**Low latency and high throughput dynamic network infrastructures for high performance datacentre interconnects**

Small or medium-scale focused research project (STREP)
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# Deliverable D6.5

## Final report on dissemination, standardization and exploitation activities

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**Dissemination Level**

| | | |
|---|---|---|
| ☒ | **PU:** | Public |
| ☐ | **PP:** | Restricted to other programme participants (including the Commission Services) |
| ☐ | **RE:** | Restricted to a group specified by the consortium (including the Commission Services) |
| ☐ | **CO:** | Confidential, only for members of the consortium (including the Commission Services) |

## Abstract

The Work Package 6 is in charge of enabling external visibility to the LIGHTNESS project technical achievements. In the three years' project lifetime, we work closely with industrial and research communities, disseminate and promote the LIGHTNESS technical achievements. In this deliverable, we presented the final report on the dissemination activities, standardization activities, collaboration activities, as well as exploitation activities carried out during the project lifetime.

For dissemination activities, LIGHTNESS partners have contributed in 11 journal papers, 31 conference papers, 1 magazine article, 20 invited talks and 4 co-organized workshops. We also show the final demonstration of the LIGHTNESS project in the Exhibition of the 41st European Conference on Optical Communications (ECOC 2015), in Valencia, Spain, on September 27-30, 2015, in which we draw lots of interests from industries. All these contributions give LIGHTNESS high visibility in cloud services and Data Centers industrial and research communities.

For the standardization activities, LIGHTNESS partners participate and contribute to major standardization bodies, like ONF, and promote the technical solutions of LIGHTNESS.

For the collaboration activities, LIGHTNESS has collaborated with other EU FP7 projects (i.e. COSIGN, STRAUSS, and PACE) with activities ranging from joint publications, workshop organization, sharing the technical approaches and vision developed in each respective project.

For the exploitation activities, the novel LIGHTNESS data plane and control plane technique and solutions are exploited by the industrial and academic project partners.

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# 0. Executive Summary

LIGHTNESS project is to design, implement and experimentally evaluate high performance data centre interconnects through the innovative photonic switching and transmission inside data centres to fulfil the ever increasing popularity of computing and storage server-side applications.

The Work Package 6 (WP6) is in charge of enabling external visibility to the LIGHTNESS project technical achievements. To promote the visibility, WP6 focused on four main activities: dissemination, standardization, collaboration, and exploitation.

For the dissemination activity, the partners of LIGHTNESS contribute in top-tier journals, magazines, workshops and etc. which enable LIGHTNESS highly visibility in cloud services and DCN communities. In year 3 particularly, LIGHTNESS showed the final demonstration with data plane and control plane setup in ECOC 2015 that attract a lot interests in the exhibition. For the standardization activity, LIGHTNESS partners participate and contribute to major standardization bodies which increase the overall impact of the LIGHTNESS technical solutions and results. LIGHTNESS collaborates with other related national, European and international projects and organizations for workshop organization and joint publications sharing the technical outputs developed in each single project. For the exploitation activity, LIGHTNESS provided individual exploitation plans and roadmaps for the application of the project concepts, architectures and results in future commercial (for industrial partners and SMEs) and non-commercial activities (for academic and research oriented partners).

This document "Final report on dissemination, standardization and exploitation activities" reports all the dissemination, standardization, collaboration, and exploitation activities that have been involved during the three years' project life cycle.

# 1. Introduction

This deliverable is to report all the WP6 activities carried out during three years' project life cycle. The report focuses specially in four activities: Firstly is dissemination activity with publications, invited talks, demonstrations, and workshops; Secondly is the standardization activity of presenting the outcome of the LIGHTNESS project to the main standardization bodies; Thirdly is the collaboration activity with other European projects; Lastly is the exploitation activity aiming at transferring the project outcome into industry. All of these activities promote the visibility of LIGHTNESS to the optical and DCN communities.

## 1.1. LIGHTNESS dissemination activity

The technical activities carried out in LIGHTNESS have brought to a significant number of scientific publications in prestigious and highly impacting journals, e.g., IEEE Journal of Lightwave Technology (Impact Factor 2.965), OSA Optics Express (Impact Factor 3.488) and IEEE Journal on Optical Communications and Networking (Impact Factor 2.064), and conferences, e.g., ECOC, OFC. Such activities have guaranteed the proper visibility of the LIGHTNESS technical achievements, not only in the optical technologies community but also in the HPC and data centre communities.

Moreover, a significant number of invited talks from LIGHTNESS partners have further contributed to increase the visibility of the achieved results. The public demonstrations carried out require special emphasis. The first one at EuCNC 2014 has been awarded with the Best Booth Award while the results of the final demo have been accepted as post-deadline paper at ECOC 2015. Finally, it deserves to mention that LIGHTNESS partners have actively contributed to organize a range of workshops about technologies and solutions towards future data centres with the participation of both academics and industry.

## 1.2. LIGHTNESS standardization activity

Cooperate and contribute to the standardization organizations can promote the LIGHTNESS technical solutions and achievements

In LIGHTNESS, we developed and tested our unique control plane and data plane architecture, and demonstrated the integration of the optical control plane and data centre solutions. The results and output of LIGHTNESS has attracted high interest for the data centre and cloud industries, and as well as the standard communities. In the third year specially, we present the outcome of the LIGHTNESS project to the main standardization body ONF, and organize the workshop with it.

## 1.3. LIGHTNESS collaboration activity

The collaboration with other European projects is a further channel that LIGHTNESS has explored and used to validate its architecture, technology and implementation choices while exchanging and analysing information, outcomes and results with research initiatives targeting similar and compatible research and technological areas. This has improved the dissemination potential of LIGHTNESS outcomes, generating a good impact into the European research community, while enabling closer interactions with industry players.

During this final year, LIGHTNESS mostly focused in the consolidation of those collaborations already in place since the last year with FP7 COSIGN [4], STRAUSS [5] and PACE [6]. In this context, LIGHTNESS got fundamental inputs and feedbacks to finalize its development activities and validate the proposed architecture for an SDN enabled programmable hybrid optical data centre network.

## 1.4. LIGHTNESS exploitation activity

Through all three years, we aimed at identifying potential routes for deploying LIGHTNESS concepts and results in the data centre networking filed. In the third year, LIGHTNESS has finalized the development of its proposed architecture, carrying out extensive integration, experimental assessment and demonstration activities. On top of these technical activities that have validated the LIGHTNESS concepts and outcomes, the consortium consolidated the exploitation work carried out in the previous two years towards the identification of routes and roadmaps to apply the project results into concrete business and research activities.

While commercial oriented exploitation roadmaps have been defined for industrial and SME partners (Interoute and Nextworks), non-commercial exploitation plans have been identified by academic and research oriented partners (UPC, TUE, BSC and University of Bristol) to foster their knowledge and know-how while consolidating their position and reputation in the research community.

# 2. Dissemination outcomes

In this Section, the complete list of scientific publications derived from the LIGHTNESS technical activities is reported. A total of 11 journal, 1 magazine and 31 conference papers have been published, guaranteeing a proper visibility of the LIGHTNESS outcome to both scientific and industrial communities. Moreover, it has to be mentioned that LIGHTNESS partners have been invited to give a total 20 talks; most of them are in very relevant and prestigious technical events/conferences. Four technical workshops have been co-organised and the LIGHTNESS solutions have been demonstrated both at EuCNC 2014 and ECOC 2015. It worth to mention that LIGHTNESS was awarded with the Best Booth Award at EuCNC 2014 while the results of the demo at ECOC 2015 have been also published as a post-deadline paper.

## 2.1. Publications

This subsection, we list all the publications under the catalogue of Journals and Magazine publications, Conference publications, Invited talks and other media. They are ordered by date starting with the most recent one for all the three years of the projects.

### 2.1.1. Journals and Magazine publications

1. G. M. Saridis, S. Peng, Y. Yan, A. Aguado, B. Guo, M. Arslan, C. Jackson, W. Miao, N. Calabretta, F. Agraz, S. Spadaro, G. Bernini, N. Ciulli, G. Zervas, R. Nejabati, D. Simeonidou, “LIGHTNESS: A Function-Virtualizable Software Defined Data Center Network with All-Optical Circuit/Packet Switching”, IEEE Journal on Lightwave Technology, 2016.
2. Y. Yan, G. M. Saridis, Y. Shu, B. R. Rofoee, S. Yan, M. Arslan, T. Bradley, N. V. Wheeler, N. H. L. Wong, F. Poletti, M. N. Petrovich, D. J. Richardson, S. Poole, G. Zervas, D. Simeonidou, “All-Optical Programmable Disaggregated Data Centre Network realized by FPGA-based Switch and Interface Card” , IEEE Journal on Lightwave Technology, 2016.
3. A. Pagès, M. Pérez, S. Peng, J. Perelló, D. Simeonidou, S. Spadaro, “Optimal Virtual Slice Composition Toward Multi-tenancy over Hybrid OCS/OPS Data Center Networks”, Journal of Optical Communications and Networking, Vol. 7, Issue 10, pp. 974-986, 2015.

