Impact of Traffic Profile on the Performance of Spatial Superchannel Switching in SDM Networks

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Abstract *We compare the performance of three SDM switching paradigms under different traffic profiles. We show that their performance is highly traffic dependent. We also show that increasing the spectral switching granularity, significantly improves the performance of spatial group switching.*

Introduction

Space division multiplexing (SDM) over multi-core fibers (MCF), multi-mode fibers (MMF), few-mode multi-core fibers (FM-MCF), or even bundles of single mode fibres (SMF)s, would allow the network capacity to scale to orders of magnitude higher than what can be achieved with current infrastructure and to address the anticipated vast traffic growth[1].

The majority of the SDM related research is focused on fibre technology and transmission performance in order to increase the overall "capacity × reach" factor[2]. However, in order to exploit the potential SDM networking benefits and make it applicable to future networks, it is essential to introduce cost-effective node solutions with spatial (in addition to spectral) switching capabilities. Such SDM switching paradigms could include the following cases[3]: (a) *independent switching* (Ind-Sw), where all spectral slices and spatial modes/cores can be independently directed to any output port; (b) *joint switching* (J-Sw), where all spatial modes/cores are jointly switched, while spectral slices are freely switched; and (c) *fractional joint switching* (FrJ-Sw), where a number of S/G spatial subgroups (each of G spatial modes/cores out of total S modes/cores per fibre), as well as the spectral slices, can be independently switched to all output ports. A detailed comparison of these switching schemes was performed in[4] for an offline network planning scenario. The study considered a specific traffic matrix with a limited number of demands. The comparison revealed that J-Sw and FrJ-Sw can achieve cost saving up to 50% and 40%, respectively, compared to Ind-Sw at the expense of reduced switching flexibility. However, our study showed that under high traffic load the networking performance in terms of spectrum utilization for the case of FrJ-Sw and J-Sw (i.e. spatial group switching options) almost converges to that of Ind-Sw.

The assumed traffic profile (i.e. large aggregated demands) is the most typical traffic profile in core networks today, as we have traffic aggregation at the edge of the network. However, due to the introduction of application-centric services[5] and dependency of traffic increase on i) the type of network (access/metro/core), ii) the services offered by the network (e.g. 4G/5G connectivity, FTTX, TV on-demand), and iii) the type of offered applications (e.g. file sharing, video conferencing), traffic de-aggregation will be a possible networking policy. Therefore, in this paper, we want to study the cases in which lightpaths might be established based on i) a large number of small demands (typically seen in regional part of networks), ii) a small number of large demands (applicable for example in inter-datacentre communications), and iii) any combinations of last two options (found e.g. in national scale networks serving heterogeneous type of traffic demands).

In this paper, we thoroughly evaluate the impact of various traffic profiles and dimensioning approaches on the performance of SDM switching paradigms, in an online operation scenario. We show that the performance of the three SDM switching paradigms is highly dependent on the traffic profile. While J-Sw shows similar performance as Ind-Sw for large demands, it presents a reduced performance when network is fed by a large number of small demands. However, we show that the performance of the J-Sw can improve substantially when the spectral granularity of the switching paradigm is reduced.

SDM Switching Paradigms vs. SDM Fibers

Ind-Sw can be realized with a node architecture that comprises a number of conventional wavelength-selective switches (WSS), one per spatial dimension degree and ingress/egress port (Fig.1a). Commercially available 1×9 or 1×20 WSSs can be employed.

FrJ-Sw and J-Sw require a redesign of the WSSs to operate as $S\times(I\times O)$ WSSs[3], i.e. they direct I input ports, each carrying S spatial modes/cores, toward O output ports. By making

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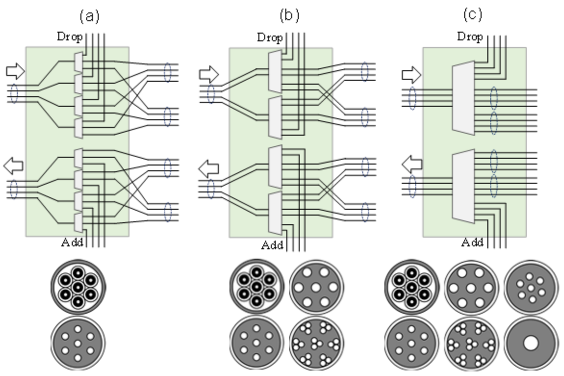

Fig. 1: Node architectures, for *S*=4 and *D*=3, enabling a) Ind-Sw, b) FrJ-Sw with *G*=2, and c) J-Sw. Only 1 degree is shown. Ind-Sw, FrJ-Sw with *G*=2, and J-Sw require eight 1×3, four 2×6, and two 4×12 WSSs per degree, respectively. Below each case, its suitable fiber types is provided.

use of joint WSSs, the FrJ-Sw and J-Sw paradigms enable reducing the number of necessary WSSs to $2\cdot\lceil S/G \rceil$ and 2, respectively, per degree, as illustrated in Fig. 1(b), (c). In this case, the required port count of WSSs increases by a factor of *G* for J-SW and *S* for FrJ-Sw.

