OPTICAL PACKET SWITCHING:
APPROACH TO PERFORMANCE MODELING AND SIMULATION

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ABSTRACT
The paper describes research progress in technologies and architectures that give hope to deliver truly transparent switching of optical packets. The importance of all-optical packet switching/routing for convergent next generation transport network and in particularly, for QoS packet transfer in core of future generation wireless networks is pointed out. Generic photonic packet switch/router architecture and its QoS possibilities as well as approach to optical packet format are studied in detail. Conditions for accurate performance modeling and computer simulation for any optical packet switch architecture are discussed. Optical components functionality modeling and optical switch/router simulation algorithms are presented as well.

INTRODUCTION

The Internet is leading to the convergence of networking developments for the future. The evolution of the fixed network (PSTN, ISDN, Frame Relay, ATM networks) and mobile networks (GSM, GPRS, 3G/UMTS networks) are being converged, with IP as the common transport protocol. The convergence of all these networks is needed to deliver end-to-end seamless services with high bandwidth in real time, security and QoS built-in.
Optical packet routing/switching has received much attention, as it is generally considered as one of the key elements for the next generation Internet in order to support the rapidly growing Internet traffic as well as high-bandwidth demands within Next Generation Networks core.
Today's 1st generation optical networks move packets between electronic IP routers over DWDM fiber optic links. The currently emerging 2nd generation optical networks use DWDM lightpaths established by optical crossconnects that are capable of arbitrarily switching wavelengths between the fibers. Packets logically flow between routers over virtual connection but physically flow over DWDM lightpaths. Optical circuit switching systems, which are based on optical crossconnects, need very large capacities to overcome the lack of flexibility resulting from small granularity. Packet routing/switching techniques offer the flexibility to provide required granularity imposed by the access (IP packets, ATM cells). Packet routing/switching systems are more complex. On the other hand they are more efficient because of reducing the connection cost through sharing the same propagation medium (interleaving of different connections over the same link). Optical packet switching/routing is a crucial goal for evolution to 3rd generation optical networks. It provides possibility to develop fully flexible and efficient packet transport with big number of optical virtual channels (Optical Label Switched Paths of Optical-MPLS). High granularity of OPS/OPR network is very desirable for large number of packet connections in transport core of wireless network and its capacity can satisfy demanding multimedia (video) applications.
Optical packet router design poses many problems, for example the actual unavailability of optical memory for data buffering purposes requires more strict demands on design than in electronic case. However using an optical approach makes the additional wavelength degree of freedom available. Thus, for example it is possible to assign different wavelengths to contending packets, therefore allowing them to coexist on the same output port.
This paper presents introductory study of issues that should be considered when logical performance of all-optical packet router is investigated and analyzed by means of computer simulation.

GENERAL ARCHITECTURE OF ALL-OPTICAL SWITCH/ROUTER

A generic all-optical packet router/switch architecture (Fig.1) requires interface, synchronization, buffering, switching and control functions [1,2,3]. Nowadays advances in optical networking show that the number of practical difficulties in building optical packet routers such as the lack of fully functional optical switching/routing and optical buffering can be effectively dealt with.