4. S. Peng, B. Guo, C. Jackson, R. Nejabati, F. Agraz, S. Spadaro, G. Bernini, N. Ciulli, D. Simeonidou, "Multi-Tenant Software-Defined Hybrid Optical Switched Data Centre", Journal on Lightwave Technology, Vol. 33, Issue 15, pp. 3224-3233, 2015.
5. W. Miao, F. Agraz, S. Peng, S. Spadaro, G. Bernini, J. Perelló, G. Zervas, R. Nejabati, N. Ciulli, D. Simeonidou, H. Dorren, N. Calabretta, "SDN-enabled OPS with QoS Guarantee for Reconfigurable Virtual Data Center Networks", Journal of Optical Communications and Networking, Vol. 7, Issue 7, pp. 634-643, 2015.
6. P. De Heyn, J. Luo, S. Di Lucente, N. Calabretta, H.J.S. Dorren, and D. Van Thourhout, "In-Band Label Extractor Based on Cascaded Si Ring Resonators Enabling 160 Gb/s Optical Packet Switching Modules," Journal of Lightwave Technology, Vol. 32, Issue 9, pp. 1647-1653, 2014.
7. W. Miao, J. Luo, S. Di Lucente, H.J.S. Dorren, and N. Calabretta, "Novel flat datacenter network architecture based on scalable and flow-controlled optical switch system," Optics Express, Vol. 22, Issue 3, pp. 2465-2472, 2014.
8. W. Miao, S. Di Lucente, J. Luo, H.J.S. Dorren, and N. Calabretta, "Low latency and efficient optical flow control for intra data center networks," Optics Express, Vol. 22, Issue 1, pp. 427-434 (2014).
9. J. Perelló, S. Spadaro, S. Ricciardi, D. Careglio, S. Peng, R. Nejabati, G. Zervas, D. Simeonidou, A. Predieri, M. Biancani, H. J. S. Dorren, S. Di Lucente, J. Luo, N. Calabretta, G. Bernini, N. Ciulli, J. C. Sancho, S. Iordache, M. Farreras, Y. Becerra, C. Liou, I. Hussain, Y. Yin, L. Liu, R. Proietti, "All-Optical Packet/Circuit Switching-based Data Center Network for Enhanced Scalability, Latency and Throughput", IEEE Network magazine, special issue on Optical Networks in Cloud Computing, to be published on December 2013.
10. S. Peng, R. Nejabati, D. Simeonidou "Role of Optical Network Virtualization in Cloud Computing ", IEEE/OSA Journal of Optical Communications and Networking, vol. 5, no. 10, pp. A162-A170, October 2013.
11. N. Calabretta, R. P. Centelles, S. Di Lucente, H. J. S. Dorren, "On the performance of a large-scale optical packet switch under realistic Data Centre traffic", IEEE/OSA Journal of Optical Communications and Networking, vol. 5, no. 6, pp. 565-573, June 2013.


### 2.1.2. Conference publications


1. N. Calabretta, W. Miao, F. Yan, H. J. S Dorren, "High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System", Photonics WEST, San Francisco, USA, 2016.
2. Hugo Meyer, Jose Carlos Sancho, Milica Mrdakovic, Shuping Peng, Dimitra Simeonidou, Wang Miao, and Nicola Calabretta. Scaling Architecture-on-Demand based Optical Networks. In Proceedings of the 17th International Conference on Distributed Computing and Networking (ICDCN 2016), Singapore, 4-7 January 2016.
3. W. Miao, F. Yan, H. Dorren, N. Calabretta, "Building Petabit/s Data Center Network with Sub-microseconds Latency by Using Fast Optical Switches", 20th Annual Symposium of the IEEE Photonics Benelux Chapter, Brussels, Belgium, November 26-27, 2015.
4. F. Yan, W. Miao, H. Dorren, N. Calabretta, "Novel flat DCN architecture based on optical switches with fast flow control", 20th Annual Symposium of the IEEE Photonics Benelux Chapter, Brussels, Belgium, November 26-27, 2015.

5. S. Spadaro, A. Pagès, J. Perelló, F. Agraz, "Virtual Slices Allocation in Multi-tenant Data Centre Architectures Based on Optical technologies and SDN", Asia Communications and Photonics Conference (ACP) 2015, Hong Kong, November 19-23, 2015.
6. G. M. Saridis, S. Peng, Y. Yan, A. Aguado, B. Guo, M. Arslan, C. Jackson, W. Miao, N. Calabretta, F. Agraz, S. Spadaro, G. Bernini, N. Ciulli, G. Zervas, R. Nejabati, D. Simeonidou, "LIGHTNESS: A Deeply programmable SDN-enabled Data Centre Network with OCS/OPS Multicast/Unicast Switch-over", ECOC 2015, PDP.4.2, Valencia, Spain, September 27 – October 1, 2015.
7. Nicola Calabretta, Kevin Williams, Harm Dorren, "Monolithically Integrated WDM Cross-Connect Switch for Nanoseconds Wavelength, Space, and Time Switching", ECOC 2015, Mo.3.2.2, Valencia, Spain, September 27 – October 1, 2015.
8. Y. Yan, Y. Shu, G. M. Saridis, B. R. Rofoee, G. Zervas, D. Simeonidou, "FPGA-based Optical Programmable Switch and Interface Card for Disaggregated OPS/OCS Data Centre Networks", ECOC 2015, Tu.3.6.2, Valencia, Spain, September 27 – October 1, 2015.
9. Y. Shu, S. Peng, Y. Yan, S. Yan, E. Hugues-Salas, G. Zervas, D.Simeonidou, "Evaluation of Function-Topology Programmable (FTP) Optical Packet/Circuit Switched Data Centre Interconnects", ECOC 2015, Valencia, Spain, September 27 – October 1, 2015.
10. Wang Miao, Fulong Yan, Harm Dorren, Nicola Calabretta, "Petabit/s Data Center Network Architecture with Sub-microseconds Latency Based on Fast Optical Switches", ECOC 2015, Tu.3.6.3, Valencia, Spain, September 27 – October 1, 2015.
11. Fulong Yan, Wang Miao, Harm Dorren, Nicola Calabretta, "Novel flat DCN architecture based on optical switches with fast flow control", Photonics in Switching 2015, Florence, Italy, September 22-25, 2015.
12. N. Calabretta, W.Miao, H. J. S Dorren (TUE), "High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System", Photonics in Switching 2015, Florence, Italy, September 22-25, 2015.
13. Fulong Yan, Wang Miao, Harm Dorren, Nicola Calabretta, "On the cost, latency, and bandwidth of LIGHTNESS data center network architecture", Photonics in Switching 2015, Florence, Italy, September 22-25, 2015.
14. H. Meyer, J. C. Sancho, W. Miao, H. Dorren, N. Calabretta, M. Farreras, "Performance Evaluation of Optical Packet Switches on High Performance Applications", International Conference on High Performance Computing & Simulation (HPCS 2015), Amsterdam, Holland, July 20-24, 2015.
15. N. Calabretta, W.Miao, H. J. S Dorren (TUE), "High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System", IEEE ICTON 2015, Budapest, Hungary, July 2-5, 2015 (invited).
16. N. Calabretta, "High Performance SDN Enabled Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System", Photonic Networks and Devices 2015 conference, Boston, USA, June 27 – July 1, 2015.
17. Y. Zhan, D. Xu, H. Yang, M. Tang, S. Peng, D. Simeonidou, "Adaptive Purchase Option for Multi-Tenant Data Center", IEEE ICC 2015, London, UK, June 18-22, 2015.
18. B. Guo, S. Peng, C. Jackson, Y. Yan, Y. Shu, W. Miao, H. Dorren, N. Calabretta, F. Agraz, S. Spadaro, J. Perelló, G. Bernini, R. Monno, N. Ciulli, R. Nejabati, G. Zervas, D. Simeonidou, "SDN-enabled Programmable Optical Packet/Circuit Switched Intra Data Centre Network", Optical Fiber Communications (OFC 2015) conference, Los Angeles, USA, March 22-26, 2015.
19. W. Miao, F. Agraz, H. de Waardt, S. Spadaro, H. Dorren, N. Calabretta, "1.3 μm SDN-enabled Optical Packet Switch Architecture for High Performance and Programmable Data Center

Network”, Optical Fiber Communications (OFC 2015) conference, Los Angeles, USA, March 22-26, 2015.
20. D. Van Thourhout , M. Tassaert , P. de Heyn, O. Raz , N. Calabretta, G. Roelkens, “Photonics Subsystems for Optical Packet/Burst Switches Based on Heterogeneous SOI and III-V integration”, Optical Fiber Communications (OFC 2015) conference, Los Angeles, USA, March 22-26, 2015.
21. S. Peng, R. Nejabati, B. Guo, Y. Shu, G. Zervas, S. Spadaro, A. Pages, D. Simeonidou, “Enabling Multi-Tenancy in Hybrid Optical Packet/Circuit Switched Data Center Networks”, paper Tu.1.6.4, ECOC 2014, Cannes, France, September 21-26, 2014.
22. F. Agraz, W. Miao, A. Ferrer, G. Bernini, H.J.S. Dorren, N. Calabretta, N. Ciulli, J. Perelló, S. Peng, G. Zervas, D. Simeonidou, G. Junyent, S. Spadaro, “Experimental Assessment of an SDN-based Control of OPS Switching Nodes for Intra-Data Center Interconnect ”, paper We.2.6.5, ECOC 2014, Cannes, France, September 21-26, 2014.
23. W. Miao, S. Peng, S. Spadaro, G. Bernini, F. Agraz, A. Ferrer, J. Perelló, G. Zervas, R. Nejabati, N. Ciulli, D. Simeonidou, H.J.S. Dorren, N. Calabretta, “Demonstration of Reconfigurable Virtual Data Center Networks Enabled by OPS with QoS Guarantees ”, paper P.6.4, ECOC 2014, Cannes, France, September 21-26, 2014.
24. N. Calabretta et al, “Lossless Wavelength Selector based on Monolithically Integrated Flat-top Cyclic AWG and Optical Switch Chain”, paper Tu.4.2, ECOC 2014, 2014.
25. S. Peng, D. Simeonidou, G. Zervas, S. Spadaro, J. Perelló, F. Agraz, D. Careglio, H. Dorren, W. Miao, N. Calabretta, G. Bernini, N. Ciulli, J. C. Sancho, S. Iordache, Y. Becerra, M. Farrera, M. Biancani, A. Predieri, R. Proietti, Z. Cao, L. Liu, S. J. B. Yoo, “A Novel SDN enabled Hybrid Optical Packet/Circuit Switched Data Centre Network: the LIGHTNESS approach”, to be presented in EuCNC 2014 conference, Bologna, Italy, June 23-26, 2014.
26. Y. Yan, G. Zervas, B. R. Rofoee, D. Simeonidou, “FPGA-based Optical Network Function Programmable Node”, to be presented in Optical Fiber Communications (OFC) 2014 conference, San Francisco, USA, March 9-13, 2014.
27. P. De Heyn, J. Luo, A. Trita, S. Pathak, S. Di Lucente, H. J. S. Dorren, N. Calabretta, D. Van Thourhout, “A compact integrated 40 Gb/s packet demultiplexer and label extractor on Silicon-on-Insulator for an optic packet switch”, in Proceedings of 39th European Conference and Exhibition on Optical Communication (ECOC 2013), London, UK, September 22-26, 2013.
28. W. Miao, S. Di Lucente, J. Luo, H. J. S. Dorren, N. Calabretta, “Low latency ad efficient optical flow control for intra Data Centre networks”, in Proceedings of 39th European Conference and Exhibition on Optical Communication (ECOC 2013), London, UK, September 22-26, 2013.
29. W. Miao, J. Luo, S. Di Lucente, H. Dorren, N. Calabretta, “Novel flat datacenter network architecture based on scalable and flow-controlled optical switch system”, (Post Deadline Paper), in Proceedings of 39th European Conference and Exhibition on Optical Communications (ECOC 2013), London (UK), September 22-26, 2013.
30. S. Di Lucente, P. De Heyn, J. Luo, D. Van Thourhout, H. J. S. Dorren, N. Calabretta, “160 Gb/s Optical Packet Switch module employing SOI integrated label extractor”, in Proceedings of 10th Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR 2013), 18th OptoElectronics and Communications Conference (OECC 2013) and Photonics in Switching 2013 (PS 2013), Kyoto, Japan, June 2013.
31. N. Ciulli, G. Carrozzo, G. Landi, G. Bernini, "An SDN framework for the orchestration of cloud and network services across data centres", Asia Communications and Photonics Conference (ACP) 2013, Beijing, China, November 12-15, 2013

