

Power Consumption in Multi-core Fibre Networks

Nooruzzaman, Md; Jain, Saurabh; Jung, Yongmin; Ul Alam, Shaif; Richardson, David J.; Miyamoto, Yutaka; Morioka, Toshio

Published in: Proceedings of 43rd European Conference on Optical Communication

Link to article, DOI: 10.1109/ECOC.2017.8346158

Publication date: 2017

Document Version Peer reviewed version

Link back to DTU Orbit

Citation (APA):

Nooruzzaman, M., Jain, S., Jung, Y., Ul Alam, S., Richardson, D. J., Miyamoto, Y., & Morioka, T. (2017). Power Consumption in Multi-core Fibre Networks. In *Proceedings of 43rd European Conference on Optical Communication* IEEE. https://doi.org/10.1109/ECOC.2017.8346158

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.

- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Power Consumption in Multi-core Fibre Networks

Md. Nooruzzaman⁽¹⁾, Saurabh Jain⁽²⁾, Yongmin Jung⁽²⁾, Shaif-ul Alam⁽²⁾, David J. Richardson⁽²⁾, Yutaka Miyamoto⁽³⁾, and Toshio Morioka⁽¹⁾

⁽¹⁾ Dept. of Photonics Engineering, Technical University of Denmark, Denmark, <u>noor@fotonik.dtu.dk</u>

⁽²⁾ Optoelectronics Research Centre, University of Southampton, UK, <u>si3g11@orc.soton.ac.uk</u>

⁽³⁾ NTT Network Innovation Laboratories, NTT Corporation, Yokosuka, Kanagawa, 239-0847, Japan

Abstract We study potential energy savings in MCF-based networks compared to SMF-based ones in a Pan-European network topology based on the power consumption of recently fabricated cladding-pumped multi-core optical fibre amplifiers.

Introduction

Space-division multiplexing (SDM) over multicore fibres (MCFs) has been studied intensively and is considered to be a promising solution for high-capacity transmission systems¹⁻⁶. Recently, MCFs as well as multi-core (MC) amplifiers with more than 30 single-mode cores have been fabricated⁷⁻⁹ and tested in high-capacity transmission experiments¹⁰⁻¹¹.

However, it is also essential to evaluate the anticipated MCF network requirements to justify the acceptance value of SDM over MCF technologies. For example, the presence of inter-core crosstalk (XT) can result in reduced transmission reach, leading to the need for more frequent regeneration of the optical signals. Therefore, estimating the number of network components, costs and power consumption of MCF networks as compared to the present SMF networks is necessary. The effects of inter-core XT on the number of required components in MCF networks has previously been analyzed¹², where it was shown that a significant number of extra 3R regenerators might be required if the network covers such a large area that the XT goes beyond tolerable levels. It remains however to be seen whether MCF networks will enable any potential savings in power consumption by decreasing the energy per bit. In this paper, we estimate the total power consumption of MCF networks compared to the current omnipresent SMF-based ones in a Pan-European network topology based on the measured power consumption of recently fabricated cladding-pumped multi-core optical fibre amplifiers⁹.

Example network used in this study

Figure 1a shows the Pan-European network topology comprising 28 nodes and 41 links¹³, which is used in this study. The diameter of this network, i.e., distance between the farthest two nodes, is 5154 km for the hop-based routing, and the average length of the lightpaths was 2017 km.

Figure 1b illustrates an example of a MCFbased node architecture having three nodal degrees: north, south and west as indicated in the figure. In current optical networks, each of the nodes consists of amplifiers as well as reconfigurable optical add/drop multiplexers comprising express and add-drop sections¹⁴. Figure 1c illustrates the architecture of an SMFbased node having three nodal degrees. In current omnipresent SMF-based networks, the number of spatial channels on a particular link is equal to that of deployed SMFs on that given link. In high-capacity networks, there are multiple SMFs on each of the links in a network. Therefore each of the nodal degrees includes a bundle of SMFs as shown. In this paper, the amplifiers that are installed inside the nodes and equipped with the incoming and outgoing fibres are respectively referred to as pre- or postamplifiers. As indicated in Fig. 1b, if the system is installed with MCFs, we need one MCF containing m number of cores. However, we need m number of SMFs in the SMF network case as shown in Fig. 1c.

Estimating relative network components involved in power consumption

In this paper, we focus on the differences between MCF- and SMF- based solutions of a particular network topology. The network components which are common in both solutions are ignored as we target to compare two solutions. When a system is deployed with MCFs, the line system will be changed significantly, while internal node architectures can remain the same depending on the uses. Therefore, we first estimate the number of components which are equipped in the line systems, such as fibres and inline amplifiers. Then we consider the difference in node architectures such as fan-in and fan-out devices, and pre- and post- amplifiers as shown in Fig. 1. Finally, from the differences in components at line and nodes, we consider only the components which consume electrical power.