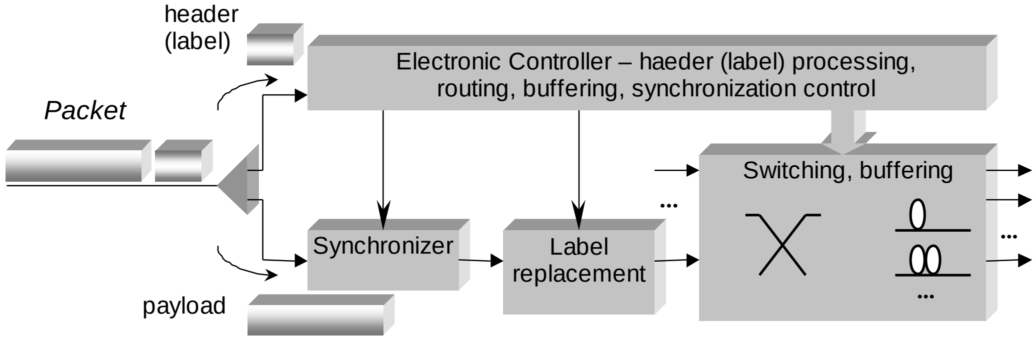

Fig. 1. All-optical packet switch/router general architecture

Packets arriving at optical router undergo header (label) decoding and this information is used to control the payload synchronization and switching, through a combination of wavelength routing and space switching. Buffering and wavelength selection are used to overcome contention within the wavelength plane.
Within an OPS/OPR the optical packet label is read and compared with a look up table. The payload is then routed to the appropriate output port with a new label attached (MPLS). An important feature is that the payload is transparently routed through the router and it remains in the optical domain, while the label processing and router control are electronic.
Packet format is of a fundamental consideration in any packet transmission system. A representative example is the optical packet format defined by the KEOPS project, which is showed in Fig. 2. The use of fixed length packets can significantly simplify the implementation of packet contention resolution and buffering, packet switching, as well as packet synchronization [2].
The control plane can be implemented either in electronic or optical domain. However, electronic and optoelectronic components remain attractive alternatives to photonic devices in functions such as address processing and buffering control [2]. Large photonic packet switches will probably rely on electronics for control functions, with the packet routing and buffering being carried out by photonic means. This approach provides very large capacity through the transparency of the photonic devices, combined with the functionality and processing power of electronic control circuits.
One of the main challenges of control unit is optimization of the resources utilization to provide the required logical performance [4]. As far as the increase of the switch throughput imposes more packets to process, the control electronics becomes the bottleneck of optical packet switches and constrains the optical packet duration. The solutions could consist of a proper design of the packet length, taking into account the control limitations, packet grouping to reduce the number of headers to process and techniques adopted from ATM technology, namely labels swapping (MPLS).
Among other things the control plane is responsible for synchronization (priority management), optical buffering, and switching. The aim of the synchronizer is to assure that optical packets that are coming from different input fibers and on different wavelengths align on the local rhythm of OPR (packet duration). It enables a synchronous (packet level) switching in the switching fabric. Optical buffers have special characteristics with respect to conventional electronic buffers, and thus they need special control algorithms to offer expected functionality especially when advanced QoS mechanisms are implemented. One of the main tasks of control logics is to prevent packet contention that primarily occurs at the output of switching fabric. Therefore appropriate switching algorithms and also the other control functions should coexist in order to optimize the resource utilization and improve the logical performance.

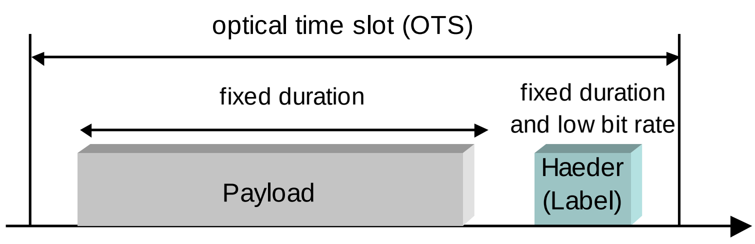

Fig. 2. KEOPS optical packet format

QUALITY OF SERVICE (QOS) MECHANISMS

QoS in all-optical packet switch/router can be offered by combining [1,4]:

- WDM techniques - to avoid the collision,
- Time-domain techniques (buffers) - to solve the contention,
- eventually spatial techniques (deflection routing) - to reshape the traffic profile and increase the acceptable load of the switching planes.