### 2.1.3. Invited talks

1. N. Calabretta, W. Miao, F. Yan, H. J. S Dorren, “High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System”, Photonics WEST, San Francisco, USA, 2016.
2. S. Spadaro, “Virtual Slices Allocation in Multi-tenant Data Centre Architectures Based on Optical technologies and SDN”, Asia Communications and Photonics Conference (ACP 2015), Hong Kong, November 19-23, 2015.
3. N. Calabretta, “High performance and low latency data center networks exploiting optical switching technologies”, Symposium on “Optical Communications and Networks for Datacenters”, ECOC 2015, Valencia, Spain, September 30, 2015.R. Nejabati, “Towards a Completely Softwareized and Functional Programmable Optical Data Centre”, Symposium on “Optical Communications and Networks for Datacenters”, ECOC 2015, Valencia, Spain, September 30, 2015.
4. N. Calabretta, W.Miao, H. J. S Dorren (TUE), “High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System”, Photonics in Switching 2015, Florence, Italy, September 22-25, 2015.
5. N. Calabretta, “High Performance SDN Enabled Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System”, Photonic Networks and Devices 2015 conference, Boston, USA, June 27 – July 1, 2015.
6. N. Calabretta, W.Miao, H. J. S Dorren (TUE), “High Performance Flat Datacenter Network Architecture Based on Scalable And Flow-Controlled Optical Switching System”, IEEE ICTON 2015, Budapest, Hungary, July 2-5, 2015.
7. G. Bernini, “Experience with control applications and optical extensions in OpenDaylight: tips, tricks and...headaches”, PACE workshop, co-located with ONDM 2015 conference, Pisa, Italy, May 11-14, 2015.
8. D. Simeonidou, “Enabling Highly Programmable Optical Data Centres”, workshop on “Do Small, Large, And Mega Data Centers Need Advanced Photonics Technology?”, co-located with OFC 2015, Los Angeles, USA, March 23, 2015.
9. M. Channegowda, “FP7 European Project LIGHTNESS: Redesigning the network to make your data center scalable and future proof”, DataCentreDynamics Converged London 2014, London, UK, November 19-20, 2014.
10. W. Miao, “Reconfigurable Virtual Data Centre Networks Based on OpenFlow-enabled OPS”, $19^{th}$ Annual Symposium of the IEEE Photonics Benelux Chapter, Enschede, Holland, November 3-4, 2014.
11. N. Calabretta, Wang Miao, Jun Luo, S. Di Lucente, H. Dorren, “Experimental assessment of a scalable and flow-controlled optical switch system for flat datacenter networks,” 16th International Conference on Transparent Optical Networks (ICTON) 2014, Graz, Austria.
12. G. Zervas, B. Rofoee, Y. Yan, D. Simeonidou, “Network Function Programmability and Software-Defined Synthetic Optical Networks for Data Centres and Future Internet”, to be presented at Photonics in Switching (PS) 2014, San Diego, CA (US), July 13-17, 2014.
13. Nicola Calabretta, “Scalable and Low Latency Optical Packet Switching Architectures for High Performance Data Center Networks,” Photonics in Switching (PS) 2014, San Diego, CA, US, 13 – 16 July 2014.

14. G. Bernini, "LIGHTNESS: An SDN enabled hybrid optical packet/circuit switched data centre network", PACE workshop on "New Uses for Path Computation Elements", Vilanova i la Geltru, June 16 2014
15. R. Nejabati, S. Peng, M. Channegowda, D. Simeonidou, "SDN an Enabler for Multi-Dimensional and Multi-Tenant Optical Networks, in Proceedings of 8th International Conference on Optical Network Design and Modeling (ONDM 2014), Stockholm, Sweden, May 19-22, 2014.
16. N. Ciulli, "SDN principles applied to datacentres and metro-core networks: Towards a network operating system", SDN&OpenFlow World Congress, SDN INNOVATION FORUM, Bad Homburg, Germany, October 18, 2013.
17. S. Spadaro, "Opportunities for Photonic Packet/Circuit Switching in Large Scale Data Centers", Symposium on Next Generation data centres – Paving the way for the Zettabyte Era, European Conference on Optical Conference (ECOC) 2013, London, UK, September 24, 2013.
18. J. C. Sancho, "The LIGHTNESS project", in the framework of the RoMOL project, a High Performance Computing research project founded by the European Research Council.
19. S. Spadaro, "Optical networking for High Performance Computing", Photonics in Data Centers and Computing Symposium, Photonics and Switching (PS) 2012 Conference, Ajaccio, France, September 12, 2012.
20. D. Simeonidou, "The LIGHTNESS project", Future Networks 10th FP7 Concertation Meeting, Brussels, 10-11 October 2012.

### 2.1.4. Other Media

1. "LIGHTNESS: Anticipating the mobile traffic boom", interview to Matteo Biancani for the EU digital agenda, https://ec.europa.eu/digital-agenda/en/news/lightness-anticipating-mobile-traffic-boom
2. "LIGHTNESS: l'innovazione di Interoute verso il 5G", interview to Matteo Biancani published on the Interoute Italia blog (Italian), http://www.interoute.it/blog/intervista-biancani-lightness
3. "Interoute presents the LIGHTNESS SDN datacentres project", interview to Matteo Biancani published on DataCenters.com, http://www.datacentres.com/dc-news/interoute-presents-lightness-sdn-datacentres-project
4. "Interoute Italia presents SDN-powered data centre project", published on Telecompaper, http://www.telecompaper.com/news/interoute-italia-presents-sdn-powered-data-centre-project--1109023
5. "Interoute presents the LIGHTNESS project: all-optical software defined data centres on the road to 5G", published on several media channels
    - Bloomberg Business, http://www.bloomberg.com/research/markets/news/article.asp?docKey=600-201510210505M2______EUPR_____014c00000b33db69_3600-1
    - RealWire, http://www.realwire.com/releases/Interoute-presents-the-LIGHTNESS-project-all-optical-software-defined-data
    - Your Communication News, http://www.yourcommunicationnews.com/interoute+presents+the+lightness+project%3A+all-optical+software+defined+data+centres+on+the+road+to+5g_122854.html

- Digital Media Net Forum, http://forums.digitalmedianet.com/articles/viewarticle.jsp?id=4126635
- Industry Today, http://www.industrytoday.co.uk/it/interoute-presents-the-lightness-project-all-optical-software-defined-data-centres-on-the-road-to-5g/41960
- IT News Online, http://www.itnewsonline.com/realwire/Interoute-presents-the-LIGHTNESS-project-all-optical-software-defined-data-centres-on-the-road-to-5G/16276
- Virtual Strategy, http://www.virtual-strategy.com/2015/10/21/interoute-presents-lightness-project-all-optical-software-defined-data-centres-road-5g#axzz3pD4EcAeT

## 2.2. Demonstrations

The final demonstration of the LIGHTNESS project has been performed in the Exhibition of the 41st European Conference on Optical Communications (ECOC 2015), Valencia, Spain, September 27-30, 2015. The overall LIGHTNESS systems including both data and control plane have been successfully demonstrated. The setup of control plane is shown in the left of Figure 2-1, and the data plane setup is shown in the right of Figure 2-1

