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First Demonstration of Single-Mode MCF Transport Network with Crosstalk-Aware In-Service Optical Channel Control

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Abstract *We demonstrate the first crosstalk-aware traffic engineering as a use case in a multicore fibre transport network. With the help of a software-defined network controller, modulation format and channel route are adaptively changed using programmable devices with XT monitors.*

Introduction

In recent years, space-division multiplexing (SDM) in optical fibre transmission has become one of the hottest approaches to break the capacity limit of optical fibre[1,2]. Besides the attempts to demonstrate larger capacities and longer transmission distances, various network testbed experiments have now been reported[3-6].

Among the various forms of SDM, single-mode MCF transport offer some specific advantages and possibilities. For example, Pbit/s/fibre-class capacities and low-power optical transport networks are feasible using dense-SDM (DSDM) with a spatial multiplicity over 30[7,8]. In addition, the long-haul digital coherent transmission employed today over conventional single-mode fibre (SMF) can be fully supported using appropriate crosstalk (XT) management[9]. However, no testbed demonstrations have been reported so far that simultaneously satisfy these two advantages.

In this paper, we present the first single-mode MCF transport network using XT-aware and programmable optical channels with XT monitoring. In the testbed, we demonstrate a traffic engineering use case, in which optical channels are adaptively (re)configured subject to consideration of inter-core XT with the help of an software-defined network (SDN) controller.

Single-mode multicore fibre (MCF) transport network with XT-aware optical channel control

As transmission distances become longer in MCF transport networks, inter-core XT becomes a limiting factor - especially for optical channels using higher order modulation formats. In addition, the XT impairment will change in time in response to changes in optical channel assignment in adjacent cores. Therefore, the consideration of XT is indispensable to realise the full potential of MCF transport networks.

Figure 1(a) shows our proposed XT-aware single mode MCF transport network architecture. In the data-plane, three reconfigurable optical add/drop multiplexers (ROADMs) are connected with three SMF/MCF links which include inline amplifiers. In particular, the MCF links contain fan-in/fan-out (FI/FO) devices, and inter-core XT monitors to estimate the XT value for the link. The transponders have the capability of adaptively selecting between quadrature phase shift keying (QPSK), 8 quadrature amplitude modulation (8QAM), and 16QAM formats. An optical channel between ROADM 1 and 3 traverses either a MCF link (Link A) or mixed MCF and SMF links (Link B-C).

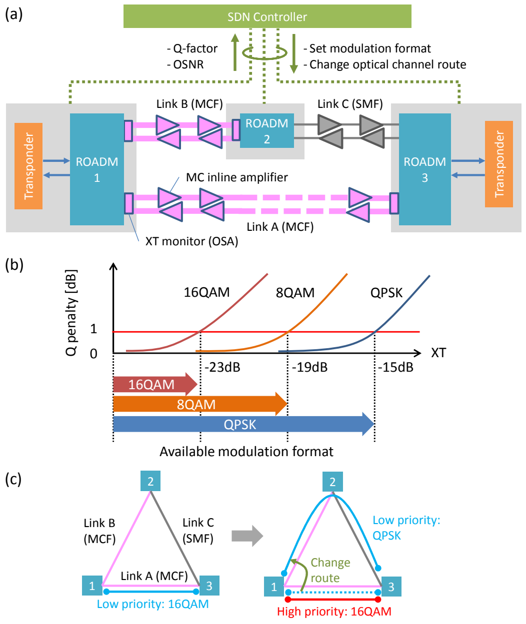

Fig. 1: (a) Architecture of the single mode MCF transport network with XT-awareness, (b) available modulation formats with respect to XT, and (c) use case of XT-aware traffic engineering.

