Computer Networks 92 (2015) 211–217

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Operational, organizational and business challenges for network operators in the context of SDN and NFV

Luis M. Contreras [a,*], Paul Doolan [b], Håkon Lønsethagen [c], Diego R. López [a]

[a] GCTO Unit, Telefónica, Ronda de la Comunicación s/n, 28050, Madrid, España
[b] Office of CTO, Coriant GmbH, St.-Martin-Straße 76, 81541 München, Germany
[c] Telenor Research, Telenor Group, Snarøyveien 30, N-1360 Fornebu, Norway

ARTICLE INFO

Article history:
Received 31 October 2014
Revised 29 May 2015
Accepted 23 July 2015
Available online 20 August 2015

Keywords:
SDN
NFV
Operation
Organization
Business

ABSTRACT

Traditional operators deploy and operate telecom networks that rely on monolithic network elements that incorporate distinct network functions and implemented with a vertical integration of control and data planes. This mode of operation is transitioning towards a new situation where the control plane is separated from the data plane, and the network functions are no longer tightly bound to specific elements in the network. The two paradigms pushing in that direction are Software Defined Networking (SDN) and Network Functions Virtualization (NFV). This paper presents a number of challenges that traditional network operators must adapt to during this transition. We categorize these challenges using three important dimensions for telecom operators: operation, organization and business.

1. Introduction

Software Defined Networking (SDN) and Network Functions Virtualization (NFV) are two major trends in the telecom industry today. SDN proposes decoupling the control and data planes in network equipment (NE) and logically centralizing that control while leaving the NE to forward traffic, and enforcing policy according to instructions received from the controller. This makes the network programmable in a way that promises to be more flexible than the current managed paradigm. NFV, on the other hand, envisages the instantiation of network functions on commodity hardware, breaking the monolithic approach of functional software and hardware that exists in today's vendor offerings. Although they are separate initiatives it appears that SDN and NFV are complimentary; one prevalent view in the industry is that 'SDN enables NFV'. Undoubtedly these new trends will change the telecom industry in many dimensions. While the technological impacts have and are being extensively studied (refer to [1] and the references inside for SDN, and [2] for NFV), the implications of these changes on network operators have not received the same attention.

This paper provides an overview of the challenges facing operators in adopting SDN and NFV in production networks. In the following sections we cover three main dimensions of those challenges: operational, organizational, and business issues. The motivation of this overview is to spur further research and analysis and, we hope, the development of innovative responses to address them. We summarize these challenges in Table I and include our initial assessment of their relative significance.

2. Operational challenges

This section covers the challenges that relate to operator activities concerned with the building and operation of networks.

* Corresponding author. Tel.: +34654966027.
E-mail addresses: luismiguel.contrerasmurillo@telefonica.com (L.M. Contreras), paul.doolan@coriant.com (P. Doolan), hakon.lonsethagen@telenor.com (H. Lønsethagen), diego.r.lopez@telefonica.com (D.R. López).

http://dx.doi.org/10.1016/j.comnet.2015.07.016
1389-1286/

Table 1
Summary of identified challenges.

Dimension	Area	Challenge
Operational	Network planning	• Comprehensive network resource planning • Multilayer planning tools
	Network deployment	• Increased testing and product homologation • Risk of overinvestment in data center infrastructures • Criticality of data centers and need for highly secure infrastructures
	Supportive systems	• Integration with existing OSS/BSS systems • Relies on Open Source developments
	Network operation	• Standardization of open interfaces that facilitate uniform control and management across technologies and vendors • Control plane resiliency • Network automation • Decoupling of service from transport
	Service provisioning	• Mapping between service requirements and network capabilities • Common APIs and information and data models
	Investment protection and migration	• Coexistence with legacy networks
Organizational	Departmental organization	• Cross-technical and cross-functional reorganization of departments
	Skills and know How	• Multidisciplinary teams
	Partnership ecosystem	• Larger number of partners requiring more coordination and management effort
Business	Analytics	• Correlation of decoupled service and transport indicators • Big Data analytics for predictive actions
	Customization	• Standard interfaces for network service and resource consumption • Isolation and security • Proper billing mechanisms
	Network and IT equipment Lifetime	• Re-programmability of equipment to extend the service lifetime
	Procurement	• Management of a larger number of vendors • Definition of new quotation models to compare prices and solutions respect to conventional products • Definition of new guarantees
	Capabilities for sharing network infrastructures	• New business models for infrastructure and capacity sharing • Impacts of regulation
	Innovation and experimentation	• Creation and maintenance of innovative teams

