A Novel Optical Passive Router Ring Architecture Using MAGNet Protocol

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Abstract

This paper introduces a family of bidirectional multi-fibre passive photonic ring architectures that may serve as a high-capacity network backbone for supporting next-generation data-centric services. We introduce a novel dual-router node design that avoids several non-ideal routing phenomena typically associated with passive networks based on cyclic graphs. Our design also achieves the requisite single-hop full-mesh connectivity needed for arbitrary node-to-node communications. A ring enlargement strategy is presented that allows this architecture to scale across a wide range of networking domains. A medium access protocol will also briefly elaborated.

Keywords : *Optical Networks, Local-Area Networks, Metropolitan-Area Networks, Wavelength Routing, Clustered Computing*

1 Introduction

The ongoing commodisation of computing and storage technologies will bring about the emergence of a network-wide computational environment. Prominent indicators of this trend include the development of commodity ad-hoc clustered computing networks based on the open-source Linux operating system [1]. There is also active research activity in the development of "computational grids" - a distributed computing environment catering initially for those complex scientific applications with significant computation, bandwidth and storage requirements [2]. This paper presents a novel low-cost passive ring architecture based on recent research developments in passive componentry and athermal active optical devices stemming from the multi-university collaborative PHOTON project [3]. It is envisaged that this type of network architecture may form the basis of a networking backbone for interconnecting multiple clustered computing sites and also for supporting high bandwidth services from the emergent data-centric traffic environment.

2 Passive Photonic Ring Architecture

The key functional device employed in the ring architecture is called a *passive wavelength router* and realized in silica using a 2D integrated optics (2DIO) platform [4]. This fabrication approach enables compact designs for passive optical devices and the ”folded” construction of the 2DIO device is depicted in Figure 1(a). The passive router is a multi-port device (Figure 1(b)) and its fixed routing function is to direct wavelengths belonging to any input port, *i*, to a specific output port, *j*. The routing function is given by $j = (i + l - 2) \bmod M + 1, \{i, j, l\} \in [1, M]$, where M is the number of ports and l denotes the input wavelength. The interconnection of passive routers in cyclic graphs, i.e. ring and mesh topologies, may exhibit several non-ideal routing phenomena: *self-loops*, *stranded wavelength loops* of capacity and *loop-backs*. We introduce a novel dual-router node design (Figure 2(c)) that avoids the aforementioned phenomena and achieves the requisite single-hop full-mesh connectivity for facilitating arbitrary node-to-node communications. Given the expected loss along the passive router cascade, our architecture specifies a multihop routing strategy for the periodic regeneration of circuitous lightpaths and improving traffic loading.

2.1 Network Structure

The node interconnection pattern in a ring of N nodes is given by:

$$\left\lfloor \frac{\left(j_{\mathrm{AR}(n)}+\frac{M}{2}-2\right)\bmod M}{\frac{M}{2}} \right\rfloor = \begin{cases} 0, & j_{\mathrm{AR}(n)} \to i_{\mathrm{DR}((n+N-2)\bmod N+1)} \\ 1, & j_{\mathrm{AR}(n)} \to i_{\mathrm{DR}(n \bmod N+1)} \end{cases}, i_{\mathrm{DR}(n')} = \left(j_{\mathrm{AR}(n)}+M-2\right)\bmod M+1$$

where AR(n) and DR(n) denotes *add* and *drop* router belonging to node n respectively. The set of all valid *intra-router unidirectional transit connections* is given by:

$$C = \left\{ j_{\mathrm{DR}(n)} \to M - \left(j_{\mathrm{DR}(n)} + \frac{M}{2} - 2 \right) \bmod M \right\}, j_{\mathrm{DR}(n)} = 1,\ldots,M$$

We choose a subset $T \in C$ (Figure 1(d)) for creating the desired network architecture and the resultant unconnected ports serve as *add* and *drop* ports. For a 8-node ring (N=M=8) we choose different transit connections for a subset of nodes in sequence I:{2-4, 3-3, 4-2, 5-1}, II:{1-5, 2-4, 4-2, 7-7}, III:{5-1, 6-8, 7-7, 8-6} and IV:{1-5, 3-3, 6-8, 8-6} where I, II, III and IV label the different *nodes types* in sequence (Figure 2(e)). This sequence specifies a *ring segment*, S = {I, II, III, IV} and the 8-node ring represents a concatenation of two ring segments (Figure 2(e)). This results in the following fixed distribution of lightpaths emanating from every node along the ring and for each of the two ring directions: 8 lightpaths over one link, 2 lightpaths over 2 links, 4 lightpaths over 3 links and 2 lightpaths over 4 links. Since the ring has an even number of nodes, there are 4 lightpaths using 4 links between any diametrically opposite node pairs. Analogous network constructions have also been determined for 4-node and 6-node rings.

