Optical Label Switched Networks: Laboratory Trial and Network Emulator n the IST-STOLAS Project

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ABSTRACT

This article reviews the performance of an optical-label-controlled packet routing node as implemented in the European FP5-IST STOLAS project including a set of general engineering rules. Experimental networking scenarios and results from a STOLAS based network emulator supporting optical overspill routing are presented.

INTRODUCTION

Optical label switched networks are considered a promising solution for networks supporting the ever continuing growth of packet-based data traffic and at the same time supporting multiple services with quality of service differentiation. The throughput of packet-routing nodes is increased by introducing label controlled routing and at the same time performing the switching of high-speed data payloads transparently without opto-electrical-optical conversion. The use of optical labeling also allows for differentiation between packet-based and circuit-based transmission by, for example, adopting labeling strategies to differentiate among labeled payloads and circuits. Within the recently concluded Switching Technologies for Optical Labeled Signals (STOLAS) project of the Information Society Technologies (IST) research framework of the European Commission, a laboratory demonstrator was built incorporating optical edge nodes, label-controlled routing nodes, performing label erasure, rewriting, and wavelength conversion, and a label controlled optical add-drop multiplexer. A network emulator based on the STOLAS principle was also built, supporting both burst switching and circuit switching. The present article is organized as follows. The next section presents a review of techniques to label optical signals, and introduces the STOLAS frequency shift keying/intensity modulation (FSK/IM) labeling method. We present the design and architecture for a label controlled node supporting FSK/IM labeled signals. We present a study of the reliability of a label controlled node based on the STOLAS concept and its comparison with other node architectures such as the broadcast-and-select one. The laboratory setup, experimental results and engineering rules for FSK/IM label controlled nodes are presented, respectively. The results of the network emulator are presented. Summary conclusions are then presented.

OPTICAL SIGNAL LABELING TECHNIQUES

Optical labeling techniques can be classified into in-band and out-of-band depending on the optical spectral allocation of payload and label information. A further classification can be made based on the processing techniques for the label data, which can be realized by using conventional electronics, all-optical signal processing techniques, or a hybrid scheme of electronics and optical methods. In Fig. 1 we present a generic classification for optical labeling techniques based on spectral allocation, labeling scheme, and signal processing techniques for the label information [1–4].

Optical signal labeling techniques should comply with some general requirements such as minimized impact on the payload data quality, efficient bandwidth use, ease of label and payload separation (regarding time synchronization and/or optical filtering), low complexity for label erasure and reinsertion, as well as flexibility for future system upgrades in terms of bit rate for payload, label signals, and channel count. Assessing the labeling techniques pre-

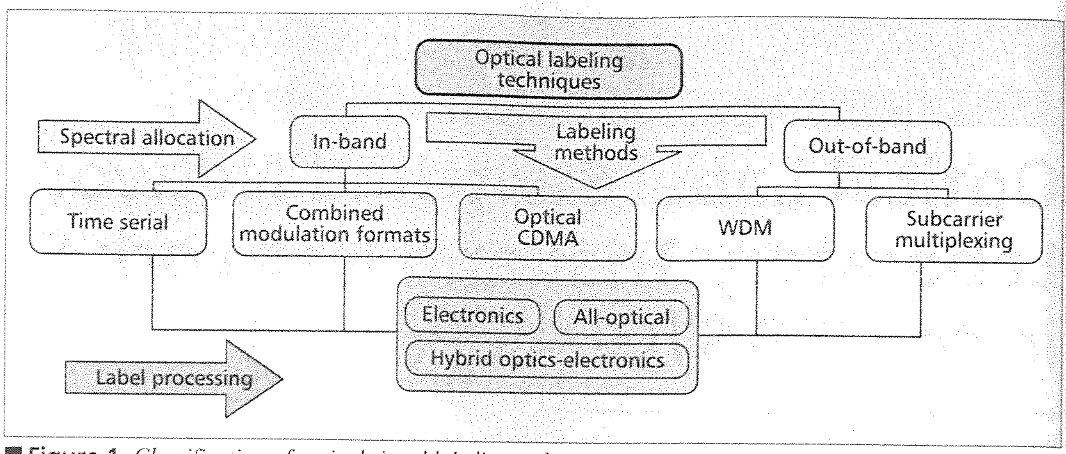


Figure 1. *Classification of optical signal labeling techniques.*

The GSCR laser can be tuned to the desired wavelength channel according to a table of current settings for its reflector, gain, phase and coupler sections while small modulation of the phase current generates the FSK signal for labelling purposes.

sented in Fig. 1 regarding the above requirements, it turns out that each has its advantages and detractors: for instance, embedding the label information in a subcarrier frequency outside the payload spectrum allows for use of already developed radio frequency (RF) equipment. However, it requires extra bandwidth making upgrades to higher bit rates of the payload signal rather complex. Another approach, conveying the label information in a dedicated wavelength channel (wavlength-division multiplexing [WDM] labeling), requires accurate bookkeeping of the correspondence between labels and payload data channels. Putting the label information just ahead of the payload data (time serial scheme) in turn requires strict time synchronization for label extraction, erasure, and reinsertion. The encoding of the label information on the payload bits (optical encoding scheme) results in an increase of the line rate. However, this scheme allows for inherent label recognition capabilities. Combined modulation formats use several dimensions of the optical carrier to embed the payload and label information. For example, intensity modulation can be used to convey the high-speed payload and angle modulation to convey the relatively low-speed label data (the opposite choice of modulation is another possibility). Although in these schemes time synchronization between label and payload is relaxed, the extinction ratio of the intensity modulated signal is compromised for the performance of the angle modulation format.

THE FSK/IM STOLAS LABELING CONCEPT

The label encoding technique studied in the IST-STOLAS project is based on using frequency shift keying (FSK) to label the payload data, which is conveyed by intensity modulation (IM) of the same optical carrier, as illustrated in Fig. 2a. This scheme has some advantages, such as:

- Data payload is coupled to the label in the same wavelength channel, which eases the bookkeeping of their correspondence in the routing nodes.
- Label and data payload are decoupled regarding timing, and thus do not need strict synchronization; only synchronization at the packet level is needed, not at the bit level.
- The label can be written anywhere over the payload; no delineation is needed for label erasure and rewriting.
- In principle, addition of label information does not need to increase the channel's bandwidth.

