1 Tb/s Optical Path Aggregation with Spectrum-Sliced Elastic Optical Path Network SLICE

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Abstract *We demonstrate highly spectrally-efficient path aggregation directly in the optical domain. Multiple hundred-gigabit class flows are aggregated into a seamless 1 Tb/s optical path and transmitted in spectrum-sliced elastic optical path network.*

Introduction

Following the introduction of new types of services, the requirement for efficient transport of the growing amount of traffic is increasing. Optical networks, which have seen rapid advances in transmission techniques and control, are expected to provide the bandwidth in the most cost-effective manner [1]. This means efficiently accommodating the currently existing traffic flows as well as the high-end services, like e.g. ultra-high definition TV, cloud computing or network storage. This variety brings a requirement to support a wide range of traffic rates. It is also envisaged that customers may require bandwidth exceeding the capacity of a single wavelength. Regardless of client's demand, the network provider's priority will be to maintain a highly-efficient transport platform; therefore, it will be necessary to efficiently aggregate traffic reaching and exceeding 100 Gb/s. This can only be achieved in the optical domain.

We have previously demonstrated a novel architecture of spectrum-sliced elastic optical path network (SLICE) which enabled transmission of bandwidth-variable (BV) paths across a flexible core [2]. Basing on the concept of the elastic optical path, we propose and demonstrate a novel optical path aggregation technology. We show merging of 6 links of 100 Gb/s and one link of 400 Gb/s into a single seamless optical path as well as transmission of the 1 Tb/s path over a network consisting of WXCs.

Optical domain aggregation

With the proliferation of 100 Gb/s interfaces, the requested capacity for communication between routers may reach 200, or 300 Gb/s. The existing layer 2 (L2) Link Aggregation technology allows virtual aggregation of multiple physical ports into a single logical link. However, the transmission of the aggregated traffic over the existing WDM physical layer is inefficient in terns of spectral efficiency. Therefore, a need arises for a new, layer 1 (L1) optical aggregation technology efficiently accommodating several 100 Gb/s links into a single super-wavelength. The SLICE platform provides a spectrum-efficient transmission of 100 Gb/s or larger traffic using flexible granular grooming. It allocates the necessary amount of optical spectrum to the end-to-end path depending on the traffic volume or user request. Optical grooming can be employed to realize the concept of optical aggregation, as shown in Fig.1. A number of L2-aggregated links supporting a large capacity service are transported at the maximum available port speed to the SLICE Ingress node. The Ingress node performs the L1 path aggregation by translating the individual flows into optical paths using the corresponding optical orthogonal frequency-division multiplexing transmitters (OFDM Tx) [3]. The transmitters generate optical paths with bandwidth matched to the required input flow. All transmitters are phase-locked and can generate paths at an arbitrary spectral location. Therefore, the individual paths may be edge-overlapped to form a seamless OFDM signal. The aggregated flows are transmitted over a flexible-bandwidth path which is allocated end-to-end in the BV wavelength cross-connects (BV-WXCs). The path terminates in the Egress node which splits the signal and demodulates the individual paths into their respective links.

1 Tb/s optical path aggregation experiment

We experimentally demonstrated the feasibility of the concept of optical path aggregation. We employ differential quadrature phase-shift keying (DQPSK) OFDM signal as a BV modulation format and flexibly-variable wavelength-selective switch (WSS) for BV filter in WXCs. The switch is formed from the optical filters, which may be based on MEMS or liquid crystal elements [4-6]. In the experiment, 7 links were generated in total; 6 links of 100 Gb/s and one link of 400 Gb/s. The links are optically aggregated into a single 1 Tb/s optical path. The path is transmitted over two WXCs in which the spectral resources are allocated

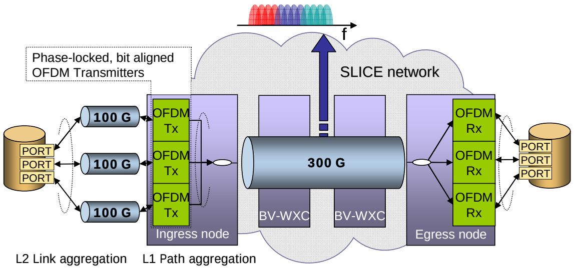

Fig. 1: Principle of optical path aggregation.

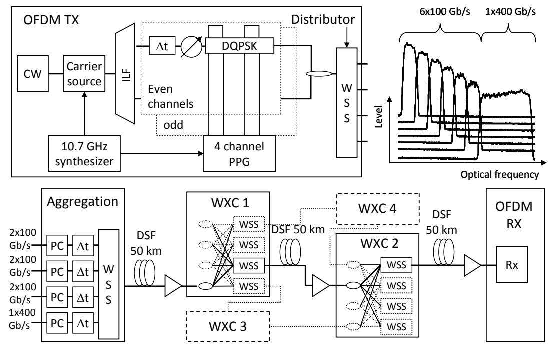

Fig. 2: Optical aggregation experimental setup.