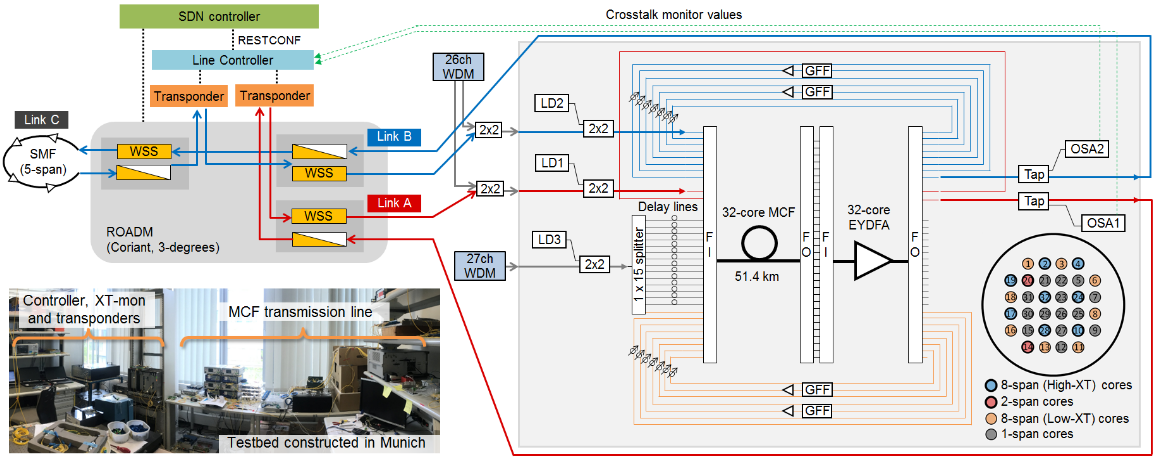

Fig. 2: Experimental setup.

In the control plane, an OpenDaylight-based SDN controller manages resource abstraction within the transport network context and provides the interface for northbound service management. The SDN controller collects inter-core XT and optical signal-to-noise ratio (OSNR) values at regular intervals from each node. Based on the monitored values, the SDN controller sets the transponders to an appropriate modulation format or configures the ROADMs to change optical channel routes.

When the XT of a link is estimated in the above scheme, a suitable modulation format can be determined from not only the OSNR of the total link but also the XT induced in the MCF link. If the allowable Q penalty due to crosstalk is < 1 dB under the relationship between Q penalty and XT, the XT requirement for 16QAM, 8QAM, and QPSK is < −23 dB, < −19 dB, and < −15 dB, respectively (Fig. 1(b)).

The testbed demonstrates the traffic engineering shown in Fig. 1(c) as a representative use case where XT-awareness is of importance. The node and link numbers indicated in the figure correspond to those in Fig. 1(a). First, the use case considers an established low-priority channel passing through a low-XT MCF span (Link A). Because the XT is lower than the required level, the span is capable of operating under a 16QAM format. Then, its route needs to be changed to a less favourable link (Link B-C) to make room for a newly-arrived high-priority channel. Because the XT level along the new route is high, use of 16QAM is no longer appropriate and the modulation has to be changed to QPSK or 8QAM.

Testbed setup and results

We built the experimental setup shown in Fig. 2 to demonstrate a MCF transport network with in-service XT-aware optical channel control.

The SDN controller manages two transponders and a ROADM as well as collection of transmission-line-specific parameters such as Q-factor, OSNR and XT values via the line controller. The line controller plays the role of an intermediate layer between physical and logical layers.

The test signals are generated by two programmable transponders capable of switching between 100 Gbit/s PDM-QPSK, 150 Gbit/s PDM-8QAM and 200 Gbit/s PDM-16QAM formats. These are connected via a three degree commercial ROADM. One of the directions is a configurable 400-km SMF link (5 x 80 km/span). The other two directions are used to switch between different cores or core chains of the MCF. This allows the investigation of different deployment and operation scenarios, including XT aware traffic engineering, the optimisation of signal allocation to MCF cores, and amplification power saving by concentrating traffic on MCF spans.