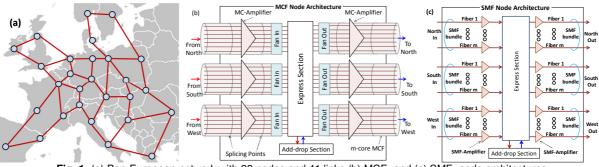


Fig. 1: (a) Pan-European network with 28 nodes and 41 links (b) MCF- and (c) SMF- node architectures

Here the summation of all voice, data and IP traffic of 2004 (i.e., 4.058 Gbit/s) over the Pan-European network¹³ was used as the reference total traffic. Traffic for year 2016 in Fig. 2 was calculated by the formula 4.058×1.5^{12} Gbit/s, which is 12 periods distant from the reference year 2004. The traffic matrices of each subsequent period are assumed to be 150% of its previous time period. Although the traffic of each node might not grow at the same rate as we assumed, this does not affect the results much as they mainly depend on the total traffic volume. Therefore, the target of this work, the power consumption comparison between SMF-and MCF-based networks, remains unaffected.

Each of the estimated traffic matrices was routed based on hop and distance routings by using the OPNET WDM guru network planner. The results from both hop and distance routing approaches were close to each other, so only the results for hop routing are presented for simplicity. The total number of wavelengths (i.e., capacity) of all the links were obtained from the routing results. Here. а maximum 80 wavelengths, each having a 50 GHz channel spacing, were assumed as the capacity per SMF or per MCF core. The capacity of each channel was assumed to be 100 Gbit/s, assuming a polarization-division multiplexed (PDM) quadrature phase-shift keying (QPSK) modulation format.

The average number of SMFs or MCFs required per link was estimated and is plotted in Fig. 2a. It is shown that around 640 SMFs are required on each link of the European network to support 68,33Pbit/s of total traffic (year 2028). In the second step, the total number of EDFAs required in both SMF- and MCF- based systems were estimated based on the results obtained in the first step. For both SMF and MCF systems, the power consumption of all the components except for the amplifiers was assumed to be the same. So only the number of amplifiers required in both SMF and MCF systems was estimated for different traffic volumes as shown in Fig. 3. In this case, the spacing between two EDFAs was

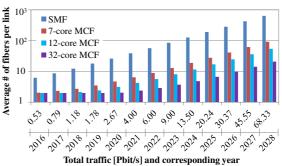


Fig. 2: Average # of fibers per link as a function of year

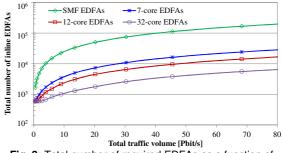
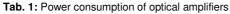


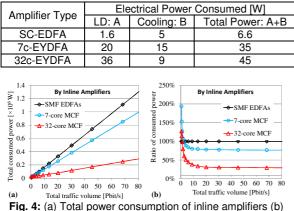
Fig. 3: Total number of required EDFAs as a function of total traffic for different size of the fiber.

assumed to be 80 km. The total number of inline amplifier for the SMF system is 167,862 whereas it is 5,566 in the 32-core MCF case at 68,33 Pbit/s of total traffic.

Assumption of power consumption between single-core and multi-core amplifiers

The electrical power consumption values of the laser diodes and cooling components for singlecore (SC) and multi-core (MC) amplifiers are summarized in Table 1. Note that we do not include any consideration of the power consumption associated with the supervisory or management functions within the amplifier as would be required in any true deployable commercial solution and which can represent a very significant power overhead. In commercial systems, MC-amplifiers might guarantee more efficient use of it by sharing overhead energy among the spatial channels. In the case of MC-amplifiers, the power consumption for 7-core and 32-core cladding pumped Erbium-Ytterbium





comparison of relative power consumption.

co-doped fibre amplifiers (EYDFAs) which were fabricated and reported recently were used^{9,15}. The power consumption value of our 7-core EDFA is entirely consistent with other reported cladding pumped 7-core EDFAs¹⁶⁻¹⁷. The power consumption value for 32-c EYDFAs represents the power consumption of our recently fabricated 32-c EYDFA¹⁸.

