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Optical packet switching using in-band multi-wavelength label *

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Abstract : A novel packet switching adopting in-band multi-wavelength optical label is introduced ,in which optical header is labeled by several optical pulses at different wavelengths in the same optical communication channel band as optical payload. The switching fundamental and its implementation techniques ,including optical transmitter with header generation and packet formation ,receiver with data restoration and switching node with route processing ,are described. A simplified experiment demonstrated the switching principle.

Key words : optical communication ; optical switching ; optical packet switching ; in-band multi-wavelength optical label ; multi-wavelength optical label packet switching (MλOLPS)

带内多波长光标记分组交换技术的研究

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摘要: 介绍了一种带内多波长光标记分组交换技术。在这种光交换中 ,光信头由若干个与光载荷处于同一通信信道内的具有不同波长值的光脉冲构成。探讨了包括信头产生和光分组形成部分的光发射机技术 ,包括数据恢复的接收机技术和包括路由处理的光交换节点技术。一个简化的实验演示了这种光交换的原理。

关键词: 光通信 ;光交换 ;光分组交换 ;带内多波长标记 ;多波长光标记分组交换(MλOLPS)

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Introduction

With the rapid development of optical communication ,optical switching has been becoming the key to break through electronic bottleneck and enlarge the communication capacity further. Optical package switching(OPS) [1] is considered as an ideal scheme , which has the advantages of little overhead and high bandwidth utilization coefficient , and some research has been made on it. At the OFC '2000 , an OPS solution using sub-carrier multiplexing label was demonstrated[2] ,in which packet header is carried on a sub-carrier and can be easily picked up ,but a narrow spectrum band width of sub-carrier is demanded. In some OPS schemes , the header employs wavelength division multiplexing (WDM) bits[3,4] , and header recognition can be much simpler but for the disadvantage of the payload and header reserving different wavelegnth channels. At the APOC '2001 , we presented a new kind of in-band multi-wavelegnth optical label packet switching[5] (MλOLPS) with advantages of header not occupying extra wavelength channel resource ,transmitting a great deal of routing information and easy processing.

This paper reports our recent research on the in-band MλOLPS. In section 2 , the principle of MλOLPS is explained. In section 3 ,we discuss some realization techniques of MλOLPS , including the packets formation in transmitter ,routing processing in node of MλOLPS and data restoration in receiver. In section 4 ,we describe a simplified experiment.

1 Principle of MλOLPS

The optical packet structure of MλOLPS[5] is shown in Fig. 1. In time domain(t denotes time) ,the header and payload are arranged at the beginning and ending of optical packet respectively. In spectrum

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domain(λ denotes wavelength) ,they are carried on a same wavelength channel, but their wavelength compositions are different. If payload is delivered at a designated wavelength ,e. g. λ_0 ,belonging to DWDM wavelength series, the header carrying route information will be constituted by optical pulses with different wavelengths within the λ_0 channel band.

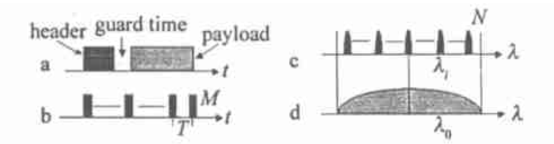

Fig. 1 The optical packet structure of MλOLPS: a —basic optical packet b —composition of optical head c —optional wavelength of header pulse d —DWDM wavelength λ_0 channel pass-band

The possible wavelength value of optical pulse used to construct the header can be designated through regulating the number N ($N = 1, 3, 5, \cdots\cdots$) of wavelength and interval δ_λ of wavelength: $\lambda_i = \lambda_0 \pm n\delta_\lambda$, where $n = 0, 1, 2, \cdots\cdots, (N-1)/2$. The number M of the header pulses and time interval T can also be pre-regulated. Then the permutation and combination of different wavelength in header can directly denote optical route information without any extra modulating and coding. Limited number M of optical pulses and limited number N of optional wavelengths will form a large amount of possible combinations ,that is to say ,the information quantity denoted by this kind of header will be huge. We can assume to form a kind of header with 15 optical pulses,i.e. M equals 15 ,like this: the first 3 pulses with carrier wavelength λ_0 can be functioned not only as header identification and synchronization, also as indicating the carrier wavelength of this optical packet, the following 6 pulses and the last 6 pulses with different wavelength can be used to indicate destination address and the source address respectively. If the number N of optional wavelengths is 5, the quantity of source addresses or destination addresses will be 6^5.

When an optical packet with such kind of in-band multi-wavelength optical label header gets switching node ,the carrier wavelength of payload and routing information can be obtained through header processor reading and translating the wave spectrum of header. Then optical switching matrix in switching node is controlled to select light-path of optical payload, and a new header is produced to ensure delivering the payload forward. The switching node diagram of multi-wavelength optical label switching is shown in Fig. 2 ,which is consisted of input interface, output interface, header processor and optical switching matrix.

