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Power Consumption in Multi-core Fibre Networks

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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 multi-core fibres (MCFs) has been studied intensively and is considered to be a promising solution for high-capacity transmission systems[1-6]. Recently, MCFs as well as multi-core (MC) amplifiers with more than 30 single-mode cores have been fabricated[7-9] and tested in high-capacity transmission experiments [10-11].

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 analyzed[12], 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 amplifiers[9].

Example network used in this study

Figure 1a shows the Pan-European network topology comprising 28 nodes and 41 links[13], 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 MCF-based 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 sections[14]. Figure 1c illustrates the architecture of an SMF-based 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 post-amplifiers. 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.

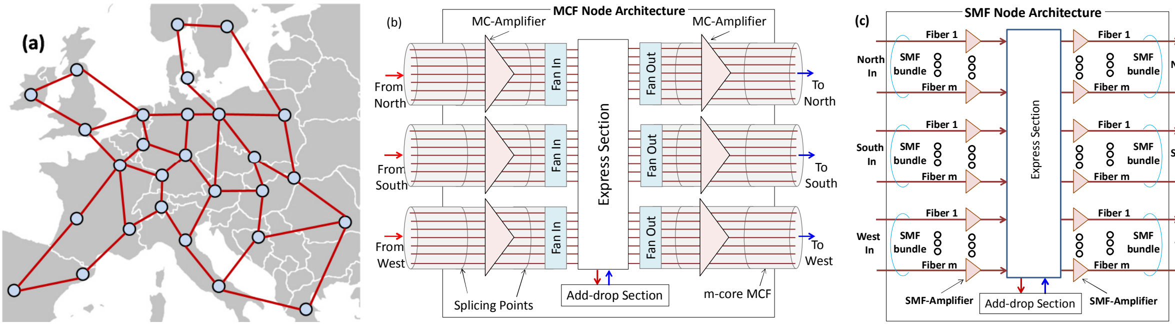

Fig. 1: (a) Pan-European network with 28 nodes and 41 links (b) MCF- and (c) SMF- node architectures

Here the summation of all voice, data and IP traffic of 2004 (i.e., 4.058 Gbit/s) over the Pan-European network[13] 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, a 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 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.

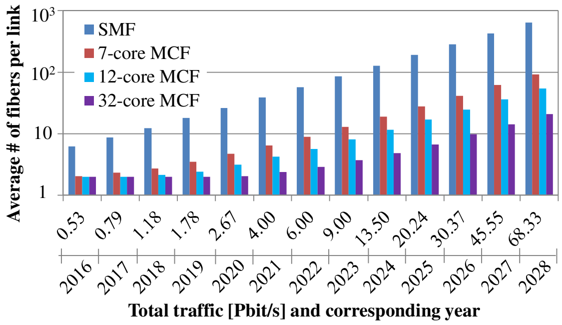

Fig. 2: Average # of fibers per link as a function of year

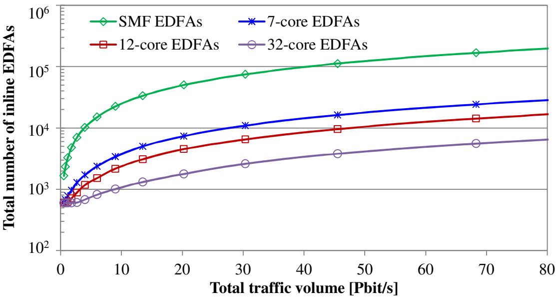

Fig. 3: Total number of required EDFAs as a function of total traffic for different size of the fiber.

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

The electrical power consumption values of the laser diodes and cooling components for single-core (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

Tab. 1: Power consumption of optical amplifiers

Amplifier Type	Electrical Power Consumed [W]		
	LD: A	Cooling: B	Total Power: A+B
SC-EDFA	1.6	5	6.6
7c-EYDFA	20	15	35
32c-EYDFA	36	9	45

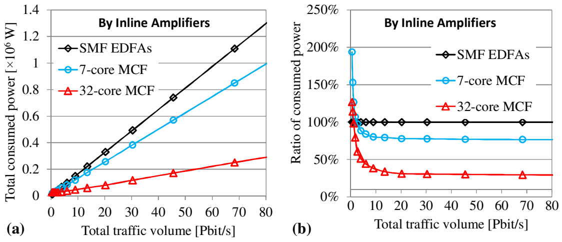

Fig. 4: (a) Total power consumption of inline amplifiers (b) comparison of relative power consumption.

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 EDFAs[16-17]. The power consumption value for 32-c EYDFAs represents the power consumption of our recently fabricated 32-c EYDFA[18].

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 pre- and 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.

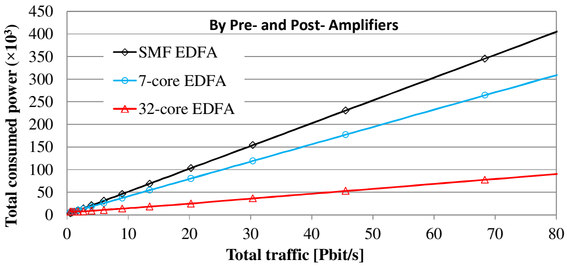

Fig. 5: Total power consumption of amplifiers at nodes

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