Estimation of the total power consumption of the optical amplifiers

The total power consumption for the three types of amplifiers for various traffic volumes are presented in Fig. 4. Figure 4a shows the total power consumption in Watts whereas Fig. 4b shows the normalized power consumption of the 7c and 32c EYDFAs relative to the single-core EDFAs. The power consumption for the MCF cases were more than that of the SMF case when the total traffic was below 2.67 Pb/s, since it was assumed that at least one pair of MCFs was installed for each link although most of the fibres remained unused for this traffic volume.

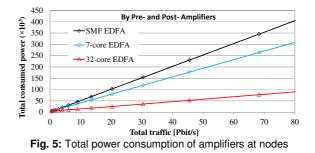
The amount of power consumption for the preand post- amplifiers was also estimated and plotted in Fig. 5. In this case one MC amplifier was assumed for each incoming or outgoing MCF. The power consumption of each amplifier was multiplied by the respective number of total pre- or post- amplifiers required in the network.

Conclusions

The potential power savings of MCF-based networks have been investigated based on the latest research data. The results were derived from the difference in power consumptions between conventional and MC-amplifiers.

Acknowledgements

This research is supported by the EU-Japan coordinated R&D project on "Scalable And Flexible optical Architecture for Reconfigurable Infrastructure (SAFARI)" commissioned by the Ministry of Internal



Affairs and Communications (MIC) of Japan and EC Horizon 2020.

References

- T. Morioka, "New Generation Optical Infrastructure Technologies: 'EXAT Initiative' Towards 2020 and Beyond," Proc. OECC, FT4, Hong Kong (2009).
- [2] D. J. Richardson et al., "Space-division multiplexing in optical fibres," Nat. Photon., Vol. 7, p. 354 (2013).
- [3] H. Takara et al., "1.01-Pb/s (12 SDM/222 WDM/456 Gb/s) Crosstalk-managed Transmission with 91.4b/s/Hz Aggregate Spectral Efficiency," Proc. ECOC, Th.3.C.1, Amsterdam, (2012).
- [4] B. J. Puttnam et al., "2.15 Pb/s transmission using a 22 core homogeneous single-mode multi-core fiber and wideband optical comb," Proc. ECOC, PDP.3.1, (2015).
- [5] A. Turukhin et al., "105.1 Tb/s Power-Efficient Transmission over 14,350 km using a 12-Core Fiber," OFC, Th4C.1, Los Angeles (2016).
- [6] Md. Nooruzzaman et al., "Multi-core Fibers in Submarine Networks for High-Capacity Undersea Transmission Systems" OFC, W4F.5, (2017).
- [7] Y. Sasaki et al., "Crosstalk-Managed Heterogeneous Single-Mode 32-Core Fibre," ECOC, W.2.B. (2016).
- [8] Y. Sasaki et al., "Single-Mode 37-Core Fiber with a Cladding Diameter of 248 µm," OFC, Th1H.2, (2017).
- [9] S. Jain et al., "32-core Inline Multicore Fiber Amplifier for Dense Space Division Multiplexed Transmission Systems" ECOC, Th.3.A.1, Düsseldorf (2016).
- [10] H. Hu et al., "Single-Source AlGaAs Frequency Comb Transmitter for 661 Tbit/s Data Transmission in a 30core Fiber", CLEO, JTh4C.1, San Jose (2016).
- [11] T. Mizuno et al., "32-core Dense SDM Unidirectional Transmission of PDM-16QAM Signals Over 1600 km Using Crosstalk-managed Single-mode Heterogeneous Multicore Transmission Line", OFC, Th5C.3, (2016).
- [12] M. Nooruzzaman et al., "Effect of Crosstalk on Component Savings in Multi-core Fiber Networks," OECC 2017 Singapore, accepted, 2017.
- [13] Betker et al., "Reference Transport Network Scenarios." MultiTeraNet Report, July (2003).
- [14] M. Nooruzzaman et al., "Low-Cost Hybrid ROADM Architectures for Scalable C / DWDM Metro Networks," IEEE Commun. Mag., vol. 54, no. 8, p. 153 (2016).
- [15] Y. Jung et al., "Compact 32-Core Multicore Fibre Isolator for High-Density Spatial Division Multiplexed Transmission," ECOC, W2.B4, Düsseldorf (2016).
- [16] K. Maeda et al., "Multicore Erbium Doped Fiber Amplifiers," Proc. SPIE 9773, Optical Metro Networks and Short-Haul Systems VIII, 977302 (2016).
- [17] K. Takeshima et al., "51.1-Tbit/s MCF Transmission Over 2520 km Using Cladding-Pumped Seven-Core EDFAs," J. Lightwave Technol., Vol. 34, p. 761 (2016).
- [18] S. Jain et al., "Improved cladding-pumped 32-core multicore fiber amplifier," Submitted to ECOC 2017.