Embedding a Mesh of Rings in a Real-world Network

a report by

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Introduction

In transport networks, synchronous digital hierarchy (SDH) or Synchronous Optical Network (SONET) represent the classic transport protocols. Others include asynchronous transfer mode (ATM), Internet Protocol (IP) or plesiochronous digital hierarchy (PDH). On the physical level, wavelength-division multiplexing (WDM) is used for point-to-point connections to satisfy the demand for transport capacity. The introduction of an optical path (OP) layer[1] has been proposed where the routing of optical channels is realised in the optical domain by wavelength routing.

Two approaches can be applied in order to design a communication network. The first one is connection-based, i.e. the routing will be computed for every connection. The second is structure-based – the network will be built up from blocks like rings or meshes. Several architectures that are based on regular topologies for all-optical networks (for example, the coloured section ring[2]) or meshed topologies (for example, the Gridconnect[3]) have been proposed and investigated. These concepts use a certain fibre topology and a homogeneous traffic matrix.

The mapping of the real-world topologies and the traffic demand on regular structures is a challenging task due to the many degrees of freedom. Jäger proposed a mapping for the Gridconnect that has the disadvantage of high computational complexity.[4] In the work of O Komolafe and D Harle, an interesting approach using a genetic algorithm to embed the Manhattan Street Network (MSN)[5] in a network has been investigated.[6] A survey on virtual topology design algorithms can be found in the work of R Duttra and G N Rouskas.[7]

The aim of this article is to present an optimised, semi-heuristic algorithm with rather low complexity for the mapping of arbitrary topology and traffic pattern on a mesh of rings. It has been tested with a case study. Only the ring identification and the routing in the logical network are investigated. No particular realisation of the rings itself will be considered here. Therefore, for example, the mapping of the resulting channels to distinct wavelengths will not be treated, but could easily be integrated in the algorithm by adding an additional layer and using one of the known algorithms for wavelength allocation, for example, 'First-Fit'. For the same reason, protection has been neglected even though this is the main reason for introducing rings.

The article begins by introducing a multilayer graph model. For the optimisation process, 'simulated annealing' (SA) is used. The results for the Pan-European Network are then analysed for different maximal ring sizes. The short summary at the end includes an outlook of further work.

Multilayer Graph Model

For the description of the network, a three-layer graph model is used (see *Figure 1*). The lower layer,

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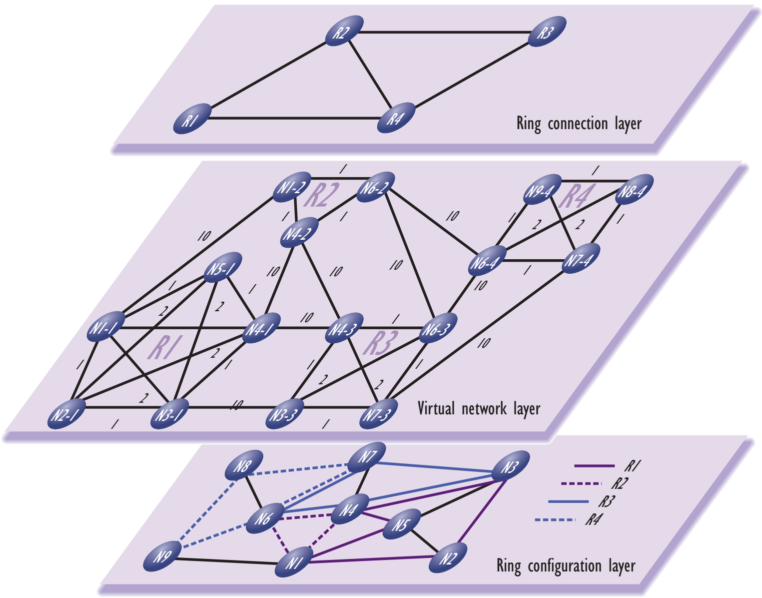
1. *K Sato, S Okamoto and H Hadama, "Network performance and integrity enhancement with OP layer technologies",* IEEE J. Selected Areas in Communication*, Vol. 12, pp. 159–170, January 1994.*
2. *A Hamel et al., "Increased Capacity in an MS Protection Ring using WDM Technique and OADM: The Coloured Section Ring",* IEE Electr. Lett.*, Vol. 32, p. 234–235, February 1996.*
3. *H A Jäger, "The Modular WDM-Gridconnect as a Passive Routing Structure with Distributed Interfacing Capabilities",* Photon. Netw. Comm.*, Vol. 1, No. 1, pp. 23–34, June 1999.*
4. *H A Jäger and T Gipser, "Mapping of Virtual Regular Mesh Network Topologies onto Arbitrary Geographical Node Distributions",* Proc. of Conf. on Netw. and Opt. Comm. (NOC)*, ISBN 90 5199 274, Vol. 3, pp. 64–71, June 1996.*
5. *N F Maxemchuk, "The Manhattan Street Network",* Proceedings of IEEE Globecom '85*, December 1985.*
6. *O Komolafe and D Harle, "Optical Packet Switching over Arbitrary Physical Topologies using the Manhattan Street Network: An Evolutionary Approach",* Proceedings of Fifth Working Conference on Optical Network Design and Modelling (ONDM01)*, Vienna, February 2001.*
7. *R Duttra and G N Rouskas, "A Survey of Virtual Topology Design Algorithms for Wavelength Routed Optical Networks", TR-99-06, Dept. of Computer Science, N. Carolina State University.*

