On Stack-Graph OPS-Based Lightwave Networks*

H. Bourdin**, A. Ferreira*** and K. Marcus†

Abstract. Most of the proposed architectures for interconnecting nodes in processor networks are based on graph topologies. Recently, stack-graph topologies based on the hypergraph theory have emerged, taking advantage of the fact that the huge bandwidth of optical fiber can be divided into several high-speed channels in networks using Optical Passive Star (OPS) couplers. We show through simulation that these stack-graph networks compare very well against graph-based ones, in terms of stochastic behavior for routing.

1 Introduction

Optical technologies such as tunable optical transmitters and receivers, and wavelength division multiplexing (WDM) allow the construction of very efficient local and metropolitan area networks (LAN and MAN, respectively), and could be used as interconnection networks in parallel computers. Using Passive Star (OPS) couplers, one can build *single-hop* systems, where every processor is able to directly communicate with one another. Clearly, however, this could represent a severe drawback when building very large networks.

Alternatively, the same kind of couplers can be used in the construction of *multihop* networks, where a node is assigned to a small and static set of predefined channels. Pairwise communication may then need to hop through intermediate nodes [7]. Thus, in multihop systems, communications take longer, but nodes are simpler, cheaper, and more reliable than in single-hop systems.

Several topologies were proposed as *point-to-point* logical architectures for WDM networks, based on graphs [6, 8, 9]. Unfortunately, these topologies either use too many channels, have too many transceivers, or suffer of a large diameter. Furthermore, an intrinsic feature of optical communications is that the channels induced by WDM can span a large number of nodes in the network. Hence, point-to-point logical topologies do not efficiently use optical technology and new avenues have to be explored.

On the other hand, *one-to-many* topologies are best represented by hypergraphs [1], that can be seen as a generalization of graphs in which edges are replaced by hyperedges [10] joining sets of nodes, instead of only two nodes. As

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** LIP ENS Lyon, 69364 Lyon Cédex 07, France.
*** CNRS - LIP ENS Lyon, 69364 Lyon Cédex 07, France.
† CSI, University of Ottawa, P.O. Box 450 Stn. A, K1N 6N5, Ottawa, Canada.

for graphs, a hyperedge represents a communication means; a message sent on a hyperedge can be read by all nodes in that hyperedge.

Our work is focused on new one-to-many architectures for multihop systems, whose main performance characteristics are their regularity and modularity [2, 4]. Positive points are that they can be incrementally expanded and the number of links between two processors is fixed, thus allowing the transmitters and receivers to be tuned to some pre-determined frequencies. The high fault tolerance ensures a reliable communication and network performance. Finally, only a small number of hops is required in any pairwise communication, and the network allows easy schemes for global routing operations [2, 4].

In this paper we present a comparative study of three hypergraph–based networks, namely the *stack-ring*, the *stack-torus*, and the *hypertorus* [2], and two very well known graph–based topologies, namely the hypercube and the two–dimensional torus [3]. In Section 3 we discuss their routing–related stochastic characteristics that were obtained through simulation.

2 Emerging networks

Many interconnection topologies have been proposed for the design of LAN's and MAN's using multihop lightwave techniques as the Manhattan Street Network[6], de Bruijn graphs based network [9] and the Supercube [9]. These networks are based on graph models, and the possibility of a node to communicate with another one is represented by an edge joining the two nodes. Thus, in any communication step, only pairs of nodes are involved. In [2, 4], it was proposed to grow the number of nodes involved in each step, profiting mostly from WDM that allows the huge bandwidth of optical fiber to be divided into a set of high-speed logical channels. Such channels can be seen as logical attributes shared among many processors. The network topologies are based on hypergraph models, and thus called hypertopologies.

Stack-rings and stack-tori can be seen as a generalization of rings and tori from graphs to hypergraphs using the concept of *stack-graphs*. Briefly, stack-graphs are obtained by piling up copies of the original graph and subsequently replacing the edges by hyperedges. Hypertori, on the other hand, are defined as a Cartesian product of stack-rings. Because of severe space limitations, we refer the interested reader to the definitions appearing in [2, 5].