However, the FSK/IM labeling scheme requires special design attention regarding the following issues:

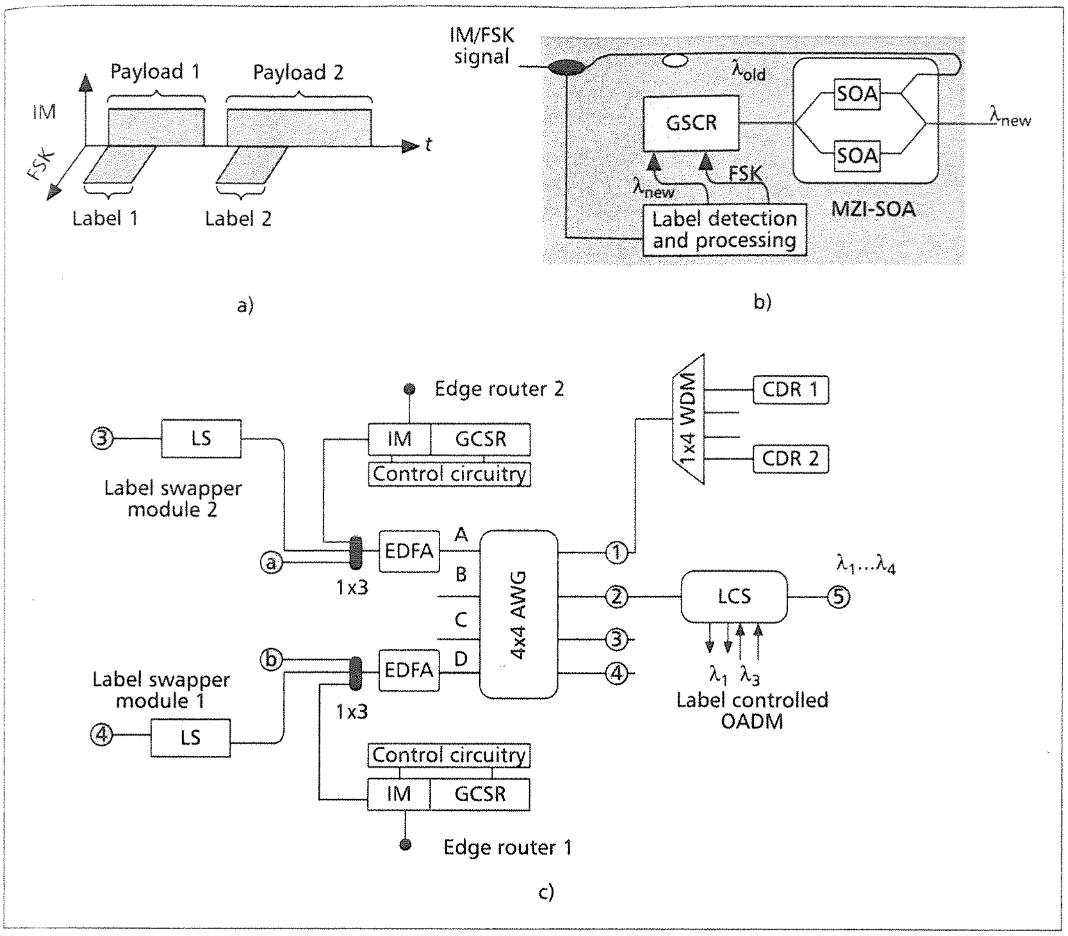
- Crosstalk of label to payload by frequency-to-intensity modulation conversion, due to such things as dispersion in fiber links, interferometric effects, and optical filtering.
- Compromised relatively low extinction ratio for the IM signal that might result in scalability limitations for the system.

We report on engineering rules for designing optical label-controlled routing nodes using IM/FSK labeled signals.

FSK/IM LABEL CONTROLLED ROUTING NODE ARCHITECTURE

EDGE ROUTER NODES: FSK/IM SIGNAL GENERATION

At the receiver end the payload information can be detected by a simple direct detection scheme. Provided the FSK tone spacing is sufficiently large (e.g., a few tens of GHz), a direct detection scheme preceded by an optical bandpass filter can be used for detection of the label [5]. Alternatively, both FSK frequency tones can be optically filtered out for further detection in a balanced photodetector receiver configuration resulting in improved receiver sensitivity. Generation of optical FSK modulation is achieved by direct current modulation of the phase section of a grating assisted co-directional coupler with a rear sampled grating reflector (GCSR) laser source. Device fabrication, tuning mechanisms, and performance of these types of lasers have been described elsewhere [6]. The GSCR laser can be tuned to the desired wavelength channel according to a table of current settings for its reflector, gain, phase, and coupler sections while small modulation of the phase current generates the FSK signal for labeling purposes. The FSK modulated signal is further intensity modulated, using an external Mach-Zehnder modulator, to



■ **Figure 2.** *a) FSK/IM labeling of optical packets; b) all-optical label swapper with a MZI-SOA based wavelength converter; c) experimental setup. IM: intensity modulator; GCSR: agile tunable laser source; MZI-SOA: Mach-Zehnder interferometer-semiconductor optical amplifier wavelength converter; AWG: array wave guide grating; LCS: label controlled switch; CDR: clock and data recovery unit.*

superimpose the high-speed payload information as indicated in Fig. 2a.

MZI-SOA WAVELENGTH CONVERTER LABEL SWAPPING NODE

Figure 2b shows the schematic diagram of a label-swapping node incorporating a Mach-Zehnder interferometric structure with two SOAs in its branches (MZI-SOA). A small part of the incoming optical power is fed to the label processing circuit. The label is detected and, with a lookup table operation, a new label is defined. A new wavelength is set by adjusting the combination of currents applied to the different sections of the GCSR laser diode. The label is generated in the label processing unit and FSK modulated by current modulation of the phase section of the GCSR laser. The incoming intensity-modulated payload data, after being properly delayed, are transferred to the new wavelength through cross-phase modulation (XPM) in the MZI-SOA wavelength converter. As the XPM mechanism in the SOAs is driven only by the intensity of the incoming packet, the old FSK label is erased. Thus, FSK/IM label erasure and reinsertion can be realized in a single MZI-SOA device with payload wavelength conversion functionality.

