SAFARI

__S__calable __A__nd __F__lexible optical __A__rchitecture for __R__econfigurable __I__nfrastructure

Deliverable D3.1

White paper and/or input to ONF/OIF on the basic design

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Executive Summary

This document reports the basic design of the control architecture to support highly scalable and flexible photonic network, which has been agreed by responsible partner members. This serves as the first deliverable in T3.1 Programmability utilization design for scalable NW provisioning.

Among the various programmable parameters expected in future scalable and flexible photonic network, the functions to be implemented in digital signal processors (DSPs) have the most significant impact in terms of control aspect of such network. Looking at the use case including catastrophic disaster or disruptive congestion, prompt and harmonized operation of enormous number of parameters is indispensable. For such purpose, hierarchical controller architecture shall be essential. The most cost-efficient way to proceed is to utilize current software implementation which has been already established. Based on the understanding of current implementation, partner members have agreed to adopt two-layered control architecture to support such use cases.

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1 Introduction

The programmability of network components as part of Software Defined Networking (SDN) was originally motivated by data centre applications and concentrated on higher layers (mainly routers). More recently, the scope of SDN has expanded to generic optical transport networks, where intelligence, flexibility and control are also required on the physical layer. Thus, attention has been drawn to the programmability of optical network components. Modern photonic networks require scalability and flexibility, or in short elasticity, which can be achieved by controlling parameters such as modulation formats, spectral allocation and forward error correction from the management (SDN) layer. The topic has been picked up by standardization bodies including Open Networking Foundation (ONF) [1] and Optical Internetworking Forum (OIF) [2], which have been focusing on the extension of the SDN architecture to optical transport and demonstrating a proof of concept for such activities [3].

In this deliverable report, we have identified the basic design of a control architecture to support scalable and flexible photonic network operation in the context of space division multiplexing (SDM) for multicore fibres.

2 Flexible optical networks

The traditional approach to WDM-based networks relies on rigid wavelength allocation with a common modulation format and fixed bitrate, according to a standardized 50 GHz grid. However, traffic demands continue to increase rapidly, both from bandwidth and dynamic perspective. To make the most of limited network resources and to facilitate network modification and upgrade, the concept of flexible (or elastic) optical network has been introduced. The term “flexibility” refers to the ability of the network to dynamically adjust its resources—such as the optical bandwidth and the modulation format—according to the requirements of each connection. Much research has been done in different aspects of optical network flexibility: see [4] for an excellent overview.

An important example for flexibility on the physical layer is the choice of modulation format. In principle, spectral efficiency can be enhanced by using higher order quadrature amplitude modulation (QAM) assuming that the channel power can be freely set. Higher-order QAM formats generally require higher OSNR to keep the same bit error rate performance at the same channel rate, so that higher power is required. However, higher launched power results in nonlinear fibre effects and so consequently the allowable channel power needs to be limited. This consequently compromises transmission reach. Figure 2-1 below [5] shows the transmission distance versus SE for polarisation-division multiplexing (PDM)-binary phase shift keying (BPSK), PDM-quadrature phase shift keying (QPSK), PDM-8QAM, and PDM-16QAM modulation formats.

In order to consider transport performance, the trade-off between the SE and transmission reach needs to be carefully considered. A programmable transceiver with the capability to select the modulation format best suited to a particular flow will therefore play an important role in future flexible long-haul networks.