2.1. Network planning

The appearance of both NFV and SDN change the design rules and common practices used in today's networks.

The dynamic invocation of network functions enabled by NFV will change the traffic patterns, the traffic engineering (TE) requirements and the need for quality of service assurance across the network. The traffic patterns will certainly be different from those we have experience with, and they may become less predictable; in any case we believe the changes will complicate the network planning and operation tasks. In response to this, traditional planning approaches like over-provisioning of capacity are not an economical option. Over-dimensioning network links to accommodate traffic where the peak load varies widely and changes frequently creates a significant Capital Expenditure (CapEx) inefficiency. An alternative is that new, on-demand, transport control and traffic management mechanisms will have to be put in place to create a network that adapts dynamically offered load.

Today's conventional networks or, more accurately, the traffic loads presented to them mean that overprovisioning, while not optimal, is tolerable. It is certainly common practice. We believe that SDN and NFV will enable new services that, in response to increasingly diverse customer and application needs, will generate greater and more variable traffic loads. It is in this context that we see SDN and NFV as being among the key catalysts for introduction of smart and dynamic traffic engineering into operator networks.

To face this challenge we think on network programmability as key feature of SDN that can permit new ways of resource optimization by implementing sophisticated traffic engineering algorithms to go beyond the capabilities of contemporary distributed shortest path routing. In addition, multilayer coordination can help to rationalize the usage of technological diverse resources for a common purpose. This new way of planning and operating networks requires a comprehensive view of the network resources and planning tools capable of handling these multilayer problems. An optimal planning process and tool chain then becomes multi-dimensional and multi-layered and has an important impact on operational cost and flexibility.

2.2. Network deployment

The traditional cycles for the deployment of new NEs in existing networks are long. A new NE or technology is first tested extensively to ensure compatibility with already deployed systems. Once validated new equipment can be introduced and integrated in the network. Conventional product homologation is done simultaneously and in an integrated way for both the control and forwarding plane; they are, after all, both present in the same NE in the current model.

The new situation, with separation of planes in SDN and separation of function from device in NFV, means that the homologation of new products to be deployed in a network should change and adapt to this new reality. For instance, in the SDN case, control plane interworking e.g. of SDN controllers, must be assessed not only with the rest of the control elements in the network (controllers, orchestrators etc.), but also with all the different forwarding devices that they will control. In the NFV case, a new network function should be checked against the infrastructure that will support it (hypervisors, servers, etc.) in addition to testing interworking with complimentary functions present in the network. Finally, if the operator decides to deploy conventional and virtual versions of the same function, both implementations should be tested in a coordinated fashion.

With respect to commissioning, NFV will definitely change the way network functions are deployed in the network. Leveraging preinstalled computing resources, deployed in data centers (DC), will accelerate the setup and running of these functions in the network. Site survey, cooling, cablings, and the rest of preparation for the technical environment are no longer necessary, avoiding site preparation delays. However, the DC investment must be done in advance, when there is not yet a clear demand and here is therefore some uncertainty and risk of overinvesting. The modular approaches for building data centers can mitigate this risk to some extent. Telecom network infrastructure is evolving towards the support of distributed cloud-computing services [3]. Some applications are bandwidth intensive and/or latency sensitive which favors the distribution and placement of resources close to the points of traffic consumption, while others have more intense compute resource requirements and in consequence can benefit from large scale resource concentration. Therefore large data centers will co-exist with micro-DCs placed in selected core locations to accelerate content delivery, reduce core network traffic, and ensure lower latency [4].