STOLAS NODE RELIABILITY

A generic architecture for a label controlled routing node is presented in Fig. 3a, where the case of two input/output fibers carrying four wavelength channels is illustrated. The tunable wavelength converters (TWCs), after the passive arrayed wave guide (AWG) routing stage, serve the purpose of making the node strictly nonblocking. Additionally, two input and output ports are dedicated for adding and dropping of channels, and two more for multicasting purposes. The reliability of a packet routing node will largely depend on the cumulative failing probability of the active components; the passive components, once installed and connected properly, will not be expected to degrade significantly.

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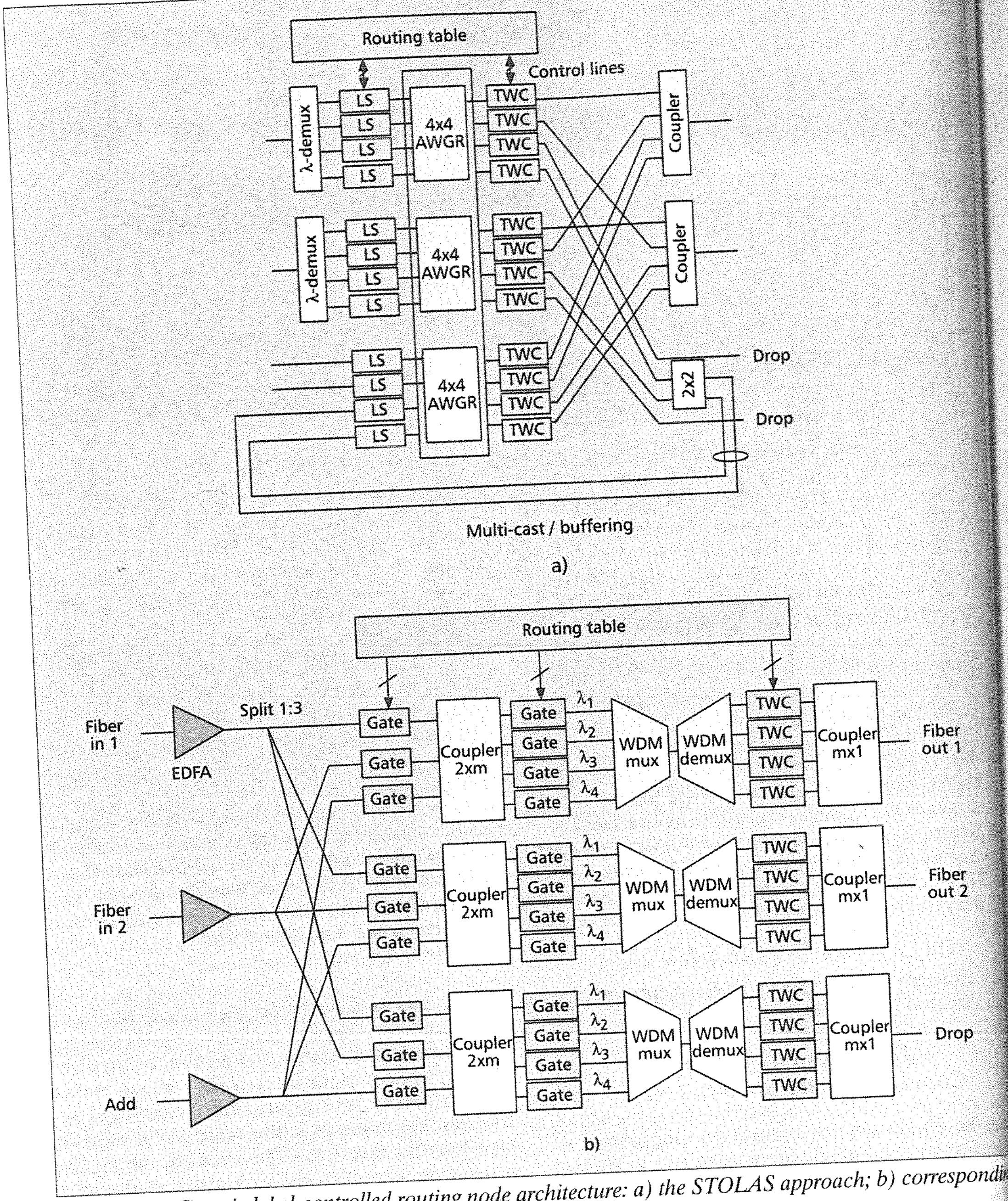
In the proposed *STOLAS node* the actual routing is done by the central AWG router, by means of allocating the appropriate wavelength to the packets in the label swapper (LS) units. Typically, such a waveguide router can be made in integrated-optics technology on a glass substrate, and hence suffers no noteworthy degradation with low expected probability of failure. However, TWCs are needed both at the label swapping unit and after the passive router, and these active elements may degrade. Such a TWC basically consists of a fast tunable laser diode

> *Tunable wavelength converters are needed both at the label swapping unit and after the passive router, and these active elements may degrade. Such a TWC basically consists of a fast tunable laser diode, and a wavelength converter based on SOAs in a Mach-Zehnder interferometer configuration.*



■ **Figure 3.** *Generic label-controlled routing node architecture: a) the STOLAS approach; b) correspondi broadcast-and-select architecture.*

and a wavelength converter based on SOAs in a Mach-Zehnder interferometer configuration. The probability that a packet is lost due to malfunctioning of the router can be expressed in terms of mainly the probability of failure of the TWC, as

$$\Pr[\text{packet lost}] = 1 - (1 - \Pr[\text{TWC failing}])^2$$
$$\approx \Pr[\text{TWC failing}].$$