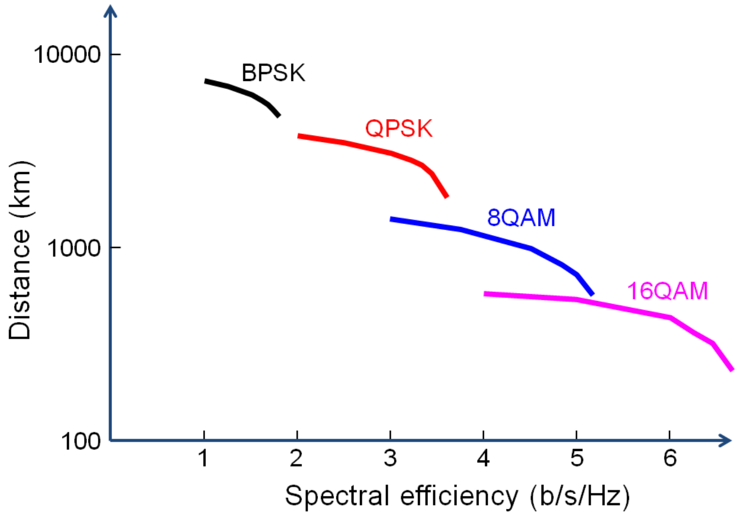

Figure 2-1: Flexibility of modulation formats

The key enablers for flexibility at the physical layer are:

1. **Flexible transceivers:** Different types of flexibility can be offered by the transceivers, including modulation format, symbol rate, FEC characteristics, super channels and channel spacing. Super-channels refer to the combination of multiple coherent optical sub-carriers to achieve a unified channel of higher data rate transmission through multiplexing the constituent channels. High bit rate super-channels, which can be provisioned and routed across end-to-end optical networks as single entities, increase spectral efficiencies and provide a means of boosting line side transmission rates to terabit levels.
2. **Flexible wavelength grid:** The flexible assignment of optical bandwidth to channels enabled by flexi-grid technology leads to higher bit rate transmission by maximizing flexibility in channel spacing. Flexi-grid also introduces the concept of virtualization of physical layer resources, which permits the occupation of multiple spectrum slots with finer grained structures such as super-channels. With flexi-grid, operators can dynamically adapt the wavelength grid to the needs of multi-haul transport applications, as well as increase spectral efficiency and thus increase the overall capacity of the system.
3. **Flexible optical switches:** To avoid costly optical-electrical-optical signal conversion at every node, programmable wavelength selective switches (WSS) are being introduced. These WSS face challenges from two directions: They need to be able to switch channels with variable bandwidth characteristics, and they must handle large numbers of independently switched lines (for example in multicore fibres) as well as wavelengths. This is an ongoing high-priority area for research.

In order to manage the flexible grid and to control the programmable hardware (optical transceivers and switches), the fourth enabler is a **flexible control plane**, which is described in greater detail in chapter 3. The control plane needs to handle routing subject to different constraints (for example crosstalk (XT) in case of multi-core fibre (MCF) as well as dynamic element management of the programmable components at very high transmission rates.

Depending on the type of network under consideration, the requirements on network flexibility and the resulting demands on management systems vary. For example, in local metro-type networks impairments such as XT play only a small role, whereas flexibility of spectral allocation is paramount. More and more, such networks are shared between different services (e.g. mobile front-haul, data centre interconnect, residential access etc.) with very different characteristics and demands. On the other hand, long distance networks face impairment-based constraints which have to be respected and compensated.

One important requirement is the rapid redirection of entire traffic, for example in case of the disruption through a wide area disaster such as earthquakes.

3 Programmable multi-core network applications

3.1 Scope

The deployment of flexible optical networks and spatial multiplex techniques like MCF applications requires a new level of hardware configuration flexibility. Emerging technologies like SDN provide the framework that addresses the increased demand for network programmability and interoperable network functions. This WP3 will investigate and describe scalable SDN based control for programmable optical hardware with a focus on multi-core network applications. It will identify and extend interfaces into a SDN based control architecture and provide the base concept for prototyping a demonstrator.