J-Sw is compatible with any type of SDM transmission medium, while FrJ-Sw and Ind-Sw are fiber-dependent. As shown in Fig. 1, alternatively, bundles of SMFs and uncoupled MCFs are compatible with all switching paradigms, while strongly coupled MCFs and MMFs require a particular type of switching paradigm (J-Sw)[3,6]. Networks based on bundles of SMFs benefit from longer optical reach and lower power consumption in the receiver side (because a high order MIMO-DSP is not necessary). Additionally, the utilization of already-installed SMFs is likely to be the most cost-effective option for near-term realizations of SDM networks. On the other hand, MCFs, MMFs, and FM-MCFs offer reduced-size cables with higher density and lower weight.

Simulations Environment

In this study we use the Spanish national network of Telefónica. It comprises 30 nodes (average nodal degree 3.7, max. 5), 14 of which build in add/drop capability (A/D), as well as 56 links with an average length of 148 km.

In order to have a fair comparison among the

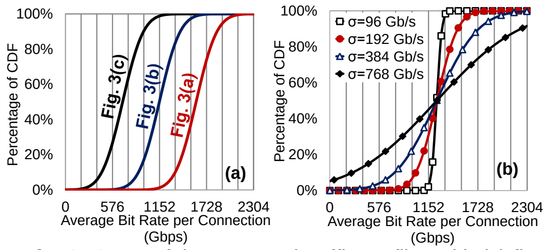

Fig. 2: CDFs of the assumed traffic profiles with (a) fixed σ=200 Gbps and μ=700, 1150, and 1600 Gbps, (b) fixed μ=1248 Gbps, and σ=96, 192, 384, 768 Gbps

three SDM switching paradigms, regardless of any transmission medium related performance constraints, bundles of 12 SMFs were considered for all links in the network.

Moreover, based on the network characteristics and the related performance evaluation studies[7], DP-8QAM at 32-Gbaud was chosen as the modulation format offering the best compromise between transmission reach and spectral efficiency. A 50-GHz channel spacing is used except in the last study (Fig. 5).

According to the above and considering an available spectrum per fibre equal to 4.8 THz (C-band) on the ITU-T 12.5-GHz grid, discrete event simulation studies were carried out for the purpose of performance evaluation. More specifically, the routing, space, and spectrum allocation (RSSA) problem is solved with a k-shortest path (k = 3) and spatial and spectral resource allocation algorithm, that follows a first-fit strategy, starting with the shortest computed path[7].The load generation followed a Poisson distribution process. Traffic demands for each source-destination pair were generated randomly following a normal distribution with mean μ and standard deviation σ over the range of study, namely 50 Gbps to 2.25 Tbps. Blocking Probability (BP) was used as a quantitative performance measure.

Results and Discussions

In the first part of the study, we consider three traffic profiles corresponding to the three previously mentioned cases: small, large and medium-size demands. The distribution of demands for the 3 different mean demand values and fixed σ is shown in Fig.2a, while the effect of the deviated demands over a fixed

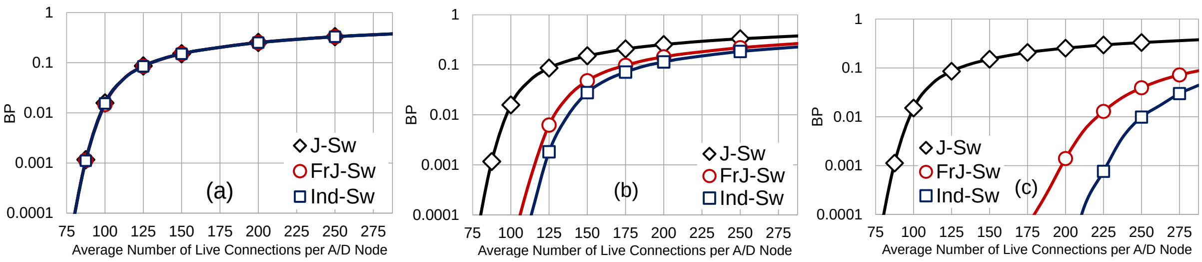

Fig. 3: BP in terms of average number of live connections per A/D node for three profiles of traffic forming of small, large and medium size demands which their distributions are plotted in Fig. 2: a) μ=1600, b) μ=1150, and c) μ=700 Gbps.