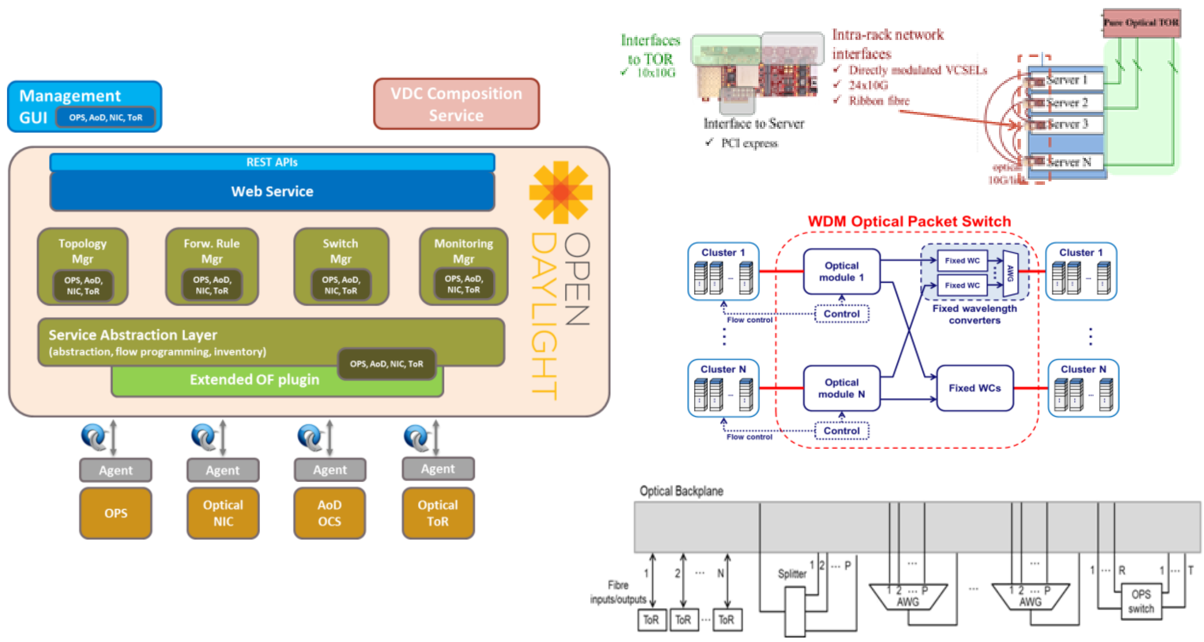


**Figure 2-1: LIGHTNESS overall demonstration**

In particular, the experimental validation of the hybrid optical switched data centre network (including OCS, OPS and Optical NIC) and the SDN-based control and their integration have been performed through the proper dynamic allocation of both unicast and multicast virtual slices, mapped over OCS and OPS.

Figure 2-2 show the LIGHTNESS booth and the people involved at ECOC Exhibition 2015.

**Figure 2-2: LIGHTNESS Booth at ECOC Exhibition 2015**

It worth to mention that the LIGHTNESS partners presented a demonstration entitled "SDN-enabled all-optical and programmable Data Centre Network for low latency server-to-server connectivity", in the framework of the Exhibitions and Demos Session of the European Conference on Networks and Communications (EuCNC) 2014, held in Bologna (Italy) on 24-26 of June, 2014. The LIGHTNESS demo was awarded the Best Booth Award.

## 2.3. Organization of international workshop

In the last year of the project, the LIGHTNESS members have co-organised some technical events related to both data plane and control plane technologies for future data centre networking design. In the following, the details of the symposium organised are listed:

1. Symposium on "Optical Communications and Networks for Datacenters", co-located with ECOC 2015, Valencia, Spain, September 30, 2015.
   Organisers: **Dimitra Simeonidou (University of Bristol),** Ken-ichi Kitayama (Osaka University)

2. Workshop on "The Software Defined Network – Programmable City", Bristol, July 7, 2015
   Organizers: **University of Bristol, ONF**

3. Workshop on "Do Small, Large, And Mega Data Centers Need Advanced Photonics Technology?", co-located with OFC 2015, Los Angeles, USA, March 25, 2015.
   Organisers: Rich Baca (CommScope), **Nicola Calabretta (TUE)**, Mark Feuer (CUNY College of Staten Island), Adel Saleh (University of California Santa Barbara).
4. Workshop on "Creating European Vision for Future Optical Data Centre Evolution", in cooperation with the EU FP7 IP project COSIGN, Barcelona, Spain, May 14, 2014.

# 3. Standardization activities

During the three years' project whole life time, we tested our unique control plane and data plane architecture, and demonstrated the integration of the flattened hybrid OPS and OCS data centre network solution. We promote our solutions to the standard communities, especially, in the third year, with all the implementation and experiment results ready, we actively involved in the workshop and presentations with the standardization bodies for increasing the overall impact of the project results. We have mainly contributed our research outcomes of LIGHTNESS to ONF.

## 3.1. ONF

Open Networking Foundation (ONF) [1] is a user-driven organization dedicated to the promotion and adoption of Software-Defined Networking (SDN) through open standards development. ONF emphasizes an open, collaborative development process that is driven from the end-user perspective.

Through the work that we have done in the past three years, LIGHTNESS experimentally proved its proposed flat optical DCN architecture. We have developed OpenFlow extensions for the OPS node, OCS node, optical components (i.e. WSS), and FPGA-based hybrid optical Network Interface Card (NIC). University of Bristol, as research associate member of ONF, shared with ONF director and ONF optical transport working group (OTWG) these latest output developed for LIGHTNESS. Moreover, University of Bristol participated in OTWG providing information on OpenFlow specification needed for next generation of optical technologies and the northbound API for transport networks.

In July 2015, the University of Bristol hosted an ONF workshop titled "The Software Defined Network – Programmable City". International participants from industry, academia, local government, and standards bodies joined more than twenty speakers for the workshop. At this event, Professor Dimitra Simeonidou presented the Bristol is Open (BIO), an open programmable city and the SDN work produced in the High Performance Networks Group of University of Bristol will be adopted to the smart city platform. The presentation also described and acknowledged the contributions of LIGHTNESS.

**Figure 3-1: ONF workshop “The Software Defined Network – Programmable City” in Bristol**

In addition, Dr. Reza Nejabati from University of Bristol presented to the ONF on LIGHTNESS in Palo Alto in February 2015. The OpenFlow extensions for optical technologies defined and developed for the LIGHTNESS SDN control plane were presented and discussed with the ONF community.

## 3.2. IETF and IRTF

The Internet Engineering Task Force (IETF) [2] is the Internet’s leading technical standards body. It is an open forum where a large international community composed by network operators, vendors and researchers in general targets the evolution of the Internet architecture and its operation. The main goal of IETF is to improve the Internet architecture at different levels, which means proposing new network designs, control and management solutions, network protocols mostly to influence the way Internet is deployed and operated. This is carried out by dedicated Working Group, each responsible to carry out standardization activities in a specific area. In parallel, the Internet Research Task Force (IRTF) [3] is another standards body, very close and related to IETF that acts as its incubator first stage discussion for a for longer term research outcomes related to the Internet. IRTF is built of several Research Groups, addressing new ideas and solutions for Internet protocols, applications, architecture and technology that are considered not yet mature for IETF Working Groups.

In the previous years, LIGHTNESS standardization efforts concentrated on following the evolution of activities in IETF and IRTF Working and Research Groups related to LIGHTNESS topics. In parallel, the LIGHTNESS consortium prepared a kind of roadmap to plan potential submissions to some of these groups, according to the specific research carried out in the project. In particular, two groups were identified as candidates to propose the LIGHTNESS architectural solution, mostly concerning the SDN control plane. IRTF SDN Research Group (SDNRG), which investigates SDN at different levels, including new architectures, solutions for scalability, resource abstraction, programming languages and paradigms particularly useful in the context of SDN. As a second group, the IETF PCE Working Group, that provides architectures, protocols, deployment and cooperation models for the PCE as a path computation engine in networks encompassing heterogeneous technologies. The identification of these two groups, as well as the selection of potential contributions to be applied has been facilitated by the collaboration with the FP7 PACE project, as detailed in section 4. PACE, as a collaboration and support action project, was used by LIGHTNESS (through Nextworks and UPC that are PACE members) as a discussion forum to evaluate standardization options and potentials for LIGHTNESS concepts and solutions. Indeed, PACE includes key IETF and IRTF participants and contributors as Old Dog Consulting, Telefonica and CTTC that stimulated these discussions.

The roadmap defined and refined during the past two years is presented for sake of completeness in this document in Table 3-1. Although the priority of the above potential contributions was set as high (for SDNRG) and medium (for PCE WG), thus identifying them as crucial activities within LIGHTNESS, the project did not provide any official submission in IETF and IRTF. It is important to highlight that this has been a carefully planned and discussed decision mostly among involved partners in the table above, rather than a lack of effort in standardization activities. During this last year of the project the actual potentials of a successful submission in IETF and IRTF groups have been further analysed, with the aim of targeting a contribution with high possibility to go further a single “-00” submission that at the end is just a non-reviewed submission.

| SDO/WG | Standardization elements | Contribution | Priority | Partners |
|---|---|---|---|---|
| *IRTF SDNRG* | Requirements, architectural choices and approaches, deployment frameworks for SDN control of multi-technology and hybrid optical data centre networks | New I-D submission / Contributions to existing I-Ds | High | NXW, UNIVBRIS |
| *IETF PCE WG* | Requirements and applicability of active PCE in data centre scenarios | Contributions to existing I-Ds | Medium | NXW |

**Table 3-1: IETF and IRTF standardization plan for the third year**

The support from PACE in this particular aspect has been crucial. IETF PCE (where Telefonica has a leading role) in particular mostly focused on consolidated architectures and protocol aspects, rather than on new approaches or specific extensions to existing frameworks. The actual possibility for LIGHTNESS to propose successful new Internet Drafts related to data centre scenarios was extremely low. Similarly, IRTF SDNRG (chaired by Daniel King from Old Dog Consulting) is somehow targeting data centres scenarios but more on the aspects that focusing on Network Functions Virtualization

(NFV) and Service Function Chaining (SFC), rather than SDN protocol and architecture extensions in support of optics as in LIGHTNESS. Thus, taking into account these considerations, the LIGHTNESS consortium believes that submitting a single “-00” version of an Internet Draft in IETF and IRTF, without concreting opportunities to have the proposed ideas well received and accepted in these standardization communities, would neither gave any added value nor improved the impact of LIGHTNESS.

# 4. Collaboration with other relevant project

During this final reporting period, LIGHTNESS continued some collaborations initiatives started in the previous years of the project.

