. Palacios, Andrea Di Giglio, ***Chairs and Co-chairs, CaON***
N. Ciulli, J. A. Garcia, R. Nejabati, X. Masip, R. Muñoz, G. Landi, M. Yannuzzi, R. Casellas, ***Members, CaON***
Converged and Optical Networks cluster FP7Future Networks
**Tel: (34)93 553 2515, Fax: (34) 93 553 2520, e-mail: sergi.figuerola@i2cat.net*

ABSTRACT
This is a positioning paper that presents some of the trends in optical networks, considered within the CaON (Converged and Optical Networks) cluster. The trends exposed are focused on the convergence of optical networks and IT infrastructures, optical virtualisation and the control and management in support of emerging cloud computing applications for the Future Internet. The paper introduces the CaON reference model as a key enabler in support of the Future Internet, and proposes a high level, multilayer architecture that spans from the physical domain to the applications. The CaON reference model is the main outcome of the joint effort between the projects belonging to the CaON FP7 EC cluster, and reflects the level of agreement between all of them. The purpose of this reference model is to present the architecture that the cluster foresees for the Future Internet.

Keywords: bandwidth provisioning, flexibility, scalability, ICT convergence, optical networks.

1. INTRODUCTION

Some of the main trends of optical networks towards the success of the Future Internet involve are seen as the convergence of optical networks and IT infrastructures, in support of emerging new cloud computing applications. These emerging applications require flexible and adaptive optical network services, which are not currently available within the operator's domain. Therefore, there is the need to define a reference model that different projects and research efforts can take as a basis for the development of new technologies. In that sense, this paper presents the CaON reference model as a key enabler in support of the Future Internet. This reference model proposes a high level multilayer architecture that spans from the physical domain to the applications. In fact, this architecture is key for the CaON community, since it provides a common point of agreement for the understanding of future research trends.

While the CaON cluster is covering the research trends across the different layers represented in the CaON reference model, this paper puts emphasis on optical virtualisation, on the convergence of network and IT and on its control and management. The paper is structured as follows: first, it presents the rationale of Future Internet, with the impact that cloud computing and media applications growing demands have on optical networks. This is followed by an overview of the CaON reference model and the research challenges that facilitate the convergence of optical networks and IT. Finally, and based on the previous rationale, the conclusions present the main requirements of the CaON cluster with regards to bandwidth provisioning, flexibility, scalability and ICT convergence.

2. RATIONALE

Optical infrastructures are the physical substrate that historically has enabled the wide deployment of the Internet and continue to be critical for Future Internet. Their flexibility, transparency, capacity, low cost (cost/bit), isolation capabilities and advanced provisioning services make them a key enabler for the evolution and convergence of Future Networks. While Internet has become one of the basic infrastructures that support the World economy networked computer devices are proliferating rapidly, supporting new types of services, usages and applications. In the last years there has been a trend (and a requirement) for a convergence of the different networked platforms towards a unifying architecture or reference model for seamless end-to-end communication regardless of the device technology and infrastructure domain. Particularly, some of these different areas, technologies and innovations at the infrastructure level are going to generate a big impact on the evolution of our society. Thus, the definition of new architectures is a key area of basic research for the coming years, with new technologies at the transport and access networks.

Emerging applications are entering the arena of Telco services with an unprecedented end-user acceptance. Much alike the Internet has settled into daily life, Cloud Computing is making its way towards becoming the invisible stratus on which companies base their IT processes and users get their content. From the infrastructure perspective, it means understanding traffic demands to adopt the technology combination that best fits its support. The introduction of Cloud Services in a massive fashion entails new constraints that may be convergent with the ones that come from the distribution of contents among the network. Here is where the transport optical network will adopt a key role in Cloud service provisioning: it may provide connectivity capabilities for residential and business customers towards the Data Centers and the external Internet, and highly reliable, low delay and high bandwidth demanding interconnections between the cloud/Content Delivery Networks DCs themselves. Thus, to successfully respond to these traffic demands, optical networks must support:

- A high request rate of requests from DCs while the rest of traffic remains unaffected.
- Bandwidth and QoS assurance between end users & DCs (*i.e.* for real time applications).
- QoS enhancement (via better use of existing networks and data centres).
- Flexible networking services enabling on demand fast data transfers.
- High capacity and scalability and costs optimization (DC and network).
- Responsiveness to quickly changing demands and Infrastructure customisation.
- Enhanced service resilience (cooperative recovery techniques).