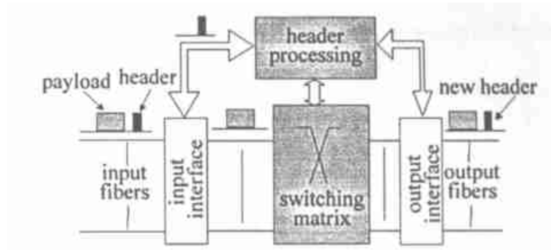

Fig. 2 The optical switching node of multi-wavelength optical label switching

2 Realization technology of MλOLPS

2.1 Packets formation in transmitter

The transmitter of MλOLPS should be able to pack the incoming data (initial data flow to be transmitted) into optical packets with fixed format and send them out. It consists of an optical payload generator ,a header generator and a packets formation part. Its principle is shown in Fig. 3.

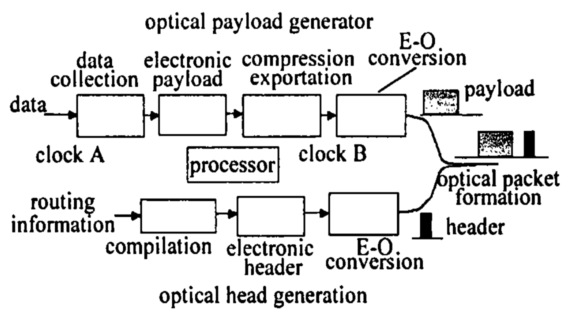

Fig. 3 Transmitter schematic of MλOLPS

In an optical payload generator ,initial data flow with clock signal A are collected and divided into data groups with fixed length. Then the groups are exported according to another clock signal B, and electronic payloads (payloads in electrical domain) are formed ,and the optical payloads can be generated by E-O conversion. Because the clock B is much faster than the clock A, that is to say, the data flow transmitted with high compressed ratio after dividing into groups, the data rate of optical payload is much higher than the initial data signal. For example ,if the ratio of the two clocks is 100 :1 ,after being arranged into payloads , the 1ms time length initial data flow will be sent out in 10μs , i. e. 10μs time length. So there will be enough time-interval between payloads and can be used for optical header ,guard time ,etc.

Because the optical header is consisted of different wavelength pulses ,and the routing information is denoted by the permutation and the combination of different header wavelengths , the structure of electronic header (header in electrical domain) is correlated with E-O conversion patterns. Fig. 4 shows two capable schemes of electronic header. If E-O conversion is realized by modulating optical wavelength with electronic signal amplitude , the electronic header should be a serial electrical pulse with different amplitude ,as shown in Fig. 4a. If E-O conversion is conducted by a group of single frequency/ wavelength laser diodes ,the electronic header should be a group of parallel pulses with different sequence , as shown in Fig. 4b , and the optical header can be synthesized with the optical pulses derived from the E-O conversion.

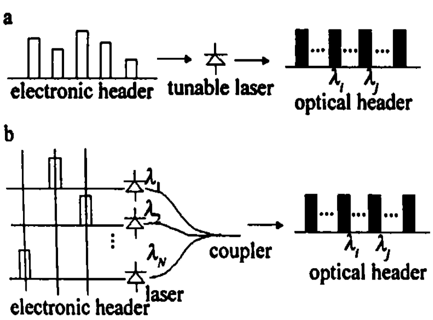

Fig. 4 Architectures of electronic header

In an optical packet formation part , optical header and optical payload are combined to form optical packet by an optical fiber coupler. Of course , the generation of header and payload must be all controlled under a uniform processor to ensure the accuracy of synchronization and pulses sequence.

2.2 Routing processing in node of MλOLPS

The optical node of communication network performs optical route selecting , and it should recognize the optical header of each channel first. When a MλOLPS packet arrives at the switching node , its header with multi-wavelengths label will be dropped in the input interface. In accordance with this switching mode , we adopt a kind of optical header extracting technique[6] using optical circulator and tunable fiber Bragg grating (FBG) array to separate the header from payload and recognize the header in optical domain , as showed in Fig. 5. The array is consisted of N optical circulators and N tunable FBGs whose normal reflective wavelengths correspond to the header wavelengths: λ_1 , λ_2 , ……λ_N (within a communication channel). If an optical pulse's wavelength equals the grating reflective wavelength , the pulse will be backed to the nearest circulator and go out from the other port of the circulator , and a corresponding detector can catch it. So , when the header arrives , its pulses with different wavelengths will be separated and received by the detectors respectively. Analyzing these signals coming from the detectors ,processor can acquire routing information , synchronization signal ,etc. After finishing the header pulses collection ,processor moves the FBGs' working wavelengths from the communication channel ,and the followed payload can pass through the array to the switching matrix without any power splitting. At the same time , the processor controls the optical switch matrix to select suitable route and generates a new header for the payload according to the recognized routing information. In the output interface ,the new header is combined with the payload ,and a refreshed optical packet is formed and forwarded to next node or terminator.