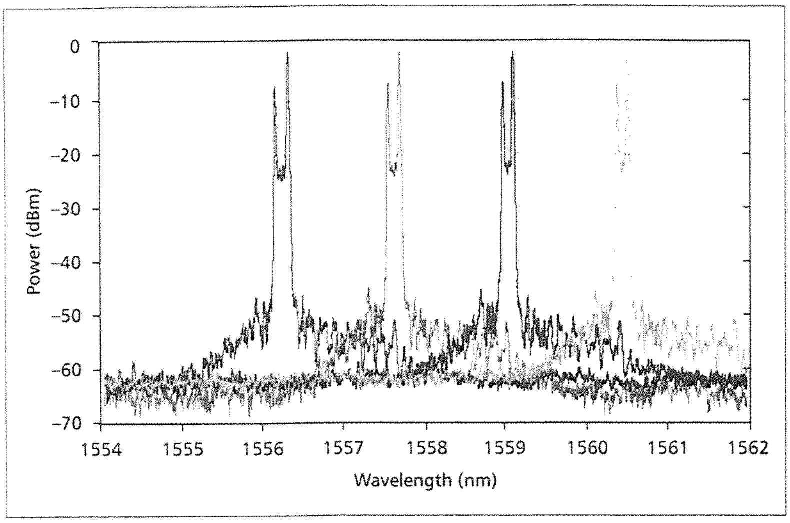
To compare the *STOLAS node* with alternative node designs, a broadcast-and-select node (B&S) architecture is considered (Fig. 3b). After optical amplification in order to compensate for splitting losses, the input packets are broadcast over a bank of switching stages. In each stage a fast optical gate selects the input fiber port, and after a power coupling stage a second set optical gates in combination with the succeedi wavelength multiplexer selects the wavelengt The broadcast process inherently supports mul casting. For comparison purposes, the B&S no includes two input and output fiber ports, a one add and one drop port. It can be shown th the probability of packet lost due to malfu tioning of the router can be expressed as

$$\Pr[\text{packet lost}] = 1 - (1 - \Pr[\text{gate failing}])^2$$
$$\cdot\, (1 - \Pr[\text{TWC failing}])$$
$$\approx \Pr[\text{TWC failing}] + 2\Pr[\text{gate failin}$$

Comparing these two node designs, it can observed that the B&S node requires mo active components than the *STOLAS node*, a thus has a higher chance of malfunctioning. Moreover, the packet loss probability due to failures in the B&S node is higher than that in the STOLAS node provided that

$$\Pr[\text{gate failing}] > 1/2\,\Pr[\text{TWC failing}].$$

Furthermore, in the B&S node design a failure of a port-selecting gate affects all wavelengths on that input port intended for a particular output fiber. Similarly, when a wavelength-selecting gate fails, it affects all packets being carried by that wavelength from every input port intended for a particular output fiber. In the STOLAS node design, however, a failing TWC at the input side of the waveguide router affects only a single and given wavelength arriving from a specific input fiber port.



■ **Figure 4.** *Optical spectrum of the four STOLAS channels, with imposed FSK modulation (0.01 nm resolution bandwidth).*

EXPERIMENTAL RESULTS FROM A SYSTEM DEMONSTRATOR SUPPORTING IM/FSK LABELING

Figure 2c shows a schematic diagram of the system demonstrator for the edge router, the core label swapper, and an optical label controlled optical add-drop multiplexer (OADM) supporting FSK/IM labeled signals as implemented in the IST-STOLAS project. The payload data is conveyed in IM operating at 10 Gb/s while the optical label is in FSK modulation operating at 50 Mb/s. The control circuitry, including label generation and wavelength selection, is implemented by using field-programmable gate arrays (FPGAs). The edge router module also includes an optical intensity modulator. The optical label swapper module is composed of an MZI-SOA wavelength converter and an agile tunable laser source as in the case of the edge router module. The control circuitry comprises a burst mode label receiver, a detector of the start of the payload signal, and label processing functions implemented in FPGAs. The information on the start of the payload is used to assist the time synchronization to superimpose the new FSK label, to ensure that no FSK is superimposed before IM is present on the lightwave carrier. The label controlled OADM is composed of a WDM (de)multiplexer and two switches, used to either drop or add signals, depending on the label information (Fig. 2c). Its electronic circuitry includes an FSK burst mode label receiver and label processing functions. In this case the control circuitry does not need to include label generation. The routing fabric is implemented by using a 4 × 4 AWG passive router. At the receiver side, 10 Gb/s clock and data receiver modules are used to detect the payload data.

FSK/IM LABELED PACKET GENERATION AND DETECTION

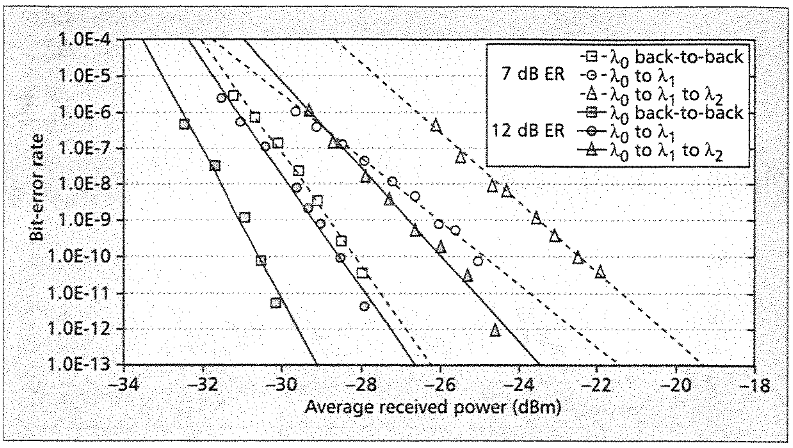
Four wavelength channels were implemented, operating at the wavelengths 1556.75, 1557.36, 15558.98, and 1560.61 nm. The label signal, operating at 50 Mb/s, was FSK modulated with a frequency deviation of 20 GHz for each of the four channels. Figure 4 shows the optical spectrum of the generated FSK/IM signals for each of the channels. The average power of all channels is around 0 dBm after imposed IM modulation, with an extinction ratio in the range of 6–7 dB.

The power unbalancing observed in Fig. 4 between the FSK tones is due to the structure of the selected label format that does not contain an equal number of logical ones and zeroes. However, there was no observed residual intensity modulation due to the FSK modulation on the generated IM pulse patterns.

NETWORKING SCENARIOS

Using the experimental setup shown in Fig. 2c, several networking scenarios can be tested. For instance, a routing scenario including two label swapping stages has been realized in the following way. An optical FSK/IM labeled burst was generated by using the edge router module 1 and subsequently fed to input port D of the AWG, were it is routed to output port 4. This signal was then fed to the label swapping module 1, where label erasure, label insertion and wavelength conversion were performed. The new labeled signal was directed to input port 3 of the AWG and routed via port C to the input of the second label swapping module (label swapper 2). After this second label swapping stage, the signal was routed to the payload receiver by using input port 1 of the AWG router. A more complex scenario is obtained if optical labeled signals are generated at edge router 2. For illustration, we present experimental results of the two-stage label swapping scenario described above.