Figure 1: Three-layer Graph Model



which is referred to as the ring configuration layer, contains the real network nodes and the real fibre topology. The actual configuration is a set of rings. Each ring consists of a set of nodes and edges of the network. A 'face' is the smallest possible ring in a network. By using the face concept, it is possible to construct rings in a systematic way with low complexity. The enlargement of a ring involves adding further faces, while shrinking is achieved by deleting faces.[8]

The second layer is the virtual network layer. It describes the effective logical topology, which results from the set of rings of the lower layer. Here, for every connection request of the traffic matrix, a path through this logical network has to be found. Every ring in the lower layer is translated into a complete graph of the virtual network layer. In a complete graph, a direct link exists between every node pair. Nodes that belong to several rings create multiple copies in the effective graph, where all copies are connected by a bridging link. This layer would represent the OP layer, when an all-optical realisation is used for the rings. The third layer is the ring connection layer. Every ring in the configuration is represented by one node. For each network node that belongs to two or more rings an edge between the corresponding ring nodes has to be added. The routing for hop-connections that travel through several rings is computed using this representation, which reduces the complexity significantly. In the example in *Figure 1*, a configuration with four rings on a given network topology is depicted.

The Optimisation Process

The general aim is to minimise the ring configuration and the routing on the virtual network with respect to a given objective function so that all traffic demands are fulfilled and the boundary conditions – for example, the capacity per link – are not violated. For the optimisation process, the evaluation of the configuration is of crucial importance. Here, the design strategy for the network has to be incorporated. In this work, the cost for a configuration Ccfg = Cr + Cp is composed of two parts as follows:

- cost Cr of the realisation for the configuration, for example, the sum of the distance for all paths or a constant for every existing ring; and
- cost Cp for the violations of boundary conditions, for example, the excess of the maximal ring size.

Due to the high degrees of freedom in network optimisation problems, it is not possible to compute all of the configurations to find the optimum solution, therefore, approximation methods must be relied on. One well-known method that has succeeded in solving this class of problem is SA. Any other known optimisation method, such as tabu-search or genetic optimisation, which are not trapped in local minima, could also be used. Beginning with a valid start configuration, in every step, a neighbour configuration is derived from the actual configuration by choosing at random one of the following operations:

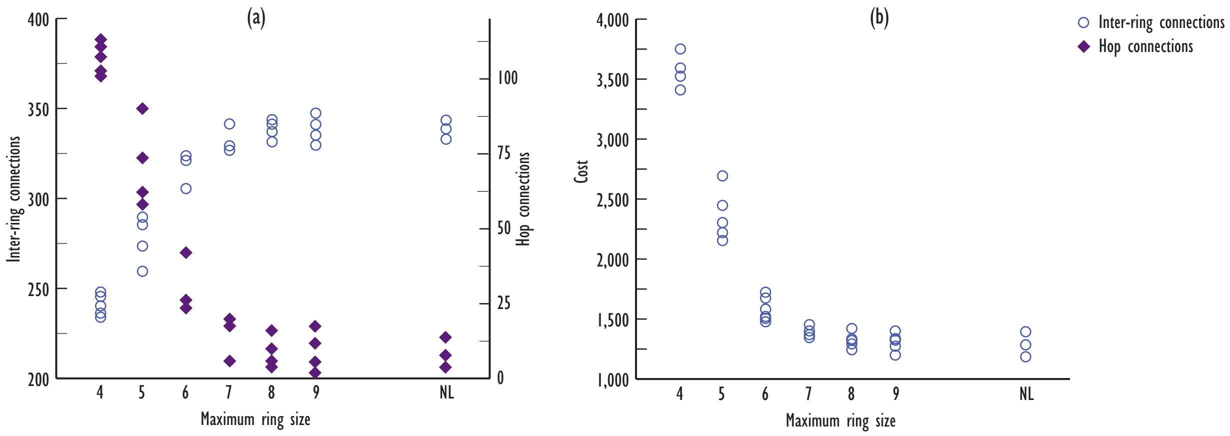
- adding one face to one of the rings;
- creating a new ring with a random face;
- deleting a face of a ring – when there are no faces left, the ring is destroyed; and
- changing the order in which the hop connections are assigned.