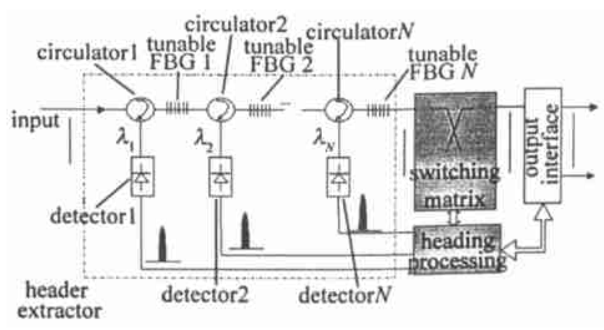

Fig. 5 Principle of optical header information extracting

2.3 Data restoration in receiver

In contrast to the function of optical transmitter , the optical receiver restores optical packets to original data flow. As shown in Fig. 6 ,optical receiver transforms the optical packets with fixed format into electrical signal first. Then, the header of electronic packet is removed, and the electronic payload with clock B is decompressed to low rate data signal according to the clock A. Through correctly compiling the decompressed data, the original data signal can be obtained. Because the data rate of header is much lower than payload, the header is easily to delete in electrical domain. Corresponding to the clock signals of transmitter, the clock B is the high rate clock of optical payload and the clock A is the low rate clock of original data flow.

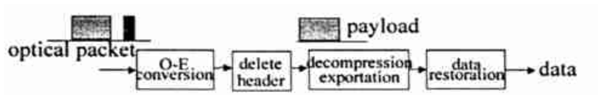

Fig. 6 Receiver schematic of MλOLPS

3 A simplified principle experiment

To verify the feasibility of such switching method, we designed a simplified experiment, as shown in Fig. 7～Fig. 12. Fig. 7 is the experiment diagram, and Fig. 8 explains the fundamental of switching node. Four terminators are connected with an optical switching node through optical transmitter (Tx) and optical receiver (Rx) respectively to accomplish data switching. In order to simplify the process of procedure further, the optical transmitter of each terminator adopts a same optical carrier wavelength, λ_0 = 1550.92nm. The optical header pulses work at 3 optional wavelengths within the same 200G DWDM channel: λ_1 = 1550.52nm, λ_2 = 1551.32nm and λ_0 = 1550.92nm. The spectra of optical header and payload are shown in Fig. 9. Data rate of the optical payload is 622Mbit/s with the time duration of 21μs, and the header's is 1Mbit/s with 7μs duration. The header is composed of 7 optical pulses: the first 3 pulses with carrier wavelength λ_0 is acted as header identification and synchronization, the last 2 pulses with wavelength λ_0 is used as indicating the end of header, and the middle 2 pulses is used to denote destination address: (λ_1, λ_1), (λ_1, λ_2), (λ_2, λ_1), (λ_2, λ_2) stand for the terminators, from the first to the fourth respectively. The optical packet structure is shown in Fig. 10.