3. THE CaON REFERENCE MODEL

The CaON reference model (Fig. 1) [1] presents a multi-layer architecture for the convergence of ICT for the Future Internet. This reference model is also the base to bring innovation at upper layers and to enable a real and powerful cloud networked infrastructure deployment, where the optical network can dynamically react to different and new applications behaviour. This is a bottom-up reference model, where the infrastructure and provisioning layers, together with cross-layer SLA and the management, is the key focus for future research trends.

The CaON physical infrastructure layer covers the whole range of optical networks technologies, and provides a virtualisation capability for the virtualisation of optical network resources. This virtualisation capability offers a more flexible way to deal with infrastructure resource utilization by overcoming the multilayer and current network segmentation. It also provides a whole new set of functionalities (flexibility and new dynamic provisioning services) that enable the convergence of optical infrastructures to support cloud services delivery. Besides facilitating the emergence of new business models by enabling the entrance of new players, there are still many research topics that need to be addressed (*i.e.* how isolation is managed and the impact that non-liner effects have on it). The main topic covered in the papers is the provisioning layer, Fig.1. This layer requires a CP architecture that may provide and enable a new set of functionalities like:

- Open CP and enhanced UNI's interfaces with guarantee scalability for multi-domain and multi-technology.
- Automated e2e service provisioning and monitoring between different network segments and operators.
- Network resources optimization by an integrated control of different network technologies.
- Network/IT resources optimization by means of cross-stratum interworking mechanisms.
- Operation over Virtual instances of the network infrastructure.
- Convergence of analogue & digital communications unifying heterogeneous technologies.
- Unified OAM mechanisms able to operate in a complex multi-technology/domain/carrier behaviour.

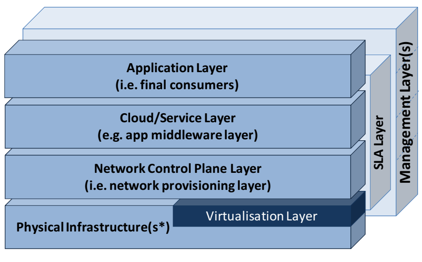

Figure 1. CaON reference model.

The reference model also considers two vertical layers (out of the scope of this paper). These are the SLA and the management layer. The former takes into consideration the mapping of the SLA requirements from the application layer down to the infrastructure resources, while the latter is in charge of extending management functions across the different layers in coordination with the control plane and the provisioning layer.

4. OPTICAL NETWORK CONVERGENCE

The ICT convergence mainly deals with dynamic, flexible behaviour of network infrastructures and the integration of their operation processes with the IT infrastructures systems and services. However, the end challenge is the capability to provide an application-aware infrastructure through a new and well-defined set of Network/Infrastructure Service Interfaces. Actually, the dynamicity of those applications and collaborative group environments require that such infrastructures are provisioned on demand and that are capable of dynamic (re-) configuration [2]. Such environments also require mechanisms to optimize the resource usage and to reduce the service provisioning time, which so far is still manual and implying large delays compared to application service needs. Thus, the availability, performance, security and cost-effectiveness of application-aware infrastructures remain critical, as they support business decisions and data in a fast-paced, economy-driven environment.

Currently, the provisioning of services over hybrid infrastructures (composed of both IT resources such as computing or storage as well as high capacity optical networks) need unified management. This also means that the usage of cognitive, flexible, elastic and adaptive technologies for optical networks, both at the metropolitan and core network segments, with dynamic control plane functionalities and software defined networks (SDN) [3] procedures for the whole integration with the DC network infrastructures, is a must. SDN gives the owners and network operators a better control over their networks, allowing them to optimize the network behaviour to best serve their and their user's needs. However, current disjoint evolution has ended up with totally decoupled solutions for each type of resource and infrastructure. Therefore, there is a key technical challenge towards this ICT convergence: to optimize the (i) infrastructure sharing for lowering OpEx/CaPex, and (ii) the (dynamic) services and applications deployed on top of hybrid infrastructures with energy considerations.