Multiple users (either internal or external to the operator) will use the same infrastructure that should be prepared to absorb their changing demands while satisfying committed SLAs.

Resource and energy usage are important aspects of the efficiency with at which a network operates. Since service availability differs according to customer and application needs we can use SDN and NFV to orchestrate a mix of service availabilities that trade efficiency (cost) against degree of protection (robustness).

Finally, the criticality of the DCs employed in the new model requires the implementation of strict and broadly based security measures.

2.3. Support systems

Both SDN and NFV rely extensively on software. This becomes clear in SDN since all the control capabilities are implemented in software programs running on the (logically) centralized controller. In the case of NFV, in addition to the software realization of the network functions themselves, capabilities for both control (e.g., for service chaining) and orchestration (e.g., of data center resources) are needed for deploying the virtualized functions in the network.

All these software components have to be integrated smoothly with the Operation Support Systems (OSS) and Business Support Systems (BSS) systems of running networks [8]. This integration should cover not only the Fault, Configuration, Accounting, Performance, and Security (FCAPS) framework [5], but also the inventory of the network. This is important because the decoupling of functions from devices alters the current way of performing service inventory in addition to increasing its dynamism. The conventional relationship between service and network device that exists at the moment disappears. Whereas the inventory of the services was directly inferred from the supporting network device now the advent of NFV breaks that binding.

In addition, the processes of assurance and fulfilment may now occur at different times. For instance, configuration and activation (including forwarding rules) of virtual network functions might be done weeks after the instantiation of such virtual network functions to a given network infrastructure (for instance, because some threshold motivates scaling out the network function).

It is almost certain that any deployment of SDN and/or NFV will include Open Source (OS) software. Indeed many Tier-1 network operators are involved in or sponsoring organizations dedicated to producing software artifacts precisely for this purpose. OpenDayLight [6] and OPNFV [7] can be considered examples of that movement. This is a fundamental change from the present mode of operation (PMO) where vendor proprietary software is the norm. The use of OS software affords advantages but presents significant challenges as well. One frequently quoted advantage is the ability for operators to develop features on their own, more quickly than their vendors can and thereby achieve shorter time to market with new services or capabilities. For many operators this involves a potentially significant change to their organizational skill set; they must become SW developers with all the testing, integration, quality assurance, maintenance and other SW lifecycle activities that entails. The OS software complements this transition by providing many pre-built components of SDN and NFV infrastructure but challenges it in that there is a need to manage the relationship with the OS community that develops these components and, unlike the vendors in the PMO, there is no telephone hotline line to call when something goes wrong.

How the OS developments can complement or to some extent substitute the existing core OSS and BSS systems is not yet clear. Most likely these solutions will be integrated through standard interfaces to provide certain capabilities of management and control over the programmatic infrastructure and the virtualized functions, but yet relay on conventional systems for certain other functions (e.g., billing).

2.4. Network operation

Multi-service networks today are composed of a variety of transport technologies. End-to-end path provisioning requires that control and management capabilities to be present for all the technologies employed on the path. Today there is no integrated way of operating this diversity of technologies in a common way. A uniform control and management capability across multiple technologies and network layers would tremendously simplify the operation of new networks.

Furthermore, for each technology or network layer, a number of vendors are typically found in a single network. This implies different implementations of the same concepts and standards, which are not always totally compatible because of specification gaps and proprietary differentiators.

In this situation the network programmability concept of SDN can, when used with suitable models and abstractions, provide common ways of operation independent of the technology or vendor thus simplifying network operations. The standardization effort in this case has to focus on defining open interfaces, often referred to as Application Programming Interfaces (APIs) or North Bound Interfaces (NBIs), and appropriate models to allow interoperability.

Controlling and operating a network using logically centralized control as envisaged in SDN, allows increasing the level of automation of network operations. Self-learning and self-healing capabilities can be expected to be developed for facilitating the operation and maintenance of the networks based on those controllers, minimizing manual intervention.

