Message passing for routing and network design in optical communication

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Optical communication networks underpin the global digital communications infrastructure and carry most of the Internet traffic. They comprise thousands of kilometres of optical fibres, organised in a complex web of constituent sub-networks. The exponential growth in Internet traffic and energy consumption threatens to overload the existing infrastructure. One of the key requirements is the routing and wavelength assignment (RWA) for all traffic demands across this complex heterogeneous network in a way that optimises a given objective function, be it low latency, high throughput or resilience. The main constraint in RWA is that any complete individual route, from source to destination, uses the same single wavelength and that separate routes using the same wavelength cannot share the same fibre. This constraint makes the general hard computational routing problem even harder. Given that routes are constrained to be contiguous and interaction between paths is non-localised, local optimisation methods are insufficient and global optimisation is required. However, global RWA of multiple communication requests is computationally-hard and is currently addressed in small systems by integer/linear programming and its variants, Monte Carlo search, greedy algorithms and various heuristics. The main challenge we address is the RWA under heavy traffic using multiple wavelengths and a large number of origin-destination pairs for various objective functions. This is carried out by mapping the RWA task in the presence of multiple wavelengths onto multi-layer replica of the original graph and utilising probabilistic message-passing techniques, developed independently in several fields including statistical physics, to solve it. These methods allow for messages, in the form of conditional probability values to be passed between nodes and the replicated networks representing the different wavelengths, in a way that keeps the algorithms scalable even for a large number of wavelengths, transmission requests (corresponding to source-destination pairs) and nodes. The algorithm has been tested for a variety of sparse network topologies, both synthetic random graphs and real optical communication networks, and for different objective functions, showing excellent results in obtaining high quality approximate solutions. Another major task in designing and maintaining optical communication networks is the removal of unnecessary edges or adding new ones in a manner that minimises the impact on throughput in the former and maximises the benefit in the latter. Many edges in operational optical communication networks are legacy fibres that are costly to maintain but are not removed due to the possible operational impact; similarly, adding fibres is expensive and one clearly would like to maximise the benefit from it. Many of the methods used currently for these tasks are topological in nature without considering the typical communication requests, while others rely on simulations or heuristics. We consider the two-level optimisation tasks, of edge removal/addition in parallel to optimal multi-user routing in order the identify the best edges to be removed/added with minimal/maximal impact on a given objective (e.g., throughput, latency or resilience). The methodology used is based on message passing and the resulting algorithms have been tested on synthetic and real networks, showing excellent results compared to existing heuristics.