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Publication date:
2015

Document Version
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Henrik Wessing[1], Kurosh Bozorgebrahimi[2], Bartosz Belter[3], Anna Tzanakaki[4], Susanne Naegele-Jackson[5], Victor Olifer[6], Andreas Metz[7], Josef Vojtech[8] and Pavel Skoda[8]

1. Technical University of Denmark (DK), hewe@fotonik.dtu.dk, +4545253804
2. UNINETT (NO), kurosh@uninett.no
3. PSNC - Poznan Supercomputing and Networking Cenrter (PL), bartosz.belter@man.poznan.pl
4. University of Bristol (UK), at12368@bristol.ac.uk
5. University of Erlangen-Nuremberg (DE), Susanne.Naegele-Jackson@fau.de
6. Jisc Technologies (UK), Victor.Olifer@jisc.ac.uk
7. Institut für Rundfunktechnik (DE), metz@irt.de
8. CESNET (CZ), {josef.vojtech|pavel.skoda}@cesnet.cz

Abstract: This study identifies key requirements for NRENs towards future network architectures that become apparent as users become more mobile and have increased expectations in terms of availability of data. In addition, cost saving requirements call for federated use of, in particular, the optical spectral resources. In this work, the key findings from related projects are integrated to provide the building blocks for efficient use and sharing of spectrum. A new network architecture is derived to support exactly the service orchestration and the federated use of resources. It comprises four layers from the heterogeneous multi-technology physical layer up to the service provisioning and orchestration.

Keywords: Cloud services, federations, network architecture, alien waves, OLX.

I. INTRODUCTION

In the future, the NRENs face a number of requirements from user, technology and cost perspectives. The work in GN3plus JRA1 Task 1 has focused on these requirements and has focused on integrating the key findings from all other tasks including Open Calls in JRA1 in the quest for a viable solution. The users today are everywhere and they expect 24/7 access to their data with an acceptable quality. This boosts the demands for fixed and mobile cloud services, which again places severe requirements on the way the future network is equipped and managed. In addition, the NRENs typically face a demand for significantly more bits/s at lowest possible latencies for the same or even less costs. Such different requirements call for a new network architecture which in particular takes federated use of resources into consideration.

II. REQUIREMENTS TOWARDS FUTURE NETWORK ARCHITECTURES

The collection of requirements towards future architectures is based on literature, work in related GN3plus JRA1 tasks associated with Mobile Aggregation [GN3p-JRA1-T3] and Open Cloud Exchange [GN3p-JRA1-T2]. In addition, key findings from the European projects CONTENT [CONTENT], BonFire [BONFIRE], and GEYSERS [TZA-2014] are included. The requirement analysis reveals that the current network technologies and architecture cannot offer the fully dynamic and flexible transport services needed for the future service orchestration; a service orchestration which should include both IT and network infrastructure resources. Also, from the cloud perspective, it is needed to provide the infrastructure to support GEANT Open Cloud Exchanges (gOCX) and further for cost reduction purposes implement Open Lightpath Exchanges (OLX).

III. TECHNOLOGIES TOWARDS FEDERATED USE

Cost reduction through optimised and federated use of fibres and spectrum requires several technologies and tools in different layers. The GN3plus JRA1 Task has collaborated closely with the two Open Call projects REACTION [REACTION] and MOMoT [MOMOT] which deal with the optical spectrum from bandwidth improvement and alien wave aspects, respectively. The role of AWs or maybe better alien bandwidth in flexible networks is very important. The cost of photonic transmission is a significant expenditure for each NREN, but once photonic layers support Alien transmissions, many cost-effective third party networking solutions may be implemented into existing transmission systems. Moreover the AW concept allows sharing of unused capacity with interested parties that may significantly reduce overall network cost. As example a common present 100G transmission system can deliver 4.4 Tbps capacity and there still remains half of spectrum available for sharing [VOJ-2014].

IV. SUGGESTED ARCHITECTURE

Based on what has been previously outlined, a layered architecture with the aim to support QoS-guaranteed, seamless and coordinated cloud and mobile cloud services across heterogeneous domains addressing the needs of the NRENs is proposed. **Physical Infrastructure Layer:** To support the required services the physical infrastructure interconnects end users with computational resources hosted by geographically distributed data centres through a heterogeneous network comprising optical and wireless network domains.

Physical Infrastructure Management: The infrastructure management layer is responsible for providing management of physical resources and enabling capabilities such as sharing resources.

Control Layer: The converged virtual infrastructures delivered through the infrastructure management layer described in the previous section can be jointly operated through a unified control layer based on e.g. the Software Defined Networking (SDN) paradigm.