WP3 will concentrate on connection provisioning scenarios in MCF network applications. Wavelength and spatial routing aspects are expected to be common with multi-mode applications and will be considered only if needed to validate proposed concepts

3.2 Challenges

XT between neighbouring cores was already identified as the main additional impairment that may reduce transmission reach for multi-core optical transport. Wavelength/core routing and assignment complexity will significantly increase when considering this new type of inter-core XT. In addition, a high number of cores per fibre significantly increases hardware and software resource demand when deploying MCFs. Besides physical aspects like network element size also manageability of such large transport systems creates capacity issues for management applications and control traffic bandwidth. It is therefore necessary to reduce management complexity by mechanisms such as network abstraction (e.g. multi-core link aggregation) and delegation. This strategy embraces transport network architecture as well as management function distribution aspects.

Figure 3-1 shows a hierarchical controller model indicating a line and a service control layer. The line control layer directly manages programmable optical hardware and plays the role of intermediate layer between physical and logical layers. The service layer manages resource abstraction within the transport network context and provides the interface for service management.

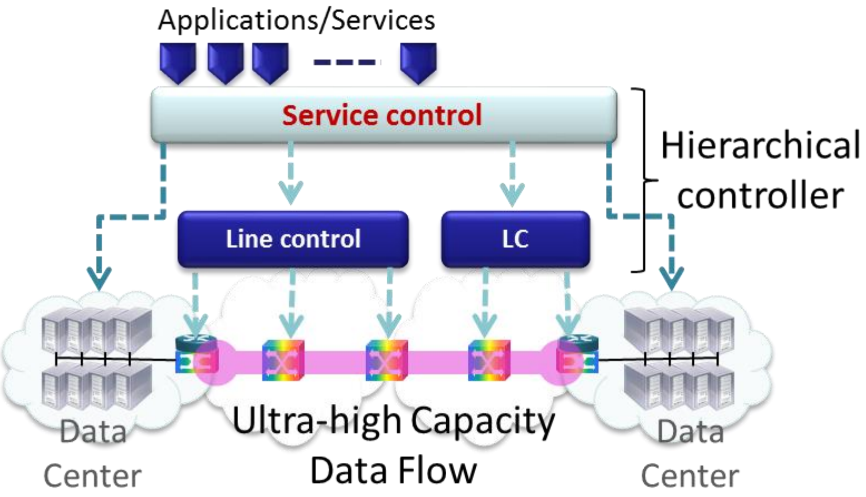

Figure 3-1: Hierarchical controller model

WP3 will define a transport and control model that will be applicable for short-reach applications where XT is negligible as well as long haul applications that require detailed evaluation of MCF specific impairments. It is expected that MCFs initially will be deployed to relax capacity restrictions at highly utilized links and therefore will have little impact to the e2e degradation of optical signal quality. With the increase of the number of MCF segments in the network this simplification becomes invalid and connection provisioning requires more careful consideration of MCF specific impairments.

3.3 Use Cases

One of the most important use cases of scalable and flexible optical networks is represented by a recovery scenario from network failures such as catastrophic disaster and disruptive traffic congestion. As the model network for the use cases, optical ultra-highway between data centres was considered as the candidate network using MCFs [6] as the transmission line. The requirements for the network were studied to establish/delete/change ultra-high capacity parallel connections on-demand. In the above cases, it is important to control numerous parameters such as several tens of nodes, nearly hundred wavelengths, over thirty cores, several modulation formats, and so on.

Figure 3-2 and 3-3 show the XT issue in an MCF deployment scenario. Here, we consider the use case that the MCF is incrementally deployed in multiple steps to realize future ultra-high capacity network. Firstly, the network is composed of conventional single-mode fibres (SMFs). In the second step when one of the SMF links (A-B) is replaced by an MCF, if the distance of the MCF link is limited and the XT meets the guaranteed value, it is not necessary to consider the XT value in network design (XT-Free). At this stage, the deployment of MCFs is only sparse. In the third phase when the SMF link (B-C) is also replaced by an MCF, if we set a long connection path from A to C, we need to select the applicable core in the MCF depending on the XT and the modulation format. The non-sparse MCF deployment represents a network that requires careful XT consideration for network planning and operation.