Two values for the extinction ratio of the IM signal (7 dB and 12 dB) were considered. As we can observe from Fig. 5, after single label swapping, a power penalty of 2.7 dB and 1.9 dB at a bit error rate (BER) of 10^{-9} are observed for the 7 dB and 12 dB extinction ratio cases, respectively. After a second label swapping stage the power penalty is more severe, amounting to 5.3 dB and 4.4 dB for 7 dB and 12 dB extinction ratios, respectively. The reason for this degradation is found in the insufficient operation speed of the MZI-SOA wavelength converters used in



■ **Figure 5.** *FSK/IM label swapping. Bit error rate of the 10 Gb/s payload after a single and two stages of label swapping for the case of 7 dB and 12 dB IM extinction ratio (ER).*

the setup. Moreover, as the signal after wavelength conversion should preserve the same extinction ratio for proper performance of the FSK signal, the regenerative properties of the wavelength converter are not fully exploited, especially for the 7 dB IM extinction ratio.

ENGINEERING RULES

The engineering rules proposed below concern the main operations required in a label switched network, namely to the labeling process, label detection, label swapping (including label erasure), wavelength conversion and re-writing of a new label, signal transmission and node cascadability.

LABELED BURST GENERATION

The following rules apply to the burst generation process:

- The minimum payload length is determined by the length of the label signal.
- The time synchronization of the label and payload is just limited to ensure that the label signal is superimposed on top of the payload (IM) signal; not earlier than the start of the payload and not later so that it exceeds the end of the payload section.
- An important design parameter in the combined FSK/IM burst generation is the choice of the extinction ratio for the IM signal. A value of the extinction ratio, providing the same receiver sensitivity for both signals, has been found to be in the range of 6 to 7 dB for a reference system operating at 155 Mb/s FSK and 10 Gb/s IM. The extinction ratio requirement could be relaxed if signal coding such as 8B/10B or 64B/68B is used or if a lower bit-rate for the label data is employed.
- A FSK frequency deviation of 20 GHz has been chosen for the laboratory trial. In this way simple FSK detection is realized, at the same time allowing for tolerable wavelength drifts of the tunable laser sources. A smaller frequency deviation could be used; however stricter optical filtering and wavelength stability will be required.

LABEL DETECTION

Label detection can be simply realized by a direct detection scheme using an optical bandpass filter centered on one of the frequency tones of the FSK signal. A scheme using direct detection and a balanced receiver, where both FSK tone are filtered is another alternative, resulting in improved receiver sensitivity. Flattop shaped optical filters are preferred over Fabry-Perot or Gaussian shaped types [7].

CASCADE OF OPTICAL FILTERING STAGES

Signals in an optical label switched network will encounter several stages of optical filtering due to e.g., wavelength (de)multiplexers. Therefore special attention should be paid to the design regarding optical filtering, wavelength channel spacing and FSK frequency deviation parameters, so that no residual frequency-to-intensity modulation is introduced by filter shape or wavelength misalignment between the filter central wavelength and laser source emission wavelength. Computer simulations and experiments show that systems, operating at 10 Gb/s IM data rate, using a Gaussian shaped optical bandpass filter or AWG router (second order Gaussian shaped with a 3 dB bandwidth of 75 GHz), allow for a frequency misalignment between laser and filter, limited to 15 GHz for a power penalty of the payload data of less than 3dB [7]. When using a more flat-top shaped filter, the influence of filter misalignment is negligible for the same frequency misalignment of 15 GHz. Considering a FSK frequency deviation of 15 GHz, it can be concluded that a 50GHz ITU WDM system is feasible, provided the wavelength alignment discussed above is met.

LABEL SWAPPING

Label erasure and insertion can be performed in a single MZI-SOA wavelength conversion stage [5]. However, the MZI-SOA should not introduce any patterning effects. Experimental results have shown that no signal degradation is observable due to chirp induced in the wavelength conversion stage [8].