4.1 Management and control planes convergence

Management and control planes convergence is required for future-proof and Internet-scale enterprise applications. Distributed applications require ICT convergence in order to optimize the service workflow and the overall performance for cloud computing. Dynamic provisioning of one type of infrastructure resources only considers part of the problem, and typically leads to a waste of resources due to over-provisioning, mostly in networks, and sharing limitations in all kinds of resource usage. The challenge is on providing a common and transparent infrastructure, able to integrate different technologies and services, where virtualisation is not the end solution but an adequate technique for overcoming many limitations. Some future research considerations are:

- Unified and converged resources description languages and frameworks.
- Multi-granular, cognitive, elastic and flexible adaptive optical networks (*e.g.* HW configuration).
- Isolation and flexibility of circuit oriented networks (resource virtualisation).
- Definition of the impact of these new technologies on legacy business models.
- Inter-administrative domain issues between networks and DCs.
- Non-standard service provisioning (Alien wavelength services).
- Carrier grade cloud and DC integrated infrastructure services.

4.2 Optical network virtualization

Current physical infrastructures are mainly constrained by the amount of resources they can deal with, and this has to be solved. New Infrastructures will be composed of heterogeneous resources that allow the delivery of any type of service between different nodes. Resources like network elements, connectivity, storage and computation are those that take part as core elements of the physical substrate and enable the creation of cloud infrastructures. The challenge, however, is on the level of flexibility, automation, optimization and transparency to deliver a service and the need to map the abstraction (virtual representation) of physical resources and network topologies with the applications and service requirements. Virtualisation will help on overcoming the multilayer and current network segmentation. Thus, it will bring the envisaged flexibility and transparency for the network infrastructures, with the capability to virtualise the physical network infrastructure, federate resources from different providers, and provide the needed open interfaces, Application Programming Interfaces and Software Development Kits to allow that control and management planes deliver any type of service, independently of the physical substrate. One of the main challenges behind virtualisation is isolation, that is, the virtual resources must be isolated from each other. Isolation and coexistence are the two most important characteristics of virtualized optical networks. It is because they will be concurrently managed and operated, and will share the same physical substrate. At the analogue domain, optical network virtualization is expected to be a key technology for addressing future global delivery of high-performance network-based applications such as Cloud Computing and DCs connectivity among others. Unlike L2 and L3, optical network resources and transport formats are characterized by their analogue nature. Optical layer constraints, such as wavelength continuity and physical layer impairments (PLIs) differentiate optical and other network resources. Therefore, future research should take into account the physical characteristics of optical networks and its implication on network elements and transport technologies, and how coexistence of analogue and digital systems is provided.

5. CONTROL PLANE EVOLUTION

The Future Internet growth is enabled not only by the bare optical transport technologies with enhanced capabilities, but also by the control plane (CP) tools and procedures that can guarantee the related provisioning, monitoring and survivability of the involved resources and services. The research in network CP is currently focused on consolidating the control procedures adopted for the underlying optical infrastructure, and on extending a generalized (single-instance) control approach to include more and more technologies. Both objectives involve different architecture aspects with different degrees of maturity: they can range from evolutive extensions to the control plane protocols when there is the need to incorporate new advances in optical data plane technologies (such as new Optical Transport Network multiplexes or grid-less networking) [to radically new approaches], and can scale up to more extreme and demanding interactions between the CP and the network service layer for controlling new types of enhanced connectivity services. Additionally, since optical networks represent the core substrate responsible for inter-carrier data transport, other key research topics addressed in this area include possibly standardized multicarrier and multivendor control solutions to make more effective and open the current implementations. Some trends in the current CP evolution are:

• Opening the control plane domains towards true multi-vendor and multi-carrier scenarios.
• Decoupling of the optical transport from the control plane(s).
• More flexible and powerful User to Network Interfaces (UNI); *i.e.* equipping the control plane with more advanced interfaces to external end-user "systems" (*e.g.* clouds) for any type of BoD provisioning service.