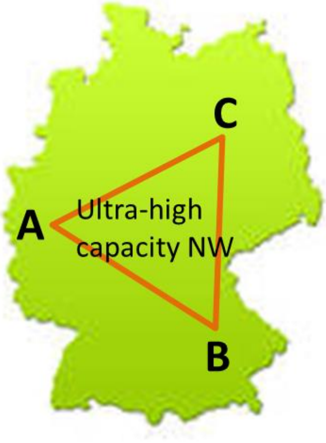

Figure 3-2: An example of future ultra-high capacity network in Germany

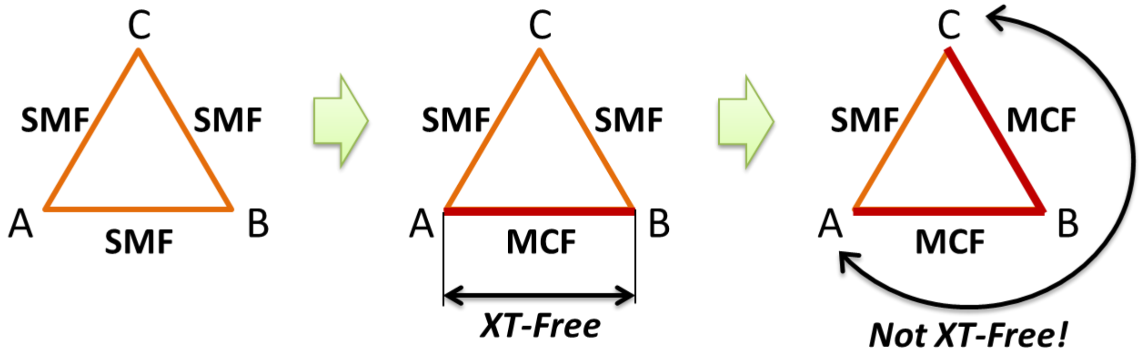

Figure 3-3: MCF deployment scenario

Depending on the XT impact on reach and bandwidth of multi-core transmission, network management may either model an MCF as a bundle of individual SMF fibers and relief optical impairment aware connection routing from considering XT. Or, require the routing engine to evaluate actual XT measurements and implement core allocation and modulation format algorithms that guarantee requested connection quality. WP3 will investigate both approaches.

3.4 Architecture

3.4.1 Transport Architecture

For network applications with low or almost negligible multi-core XT, the envisioned transport architecture should provide means to reduce the amount of information required to compute a light path across an MCF enabled network. Ideally, the fibre would appear as a link aggregation with increased transmission capacity and a multiplicity of individual wavelengths. Spatial multiplex capabilities should be managed by lower layer functions. Multiple-input and multiple-output (MIMO) sender/receiver techniques may support different patterns combining wavelength and spatial selectors to create coarse- or fine-grain switching granularities (e.g. switching the whole core or a single wavelength in each core).

However, non-sparse MCF deployment or inhomogeneous MCF amplification requires consideration of inter-core dependencies which are ignored in a simple aggregation model. Furthermore, multi-core XT monitoring will be implemented via non-intrusive path level monitoring. Therefore, a multi-core termination function may not include XT monitoring information. WP3 will investigate options to summarize XT impairments in terms of per MCF penalties (independent of any specific core) that would simplify multi-core routing and can be used to extend a link aggregation model.

3.4.2 Control Architecture

WP3 will utilize a layered SDN control architecture build on dedicated components for application (Orchestrator) and network control (Transport Controller). At the network element level, non-intrusive multi-core XT monitoring is implemented by a DSP (Line-) controller. Layered control provides means to represent transport resources at each level with increasing level of abstraction. Controller components will communicate using standard protocols such as OpenFlow, Netconf and RestConf. WP3 will select the set of protocols and define required extensions that are needed to carry MCF specific information.

