Abstract

As the use of 5G/6G services, video applications on the internet, and cloud services and data centers become more popular, network traffic is constantly increasing. This means that there is a continuous need for expanding the capacity of optical networks. In the past, efforts were made to improve spectral efficiency through techniques like high-order modulation and constellation shaping. However, the Shannon limit sets a limit on spectral efficiency at a specific transmission distance, which means that there is a greater reliance on utilizing the optical spectrum from either the same optical fiber or other optical fibers. This can be achieved by extending to more wavelength bands or deploying more fibers, or through spatial division multiplexing. These methods will need to be increasingly utilized to keep up with growing network traffic. In this thesis, Multi-band optical fiber transmission is generally proposed and investigated for capacity upgrades in optical transport networks. To comprehensively assess the potential of multi-band transmission, key metrics such as the potential capacity increase, energy consumption, and the number of required interfaces must be evaluated for different transmission scenarios. Thus, first of all, it has been considered progressive spectral exploitation, starting from the C-band only and up to C+L+S+U-band transmission, for both transparent and translucent solutions that exploit optical signal regeneration. By considering accurate state-of-the-art physical layer models for each investigated multi-band configuration, a networking performance metric that enables the comparison of different solutions in terms of capacity allocation and energy consumption has been driven. For a translucent network design, different regenerator placement algorithms are compared, with the aim of minimizing energy consumption and costs. The proposed network-wide numerical analysis shows that, for spectral occupations exceeding the C+L-band, translucent solutions can significantly increase network capacity while leading to a similar energy consumption per transmitted bit as in the transparent design case, but they require the deployment of additional line interfaces.

Significantly, these results provide evidence that the transparent exploitation of an additional transmission band produces a capacity increment that is at least comparable to that of a translucent solution based on already-in-use bands. Since this is attained at the expense of fewer line interfaces, it is a key finding suggesting that extending the number of bands supported is a cost-effective approach to scaling the capacity of existing fiber infrastructures. Moreover, it has been compared and analyzed comprehensively the network capacity, along with the required number of interfaces and amplifiers for different network topologies, for both regular and extended bandwidth (super) bands which recently proposed to efficiently use already installed devices. Thus, two multi-band transmission (MBT) scenarios: first, the regular configurations, consisting of the C+L-band and C+L+S1-band – being S1 half of the standard S-band, with total bandwidths of 9.6 and 14.4 THz, respectively, and second, extended bandwidth configurations for the C- and C+L-band, with total bandwidths of 6 and 12 THz, respectively have been investigated in this thesis. Both transparent and translucent network design scenarios are applied. The numerical network assessment process assisted by an accurate physical layer model, for all MBT configurations in this part, was performed as well. It has been shown that compared to regular bands, super bands significantly increase network capacity for both uniform and nonuniform traffic distributions. Crucially, super bands require fewer line interfaces, suggesting that extending the bandwidth of already deployed bands is a cost-effective approach when up-scaling existing fiber infrastructures, in comparison to adding extra bands. Finally, To improve the network capacity signal regeneration has been done in the band(s) with a poor QoT such as the S-band; So, the performance of the optimized S-band network has been compared to that of the U-band in MBT configurations. Initially, signal regeneration was implemented in the S-band to improve its performance and achieve transmission data rates comparable to the C and L-bands in the transparent network design. Subsequently, the advantages of the S-band over the U-band in MBT configurations were evaluated. It has been shown that signal regeneration in the S-band channels results in gaining network capacity efficiently and cost-effectively.