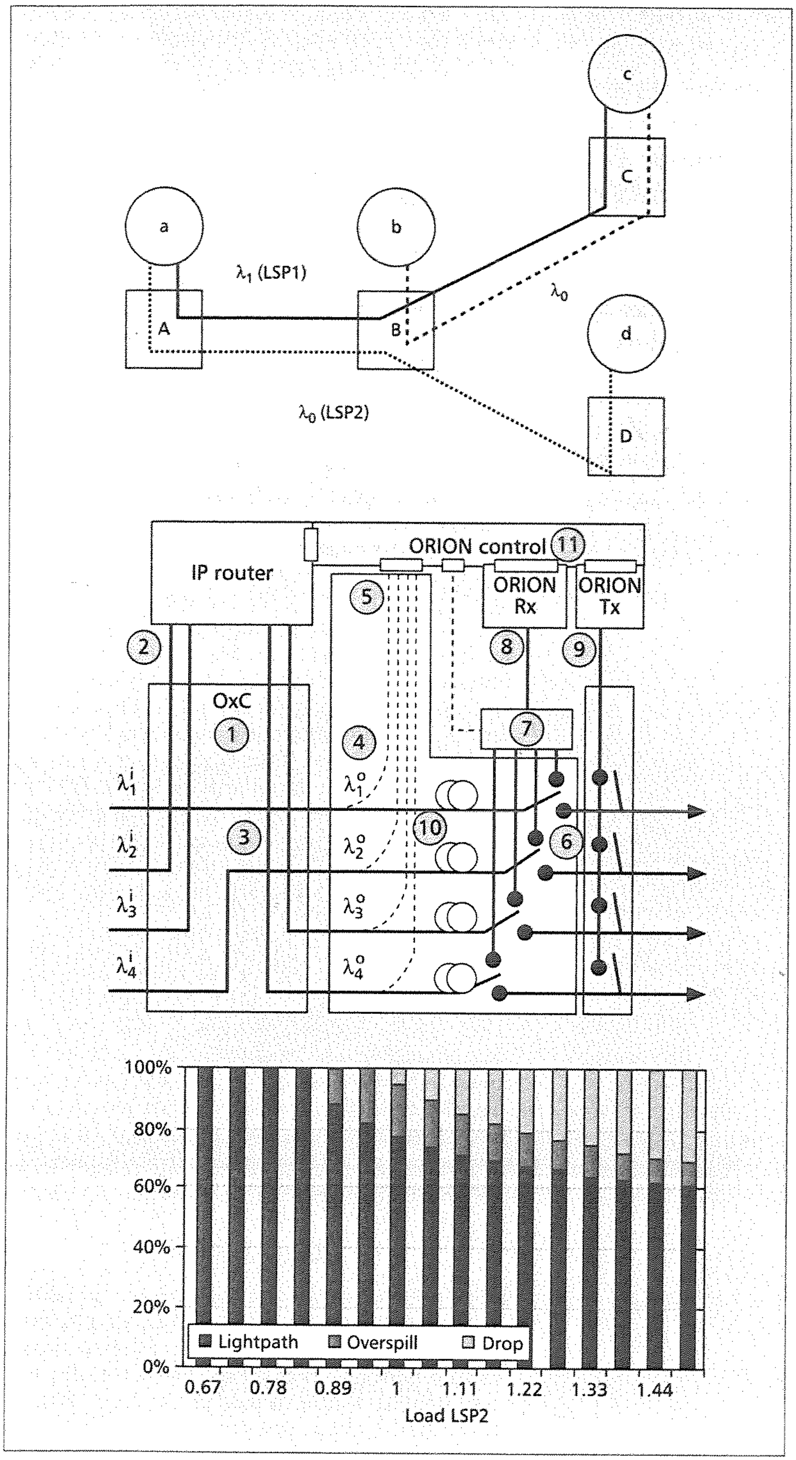
TRANSMISSION OF FSK/IM SIGNALS

The spectrum of the resultant FSK/IM is broader compared to pure IM signals, mainly due to the frequency deviation of the FSK signal. By using a frequency deviation in the range of 10 GHz to 20 GHz, dispersion compensation becomes mandatory. Experimental validation of the propagation of optical FSK/IM labeled signals over a transmission link composed of 88 km standard single mode fiber (SMF) and a matching length of dispersion compensating fiber (DCF) has been demonstrated for a 10 Gb/s payload with 312 Mb/s FSK label [5]. This indicates that transmission of FSK/IM signals in a metropolitan area network scenario is feasible, provided dispersion compensation is employed.

ORION NETWORK EMULATOR RESULTS

One direct application of the FSK/IM labeling technique studied in the STOLAS project is the ORION [9] concept, a hybrid way of transporting packets throughout the network. It uses both wavelength and packet switching, with the nodes applying one of the two modes dynamically as follows.

Basically, the preferred transport method is through established (preferably end-to-end) wavelength paths in the network. However, it is very well known that a wavelength switched network is in general less efficient and flexible than pure packet switching. Thus, if the need arises, the network is able to switch to packet switched mode (coined "overspill mode") for a certain time (for a certain class of packets). To distinguish between the two transport modes a mechanism is needed, which is where the STOLAS FSK/IM labeling technique can be applied. The difference between ORION and the STOLAS ways of switching is that data is only equipped with a label if it should not be treated as wavelength-switched. If no label is present, the wavelength switching regime applies, and the data all-optically reaches its destination. Additionally, depending on the implementation, the label can be very simple. In the most extreme case, only recognition of the presence of the label is required. This means ORION can be used as a migration path, moving toward a STOLAS approach as the technology matures.



■ **Figure 6.** *ORION principle of operation (top), a generic node architecture (center) and a sample result from the developed emulation platform, detailing loss, throughput, and overspill statistics (bottom).*

Figure 6 explains in a little more detail how ORION works. It depicts a simplified network with four nodes *a*, *b*, *c*, and *d*. Each node consists of a router working on a per packet/burst basis (e.g., an electronic IP/MPLS router) and an optical part that passively routes wavelengths (e.g., an all-optical OXC). In the figure three lightpaths are established: A–C on λ_1, as well as A–D and B–C on λ_0. Two label switched paths (LSPs) are mapped onto these lightpaths, LSP1 on A–C, LSP2 on A–D. Now suppose all lightpaths have a capacity of 10 Gb/s. Under normal conditions all traffic from *a* destined to *c* (LSP1) will pass *b* transparently (through the OCC B). Now assume LSP1 has 12 Gb/s of traffic. In a simple wavelength-switched network, this would result in loss, as there is only 10 Gb/s available. In ORION, however, the remaining 2 Gb/s can also be serviced by sending the data in overspill mode over wavelength λ_0. Since overspill data behaves like a packet-switched network, it will reach the electronic IP/MPLS router at destination *b* instead of bypassing it. Note that this simply would not be possible with deflection routing. In order for this to work, special node architectures are required for ORION, as depicted in Fig. 6 (upper right). In this example each overspill packet is equipped with an orthogonal (STOLAS) label, and the listeners (5) on Fig. 6 (upper right) can detect this signal. As a result, 1 × 2 fast switches are set up (6), and the packet is directed toward the IP/MPLS router for further processing. Thus, by adding 1 × 2 fast switches, capable of switching on the order of a fraction of a packet's length, and the FSK/IM signal labeling as studied in STOLAS, an ad hoc change to packet-level switching can be achieved if necessary. The main advantage of this approach is that it is very bandwidth-efficient (compared to, e.g., wavelength switching) while the number of operations per packet (as compared to e.g. packet switching) are drastically reduced. The added complexity and control of course do add cost. Note that the OXC can still be a very slow one and the IP/MPLS fully electronic, which means that migration may be simpler than moving to a full-scale all-optical packet switch right away. To demonstrate the concept itself, and specifically to demonstrate that a standard generalized multiprotocol label switching (GMPLS) control plane could be used to control an ORION network [10], an emulator was built. Each ORION

The results of the network emulator for overspill routing show that it efficiently combines the advantages of transparent payload routing by optical circuits and the improved bandwidth efficiency and flexibility offered by (burst) packet switching.

node is a PC running custom switching software, emulating a full optical switching matrix. Since ORION obviously adds cost (in terms of components and operational complexity), there should evidently be some benefit. To illustrate this we continue our example presented in Fig. 6 (right), and discuss some results obtained from traffic experiments on this topology. As mentioned, from an ORION perspective, the given topology means that LSP1 and LSP2 can use overspill on each other's wavelengths on link A => B (the link we will study here). We then generated Poisson-like traffic of fixed packet size (512 bytes) through both LSP1 and LSP2. The load of LSP1 was fixed at 66.6 percent (2/3) of its capacity, while the load on LSP2 was gradually increased from 66.6 up to 150 percent (overload). During this experiment we measured throughput and how traffic was transported. All other links are configured to have ample capacity for the experiments.