2.2 Modular Ring Enlargement Concept

Larger rings may be created using a modular enlargement scheme. For example ring R = {S, S, ...} for ring sizes N (N mod 4=0, $N \geq 8$) (Figure 2(f)). Connections traversing more than one ring segment will be transported as a semi-lightpath[1]. A non-modular enlargement of rings is also possible using pre-specified node types. However, it can be shown that undesirable routing effects may result for certain cases.

3 Node Architecture and Medium Access

A medium access protocol called *Medium Access for Grid Networks* (*MAGNet*) is designed for this type of passive ring architecture. The node architecture adopts either a FTFR[2] or TTFR structure (Figure 2) – the transmitter architecture is based on an array of fixed-wavelength lasers or a limited array of agile-wavelength lasers for every *add port*. A wavelength on every *drop port* is received independently using an array of fixed-wavelength receivers. Data packets entering the network is given a fixed port and wavelength assignment based on its destination and mapped onto a frame structure depicted in Figure 3. Given the passive forwarding nature of the network, wavelength routing is entirely deterministic. Each wavelength operates at the 10 Gbps line rate and we examine routing policies for supporting a multi-priority traffic environment. We conclude that tunable nodes offer comparable performance to those designs featuring fixed wavelength transmitters.

Acknowledgements

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References

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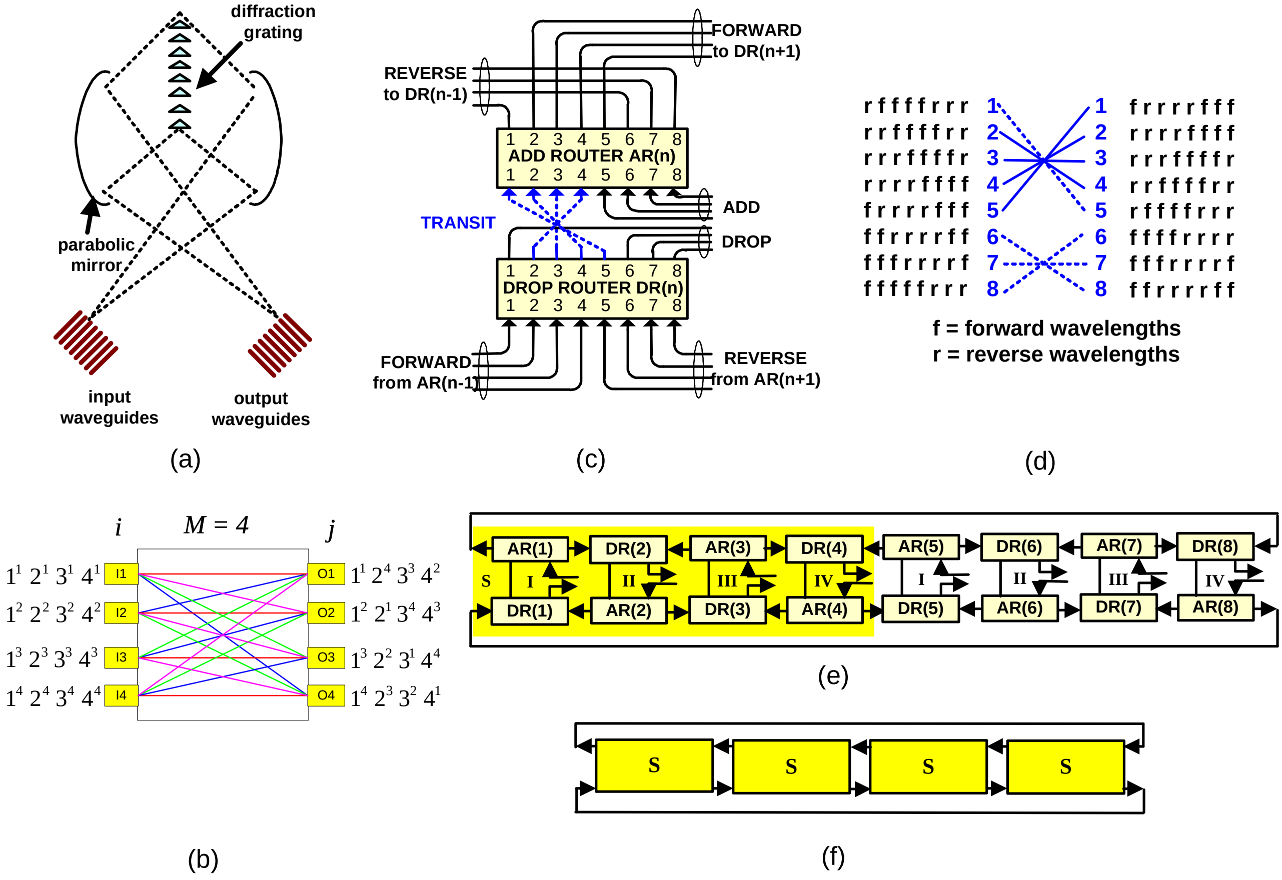
[1] A semi-lightpath is defined as the *virtual* connection that is created from a concatenation of more than one wavelength-continuous lightpath. Each constituent lightpath is electrically terminated, i.e. the virtual connection may undergo more than one optoelectronic wavelength conversion.