Following the plans for collaborations with other research projects defined at the end of the first year in deliverable D6.3 [1], during the second reporting period LIGHTNESS kicked-off some fruitful collaboration initiatives with the following FP7 projects:

- FP7 Combining Optics and SDN In next Generation data centre Networks (**COSIGN**)
- FP7 Scalable and efficient orchestration of Ethernet services using software-defined and flexible optical networks (**STRAUSS**)
- FP7 Next Steps in Path Computation Element (PCE) Architectures (**PACE**)

## 4.1. FP7 COSIGN

COSIGN [4] is a three-year FP7 research project that just passed the halfway mark, and it is designing and developing an innovative Data Centre architecture with new data plane technologies aiming to both scale to capacities far beyond state of the art and reduce the latency to a minimum. Full integration with control plane solutions and orchestrations make it possible to integrate the DCN resources with the computational, memory and storage resources for integrated administration and optimization. COSIGN is challenging classical architectures and technologies by introducing advanced technologies for transmission and optical and electronic switching. On top, the COSIGN control plane offers an open SDN-based solution for multi-tenant network virtualization and dynamic allocation of optical resources, with flexible and application-aware connections established on demand over the multi-technology datacentre network. An orchestration layer, is designed to coordinate the underlying COSIGN layers with the application/server layer while computing data transfer paths and configuring data plane devices to enforce the computed paths.

The overall architecture is now in place with scenarios for short-term, medium-term and long-term solutions. Designing solutions that integrate disruptive hardware solutions for the DCN with software realization matching generic trends for control plane strategies and broader integration of different kinds of resources has been the major task so far, and the project is now entered the phase of developing and demonstrating the new ideas and solutions.

The collaboration with COSIGN during the third year of the project has been mostly a progress and consolidation of the joint activities kicked off and carried out in the second year. Most of the partners in the LIGHTNESS consortium are also members in the COSIGN project (Interoute, TUE, Nextworks, UPC, University of Bristol), and technical discussions, collection of feedbacks and inputs occurred frequently during face-to-face meetings and conference calls of both projects. On top of this collaboration environment, a deep exchange of information for the architectural choices in both projects has been maintained and continued. In addition, feedbacks for implementation strategies mostly concerning the SDN control planes have been frequent and very fruitful. Since COSIGN started its SDN development activities during this year, the lessons learnt and expertise in general gained in LIGHTNESS with the implementation of OpenDaylight extensions in support of optical technologies helped the definition of COSIGN development plans. With respect to last year, when COSIGN was just started and benefited from lot of inputs coming from LIGHTNESS, during this reporting period, the exchange of feedbacks has been more balanced. The background expertise from some of COSIGN partners (e.g. IBM, DTU) on SDN and OpenDaylight has been important for the finalization of software developments in COSIGN. In particular, LIGHTNESS benefited from the presence in COSIGN of IBM in its last SDN and network virtualization application (the Virtual Data Centre composition) developments and validation activities. Indeed, IBM, as key industry player with deep involvement in OpenDaylight and OpenStack open source communities gave fundamental inputs and suggestion on the proper approach to be followed for the development of the VDC composition application and its integration with OpenDaylight.

As a further prove of the alignment of COSIGN and LIGHTNESS approaches, at both architectural and implementation level, the LIGHTNESS system in its final demonstration scenario (including VDC composition application, OpenDaylight controller and programmable hybrid NIC) is targeted to be adopted as the starting point of work (to be properly enhanced with COSIGN extensions and additional functionalities) for the long-term scenario in COSIGN coordinated by University of Bristol.

## 4.2. FP7 STRAUSS

STRAUSS [5] is a three year EU & Japan research and development cooperation project. The STRAUSS project aims to control and manage a network scenario covering multiple technology domains and provision end-to-end services. As STRAUSS is stepping into its third year, it is integrating of data plane and control plane paradigms and orchestrator. The developed infrastructure covers different/heterogeneous technologies based on: i) optical packet switching technology to provide scalable and cost/energy-efficient traffic grooming at sub-wavelength granularity, ii) optical spectrum switching technology to provide flexible spectrum management capabilities, and iii) software-defined and sliceable (multi-flow) bandwidth-variable transponders (BVT) supporting multiple data flows with different modulation formats and bit rates.

LIGHTNESS collaborates with STRAUSS while University of Bristol is a partner member of both projects consortiums. STRAUSS is developing an orchestration platform that performs end to end connectivity service provisioning for cloud environment over multiple transport technology domains. LIGHTNESS provides network technologies based on OPS and OCS mainly for intra DC environment. LIGHTNESS makes available to STRAUSS its test-bed in University of Bristol, and reference STRAUSS's interDC network setup. STRAUSS will have opportunity to test and evaluate experimentally its orchestrator for coordination between inter and intra DC network with multiple technology domains.

## 4.3. FP7 PACE

PACE [6] is a Coordination and Support Action (CSA) under the FP7 programme, which aims to consolidate the existing developments in the Path Computation Element (PCE) under a single umbrella. Then push the frontiers of the deployment and reach of PCE in next-generation networks. This consolidation activity include members of the project consortium and beyond to include majority of current and future research projects of which PCE is a relevant technology. Practically, PACE aims to concentrate and rapidly push forward PCE-based frameworks for research, development, technology transfer and innovation, as well standardisation. PACE also try to shape, secure and sustain the EU-based competence, leadership and commitment to innovation into and beyond the era of SDN, NFV and application-based network operations. To do this, PACE developed a web based portal where to concentrate material related to PCE and the project itself, and ease collaborative actions within a concentrated community of industrial leaders, developers, and academics.

PACE envisions achieving these objectives by focusing its efforts on three inter-related, parallel tracks: i) standardization activities to catalogue, coordinate and support PCE standardization activities and offer technology gap analysis, ii) outreach activities by establishing liaisons with other projects to identify roadmaps for collaborative research, and by organizing and promoting thematic open workshops and meetings in leading conferences targeting both collaboration and education, iii) open-source PCE, by contributing towards the development and creation of well-documented, easily extensible open-source PCE platform and additional tools, including also a testbed platform for experimental validation activities.

Last year, as a CSA project, PACE supported and advised the LIGHTNESS architectural work for the identification and evaluation of PCE functions within the SDN enabled control plane for optical data centre networks. Basically, that collaboration converged into the definition of LIGHTNESS control plane architectural documents, in particular into the specification of path computation functions and services at both intra and inter data centre level, as well as in the definition of virtual network topology computation and calculation strategies and procedures. This year, the collaboration moved towards support actions and feedbacks from the PACE community concerning the LIGHTNESS development of those computation functions needed at the VDC composition application to calculate the optimal virtual network slices (built by a concatenation of configurations of the optical devices). This collaboration and collection of feedbacks was mostly carried out in the form of direct discussions triggered by Nextworks and UPC (also members of PACE) during PACE meetings, events and conference calls. In particular, the PACE workshop on "Path Computation Element and beyond: innovating control and management functions towards fully reconfigurable software-centric networks", co-located with ONDM conference, where Nextworks presented the LIGHTNESS experience in developing optical control functions with OpenDaylight, has been a further occasion to validate the implementation strategies taken in LIGHTNESS.

As a planned action for collaboration with PACE this year, deliverable D6.4 [7] stated that LIGHTNESS was expecting to receive support considering standardization efforts towards the potential submission to IRTF and IETF of use-cases, requirements, and deployment frameworks for SDN-based control of data centre networks. As already stated in section 3, no official contribution to IRTF or IETF (i.e. in terms of Internet Drafts) has been produced by LIGHTNESS. However, it is important to highlight that the LIGHTNESS consortium, properly advised by PACE members leading IRTF and IETF activities around PCE and SDN (mostly Old Dog Consulting and Telefonica), as an actual support and collaboration action, intentionally decided to not submit Internet Draft or other official contributions. The main reason behind this is that IRTF and IETF are bodies mostly focused on architectural and protocol aspects, rather tha a placefor where to present either new technological disruptive solutions or specific extensions to existing frameworks as the core of LIGHTNESS actually is, with novel optical technologies for data centre networks at the data plane and enhanced SDN control plane features for optics at the control plane. In this context, the submission of a single "-00" LIGHTNESS Internet Draft (e.g. presenting the overall architecture or specific SDN extensions) with poor (if no zero) potential of adoption as working group document has been prevented.

# 5. Exploitation activities and future plans

Exploitation has been of high interest in LIGHTNESS and aimed at creating major impact in the way that future data centre networking is performed and the way that the combination of optical technologies, SDN and OpenFlow is exploited. In particular, it has been observed that since the kickoff of the project, the awareness that network flexibility, programmability and scalability in data centre environments are real challenges that service and cloud providers are facing when deploying new services, has been consolidated in the community. LIGHTNESS played a key role here, and its proposed architecture mixing hybrid optical technologies at the data plane with advanced SDN control functions and services perfectly fit with the needs of future data centre. In particular, LIGHTNESS contributed to generate interest in the community around the adoption of optics in data centres, towards full optical data centre network architectures.

This has been achieved throughout the project lifetime by informing and convincing industrial and research communities the benefits, advantages and new opportunities coming from this new data centre architectural approach. In particular, LIGHTNESS has pursued its vision while carrying out its technical work. It has widely disseminated technical knowledge, findings, and experience to a broader audience. LIGHTNESS has organized and participated in conferences and standardization events (i.e. ONF) to publicize its outcomes. Furthermore, workshops, symposiums and demonstrations have been organised, with the objective to create and inform a heterogeneous community of operators, service providers, vendors about the LIGHTNESS vision, directions and results, and at the same time gather information on any related efforts and initiatives. This has also laid the foundations for collaborations with external entities and researchers throughout the project, as detailed in previous sections, but has also provided motivation for individual and collective exploitation of the project's results.