6. Evolution in Optical Networks towards cognitive and self-managed networks

Next generation optical networks will progressively deploy cognitive technologies, becoming cognitive optical networks. In short, this term refers to networks that are able to learn, optimize and adapt themselves in reaction to state changes with little to no (operator) intervention. Clearly, the adoption of such technologies will have strong implications and impact on the data, control and management planes. It is noteworthy that Cognitive Optical Networks are becoming feasible thanks to the adaptive capabilities of both HW and SW components.
Specific examples of dynamic adaptation involve optical transmission (with software-defined /cognitive transceivers with learning-capabilities) as well as optical transport (with cognitive framing and encapsulation) and optical switching (with self-flexible and adaptive on demand switching, leveraging the new grid-less spectrum management paradigms and approaches). Current and in development technology capabilities, such as format transparent wavelength or signal format conversion, regeneration or network-wide optical frequency/time/phase determination, will support the realisation of such cognitive functions. Moreover, hardware programmability may also turn state-of-the art optical modules into cognitive-enabled optical system.

Further research should be focused on developing an open platform to dynamically re-purpose, evolve, self-adapt and self-optimize functions/devices/systems of the optical network infrastructure. An open platform for these optical/opto-electronic technologies would allow for environment-aware, self-* systems that can change any parameter based on interaction with the environment with or without user assistance. New control and management plane architectures, protocols and algorithms should support highly flexible cognitive future optical infrastructure in a heterogeneous optical environment.

7. CONCLUSIONS

The main research topics that optical networks should address, with regard to the topics presented, are:

Optical Network and IT convergence for enabling high performance: Service provisioning over hybrid infrastructures composed of both IT resources (*i.e.* computing, storage, data centres) and high capacity optical networks. It will require the capability to virtualise the physical optical network infrastructure independently of whether the physical substrate is analogue or digital and to federate resources from different providers. It also needs unified management and provisioning procedures, including considerations for dynamic CP functionalities and SDN procedures for the whole integration with the IT network infrastructures.

Optical network control plane: (i) true multi-vendor and multi-carrier control plane solutions, (ii) Split architectures that decouple the control plane intelligence from the optical transport equipment – depending on the split point, several architectural options might support this (*i.e.* OpenFlow as an open, vendor-independent interface to network data plane; multi-technology and multi-domain path computation services), SDN at large., (iii) enabling control plane interfaces to external end-user "systems" (*e.g.* clouds) for any type of bandwidth-on-demand provisioning service, and above all seamlessly integrated with the service layer workflows.

Cognitive, self-managed optical networks: Development of technology platforms to dynamically re-purpose, evolve, self-adapt and self-optimize functions/devices/systems of the optical network infrastructure. Research should focus optical/opto-electronic physical layer technologies that would allow for environment-aware, self-x systems that can change any parameter based on interaction with the environment with or without user assistance. Research on cognitive control and management plane should enable network-wide infrastructure dynamic self-adaptation, self-handling across heterogeneous systems.

ACKNOWLEDGEMENTS

The authors acknowledge all the projects and members of the CaON FP7 EC cluster for their discussion, support and contributions to the CaON white paper, and specially GEYSERS (ICT-248657), STRONGEST (ICT 247674), MAINs (ICT-247706) and ONE (ICT 258300).

REFERENCES

[1] CaON cluster members: The CaON research challenges (white paper). http://caon.i2cat.net/
[2] G. Landi, N. Ciulli, J. Buysee, K. Georgakilas, M. Anastasopoulos, A. Tzanakaki, *et al.*: A network control plane architecture for on-demand co-provisioning of optical network and IT services,. in *Proc. FNMS 2012*.
[3] S. Azodolmolky, R. Nejabati, E. Escalona, R. Jayakumar, N. Efstathiou, D. Simeonidou: Integrated OpenFlow-GMPLS control plane: An overlay model for software defined packet over optical networks, in *Proc. ECOC 2011; Geneva, Switzerland, Sept. 2011.*