Figure 6 (lower right) shows the throughput of LSP2. Although there are some buffers present, the overspill mechanism already starts to work around a load of 0.85. This is due to the Poisson-like traffic generation process and traffic peaks being too long for the buffers to compensate, a typical result when connections are statistically multiplexed. The overspill mechanism, however, captures the otherwise lost traffic and transports it over LSP1 (λ_0), which is lightly loaded. Once a severe overload scenario occurs, however, overspill cannot prevent losses, even though on average there is capacity enough. It does, however, continue to function, allowing a higher throughput (+5 to +20 percent) than does the strictly wavelength-switched scenario by utilizing LSP1. Note that lightpath traffic on LSP1 always had zero loss, thus confirming the zero-impact behavior of overspill. Another feature of ORION, reduced packet processing, is also clearly visible in this (simplified) example: Node B only sees the overspill traffic, so a very low-capacity router is sufficient (compared to packet-switched operation).

CONCLUSION

Employing optical labeling of payload, containing IP packets or bursts of IP packets, significantly enhances the throughput and efficiency of optical routing nodes. It is achieved by processing the routing information carried by the label data, at moderate bit rates, in opto-electronic modules and keeping the high speed payload data in the optical domain. For example, our studies show that by using agile tunable laser sources, with FSK modulation capability, wavelength converters, and passive wavelength routing elements, a scalable modular label controlled router, featuring high reliability can be built. As shown from the STOLAS project laboratory trial results, the cascadability of FSK/IM label controlled nodes is mainly limited by the insufficient speed and patterning effects of the wavelength converters that can be overcome by the ongoing progress and development of high-speed MZI-SOA wavelength converters up to 40 Gb/s and above.

Optical labeling by using FSK/IM represents a simple and attractive way to implement hybrid optical circuit and burst switching in optical networks. An example of this application is the presented overspill routing. The results of the network emulator for overspill routing show that it efficiently combines the advantages of transparent payload routing by optical circuits and the improved bandwidth efficiency and flexibility offered by (burst) packet switching.

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BIOGRAPHIES

IDELFONSO TAFUR MONROY (itm@com.dtu.dk) graduated from the Bonch-Bruevitch Institute of Communications, St. Petersburg, Russia, in 1992, where he received an M.Sc. degree in multichannel telecommunications. In 1996 he received a Technology Licenciate degree in telecommunications theory from the Royal Institute of Technology, Stockholm, Sweden. The same year he joined the Electrical Engineering Department of Eindhoven University of Technology, The Netherlands, where he earned a Ph.D. degree in 1999. His research interests are in optical communication networks and communication theory.

TON KOONEN is since 2001 a full professor in the Electro-Optical Communication Systems group, partner of the COBRA Institute, at Eindhoven University of Technology. Prior to that, he spent more than 20 years at Bell Labs—Lucent Technologies as a technical manager of applied research. He is a Bell Labs Fellow (the first in Europe). Next to his industrial position, he was a part-time professor in photonic networks at Twente University from 1991 to 2000. His main interests are currently in broadband fiber access networks and optical packet-switched networks. He has initiated and led several European and national R&D projects in this area, on label-controlled optical packet routed networks (the EC project STOLAS), dynamically reconfigurable hybrid fiber access networks (fiber-coax, fiber-wireless), and short-range multimode (polymer) optical fiber networks. He has co-authored more than 200 conference and journal papers.

Juan Jose Vegas Olmos received a B.Sc. in telecommunications engineering from Universitat Politecnica de Catalunya, having carried out his graduate project at the Royal Institute of Technology, Sweden. He continued his studies and received an M.Sc. in electronics engineering in 2003. Since January 2005 he also holds a Licenciate degree in business administration. In April 2003 he came to Eindhoven University of Technology. At present he is a Ph.D. student in the Electro-Optical Communications group.

Johan van Berkel received a Master's degree in electrical engineering from Eindhoven University of Technology in 2002. He continued his education at the Stan Ackermans Institute of the university, from which he received his P.D.Eng. degree in 2005. Part of his P.D.Eng. thesis research work was performed within the framework of the STOLAS project regarding the study of signal impairments in FSK/IM label switched networks. Currently, he is with Catena Radio Design, the Netherlands.

Jean Jennen graduated cum laude based on "A Wavelength Control Circuit for a Tunable Optical Receiver," a study carried out at AT&T Network Systems. He received his Ph.D. from the Eindhoven University of Technology in June 2000 for *Noise and Saturation Effects in High-Speed Transmission Systems with Semiconductor Optical Amplifiers*. Currently, he is a member of technical staff at Bell Labs Research. His research interests are in high-speed optical transmission and multiwavelength core and metropolitan area networks.

Christophe Peucheret received his engineering. degree from Ecole Nationale Supérieure des Télécommunications de Bretagne, Brest, France, an M.Sc. in microwaves and optoelectronics from University College London, and a Ph.D. from the Technical University of Denmark (DTU). He is currently an associate professor at the Department of Communications, Optics and Materials (COM•DTU) at the university, working in the field of modulation formats for transmission and optical networking. He has been coordinating COM•DTU's activities in the STOLAS project.

Evi Zouganeli holds a Ph.D. in optoelectronics (1992) and an M.Sc. in telecommunications (1988), both from University College London, a B.Sc. in applied physics from University of Patras, Greece (1985), and a Master of Management (2001) from the Norwegian School of Management. After postdoctoral work at the Swiss Federal Institute of Technology she joined Telenor R&D in 1994, where she has focused on high-capacity optical networks, broadband access, network migration and upgrading strategies, and technology evaluations on contract from Telenor Business Units and in a number of European collaboration projects. She is a member of a number of international technical management committees and is currently a senior research scientist at Telenor R&D.