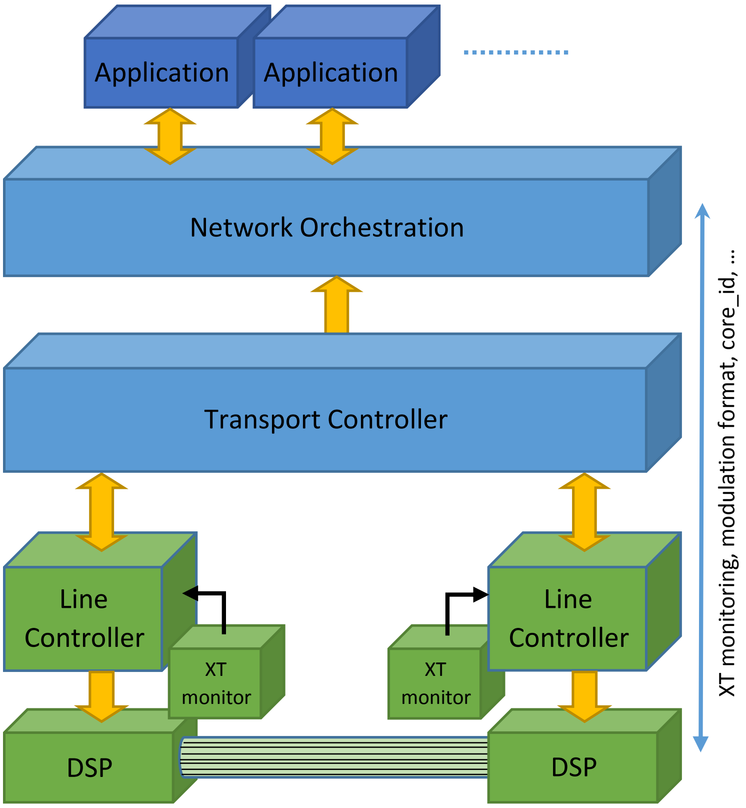

Figure 3-4: Control Architecture

The architecture will be able to support WSS switching functions and wavelength routing capabilities. However, optical switch and routing functions (WDM/SDM) are not a focus area of WP3.

3.5 Programmability

Flexible optical networks introduce the need for programmable optical hardware where it is essential to efficiently configure optical channels to carry data with carefully chosen modulation format and FEC attributes. In general, any optical network management interface may be disclosed and embedded in an application programming framework. A study identified the DSP [7] as the main programmable hardware in optical transport networks. The DSP has the capability of coding and modulation function which determines data capacity and transmission distance. In the context of SAFARI a set of connection termination attributes such as modulation format and core allocation will be considered to become programmable in order to control and mitigate inter-core XT. Based on current OpenFlow extension requirements supporting OTN flows [8], WP3 will define protocol and data model extensions in support of OTN transport across MCFs.

Multi-core routing aspects such as SDM aware ROADM architectures, SDM switching or SDM aware routing algorithms are not a core interest of WP3.

4 Conclusion

We present the basic design of the control architecture to support highly scalable and flexible photonic network. The architecture has been derived by considering following aspects; future-proof scalability and flexibility which can support novel DSPs and MCFs, and implementation cost to realize the control software suits.

Based on the basic architecture, we will add more details to support actual programmable parameters which will be defined in relevant partners. Also, control sequence/flow will be discussed and covered in the next deliverables.

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List of Abbreviations

DSP	Digital Signal Processor
ONF	Open Networking Foundation
OIF	Optical Internetworking Forum
SDN	Software Defined Networking
SDM	Space Division Multiplexing
OSNR	Optical Signal-to-Noise Ratio
PDM	Polarisation-Division Multiplexing
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
WSS	Wavelength Selective Switch
XT	CrossTalk
MCF	Multi-Core Fibre
SMF	Single-Mode Fibre
FEC	Forward Error Correction
MIMO	Multiple-Input and Multiple-Output
ROADM	Reconfigurable Optical Add-Drop Multiplexer

Document History

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03	14/10/2015	T. Inui	Finalized draft