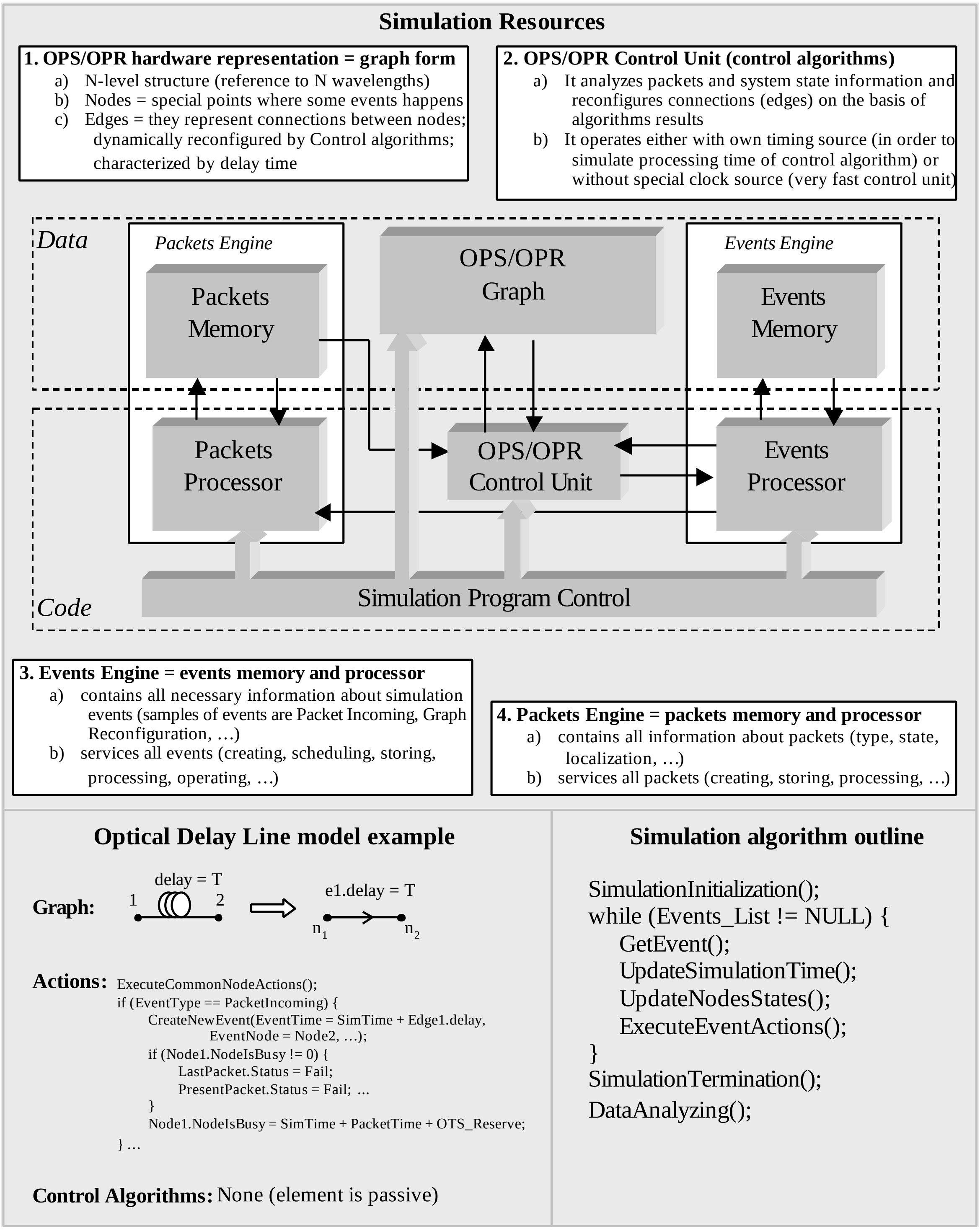

Fig. 3. Diagram of the OPS/OPR simulator

Contention between any two packets being transmitted simultaneously is resolved in the first instance by transmitting each on a different wavelength. If this fails due to all wavelengths being occupied, buffering is applied in order to delay some of the packets until a free time slot is available. Exploiting wavelengths to resolve contention reduces this way the required buffer capacity. The dynamic wavelength allocation permits sharing of capacity between wavelengths, yielding lower packet contention probabilities and requiring smaller optical buffers at each node than other techniques.
Different buffer and scheduling management mechanisms that support services differentiation can be adopted from classical packet networks. Properly designed hardware optical components structure and adequate control algorithms play essential role in those applications. Another important issue in QoS providing is packet labeling. It allows recognizing and operating with packets belonging to different Virtual Paths and different Classes of Service.

SIMULATION OBJECTIVES

Research in all-optical packet switching/routing aims at imparting the ability to direct packets to within the optical layer and to remove the need to pass packets through the electronic layer. Both the lack of fully functional optical memories and also the opportunity to use DWDM features impose new goals for system designers and demands for novel research methods and tools. The QoS support is a major requirement in Next Generation Networks first of all for real-time applications like voice and video communications. Therefore optical switch/router performance and QoS parameters analysis issues in different architectural configurations and under different traffic conditions (VoIP, video for mobile communications, data traffic) is very important.
Brief design guidelines of the OPS/OPR simulator are presented in Fig. 3. The aim of the simulator design is to provide an easy way for testing of different OPR architectures and algorithms in respect of packets transport logical performance. The logical function of optical components (packet splitting, delaying, switching) will be implemented and some physical parameters will be considered (for instance packet optical power in order to specify packet degradation) as well. Some aspects like delay slip of control algorithm activation could need some probability.
Packet loss ratio and packet delay (mean and variation) are the main logical performance figures of merit that have to be analyzed, however the simulator architecture allows to study more detailed router characteristics like performance bottlenecks for instance. Different traffic scenarios like constant rate traffic (real-time traffic), Poisson traffic, semi-similar traffic will be tested as well different control algorithms will be implemented and investigated.
The simulation environment bases on a discrete-event simulation algorithm, so any free distributed simulation system (for instance Ns2, OMNeT++) could be employed after some adaptation. However in this case the code performance is not optimized and therefore new software development is a better solution.

CONCLUSION

Difficulty in analytical modeling of more advanced all-optical router architectures causes necessity to use simulation algorithms in order to analyze packet routing performance. The main advantages of computer simulation and modeling are among other: lower costs, flexibility, possibility to model not yet realized components, ease to make fast changes in setup. Main disadvantage is virtual, not real environment, which only approximates both components and system actual behavior. However, advanced simulation programs became a standard tool to analyze telecommunication networks.
In the paper the introductory analysis of all-optical QoS packet switch/router for the purpose of packet transmission performance simulation was presented. The OPS/OPR features and some aspects of packet transport plane as buffering opportunities and control functions that should be assumed before computer implementation were explored. The fundamental requirement relating to architecture as well as objectives of the simulator was demonstrated.

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