In this increasingly automated environment it will be extremely important that the control elements behave predictably, deterministically and are free from malfunction.

Furthermore, the centralization of control decisions could impact operational reliability if proper resiliency mechanisms are not employed. For instance there are stringent synchronization requirements for databases containing network and connection status that must be met in order to avoid data inconsistency.

The emergence of NFV also presents a fundamental change in the paradigm of network operations [8]. While the network function itself remains the same, the supporting infrastructure radically changes, transforming the operation from network oriented to cloud-oriented. This brings new concepts to the operation of a telecom network such as multi-tenancy, workload migration and the virtual binding of physically separate elements.

In the new model, the operations now include computing and storage as well as networking. Problem tracing, troubleshooting and backup activation all now change, requiring the production of new contingency plans and new guidelines for network operation. As an example, alarm handling and correlation has to be revisited to reconcile the current monolithic and the new virtual approaches under a common operational model. The transition to the new mode of operation will have to consider failures in the IT infrastructure itself separately from failures of the specific network functions.

2.5. Service provisioning

Service provisioning will also be impacted. Programmable transport capabilities and function instantiation together break the service creation determinism observed in the PMO. If the service is actually decoupled from the transport network then a new level of abstraction has to be defined, in this case at service level, to allow the operation of the service, either at its creation or during maintenance.

The capability to dynamically instantiate services makes it necessary to ensure a proper mapping between service requirements and network capabilities. Mechanisms for exposing such capabilities have to be developed and procedures for negotiating service SLAs have to be defined to ensure that the service delivery is not affected by the underlying network, independently of where the service is instantiated. These mechanisms and procedures should include information relative to service verification, maintenance, and accounting.

Common APIs, programmatic interfaces and information and data models have to be developed and standardized to facilitate the proper abstractions required at both service, resource, and device level.

2.6. Investment protection and migration

The introduction of SDN and NFV into existing networks will occur progressively or perhaps selectively i.e. in some parts of the network but not others. This is not just a matter of SDN/NFV product availability; current assets in telecom networks will continue to be amortized for investment protection. In consequence these two new approaches will have to coexist with conventional networks and technologies for a long period. There is then a need for interworking between conventional and SDN/NFV systems, without impacting service during the migration period. That interworking has to be implemented for both the control and forwarding planes. During this migration phase the network should behave as it does now while, at the same time, allowing incremental deployment of the new possibilities due to SDN and NFV.

3. Organizational challenges

In this section we analyze the impacts of the introduction of SDN and NFV on operator's organization.

3.1. Departmental organization

A typical operator's technical organization is structured in departments (e.g., network architecture, engineering and planning) which are divided into technological silos (e.g., service platforms, IP, transmission and radio). The advent of SDN and NFV will shake this structure since both the departmental frontiers and the technical boundaries become blurred. This traditional structure has to be re-adapted to the new cross-technical and cross-functional reality brought about by both innovations.

For instance, the technical teams will deal with multiple technologies like IT and optical transport resources simultaneously. As another example, an engineering decision on concentrating several functions on the same server can produce impacts on the planned network capacity reaching the hosting data center and the service architecture previously defined.

3.2. Personnel skills and know how

As mentioned before both SDN and NFV heavily relay in software. The work with these technologies will require professional profiles that include familiarity with IT technologies as a complement (not a substitute) of the current Telco-oriented skills widely present in the operator's staff. Multidisciplinary teams will need to work together to accomplish all the operational functions described in the previous section.

Aligning these employees' diverse experiences and skills to focus on how things affect customer's services will require special attention and coordination.

3.3. Partnership ecosystem

Traditionally operators have relied on equipment and system vendors to create and develop their networks. Monolithic boxes and solutions hindered the development of a broad partnering ecosystem. This situation is now changing.