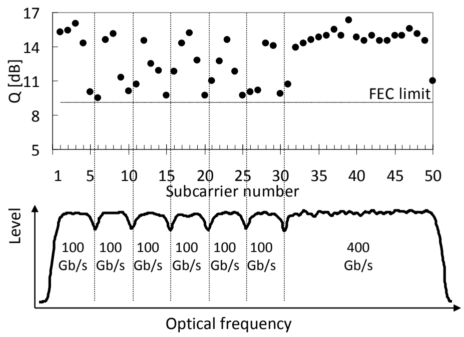

Fig. 3: Experiment spectra and results.

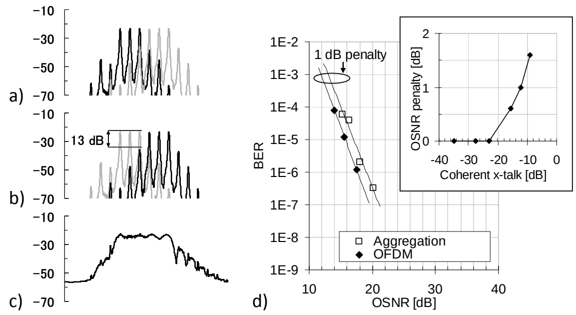

Fig. 4: Optical aggregation penalty investigation.

end-to-end to match the bandwidth of the path exactly. Because of the lack of 7 individual OFDM transmitters, a single OFDM signal source was divided into individual links, as shown in Fig. 2. A multi-carrier source generated 50 carriers spaced by 10.7 GHz. The carriers were split into even and odd branches with interleave filter (ILF) for individual modulation with pre-coded pseudo-random bit sequence (PRBS) of length 2^{15}-1. Two I/Q modulators generated 21.4 Gb/s DQPSK signals in subcarriers of the even and odd branch. Data of the odd branch was shifted by 1024 symbols with respect to the even branch and both branches were bit-aligned before merging by an optical coupler to form the optical OFDM signal [7,8].

Individual links were generated by selecting the desired number of modulated subcarriers in a WSS. The aggregation can be carried out using an optical coupler; however, we employed a second WSS when aggregating the optical path in order to reduce the coherent crosstalk. The aggregated path with the total bit rate of 1 Tb/s was transmitted from the point of aggregation over two WXC nodes of a mesh network to the OFDM receiver over three 50 km-long spans of dispersion-shifted fiber (DSF). The performance of individual subcarriers was evaluated through Q parameter calculated from the bit-error ratio (BER).

The spectrum of the aggregated path is shown in Fig. 3, together with the corresponding values of Q parameter for each of the subcarriers. The spectrum exhibits dips of approximately 6 dB caused by the two stages of filtering in the WSS. The filtering results in Q-parameter degradation of the link edge subcarriers. Nevertheless, after the 150 km-long transmission the performance of the 1 Tb/s aggregated path, expressed in Q parameter, was 9.5 dB or better, which is above the limit set by the forward error correction coding (FEC) of 9.1 dB.

It should be stressed that the degradation of edge subcarriers is not inherent to optical aggregation, but rather caused by the experimental arrangement. In order to verify the performance of aggregated link edge carriers, we generated two phase-locked links consisting of 3 subcarriers each, as shown in Fig. 4 a and b. The links were modulated with DPSK OFDM signal and aggregated (Fig. 4 c). The OSNR performance of the edge carrier is shown in Fig. 4 d. The penalty after optical aggregation is approximately 1 dB. We found the source of degradation to be the coherent cross-talk from the adjacent channel's residual carrier at a level of -13 dB (Fig. 4 b). We measured the penalty caused by the coherent cross-talk and plotted the result in the inset of Fig. 4 d. At -13 dB the coherent cross-talk causes a penalty of 1 dB, which explains the degradation in the edge carrier. In an actual system, each OFDM Tx is expected to generate a well-defined spectrum with only the required number of subcarriers, thereby alleviating the problem of penalty at the edge of each link.

Conclusions

We experimentally demonstrated optical aggregation and transmission of a seamless 1 Tb/s path directly in the optical domain. Optical path aggregation using the SLICE network architecture enables highly spectrally-efficient transmission of services requiring bandwidths of 100 Gb/s and beyond. We are confident that the extended functionality of the optical layer will accelerate the convergence of high-end services and existing traffic into a single, efficient optical platform.

References

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