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Short-term fairness in slotted WDM rings

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ABSTRACT

Single-hop WDM ring networks are promising architectures for future broadband access and metro networks. However, ring networks exhibit significant fairness issues, which must be handled by a fairness enforcing protocol. Fairness is usually ensured over a time window of several network propagation delays. Thus, data flows might experience large access delays which might be not compatible to support time-sensitive applications. We solve this issue proposing the Multi-Fasnet protocol, which is able to enforce fairness in a relative short time scale, in the order of few propagation delays, without trading off the aggregated throughput network performance. We discuss Multi-Fasnet limitations and propose several novel strategies that achieve high and fair network throughput as well as low, bounded and fair access delays.

1. Introduction

Most of today's metropolitan area networks are based on circuit-switched Synchronous Optical NETwork/Synchronous Digital Hierarchy (SONET/SDH) architectures. Initially designed to transport constant-rate voice traffic, SDH networks are unable to cope with today's constantly increasing bursty data traffic demands. Ethernet-based metropolitan area networks are arguably more flexible, scalable and cost-effective than legacy SDH architectures [1–3]. Despite these advantages, Ethernet-based MANs still represent an *opaque* solution. Indeed, optical technology is used exclusively to support point-to-point connections between nodes and each node must perform optical-to-electrical (O/E/O) conversion, and electronically process the entire traffic for routing/switching. Since O/E/O conversion represents the largest cost when operating optical fiber networks [4], reducing or eliminating O/E/O conversion of in-transit traffic is a key design objective for future MANs.

Optical packet switching (OPS) architectures have been proposed as candidates to meet the requirements of more dynamic and demanding future networks. However, truly header-based packet switching in the optical domain is not mature yet, and, likely, too complex to design. Instead, single-hop Wavelength Division Multiplexing (WDM) architectures are a viable approach [5–15] to provide all-to-all connectivity among nodes distributed over a fiber ring. These networks usually operate in a time slotted fashion: slots propagate on the ring and each node can add/drop data to/from in-transit slots by means of one optical transmitter and receiver pair. Tunability is required at least on one end to enable single-hop, all-optical, connections between nodes.

Since nodes can add traffic only exploiting empty slots, data collision is avoided but upstream nodes can reduce (or even block) the transmission opportunities of downstream nodes. Thus, a fairness control scheme must be adopted to provide equal access opportunities to all nodes. Classical fairness definitions mainly refer to throughput fairness,

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which is usually obtained over fairly large time scales to avoid compromising the overall network performance. Our major novel contribution is to propose new solutions that provide short-term throughput fairness, i.e, over a relatively short time scale, in the order of few network propagation delays, without deteriorating the overall network performance. As such, nodes can access network resources with bounded delays even under (transient) network overloaded conditions, without penalizing time-sensitive, interactive, "mice" (i.e., low-bandwidth) flows as it would happen with traditional, long-term, fairness control schemes.

The paper is organized as follows. Section 2 introduces the related work and motivates the novelties of our approach. We describe in Section 3 the considered network architecture and in Section 4 the fairness issues arising in this network. In Section 5 we recall the original Fasnet protocol and we discuss its adaptation to the considered network. In Section 7 we present simulation results under different traffic scenarios. Finally, we derive conclusions in Section 8. The main notations used in the paper are summarized in Table 2.

The novel contributions include a complete paper restructuring and rewriting, a formal fairness definition, more extensive results under several traffic scenarios, discussions on receiver allocation strategies and on how to cope with nodes with different traffic requirements and a sensitivity analysis of protocol parameters.

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2. Related work and motivations

Fairness is a well studied subject both in electronic [16,17] and optical networks [18,19].

It is well known that ring and folded bus topologies introduce unfairness in node access opportunities. In this paper, we focus on fully distributed solutions capable of solving the unfairness of ring and bus topologies, disregarding any centralized access control scheme. Furthermore, to avoid imposing any constraint on input traffic, reservation based approaches are also not considered.

Fairness protocols were proposed in the past for both ring based [20,21] and bus based electronic networks [22]. The design of fairness protocols in a WDM multichannel network imposes new challenges with respect to traditional electronic single channel networks. Indeed, since nodes are typically equipped with one transmitter only, coordination among access to different WDM channels is required to ensure good overall network performance. Furthermore, the specific network architecture considered in this paper presents some additional constraints. Indeed, the techniques proposed in WDM rings [21] as extensions of fairness protocols devised for electronic networks (e.g., MetaRing, ATMring) cannot be directly used in the context of folded bus topologies, where a node is in the same position when accessing network resources on all the available channels. Thus, traditional solutions must be adapted to the studied scenario.

The MetaRing protocol, originally proposed to address fairness in ring networks where a single channel is available, provides good throughput performance and has already been adapted to the WDM scenario [21]. Later, the Multi-MetaRing protocol was introduced as a further extension in the context of folded bus based networks [23].

The vast majority of the previously proposed distributed fairness schemes [20,21,23] ensure fairness on a time scale in the order of several propagation delays. Consider that the network end-to-end propagation delay is typically fairly larger than the average packet transmission time. For example, in a metropolitan area network, a 50 km span leads to a 250 μs propagation delay, while a 1000-bit packet at 1 Gbit/s lasts 1 μs. Thus, hundreds packets can be transmitted in a time corresponding to a network propagation delay, and throughput fairness is obtained only after a large number of packet transmissions. Among the long-term fairness schemes, we refer in this paper for performance comparison purposes to Multi-MetaRing, which was shown to be suited to the WONDER network and able to provide high throughput efficiency in [23].

Multi-MetaRing is representative of access schemes offering almost ideal throughput efficiency and fairness, but operating over long time scales, hence being less suited to react to fast traffic dynamics. Instead, the approach proposed in this paper acts on a *shorter* time scale of few round-trip propagation delays without compromising the overall network throughput. Providing fairness on a shorter time scale permits to keep bounded access delays for low-bandwidth time-critical applications, even in highly loaded conditions, as shown in the performance results section.

3. Network architecture

We consider a WDM optical packet network named WONDER [24]. Fig. 1 presents the architecture of the WONDER network. WONDER comprises N nodes connected through two counter-rotating WDM fiber rings. Each ring conveys W wavelengths, with $N \geqslant W$. Differently from traditional bidirectional dual ring networks, one ring is used for transmission only, while the second ring is used for reception only. Transmission wavelengths are switched to the reception ring, thanks to a loop-back fiber, in a folding point, as shown in Fig. 1. Note that, this folding point can be created on a dynamically selected node, exploiting an Optical Switch (OSW) [25].

The network operates in a synchronous, time slotted fashion, and slots propagate on the bus. To avoid data collision, network nodes access the WDM slotted ring by inserting fixed size packets in empty slots, whose duration T_{slot} is determined by technological constraints, Transmitted fixed-size packets travel on the transmission ring up to the folding point, where they are switched to the reception ring. The proposed architecture logically behaves as a folded bus network. Although this prevents the exploitation of space reuse of ring networks, it permits