IEEE COMMUNICATIONS MAGAZINE
CALL FOR PAPERS
FEATURE TOPIC: IP MULTIMEDIA SYSTEMS (IMS) INFRASTRUCTURE AND SERVICES

IP Multimedia Systems (IMS) is a standardized Next Generation Network (NGN) architecture developed to provide a common service delivery mechanism and reduce development cycle for service creation across wireline and wireless networks. Being standardized by the third generation Partnership Project (3GPP) and 3GPP2, IMS promises to reduce capital and operational expenditures for service providers along with operational flexibility and simplicity. Extensive IP-based feature rich services such as Voice over IP (VoIP), online gaming, videoconferencing, and content sharing will be offered on one infrastructure. Switching between services will be seamless. IMS is access agnostic. Users of GPRS, UMTS, CDMA2000, WiMAX, DSL and Cable will be able to access services provided over the IMS infrastructure. Core IMS components such as Call/Session Control Function (CSCF), Home Subscriber Server (HSS), Media Resource Function (MRF) and Application Server (AS) must be scalable and built with at least five nine reliability.

To keep its promises, IMS need to overcome many obstacles including implementations. Although early IMS trials and deployments are underway, various challenges in architecture, protocols, and operations are being worked in the industry. This feature topic is intended to include papers that will address these challenges at the infrastructure and service levels. Authors are invited to submit complete unpublished papers that are not under review in any other conference or journal in any of, but not limited to, the following or related topic areas:

- IMS architectures for wireline and wireless networks
- Status of IMS standards
- IMS Service architectures, killer applications and services
- Security issues with IMS
- IMS Signaling
- IMS Performance and Service Reliability
- IMS Network and Service Management
- Status of, and experiences with, IMS implementation and deployment

Papers should be of tutorial in nature and authors must follow the IEEE Communications Magazine's guidelines for preparation of the manuscript. Please refer to "Information for Authors" on the IEEE Communications Magazine web site (http://www.comsoc.org/pubs/commag/sub_guidelines.html) for further detail. Manuscripts should be submitted by September 31, 2006 through Manuscript Central at http://commag-ieee.manuscriptcentral.com/. Please select "March 2007/ IMS Infrastructure and Services" in the drop down menu.

SUBMISSION SCHEDULE

Manuscript Submission:	September 15, 2006
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Publication Date:	March 2007

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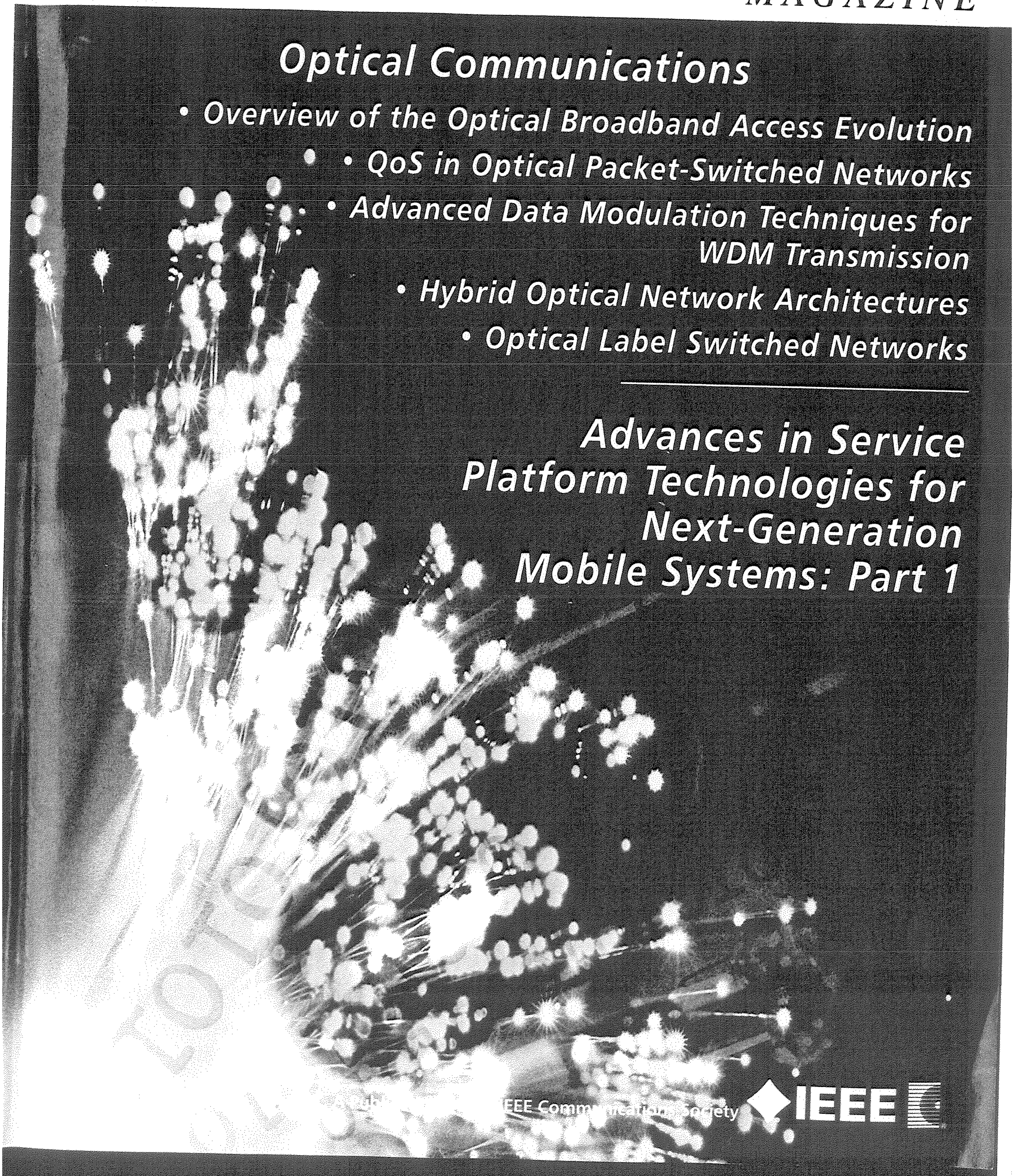

Optical Communications

- Overview of the Optical Broadband Access Evolution
- QoS in Optical Packet-Switched Networks
- Advanced Data Modulation Techniques for WDM Transmission
- Hybrid Optical Network Architectures
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