[2] FTFR – Fixed Transmitter, Fixed Receiver, TTFR – Tunable Transmitter, Fixed Receiver



(a)

(c)

(d)

(e)

(b)

(f)

Figure 1: (a) plan view of integrated passive router layout; (b) routing function; (c) dual-router node design; (d) intra-router transit pattern; (e) 8-node MAGNet ring; (f) 16-node MAGNet ring demonstrating modular enlargement

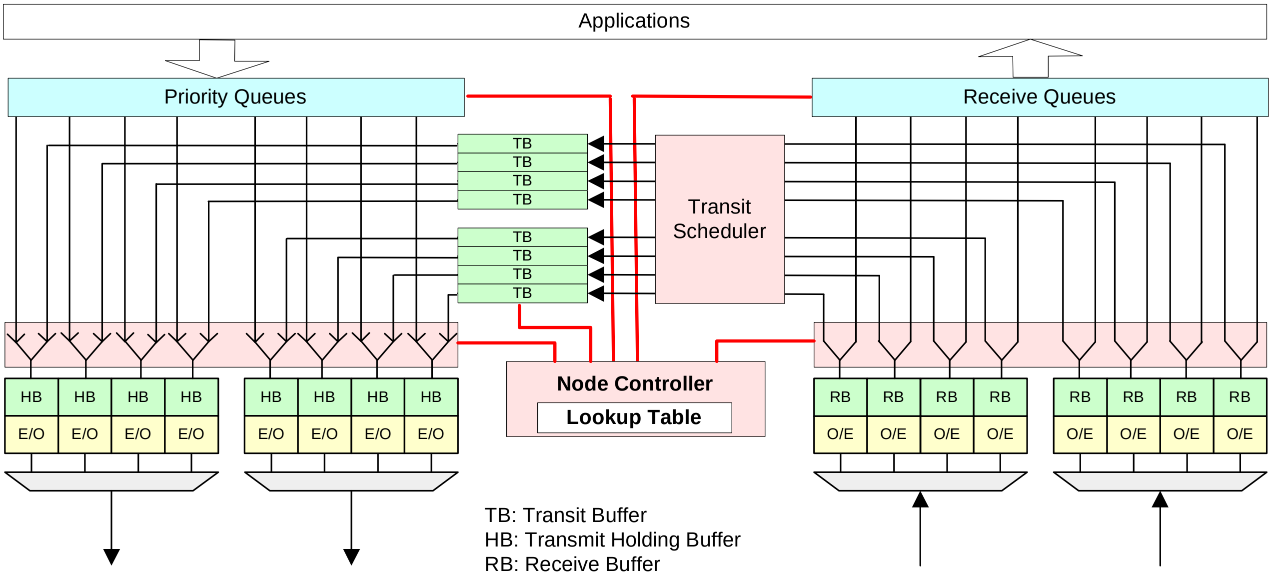


Figure 2: FTFR node architecture

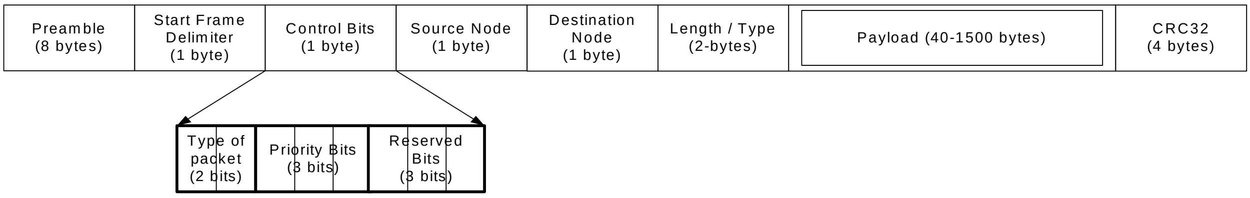


Figure 3: MAGNet frame structure