In order to speed up the optimisation process, the probabilities for the different operations may be adapted.

The objective function for the actual configuration and the neighbour configuration are compared. When the cost for the neighbour configuration Cncfg is lower than for the actual configuration Ccfg, it is accepted, otherwise, only with a certain probability, which decreases during the optimisation procedure. This prevents it being trapped in a local minimum of the objective function.

8. *C Mauz, "Mapping of arbitrary traffic demand and network topology on a mesh of rings network",* Proceedings of Fifth Working Conference on Optical Network Design and Modelling (ONDM01)*, Vienna, February 2001.*
9. *P Batchelor et al., "Study on the implementation of optical transparent transport networks in the European environment – results of the research project COST 239",* Photon. Netw. Comm.*, Vol. 2, No. 1, pp. 15–32, January–March 2000.*

Figure 2: Configuration Cost (a) and Inter-ring and Hop Connections (b) for Different Maximum Ring Sizes



One typical outcome for the resulting ring configuration is *Ring #0: (N6 N8 N3 N2 N1 N10 N7 N11)* *Ring #1: (N8 N6 N5 N2 N3 N1 N9)* *Ring #2: (N7 N11 N6 N4 N3 N2 N1 N10)* *Ring #3: (N5 N2 N1 N10 N9 N7 N11 N6)*

A Case Study for the 'Pan-European Network' of the COST 239 Project

In the framework of the European research action Cooperation europeenne dans le domaine de la recherche Scientifique et Technique (European Cooperation in the Field of Scientific and Technical Research) (COST) 239, several case studies for a Pan-European network have been performed.[9] Using the COST 239 scenario as a test example, 348 connections in total had to be established. The optimisation process required 615 steps to find the final configuration with only four rings. This has a total cost of 1,217. The rings may handle most of the connections and only 10 hop-connections are necessary. On average, every node belongs to 2.82 rings. The mean ring-size n_{mean} = 7.75 is close to the imposed maximum of n_{max} = 8.

In *Figure 2a*, the cost for the resulting ring configuration is depicted as a function of the maximum ring size. The label 'NL' indicates that there has been no limit on the size of a ring. For every parameter that has been set, five realisations have been calculated to estimate the variations among different outcomes. As expected, with increasing ring size, the cost for the realisation decreases. For rings that are larger than eight nodes, the results are similar and further improvement may not be achieved. This is due to the fact that only 11 nodes are present in the COST 239 network. The variation among the different realisation costs is of the order of 15% and may be further lowered by a longer optimisation process.

With larger rings, it is possible to satisfy more connections in the rings – circles and left axis – in *Figure 2b* and to achieve less hop-connections – stars and right axis. For rings that are larger then seven nodes, most of the connections can be handled by inter-ring connections. The algorithm allows the treatment of networks with up to 100 nodes on standard PC hardware.

Conclusions and Outlook

A three-layer graph model with a ring configuration layer, a network layer and a ring routing layer has been presented. The use of faces as building blocks allows for a systematic and efficient description of the ring configuration. The allocation of the connections for the traffic demands takes place on the resulting effective network. The computation of the routing can be speeded up by introducing the ring connectivity layer and by performing the routing of the hop-connections on this layer. SA is used to optimise the ring configuration with respect to an objective function, in which boundary conditions can be incorporated. It is possible to map an arbitrary network topology and traffic demand on a mesh of rings network. The algorithm has been tested with the COST 239 Pan European case study. To find a good realisation for this network, only 400 to 700 steps are needed.

A specific realisation of the rings has not been treated until now. The method can be extended easily to incorporate an additional layer for the wavelength paths. This would enable, for example, an optimisation with respect to the number of necessary wavelengths or the treatment of the wavelength allocation problem.

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