The transmission line consists of a 51.4-km 32-core heterogeneous single-mode MCF[7], a 32-core EYDFA[8], and in-service inter-core XT monitors[9]. To model different levels of XT impairment and their consequences in a MCF network, sets of cores were connected in series and a gain flattening filter (GFF) was inserted after every 3 spans to cover 100~400 km of MCF transmission distance. A set of 8 concatenated cores (cores 2, 4, 10, 17, 19, 24, 28, and 32) represents a 400-km high-XT line. A set of another 8 concatenated cores (cores 1, 3, 6, 8, 11, 13, 16, and 18) represents a 400-km low-XT line, and a set of 2 cores (cores 14 and 20) represent a 100-km line where the cores were chosen to minimise XT, using cores at the perimeter of the fibre. The remaining cores were used as single-span cores to fill up the fibre with de-correlated WDM PDM-QPSK signals (27 channels in the range 1550.918 -1561.419 nm).

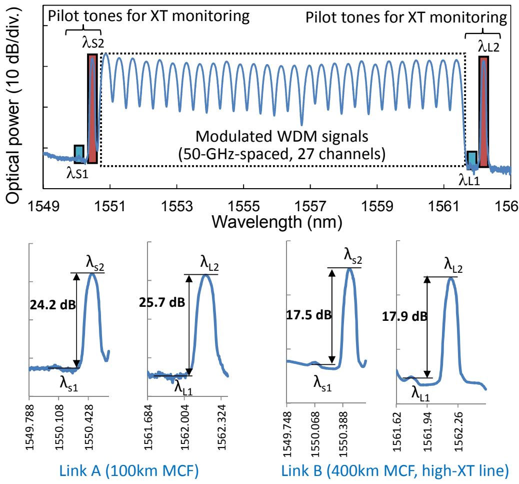

Fig. 3: XT-monitoring performance in the testbed.

Typical inter-core XT of the 400-km high-XT, 400-km low-XT, and 100-km lines were −17.4, −21.6, and −24.2 dB, respectively. The 2-span 100-km line, and the 400-km high-XT line were used as Link A, and B, respectively.

To keep track of inter-core XT without disrupting traffic in the MCF, different pilot tones (λ_{S1}=1550.116, λ_{S2}=1550.517, λ_{L1}=1561.826, and λ_{L2}=1562.233 nm) placed outside both ends of the WDM signal bandwidth were combined with the 27 channel, 50-GHz spaced, WDM signals, and these were injected into the MCF cores. Figure 3 shows the DWDM spectrum transmitted together with the reference and XT pilot tones measured using optical spectrum analysers (OSAs). The inter-core XT is estimated by comparing the optical power differences between the corresponding reference and XT pilot tones, and the XT value at the signal wavelength is linearly interpolated from the XT measured at WDM spectra edge.

Figure 4 shows real-time measurement data visualising a low-priority, 16QAM channel initially routed across the 2-core 100-km MCF link having low XT. It is pre-empted by a high-priority 16QAM channel and re-routed to the 8-core high-XT MCF link, adaptively changing a modulation format to QPSK. After a few minutes of changed modulation format, the low priority channel was successfully switched to a new route and all the established channels showed stable error free operation after FEC decoding.

Conclusions

We have presented the concept of XT-aware optical channel configuration controlled by SDN and demonstrated XT-aware traffic engineering in a single-mode MCF transport network testbed for the first time. The results have confirmed that both appropriate modulation format change based on XT monitoring and optical channel routing at ROADMs can be achieved dynamically by the SDN controller.

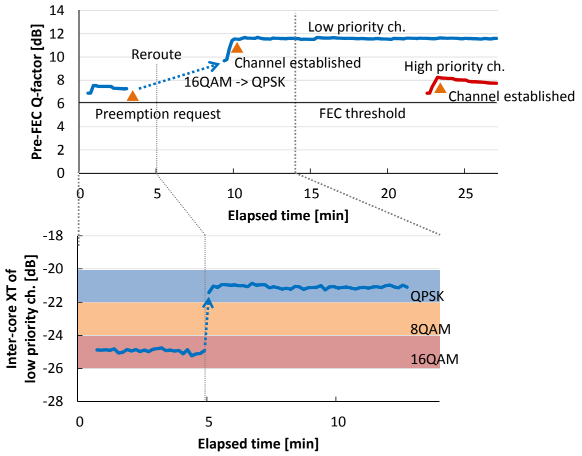

Fig. 4: Time evolution of monitored Pre-FEC Q-factor and XT values in the traffic engineering use case.

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