3 Simulation & Results

Sen and Maitra presented in [8] a simulator used to evaluate the dynamic quality of point-to-point lightwave networks. Using the same framework, we implemented a similar simulator for the hypergraph–based lightwave networks studied in this paper. There are two control parameters. The *offered load* (exponentially distributed), with channel speed equal to 100 M-bits/s, and the *channel speed* with offered load equal to 100 packets/s.

We simulated, whenever possible, (hyper) networks with 120 nodes such that all hypernetworks have diameter 3. Table 1 shows the simulated (hyper) networks, giving the chosen configuration with number of channels (hyperedges), number of fixed transceivers per node (degree), and number of processors per channel (rank).

topology	configuration	nodes	hyperedges	degree	rank
Hyperring	$\mathcal{R}_{6,20}$		6	2	40
Hypertorus	$\mathcal{R}_{5,2} \times \mathcal{R}_{3,4}$		90	4	8
Stack-torus	$\varsigma(T(5,3),8)$	120	30	4	16
Torus	$T(10,12)$		240	4	2
Hypercube	$H(7)$	128	448	7	2

Table 1. Hypertopologies with 120 nodes and a diameter of 3.

Figure 1 shows that, with respect to the packet delivery time, the hypertopologies have a better performance than the graph–based ones, although the asymptotic behavior is quite the same for all networks. Concerning the average wait time / delivery time shown in Figure 1, we recall that both parameters depend on the number of channels. Therefore, the stack-ring behaves poorly in comparison to the others, that have all a similar behavior.

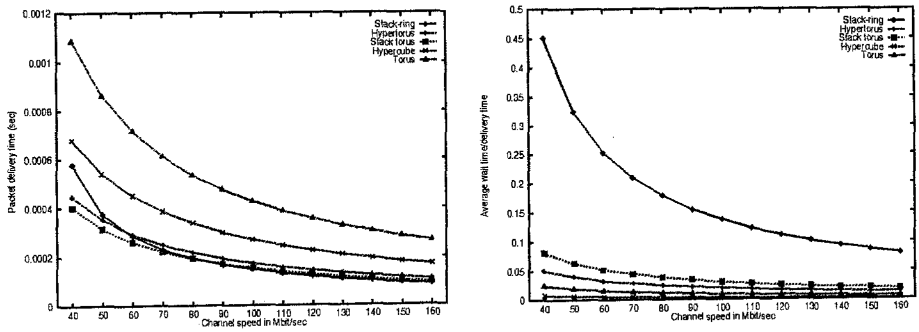

Fig. 1. Packet delivery time and wait ratio versus channel speed.

In Figure 2 one can see that the small number of channels of the stack-ring troubles its performance. With respect to the packet delivery time, the hypertopologies have the same behavior, better than both the torus and the hypercube.

From our experiments we can conclude that, as expected, because of their good (hyper)graph-theoretic properties discussed in [4, 5], the hypernetworks outperform graph–based networks in almost all aspects. However, an adequate balance among channels, degree, and diameter should be obtained for stack-graph-based LAN's, MAN's, and optical interconnection networks for parallel computers.

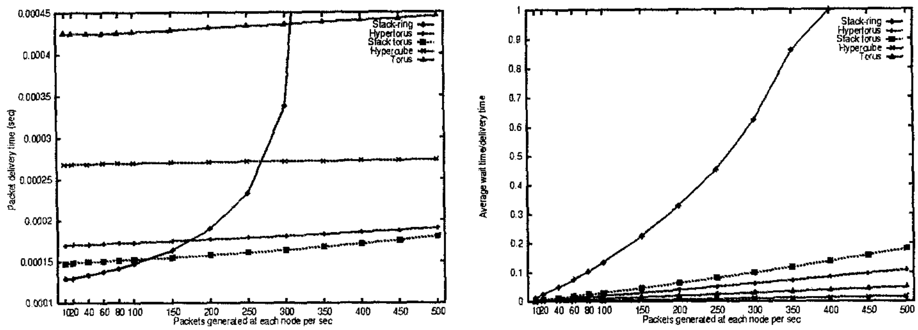

Fig. 2. Packet delivery time and wait / delivery time versus load.

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