On top of this productive joint exploitation effort, individual activities from each LIGHTNESS members have been carried out and above all, will be consolidated after the project to apply LIGHTNESS results into concrete initiatives. The LIGHTNESS consortium is composed by six organizations with complementary roles and expertise, playing in different markets and motivated by different missions: a cloud service provider and data centre owner (Interoute), a dynamic SME with strong know-how in the IT and Telecommunications sectors (Nextworks), an HPC research centre (Barcelona Supercomputing Center), and three universities (TUE, University of Bristol, UPC). Thus, the exploitation of LIGHTNESS results addresses diverse business and research sectors. While industrial partners and SMEs typically concentrates their exploitation activities to apply LIGHTNESS outcomes to either existing or new market products and services, academic and research based partners aim at consolidating their position in the research community while improving their knowledge and expertise. Moreover, these different exploitation approaches also reflect into different roadmaps and timings. Commercial exploitation for industrial partners is typically a mid-term process that has to consider and evaluate complex business and deployment aspects, as well as market evolutions which are typically slow processes. On the other hand, non-commercial exploitation for academic partners is a much faster process that allows to apply the project results in the short-term, for example by transferring them into new research initiatives (e.g. new projects) or new education activities (e.g. seminars, tutorials, classes, etc.).

## 5.1. Summary of LIGHTNESS innovations

LIGHTNESS designed and implemented a full architecture for a novel hybrid optical and SDN enabled data centre network. This has been translated into the development of a set of components at both hardware and software level. Among these outcomes and results, LIGHTNESS consortium identified two high potential innovations, which are basically technologies designed and developed in the project with concrete opportunities for commercialization and adoption in the market of software and hardware vendors on the one hand and service providers on the other.

These two innovations can be summarized as follows:

- *Novel data centre architecture exploiting hybrid optical switching and programmable NIC*
  This refers to the new data plane architectural approach proposed in LIGHTNESS with a flat fabric composed by disruptive optical technologies. This innovation mostly refers to the hardware developed in LIGHTNESS: the programmable optical NIC and the OPS switch. The evaluation and validation of their performances confirms that these technologies are ready to address the requirements of future data centres.

- *SDN controller and applications for Virtual Data Centre composition in support of a unified control of the hybrid optical data centre fabric, deploying OCS, OPS and programmable NIC technologies*
  This relates to the whole set of control plane prototypes developed in the projects, as the implementation of the LIGHTNESS SDN control plane for flexible and programmable operation of full optical data centres. It includes the enhanced OpenDaylight SDN controller, the applications running on top for enhanced virtualization, control functions and multicast services, and the control agents to enable OpenFlow on each optical device

The two innovations above represent those key LIGHTNESS concrete outcomes that have driven the exploitation analysis, plans and roadmaps of the whole project consortium. As stated before, each partner followed its own approach according to the nature of the institution. The detailed exploitation for each LIGHTNESS member is reported in the next section.

## 5.2. Individual partner exploitation

### 5.2.1. Interoute (IRT)

Interoute is the owner-operator of one of Europe's largest networks and a global cloud service platform which encompasses 12 data centres, 14 virtual data centres and 31 colocation centres, with connections to 195 additional third-party data centres across Europe. Its full-service unified ICT platform serves international enterprises and many of the world's leading service providers, as well as governments and universities. Interoute's unified ICT strategy provides solutions for enterprises seeking connectivity and a scalable, secure advanced platform on which they can build their voice, video, computing and data services, as well as service providers in need of high capacity international data transit and infrastructure. With established operations throughout Europe and USA, Interoute also owns and operates 24 connected city networks within Europe's major business centres.

The Interoute pan-European infrastructure is designed for the delivery of enterprise IaaS and virtualized services and is directly interconnected through a network owned by Interoute. Each Interoute data centre is deployed with a network fabric deeply integrated in the company pan-European infrastructure to support effective access, geographic fallback and full product range. Major services offered by Interoute and running in this large data centre infrastructure include: managed hosting services, virtualization services (as a specialized offer of managed hosting, mostly Virtual Data Centre), colocation services (that provide companies with a range of flexible alternatives to housing their systems internally).

As any other data centre operators, Interoute has a strong interest in operating its data centre infrastructure in an efficient, flexible, programmable and cost effective way, trying to optimize the resource utilization while keeping assured quality for services offered to customers. In particular, Interoute believes that management and control of data centres need to evolve towards very flexible and programmable approaches where the delivery, operation and maintenance of emerging cloud applications and virtualized services can follow the dynamicity and variety of customer requirements and new 5G architectures. Key for Interoute is to deploy more and more IT throughput towards customers while improving its service offer, e.g. with advanced features for performance monitoring, automated elasticity, service backup options, etc. This is even more needed now that Interoute recently acquired Easynet, a European leading managed service provider delivering integrated networks, hosting and unified communications solutions to national, international and global customers. While this acquisition provided additional scale, skills and services to the combined business bringing significant benefits to national and multi-national customers and prospects, new challenges arise for integration of different services and resources under the same management and coordination umbrella.

In this complex and challenging Interoute business environment, the participation in LIGHTNESS has been crucial to acquire direct knowledge and awareness of latest research trends in the area of data centre network architectures and most important control, management and control solutions. Interoute believes that data centres will be heavily impacted by new 5G technologies and architectures expected to be deployed before 2020, that will challenge data centre networks with huge amount of traffic and distributed patterns. Future data centre networks are called to be more flexible and efficient than current ones, to address unprecedented requirements of transmission speed, delay, deep control mechanisms for traffic and highly dynamic management of virtual and physical resources available to operator. In this direction, LIGHTNESS proposes a new architectural approach where a full optical flat data centre fabric is dynamically and automatically operated and controlled in software following the SDN paradigm.

In particular, Interoute has been extremely interested in the evaluation of the LIGHTNESS innovations previously described (see section 5.1) for potential adoption and integration in services and products currently offered to its customers. Thus, as part of its exploitation analysis, Interoute has carried a couple of Strengths Weaknesses Opportunities Threats (SWOT) analysis for the LIGHTNESS potential innovations: the novel optical flat data centre network architecture, and the SDN controller with applications for VDC composition.

The SWOT analysis [8] is a structured strategy planning method used to evaluate strengths, weaknesses, opportunities and threats involved in a project or in a company. A SWOT analysis can be carried out for a product, place, industry or person, and identifies the internal and external factors that are favourable and unfavourable to achieve the planned objectives, that in the case of Interoute are related to improvement and consolidation of its service portfolio and pan-European infrastructure.

**Table 5-1** summarizes, in the typical SWOT matrix format, the analysis carried out for the full optical data centre network architecture; in particular, here Interoute has analysed the pros and cons of the combined usage of the programmable optical NIC and the OPS switch, as the main novel technologies developed in LIGHTNESS.

| **Strenghts** | **Weaknesses** |
|---|---|
| • Higher throughputs<br>• Lower latencies for business critical applications<br>• Lower power consumption<br>• Scalability | • Hardware is only at prototype status<br>• Lack of deployment and validation in large scale environments<br>• Lack of backward compatibility with existing full EPS technologies and architectures |
| **Opportunities** | **Threats** |
| • Readiness to support 5G architectures and huge traffic amount<br>• Enter Big Data market<br>• Adaptation to fast changing technologies and market conditions<br>• New marketing opportunities as “greener” DC operator | • Lack of hardware vendors providing mature optical technologies<br>• Lack of standardized technologies<br>• Potential lack of compatibility across multiple vendors<br>• Alternative technologies beyond electrical 100Gbps |

**Table 5-1: SWOT analysis: full optical data centre fabric**

**Table 5-2** summarizes the SWOT analysis performed for the SDN controller augmented with VDC composition applications and algorithms.

| Strenghts | Weaknesses |
|---|---|
| • Automated operation of data centre networks<br>• Programmable and flexible provisioning of multicast services<br>• Faster deployment, evolution and scale of services<br>• Ease of maintenance of services<br>• Limitation of vendor lock-in constraints | • OpenFlow extensions specific for the project optical technologies<br>• OpenDaylight is not currently a production ready platform<br>• Need to replace current management tools<br>• Lack of joint coordination of IT and network resources |
| **Opportunities** | **Threats** |
| • Consolidation of Interoute VDC product<br>• Readiness to support 5G architectures and NFV deployments<br>• Position in the market as full SDN enabled data centre operator<br>• Ease of integration with orchestration tools like OpenStack | • Lack of software vendors providing hardware agnostic mature products<br>• Need to consider and adopt new SDN enabled network security mechanisms<br>• Proliferation of many SDN/NFV solutions in the market<br>• Lack of standardized solutions |

**Table 5-2: SWOT analysis: SDN controller and applications**

Based on these SWOT analyses, Interoute has set clear internal objectives and roadmaps for the adoption of the LIGHTNESS technologies. Starting from the full optical data centre fabric, the weaknesses identified in the SWOT analysis prevent an adoption of the LIGHTNESS novel optical technologies in the short term. The lack of stable commercial hardware products, validated in large scale environments and that follow well defined standards is the main reason behind this roadmap. Currently, Interoute is following a strict approach concerning the introduction of new hardware solutions (at all levels and layers, from cooling to IT and networking) in its data centre infrastructures. The strengths and opportunities provided by both the programmable optical NIC and the OPS switch are promising, and Interoute is very interested in their evolution and consolidation after the project. While the programmable optical NIC, which has been evaluated as a real disruptive technology, still needs considerable time and investments to become a full product to be embedded with the new generation of physical servers, the OPS switch is currently more mature in its consolidation path. Indeed, the OPS commercialization opportunities identified by TUE, combined with the chip benchmarking activities already started and above all the performance and benefits against HPC applications make the introduction of OPS products a promising opportunity for Interoute in the medium-long term, that is 2018-2020. This means that Interoute will carefully follow, support where possible, and further analyse the next stages of OPS commercialization and possibly will start lab trials in the period 2017-2019.

On the other hand, the adoption of SDN control solutions coming from LIGHTNESS is a more concrete possibility that Interoute has carefully evaluated for the short-medium term mainly to take full advantage of the strengths and opportunities identified in the related SWOT analysis. The adoption of SDN technologies is well established in the Interoute's global roadmap and it is already a reality in the inter-DC segment. This is demonstrated by the SDN deployment in the Interoute's Unified Connectivity solution, for the integration between data centre network and Interoute MPLS backbone [10], or the combined mix of NFV and SDN adopted in the Interoute Cloud Connect (ICC), launched in May 2015 [11], which is considered a key to achieve good network performance, agility and security for enterprise clients as they move towards virtualized networks and IT. "Interoute's new ICC product meets these needs head on with a number of NFV capabilities including optimized traffic with acceleration available on public clouds, all underpinned by Interoute's SDN-ready MPLS network. Interoute is setting an aggressive pace with SDN WAN, and this combined with its considerable network capacity is compelling.", as commented Joel Stradling, Research Director at Current Analysis.