NFV and SDN have the potential to change the vendor and supplier community with which an operator engages. Both technologies have the potential to enable new market entrants and both have spawned extensive standards development and Open Source software activities. New specializations may emerge in the ecosystem; we may see companies that specialize in control plane software and others that build the (white box) hardware it runs on, and yet other may specialize in testing and validating network functions and their integration from a vendor neutral point of view.

All of this may increase the number and dynamicity of relationships that have to be managed between an operator and the vendor ecosystem, which will require an additional effort for partner management from the operator side.

4. Business challenges

This last section of our work introduces challenges present in the business arena, some of which are related to the commercial sustainability of telecom operators.

4.1. Analytics

Information about the habits and network resources usage of customers is important for the development of new and advanced services. Detailed information can be obtained today, but the collection of that information is based on the deterministic steering of traffic towards the collection functions build on top of monolithic boxes.

NFV will change such determinism because of the dynamic instantiation of functions. In such situation the traffic pattern changes as the functions act as traffic attractors. While the service plane is logically maintained, the transport plane usage can change. In consequence, the collection of information has to consider both planes to present a consistent view; dataplane usage is a function both of what services the customer uses and of where the network chooses to instantiate those services, and both of them change over time. This consideration applies to billing and to accounting processes as well.

In addition, Big Data analytics for processing the data collected from computing, network, and services can help to optimize the usage of the network and DC resources in a predictive manner. Dynamic traffic engineering or virtualized network function reconfiguration are examples of actions that may benefit from the utilization of Big Data techniques.

4.2. Customization

SDN enables programmability of the network, this can allow, or simplify, the provisioning of services both by the operator or triggered externally by the customers i.e. on-demand network service consumption. To support such flexibility the transport network needs to be dynamic, allowing reconfiguration of network elements and changing their behavior without impacting other services in place.

The ability to program and reprogram the network requires the development of standard APIs both toward the customer, whose applications should not have to change because of modification in the network, and toward the dataplane which needs to remain independent of flux in the higher (software) layers of the network.

From the perspective of NFV the possibility of instantiating functions on demand provides an agile and personalized way of managing services. However since the underlying infrastructure is shared, both isolation and security are important considerations.

In both cases, billing capabilities that incorporate actual resource usage are required.

4.3. Network and IT equipment lifetime

The equipment deployed in current networks has specific lifecycles defined by vendors according to their roadmaps and product development strategies. Two main milestones characterize the time when equipment replacement becomes a concern: the End-of-Sale (EoS) and the End-of-Life (EoL). The former indicates the time when new units of a given equipment cannot be acquired directly from the vendor, while the latter refers to the date from where the equipment is no longer supported by the vendor. Normally network equipment is exploited by the operators long after the EoL date.

SDN can help to extend the lifetime of hardware assets in networks by allowing (re)programming and this will probably be used in combination with relocating the equipment according to throughput and functional demands.

In contrast, commodity IT equipment usually offers shorter lifecycles with increasing performance in terms of compute processing, storage capacity, power consumption, space, etc. Newer hardware is better able to accommodate network functions in terms of processing and number of functions supported. NFV support will be a driver to renew IT equipment as the trend to virtualize network functions continues.

4.4. Procurement

SDN and NFV will result in an *atomization* of the components – both hardware and software – that must be acquired by network operators. Where previously one single product with specific hardware supported a number of features, in the future there will be a component integration approach, where the desired operational features are the result of combining a collection of elements (atoms) with necessary integration. As we noted earlier SDN and NFV initiatives increase the number of potential vendors of these system components (atoms).

Current monolithic NEs are easily compared in terms of throughput, number of ports, computing and switching capabilities, etc., and operators have significant experience with this. In comparison the benchmarking of software systems is more difficult and is dependent of the supporting hardware, so new evaluation methods will have to be developed.

The solution pricing models have to be revisited. In principle SDN offers NE simplification potentially lowering the price for accomplishing the forwarding functions. At the same time the new centralized control plane will have costs associated with it that should be considered in the overall picture. The promise is that the combined costs of control and forwarding plane grow at less than the linear (with capacity) rate we have experienced until now. Similar considerations apply to NFV. When doing cost vs. benefit analysis care must be taken to make sure that virtualized functions actually are functionally equivalent to their legacy NE based counterparts. Apples must be compared to apples and not to oranges.