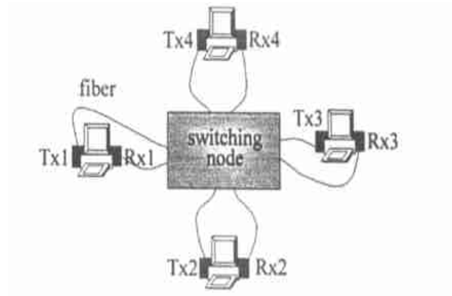

Fig. 7 Experiment diagram

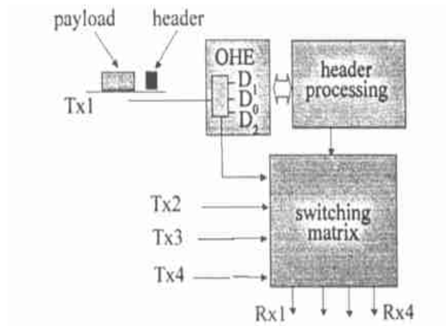

Fig. 8 Fundamental switching

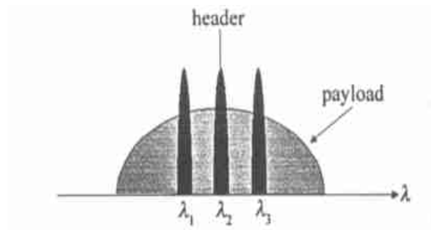

Fig. 9 Spectra of packet

λ_1 = 1550.52nm λ_0 = 1550.92nm λ_2 = 1551.32nm

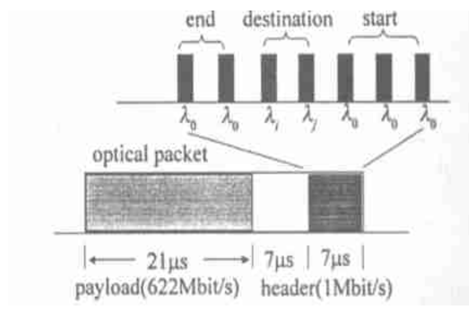

Fig. 10 Packet structure

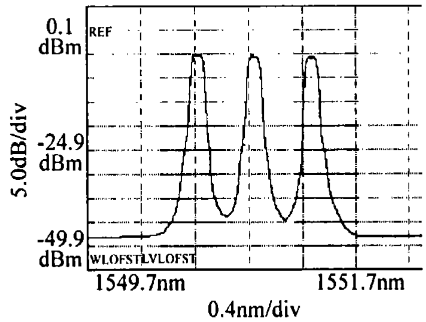

Fig. 11 Experimental herder spectrum

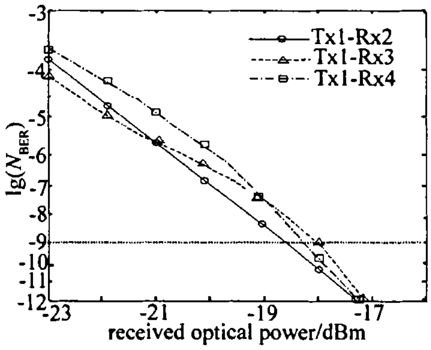

Fig. 12　BER results

Taking Tx1 transmitting signal as an example, when an optical packet enters the optical header extractor OHE (see Fig. 5), the pulses of the header can be separated according to their wavelengths. After received by optical detector D_0 to D_2 respectively, the header pulses are converted to electronic signal, and the address information can be identified. Then, processor controls the OHE to lead the optical payload to the optical switching matrix and at the same time controls the switch matrix to select optical routing and transfer the payload to pre-determined receiving terminator.

Fig. 11 shows the experimental result of the herder spectrum, and Fig. 12 is results of BER measurement. The BERs between terminators were less than 10^{-9} at a received power of about -18dBm. The simplified principle experiment proves the practicability of multi-wavelength optical label packet switching.

4　Conclusion

As wavelength is an easily recognized optical parameter, multi-wavelength optical label header can be processed comparatively easy and is of powerful anti-interference ability. In this in-band MλOLPS, the multi-wavelength header labeled by several optical pulses at different wavelengths in the same optical communication channel band as optical payload does not occupy extra wavelength channel and can carry a great deal of routing information. The optical transmitter, receiver and switching node, including header generation, packet formation and route processing can be realized. With the progress of optical signal processing technology, this kind of optical signal header may be arbitrated all in optical domain (an all optical processed MλOLPS is under study in our laboratory), and the optical switching adopting in-band multi-wavelength optical label is a promising sort of optical switching technology in all-optical processing with higher speed.

References

[1] Dambini F, Renaud M. IEEE J Select Areas in Commun, 1998, 16:1245～1259.
[2] Way W I, Lin Y M, Chang G K. Proc OFC 2000, 2000, WD6:1～4.
[3] Yang Q M, Bergman K, Hughes G D *et al*. Journal of Lightwave Technology, 2001, 19(10):1420～1426.
[4] Chan K, Tong F. Proc OFC 2002, 2002, WO4:284～285.
[5] Xiao S L, Zeng Q J, Wang J X *et al*. Proc SPIE, 2001, 4582:133～138.
[6] Wang J X, Zeng Q J, Xiao S L *et al*. SPIE, 2002, 4872:402～407.

简　讯·

层叠式体积全息照相术

体积全息照相通常通过将光敏物质曝光在干涉光下得到。阿拉巴马大学的研究人员另辟蹊径,通过层叠二进制光栅,每次产生一径束来形成体积全息。二进制光栅之间的间隔代表布喇格平面。一个典型的全息照相包含 3 个高反射率的 TiO_2 光栅,用 SU-8(一种低折射率聚合物材料)相互隔离。底部光栅置于玻璃基底上。整个制作过程中最具挑战性的便是光栅层之间的间隔。要获得合适的间隔,采用了一种针对接触面准直器的高精度层准直技术,该项技术利用了制造于底层上的光栅和照相复制光栅之间的衍射。这样,间隔便极易控制在 100nm 公差范围之内,但是层间距还不能非常理想地控制。用 2.05μm 的光来检测体积全息照相,以确定其角灵敏度。测得的峰值衍射效率超过了 80 %,但对光栅层之间的菲涅耳反射非常敏感。这种类型的全息照相术可以用作相干激光雷达系统中的光束反射和扫描器件。

(蒋　锐　叶大华　　供稿)