In the intra-DC segment, the introduction of SDN is part of the strategies and roadmaps of many data centre operators and providers. A recent technology market report from Infonetics Research, surely helps to understand these trends [9]. A survey with 153 medium and large businesses in North America showed that 79% of the interviewed are planning to introduce SDN in production trials in 2016 and in live production data centres in 2017. Moreover, many of them are planning to evaluate non-incumbent vendors, including third-party SDN vendors and open-source vendors.

These results validate the architectural choices done for the LIGHTNESS SDN control approach. In particular, Interoute is planning to introduce SDN technology with the aim of consolidating and improving the management and coordination of its top product: the Virtual Data Centre (VDC). VDC is a multi-tenant Infrastructure as a Service (IaaS) platform for on-demand computing and cloud hosting with integrated applications that enables either private or public cloud computing, offering public simplicity with private cloud security. VDC customers build their own virtual data centre through a VDC Control Centre graphical interface and they can provision virtualized servers, storage volumes and network segments within a specific zone (i.e., an Interoute data centre site). The current management and coordination procedures for the VDC lacks of flexibility and dynamicity in the provisioning and re-configuration of the virtualized resources. In particular, after the SLA management phase (that has to be performed off-line in any case), the actual provisioning, configuration, integration with existing services and release of the virtualized infrastructure to the customer has still to becarried out by network and IT administrators, not automated procedures. Thus, the introduction of SDN to fully automatize the VDC provisioning phase is a clear objective for Interoute. The target is the integration of an SDN controller inspired by the functionalities of the LIGHTNESS prototype with the current VDC management tools, mostly to implement a smooth SDN introduction leveraging on existing VDC deployment algorithms. The LIGHTNESS OpenDaylight software prototype supports the provisioning of virtual network slices bound to already provisioned virtual machines. Since the target of Interoute is to have an SDN enabled coordinated provisioning of IT and network resources, additional functionalities are needed before the introduction in production environments, that is planned for the medium term, around 2017-2019. In the meanwhile, taking advantage of the Interoute participation in the FP7 COSIGN project [4] (that is working towards this SDN enabled coordination and orchestration of IT and network resources), lab trials based on the LIGHTNESS SDN prototype are planned for the short-medium period, that is 2017-2018.

### 5.2.2. Nextworks (NXW)

Nextworks s.r.l. is a R&D SME located in Pisa (Italy) and created in 2002 as a spin-off company of the Computer Science and Telecommunications Division of the Consorzio Pisa Ricerche (CPR–DITEL). Nextworks operates in the ICT sector, collaborating with some of the major European manufacturers and operators. The company’s team boasts long-term experience and proved skills in the frameworks of Control Plane technologies for wired and wireless transport networks, design and development of complex software on both traditional and embedded platforms and in Quality of Service (QoS) in packet networks, IP telephony, digital video encoding and streaming. The activities carried out by Nextworks range from pure support consulting on one end, up to third-party software design and developments for equipment vendors and network operators on the other end (e.g. long term collaborations with Alcatel-Lucent, Ericsson and Interoute). The specific nature and technical position of these activities require a leading-edge, up-to-date know-how and technical expertise. In order to fulfil this requirement, Nextworks participates actively in EU funded research projects, cooperating with both academic and industrial partners, as a strategic investment to develop and update know-how on selected topics.

The company is organized in two major groups:

- The *Products Area Group*, which develops products for the advanced and integrated control of entertainment, domotics, control & automation, energy/power systems in residential and yachting markets. These products leverage on the company background and expertise acquired through the research activities of the Knowledge Area Group.
- The *Knowledge Area Group*, dedicated to independent consulting activities on network architectures, design and operation, 3rd-party software development for emerging network architectures and technologies, research and prototyping activities. During the years the company has produced its own GMPLS and PCE protocol stack and developed several GMPLS and PCE customizations and extensions for different customers. In the recent period, Nextworks has focused in innovative technical areas like SDN, network virtualization, cloud-network convergence and data centre control and orchestration. In these fields, the participation in EU projects like FP7 ICT LIGHTNESS, FP7 ICT CONTENT, FP7 ICT Mobile Cloud Networking, FP7 ICT TRILOGY 2, FP7 ICT COSIGN and FP7 ICT DOLFIN among the others, is being fundamental to incorporate the latest research results into novel software prototypes, creating the baseline for competitive product solutions.


**Figure 5-1: Nextworks R&D areas**

Figure 5-1 shows the main R&D areas in the current strategy of the company, where LIGHTNESS matches directly to the cloud, SDN and NFV areas, while also providing technological foundations towards the more recent 5G topics. In line with this strategy, the participation in LIGHTNESS has allowed the Knowledge Area Group of the company to consolidate and improve the know-how related to SDN solutions for optical technologies and virtualization of data centre services. The impact can be mapped on three major fields of the company's offer:

- The extension of the product portfolio with a SDN controller for optical data centre environments. The SDN control plane prototypes developed in the project, based on the open source OpenDaylight platform, can be important starting points towards the engineering of a commercial product for automated provisioning of multicast data centre services. Moreover, the integration of this component in the Nextworks' entertainment and demotics system for the yachting market enables to distribute parts of its functionalities on the cloud/local data centre. This is a fundamental step to introduce new features (e.g. the remote monitoring and control of entire fleets) and offer a more competitive product targeting integration with emerging 5G architectures.
- The consolidation and enhancement of the consulting portfolio of the company, in the area of SDN and NFV, in support of programmable and flexible provisioning of intra-DC connectivity. The specialized know-how aligned with the latest research outcomes obtained from the project is a key factor to differentiate the Nextworks' consulting offer from the competitors, mostly composed by large staff leasing companies that provide relatively unskilled personnel to their customers. On the other end, Nextworks can rely on the expertise acquired around the widely used OpenDaylight platform to develop customized software solutions easy to integrate in most of the current reference environments

requested by its partners and customers (e.g. network operator and DC providers or vendors).

- The offer of new training courses on SDN and NFV, designed for different targets, from network administrators up to SDN developers. Depending on their target audience, the courses are focused on SDN and NFV use cases and architectures and OpenDaylight controller software. The know-how and practical experience developed in LIGHTNESS project has constituted a key baseline for the definition and the preparation of these training courses, three of them held in the period Q4-2014/Q2-2015.

### 5.2.3. Barcelona Supercomputing Center (BSC)

Optical interconnections offer a potentially disruptive technology solution for High Performance Computing Data Centers. This kind of data centers is growing in size driven by the need to process multiple large scalable applications from various users in a diverse set of different industries.

Optical interconnection offers superior bandwidth and lower latencies than their counterpart electrical networks. High data rates can be realized with Dense Wavelength Division Multiplexing (DWDM) with lower cost. Optics could also provide a disruptive technology to provide connectivity through longer distances spanning several kilometres because basically light could be transmitted with less loss than electricity.

The Barcelona Supercomputing Centre-Centro Nacional de Supercomputación (BSC-CNS), serves as the national supercomputing facility in Spain with the mission to research, develop and manage information technologies in order to facilitate scientific progress. The centre hosts several supercomputers including Marenostrum supercomputer, one of the most powerful supercomputers in Europe. Additional, there are also three more HPC computers available for the scientific community---- Minotauro, that is a NVIDIA GPU cluster with 128 Bull B505 blades and Infiniband network; Tibidado low power experimental HPC with Tegra2 processors and 1GbE network, and SGI Altix 4700 shared memory machine with 64 dual core Intel Montecito processors. These HPC computers are spread in different buildings across BSC-CNS facilities. Scientific community and industries across Europe are using these HPC facilities that BSC-CNS provides in different ways. For example, several companies from the energy sector are commonly renting HPC resources from BSC-CNS to carry out computational simulations of high-end products. These simulations commonly run for several days and may require dedicated computing resources in order to mitigate any external interference from other users.

LIGHTNESS optical network solution is envisioned to optimize current computing facilities in BSC-CNS in the near term. There are two aspects that LIGHTNESS will provide a substantial improvement over the existing solutions in HPC Data Centers like BSC-CNS. The first one will be focused on improving the current technology to interconnect the multiple computing facilities that BSC-CNS provides. As it was stated before, these facilities are spread across different building in BSC-CNS premises and connecting them through optical technologies such as an OPS could be beneficial. An OPS of small size could be enough to interconnect existing computing facilities providing higher bandwidth and lower latencies than current existing electrical switches. A small 4x4 OPS device could be enough to interconnect current HPC systems.

Another use case that LIGHTNESS could fit in the near term in HPC facilities is to replace the electrical core switches in Data Center with OCS switches. This will provide a much better solution to solve the problem of isolating computing resources in current HPC facilities. As it was stated above, HPC Data Centers are renting computing resources to industry in order to perform high-end computing sensitive simulations. In this context, OCS will provide a superior isolation solution to perform such critical simulations than electrical switches because OCS could partition physically the network into multiple HPC computing machines. These solutions will be studied in detail in order to be deployed in the next supercomputing procurements coming in the following five years.

### 5.2.4. Technical University of Eindhoven (TUE)

The expertise gained at TUE from the LIGHTNESS project led to expand the scientific knowledge in the design, fabrication and testing of low latency and high throughput optical packet switch architectures and their applications in high performance computers and data centres interconnect networks. TUE is exploiting this expertise in several directions.

The first direction is the introduction of state-of-the-art educational programmes in Optical Communication courses with specific lectures on advanced data center networks to preparing Master and PhD students for innovative R&D positions in Europe, who will subsequently deploy their skills to strengthen the industrial activities in Europe. An example is the introduction in the course of Optical Interconnect Networks (3 ECTS) and Optical Fibre Communication Technology (5 ECTS) for Master and PhD students of novel teaching materials developed from the knowledge acquired in LIGHTNESS.