The contractual guarantees required of vendors also need to be re-defined. Identifying, assigning responsibility for, and replacing failed hardware units is relatively simple. Even identifying failure is more difficult in the software arena, as is assigning responsibility, especially when the software in these systems can come from multiple vendors, contain Opensource components and indeed code written by the operators themselves. Management of the anticipated short development cycles in these complex environments also poses a new challenge which needs to be addressed.

Finally the management of spare parts is also impacted. The commoditization of the hardware can reduce the cost of elements in the network however, those elements have to be fully interchangeable and, for example, support in service replacement and upgrade. What is really required is commodity hardware built to rigid specifications and benchmarking; simply specifying processor architecture for example, is not enough.

4.5. Capabilities for sharing network infrastructures

The sharing of network infrastructure between operators is now common practice as a means of reducing investment while still allowing the provisioning of service over a broad footprint.

Once again SDN and NFV might simplify the present mode of operation. Currently the sharing agreements on a common infrastructure require manual configurations to route traffic appropriately towards the infrastructure of each of operator participating in the agreement. This static configuration of resources lacks the flexibility to quickly react to changing demands. SDN and NFV can play a significant role in providing agile mechanisms for sharing, bringing to the network infrastructure the idea of multi-tenancy that exists today in data centers. To make that possible new business models for infrastructure and capacity sharing and usage should be investigated. Regulation can play also an important role in this, perhaps imposing additional requirements on the kind of interfaces to be offered among operators for interchanging control and management information.

4.6. Innovation and experimentation

It seems beyond doubt that the flexibility offered by both NFV and SDN will foster service innovation and may also help shorten the current time to market cycles. The network will be turned into a moldable environment where new concepts and ideas can be tested more rapidly than at present. The time between service inception and service deployment will be reduced, and dependencies on monolithic boxes and closed solutions will disappear.

In the same manner, it will be possible to revert to a previous service easily, then lowering the impacts in case of failures or misbehavior of new features and functionalities, with the benefit of avoiding investment in specialized equipment that can finally demonstrate not to be useful.

Concomitantly it will be possible to easily revert to a previous service, which lowers the impact of failure or misbehavior of new features and functionalities. This may also reduce speed the introduction of new services since it reduces the possibility of assets with fixed functionality being stranded by changes in service requirements.

This openness and flexibility may also help operators to test self-developed service prototypes easily on their own infrastructure (in controlled or in production environments) with full production solutions being developed later by partner vendors.

The challenge for an operator in this context resides in maintaining innovative teams (both technical and commercial) to develop differentiating services.

5. Conclusions

This paper surveyed a number of challenges introduced by the new paradigms of SDN and NFV in traditional network operators. These new ways of producing, operating and commercializing services will impact existing organizations. The difficulty of the transition to the new reality will depend on the ability of the operators to face these challenges, define solutions for them, and to what extent they are able to adapt to the new rules that SDN and NFV bring to the telecom business. The significance of the challenges described here will be different for each operator, and depend on their specific situations and institutional agility in adapting to these new environments.

We are encouraged to note that some of the challenges we describe in this paper are beginning to be addressed by industry communities. Work in organizations like ONF, IETF, ETSI, BBF and ITU-T, is beginning to focus on some of the challenges we describe herein. We hope our work stimulates even more of those activities.

Acknowledgements

The authors are grateful to Mohamed Boucadair (Orange) for his insightful comments and suggestions with respect to content addressed in this paper.

References

[1] D. Kreutz, F.M.V. Ramos, P. Verissimo, C. Esteve Rothenberg, S. Azodolmolky, S. Uhlig, Software-Defined Networking: A Comprehensive Survey, in: Proceedings of the IEEE, 103, 2015, p. 14—76.