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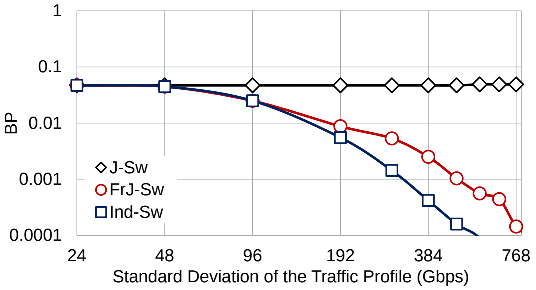

Fig. 4: BP in terms of standard deviation when μ=1248 Gbps and average number connection per A/D node is 112.

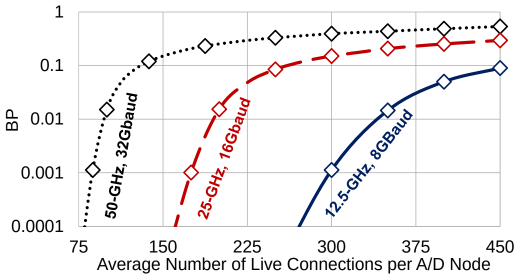

Fig. 5: BP vs average number of live connections per A/D node with fixed μ=350 Gbps and σ=200 Gbps for J-Sw assuming three levels of spectral switching granularities.

mean value is shown in Fig.2b. The lower and upper mean values were chosen according to the following: a) For μ=700 Gbps, 98% of demands requires less than half of the 12 spatial dimensions (i.e. bundles of SMF in our case study) to be allocated. b) For μ=1600 Gbps, we have large aggregated demands that result in more than 98% of them requiring more than half of the 12 spatial dimensions to be allocated. The three traffic profiles of Fig. 2a are used to obtain the results shown in Fig. 3. It is noted that in all cases traffic dimensioning is realized by varying the number of live connections per A/D node.

For high mean traffic demands (Fig. 3a), the three switching paradigms show the same performance. Since most demands require more than half of the spatial resources, the unutilised resources of FrJ-Sw and Ind-Sw cases cannot be allocated thus leading to the same results as the J-Sw case. For a traffic profile with diverse and relatively medium-size demands (Fig. 3b), FrJ-Sw and Ind-Sw start performing better than J-Sw in terms of BP, since now part of the incoming demands that require less than 6 spatial dimensions to be allocated can fit within the free spatial resources that FrJ-Sw and Ind-Sw enable them to use. For small mean traffic demands (Fig.3c) the performance difference between J-Sw and FrJ-/Ind-Sw is more pronounced, since the allocation options in space dimension are increased and small demands can fit in available spatial slots.

Previous discussion on Fig.3 strongly suggests that the optimal switching paradigm for an SDM network, in fact, depends on the nature of its traffic, specifically whether there is a prevalence of relatively small or large demands. However, since most of the demands in the core networks are aggregated traffics, J-Sw would be a suitable choice, considering its cost benefit[4].

In order to see the impact of traffic diversity on the performance of SDM switching paradigms, a complementary set of simulations is carried out, where the traffic dimensioning is done by varying σ and keeping μ and the number of live connections fixed (Fig. 2b). Note, in this study, the total offered load to the network during the whole range of the simulation is fixed to 14*112*1248 Gbps = ~1.95 Pbps.

Results plotted in Fig. 4 show that at the beginning the performance of three SDM switching is the same (similar to Fig. 3a), and by increasing σ which is equivalent to the diversity level of the traffic profile, Ind-Sw and FrJ-Sw show a remarkable improvement which justifies their suitability for networks with high level of diversity in their traffic profile.

As shown in Fig. 3 and 4, J-Sw despite its cost benefits[4], shows reduced performance in case of large number of relatively small demands. However, since WSSs allow fine switching granularity (i.e. 25 or 12.5GHz), we investigated the performance when the spatial Sp-ch occupies 25 or12.5 GHz spectrum. As shown in Fig. 5, the performance improve significantly when switching granularity increased.

Conclusions

We investigated the suitability of three SDM switching paradigms for different traffic profiles. We found that, for the case of bundles of SMFs, Ind-Sw and FrJ-Sw perform well for networks with high level of traffic diversity, while J-Sw is a favourable option for networks with large demands, considering also its cost benefit[4], However, J-Sw can perform significantly better in high diverse traffic scenarios, if spatial Sp-Chs occupy smaller spectral width which can be switched by WSSs with finer granularity.

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