The second direction to exploit the unique expertise gained in LIGHTNESS is to attract several PhD and Master visiting students from other universities with the aim to acquire the specified knowledge developed in the contest of the LIGHTNESS. Several visiting PhD students travelled to Eindhoven bringing their own budget to exploit the optical switch prototypes in novel high performance optical networks, including not only novel data center networks but also advance elastic and highly dynamic metro optical networks exploiting the fast reconfiguration time and statistical multiplexing provided by the OPS developed in LIGHTNESS.

The third direction is to exploit the fast optical packet switch prototype enabled by SDN developed in LIGHTNESS to consolidate its reputation in the international research community by offering unique and state of the art photonic switches. State of the art laboratory equipped with this unique prototype can allow for joint collaborations and eventually novel applications for advanced optical packet switched networks.

Last but not least the potential commercial exploitation and opportunity for the OPS developed in the project. As the result of the investigation carried by BSC on the exploitation of interconnecting HPC systems, even OPS with moderate amount of ports could be beneficial to interconnect existing computing facilities providing higher bandwidth and lower latencies with respect to current existing electrical switches. Based on these promising results, the route to commercialize the OPS still requires further technologies development. The prototype implemented in LIGHTNESS is based on off-the shelf components. Using such prototype has led to important results and proof of principle of the potential of the OPS. However, to double the number of ports, the amount of required optical circuits scales as the square of the port count. For practical port count, a viable solution is to integrate the SOA-based off-the shelf components and passive circuitries in compact photonics chips. Recently we have successfully demonstrated the operation of a 4x4 monolithically integrated chip with more than 120 optical components. Benchmarking this first fabricated chip provides a clear evaluation of the possible limits for further scaling the amount of components on a single chip. The results show that an 8x8 OPS photonic chip is feasible in terms of physical space and performance. Beyond this amount of ports, the modularity of the switch allows to use multiple interconnected photonic chips to build a large port switch. The technical hurdle is the packaging of such a chip. Packaging chips with large I/O waveguides has two technical issues: first is the coupling losses, and second is the costs associated with the manual packaging operation. Many universities and companies are working to find a packaging solution that not only would make those chips available to the market, but also allows by automatization a competitive costs and power consumption with alternative technologies. In this respect TUE is actively involved in find an automatic packaging technique for InP chips that will pave the way to the commercialization of the OPS architecture developed in LIGHTNESS.

### 5.2.5. Universidad Politecnica de Catalunya (UPC)

The UPC research group involved in LIGHTNESS through the active participation to the designed and implemented solutions has been able to expand its expertise mainly on optical technologies for data centres and SDN-based control and management technologies and protocols to efficiently manage and provision data centre resources.

Of primary importance is the knowledge acquired through the contribution to the design and implementation of the OpenFlow (OF) protocol extensions to also support the OPS technology and the contribution to the modification/extensions of the OpenDayLight (ODL) modules. Such expertise is intended to be exploited in different ways. As a first activity, it has been already promoted in both Master Thesis and PhD degrees at UPC the inclusion of some of the LIGHTNESS concepts and scenarios. As an example, a new subject has been very recently introduced in the framework of the Master of Telecommunication Engineering and Management (MASTEAM) of the *Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels* (EETAC), one of the school in the UPC. In particular, the subject is devoted to optical technologies for future cloud-services with special emphasis to the technical solutions provided by LIGHTNESS. Moreover, the optical-based data centre architecture has been also included in other subjects (e.g. the course about “Optical Networks”), in the framework of the Master in Telecommunications Engineering at *Escola Tècnica Superior d’Enginyeria de Telecomunicació* (ETSETB) of UPC. This way, UPC students, future researchers and industrial employees, can be properly educated on advanced data and control plane solutions for data centres. It worth to mention here that during the project lifetime, 3 Master Thesis related to the LIGHTNESS concepts and solutions have been completed at UPC. Moreover, 2 PhD students are performing research activities related to LIGHTNESS.

On the other hand, the activities carried out in the design and implementation of the SDN-based control solutions and the consequent dissemination activities provided the UPC research group with great visibility; this may open the possibility to be engaged with industrial partners about the adoption of SDN control in the dynamic provision of cloud services achieving the optimisation of the usage of the data centres resources.

### 5.2.6. University of Bristol (UNIVBRIS)

Bristol is developing an open programmable smart city region under the initiative “Bristol Is Open” (BIO). It is collaboration between the technology, media & telecommunications industry, universities, local communities, and local and national government. The project is governed by a joint venture between University of Bristol and Bristol City Council. Long term partners join an advisory panel that guides the joint venture on the evolution of the network, the creation of multi-partner experiments, the services that underpin the project and publicity and events surrounding the project. BIO is going to deliver a new network with wired and wireless infrastructure in the city centre, and a SDN-based control plane will sit on top of this enables programmability and flexibility of the city. We are going to fit LIGHTNESS solution, especially, the Architecture on Demand (AoD) technique, our programmable optical NIC, and OpenFlow (OF) agents into the BIO platform. The details of the techniques and their benefits of being used in the BIO network are as below:

In the LIGHTNESS data plane, instead of a hardwired interconnection of different network elements, a more flexible DCN architecture equipped with an AoD node is adopted, which consists of an optical backplane (e.g.,Polatis fibre switch with a large port number) with switching modules and passive devices attached. The optical backplane of BIO is also adopting the same AoD technique with Polatis fibre switch and the optical devices directly connected, which enhance the programmability and flexibility of the optical data plane.

We developed a novel programmable optical NIC for LIGHTNESS with programmable functionalities and enabling intra-rack server-to-server direct connection. By substituting the commodity NIC by our novel NIC, this solution supplies the programmability and flexibility down to the server, and highly improves the intra-rack server-to-server latency, hence improves the Data Centre Network performance. We are going to use this programmable optical NIC in BIO network as a network emulator, which can also benefit from enabling the possibility of letting the BIO users emulate their own traffic pattern.

In LIGHTNESS, the southbound interface has been implemented by means of the OpenFlow (OF) protocol, which was extended to support the particular features of the hybrid all-optical data plane proposed in the project. A set of OF-Agents was developed to enable the OF-based configuration in the network elements (NE) of the data plane. These OF-Agents reside on top of each NE, for example, AoD node, OPS, ToR switch and programmable optical NIC. The agents translate the extended OF protocol messages coming from the SDN-controller into a set of operations that the devices can understand. On the other hand, the agents collect monitoring information from the devices and send it to the SDN controller formatted as extended OF protocol messages. BIO network is SDN-enabled. To full use the features of AoD, programmable optical NIC in BIO network, we are going to employ the OF-agents working together with the NE.

The LIGHTNESS solution can definitely enhance the programmability and performance of the BIO network.

# 6. Conclusions

This deliverable reports the dissemination, standardization, collaboration with other EU projects, and exploitation activities carried out during the whole life of the LIGHTNESS project.

LIGHTNESS delivered a high-performance all-optical hybrid OCS/OPS data plane empowered by SDN-based network control plane which is capable of dynamic provisioning of high bandwidth connectivity services. With the fruitful project outcomes, WP6 enables external visibility through the activities of dissemination, standardization, collaboration with other projects, and exploitation.

With regard to dissemination activity, the technical activities carried out in LIGHTNESS have brought to a significant number of scientific publications in highly impacting journals and conferences. Furthermore, a significant number of invited talks from LIGHTNESS partners have further contributed to increase the visibility of the achieved results. The public demonstrations carried out require special emphasis. The first one at EuCNC 2014 has been awarded with the Best Booth Award while the results of the final demo have been accepted as post-deadline paper at ECOC 2015. Finally, it deserves to mention that LIGHTNESS partners have actively contributed to many workshops about technologies and solutions towards future data centres with the participation of both academics and industry.

For Standardization activity, the results and output of LIGHTNESS has attracted high interest for the data centre and cloud industries, and as well as the standard communities. In the third year specially, we presented the outcome of the LIGHTNESS project to the main standardization bodies, focusing on ONF, and organized a workshop together.

LIGHTNESS collaborated with FP7 COSIGN, STRAUSS and PACE which enabled LIGHTNESS exchanging and analysing information, outcomes and results with research initiatives targeting similar and compatible research and technological areas. LIGHTNESS got fundamental inputs and feedbacks to finalize its development activities and validate the proposed architecture.

The LIGHTNESS consortiums have also defined how the project outcomes and results will be exploited. Individual exploitation plans have been provided, addressing diverse business and research sectors. Interoute, as main industrial partner in the consortium has provided SWOT analysis for key LIGHTNESS technology innovations with roadmaps for their adoption in existing services and products. Nextworks, as an SME, has detailed how its future businesses and research activities will benefit from LIGHTNESS outcomes. Finally, the academic and research oriented partners (UPC, TUE, BSC and University of Bristol) have also defined how LIGHTNESS will impact their future research.

# 7. References


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# Acronyms

AoD Architecture on Demand

API Application Programming Interface

CDN Content Distribution Networks

DC Data Center

DCN Data Center Network

DWDM Dense Wavelength Division Multiplexing

FPGA Field Programmable Gate Array

GMPLS Generalized Multi Protocol Label Switching

HPC High Performance Computing

IaaS Infrastructure as a Service

IETF Internet Engineering Task Force

IoT Internet of Things

IRTF Internet Research Task Force

MPLS Multi Protocol Label Switching

NIC Network Interface cards

NFV Network Functions Virtualization

OCS Optical Circuit Switching

ODL OpenDaylight

OF Open Flow

OGF Open Grid Forum

OIF Optical Internetnetworking Forum

ONF Open Networking Foundation

OPS Optical Packet Switching

OTWG Optical Transport Working Group

PCE Path Computation Element

QoS Quality of Service

SDN Software Defined Networking

SDNRG SDN Research Group

SDO Standard Development Organizations

ToR Top of the Rack

VDC Virtual Data Centre