[2] ETSI NFV ISG white paper, Network Functions Virtualisation – White Paper #3, October 2014, http://portal.etsi.org/Portals/0/TBpages/NFV/Docs/NFV_White_Paper3.pdf.

[3] L.M. Contreras, V. López, O. González de Dios, A. Tovar, F. Muñoz, A. Azañón, J.P. Fernández-Palacios, J. Folgueira, Towards cloud-ready transport networks, IEEE Commun. Mag. 50 (2012) 48–55.

[4] L. Velasco, L.M. Contreras, G. Ferraris, A. Stavdas, F. Cugini, M. Wiegand, J.P. Fernández-Palacios, A service-oriented hybrid access network and cloud architecture, IEEE Commun. Mag. 53 (2015) 159–165.
[5] ITU-T Recommendation X.700, Management framework for Open Systems Interconnection (OSI) for CCITT applications, 1992.
[6] OpenDayLight, http://www.opendaylight.org/.
[7] OPNFV, https://www.opnfv.org/.
[8] TMForum ZOOM (Zero-touch Orchestration, Operations and Management project), https://www.tmforum.org/zoom/.

Luis M. Contreras completed a six-year Telecommunications Engineering degree at the Universidad Politécnica de Madrid (1997), and holds an M.Sc. in Telematics from the Universidad Carlos III de Madrid (2010). In 1997, he joined Alcatel in Spain taking several positions (R&D, standardization, product development and customer engineering) in both wireless and fixed network fields. In 2006, he joined the Network Planning Department of Orange in Spain (France Télécom group) taking responsibilities on the IP backbone and mobile packet core planning. Between 2002 and 2010, he was also adjunct lecturer (part time) at the Telematics Department of the Universidad Carlos III, where he is currently a Ph.D. student. Since August 2011, he is part of Telefónica I+D / Telefónica Global CTO, working on SDN, transport networks and their interaction with cloud and distributed services, and participating on the EU FP7 projects GEYSERS and XIFI, the EU H2020 projects XHAUL and 5GEx, and the ESA funded project CloudSat. In July 2012, he co-organized the International Workshop on Cross-Stratum Optimization for Cloud Computing and Distributed Networked Applications, co-located with the 10th IEEE International Symposium on Parallel and Distributed Processing with Applications (ISPA 2012), Leganés, Spain. He is active contributor to IETF (authoring two RFCs) and ONF.

Paul Doolan is the Director of Standardization activities in Coriant's CTO office. He and his team are active in mutiple SDOs and Fora including ITU-T, IETF, IEEE, MEF and ONF. He contributes regularly on topics in optical and packet networking with a recent focus on the application of SDN to optical networks. Paul is the author/co-author of 6 RFCs, a book on MPLS and has contributed material to several others.

Håkon Lønsethagen is a Senior Adviser at Telenor Research. He received a B.Sc in 1987 in electrical engineering and computer science from University of Colorado, Boulder, USA. He was granted a M.Sc. from the Norwegian Institute of Technology in 1988. Since 1990 he has been working with telecom network and service management and control, including systems integration and distributed systems frameworks, architectures and middleware. Since 2000 his research activities have been related to network control and management of packet-based networks and intelligent optical networks also including techno-economic analysis. His interests and focus over the last few years has been on inter-NSP differentiated and assured services quality and business models, and lately including SDN and NFV. He has participated in Eurescom projects and EU IST DAVID, NOBEL, NOBEL2 and ETICS, and he has been the WP or task leader of several projects. He has several contributions to TM Forum and is advisory board member of EU research projects SmartenIT and NEAT.

Dr. Diego R. López is a Senior Technology Expert on network middleware and services within the GCTO Unit of Telefónica I+D. Diego is currently focused on identifying and evaluating new opportunities in technologies applicable to network infrastructures, and the coordination of national and international collaboration activities. Diego is actively participating in the ETSI ISG on Network Function Virtualization (chairing its Technical Steering Committee), the ONF, and the IETF WGs connected to these activities, acting as co-chair of the NFVRG within the IRTF.