Service Orchestration: The service orchestration layer is in charge of composing and delivering cloud services to the end-users.

V. CONCLUSION

The mobility of NREN users and the requirement to always access data in the cloud identified new requirements towards network infrastructures. This work has addressed these new challenges by investigating the requirements to come up with guidelines for the NRENs for their future network architectures. The technology enablers for realising this, e.g, bringing the networks beyond 100G have been addressed, and a new modular network architecture has been derived.

ACKNOWLEDGEMENTS

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VITAE

Henrik Wessing completed his PhD study on electronic control of optical infrastructures at the Technical University of Denmark (DTU) in 2006. He now holds an associate professorship at DTU and has been involved in numerous national and European research projects, e.g., IST DAVID, IST-MUPBED, ICT-ALPHA. Henrik is now task leader in the GN3plus project Joint Research Activity 1.

Susanne Naegele-Jackson graduated from Western Kentucky University, USA, and the University of Ulm, Germany, with a Master of Science Degree in Computer Science. She received her PhD (Dr.-Ing.) from the University of Erlangen-Nuremberg in Computer Science. She has worked at the Regional Computing Center of the University of Erlangen-Nuremberg since 1998 on a variety of national and international research projects such as GTB, Uni-TV, Uni-TV2, VIOLA, MUPBED, FEDERICA and NOVI and authored and co-authored over 30 scientific publications.

Pavel Škoda received a Master of Science degree from Czech Technical University in Prague in 2008. Pavel has been focusing on fiber optics since 2005 and has been involved in number of projects designing high speed all optical devices and laser systems. Beside several national projects, he participated in GN3 and GN3+ projects and joint research collaboration with Tyndall National Institute in Cork.

Josef Vojtěch recived with honors M.Sc. degree in Computer Science, B.Sc. degree in Pedagogy and Ph.D. degree in All Optical Networking from the Czech Technical University, Prague, in 2001, 2003 and 2009 respectively. Since 2003, he has been with Optical networks project of Research and Development Department of CESNET, a.l.e., where he is responsible for development of open family of photonic devices. He participated in international projects: FI-PPP XIFI, GN3+, GN3, GN2, Porta Optica Study, SEEFIRE. He holds 9+ patents and utility models and co-authors others. He is a member of IEEE, OSA and SPIE. In 2007 he received the Research prize of the Czech minister of education.

Andreas Metz graduated from University of Applied Science Schweinfurt with a Diploma Degree in Electrical Engineering and has been working as a research engineer for the IRT in Munich since 1999. The main focus of his work has been on the time

critical transmission of audio and video signals over telecommunications systems and IT networks. He currently has the position of project manager for Audio over IP at the IRT. He is a member of several standardization working groups at EBU (European Broadcasting Union) and AES (Audio Engineering Society).

Victor Olifer is a technical specialist of Jisc Technologies (previously known as Janet) Strategic Technologies Division. He joined Janet in 2003 as the JANET QoS Development Project Manager. His current areas of interest are Optical networking, Carrier Ethernet, and SDN. Victor has two first degrees (Computer Science and Applied Mathematics) and a PhD in Computer Science. He is the co-author with Natalia Olifer of Computer Networks: Principles, Technologies and Protocols for Network Design, published by John Wiley & Sons in November 2005.

Anna Tzanakaki is a Research Fellow at University of Bristol. She is co-author of over 150 international publications, co-inventor of 1 granted and 11 published patents, and a technical referee for various journals and conferences. She serves on several conferences' Technical Program Committees. Her research interests include network architectures, technologies, and protocols in support of the Future Internet.

Bartosz Belter received his M.Sc. degree in computer science from Poznan University of Technology in 2002. He works in the Poznan Supercomputing and Networking Centre as a senior network engineer. He has participated in several FP6/FP7 and national IST projects. Currently he is a technical coordinator of two international projects: FP7-ALIEN and FP7-FELIX. He is author or co-author of papers in professional journals and conference proceedings.

Kurosh Bozorgebrahimi had been working with the Telenor 'Transport Network' and 'Innovation Group' from 1996 to 2006 before he joined UNINETT. He has participated in and managed various research and development projects within xDSL, Ethernet/NG-SDH and optical networking for Telenor Networks.
In 2006 he joined UNNNETT and had the technical responsibility for UNINETT's optical networks rollouts. His main fields of interest are access and optical networking. Kurosh received his Masters degree in Physical Electronics (Optical Communication) from the Norwegian University of Science and Technology in 1995.