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Performance overview of the quasi-synchronous operation mode in optical burst switching (OBS) networks

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ABSTRACT

Optical burst switching (OBS) is able to operate under both asynchronous and synchronous burst departures. Although the asynchronous approach is generally assumed in OBS owing to its simplicity and low technical requirements, it has been shown that performance improvements, in terms of the overall burst loss probability, can be achieved under synchronous operation. Moreover, when effective contention resolution mechanisms are applied, such improvements are significant. Since perfect synchronization is not a viable solution, we propose a novel operation mode with relaxed technical requirements, the quasi-synchronous (QS) operation.

In this paper, the performance of the QS operation mode is evaluated by an exact analytic expression, assuming a Poisson burst arrival process and a single-wavelength scenario. This mathematical analysis is completed with numerical results that validate its accuracy. Furthermore, we tackle the issue of not having well-aligned clock information between network nodes by proposing a novel re-synchronization mechanism for OBS networks. Finally, a performance study of the QS operation under different deflection routing techniques is presented. The results show that our novel QS approach achieves significant performance benefits with respect to the asynchronous operation while avoiding the architectural complexity of the synchronous scheme.

1. Introduction and motivation

Two main features distinguish optical burst switching (OBS) [1] from other optical switching technologies: the transmission of large data bursts, which are aggregated at the edge of the network, and the possibility to establish a path dynamically and on-the-fly (i.e., without acknowledgment of the availability of transmission resources). Because of the absence of optical buffering capabilities, the main challenge of OBS is to deal with high burst losses that arise due to the contention of bursts transmitted in the network.

To mitigate the burst contention problem, solutions have been proposed based on deflection (or alternative) routing. All these methods allow re-routing contending bursts from primary to alternative routes and, by these means, alleviating congestion on bottleneck links and achieving dynamic load balancing in the network. In this paper, we consider the so-called offset time emulated OBS (E-OBS) network architecture [2], which facilitates the application of alternative routing since routing decision can be taken freely inside the network without constraints on the length of routing path.

In principle, the transmission of optical bursts is asynchronous in an OBS network. That means that bursts are not aligned with each other, and thus, they arrive at a core switching node in casual instances of time. Performance improvements can be achieved if synchronous operation is applied: in fact, in such a case, contention may only occur between entire data units, and better transmission

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resource utilization can be obtained with simple contention resolution mechanisms [3]. Such synchronous operation was proposed in the past for optical packet switching (OPS) networks (see e.g., [4]), and although it has not been widely considered in OBS networks, some relevant studies can be found in the literature (see e.g., [5–9]). Besides, in [10], we verified that, with the utilization of effective deflection routing techniques, a performance gain of the synchronous operation with respect to the asynchronous one is brought about to a very motivating extent. However, all these studies consider that synchronization of data bursts is achieved by means of an input stage at each core node, which involves the use of additional hardware elements such as incremental fibre delay blocks and switching devices. All these components and the increased control complexity that they entail lead to a bulky and complex structure whose viability has not been demonstrated yet.

In this direction, we proposed a novel operation mode for OBS networks, quasi-synchronous (QS) operation, with the aim of reaching performance benefits close to those obtained with perfect synchronization while keeping a moderate hardware complexity. In the QS-OBS scenario, we do not have the need for any intricate synchronization device. In contrast, we assume both that network links are designed such that the resulting propagation delays correspond to a multiple of a given fixed time slot duration and that bursts are released only at the beginning of such time slots. In addition, to take into account that perfect synchronization is practically impossible, we accept the presence of some time deviation. The existence of this time variation between the actual arrival of bursts and the beginning of time slots causes the bursts to be not perfectly aligned at the core switching nodes. For that, we refer to the QS operation.

Specifically, we model the time deviation of the QS transmission mode as a superposition of two different sources, denoted as drift and skew, respectively. We consider the drift as an irretrievable error due to structural inaccuracy of the different devices constituting an OBS node and to the physical impairments that may change the propagation time characteristics of the different channels of a fibre. In contrast, we consider the skew as the consequence of not having well-aligned hardware clock information amongst all network edge nodes. The skew is, hence, a retrievable time deviation error and, for that reason, we propose a method to bound its value to a range where there is no (or negligible) performance degradation.

The contribution of this paper is twofold. First, we present the details of the QS scheme, highlighting its architectural benefits compared to the synchronous and asynchronous cases. In particular, we provide a detailed performance study (through both analytic and simulation models) both to analyse the effects of the presence of the drifts and skews and to find a set of values that highlights the performance of the QS scheme. Second, we compare the performance of the asynchronous, synchronous and QS operation modes with the support of different deflection routing algorithms.

The rest of this paper is organized as follows. In Section 2, we provide complete information on the analysed network scenarios. In Section 3, we first present in detail the analytic models for all the OBS transmission modes considered in this paper. Afterwards, we validate the models by simulation, with special emphasis on our novel analytic model for the QS operation in OBS networks. Then, in Section 4, we focus on the key parameters in the QS-OBS network and provide values for them that are in accordance with real OBS network scenarios. In Section 5, we present the re-synchronization mechanism that we propose with the purpose of maintaining such quasi-synchronization at edge nodes. Section 6 presents an overall comparison between the synchronous, asynchronous and our QS schemes under different deflection routing algorithms. Finally, the conclusions are presented in Section 7.

2. OBS network scenarios

In this study, we consider an E-OBS network scenario [2]: core switching nodes are enhanced with a pool of fibre delay coils that is inserted into the data path at the input port of the node. In conventional OBS (C-OBS) architectures, the processing offset time is provided at the edge node by delaying the transmission of a burst with respect to its control packet. In E-OBS, in contrast, the offset times are provided by means of these fibre delay coils at each core node. Thus, both the burst and control packet can be sent together from the edge node, avoiding several problems that result from the offset time variation inside the network, a feature that is inherent to C-OBS. For instance, concerning routing management, it is advantageous to provide offset times at each core node since routing decisions can be taken freely inside the network without any constraints on the length of the path. In contrast, in C-OBS, the maximal length of the routing path is related to the offset which, once introduced at the edge node, decreases at each hop.

In general, the transmission of optical data in the network can be either asynchronous or synchronous. Although both approaches have been studied extensively in the context of OPS networks, the research on OBS still concerns mostly the asynchronous approach.

2.1. Asynchronous OBS

In asynchronous OBS networks, optical bursts are released from edge nodes at arbitrary (random) instances of time, and they are not aligned when they arrive at core switching nodes (see Fig. 2.1A). Accordingly, the switching operation is performed asynchronously. The advantage of this approach is the simplification of the burstification process and the low complexity of the switching nodes.

2.2. Synchronous OBS

The idea of synchronous, or time-slotted, transmission in optical networks has been considered mainly in the context of OPS networks. In the case of a synchronous OBS scenario, the optical bursts are aligned and transmitted synchronously at the beginning of a fixed-duration time slot (see Fig. 2.1B). The main advantage of the synchronous approach, with respect to the asynchronous approach, is the improvement of the overall burst loss performance.