Final Report

Summary of original goals and progress made toward achieving those goals

B1.1.Optical transmission, modulation and spectral efficiency studies

Original goals: investigate novel and cost-effective components and modulation technique to increase optical transmission system and optical network spectra efficiency.
Progress: We have invented a technique to generate MD-RZ signals by using only one dual-arm LN-MOD. We have realized the expected achievement. We have investigated different modulated format signals and compared their transmission performance. Our research results have shown that MD-RZ signal can tolerate high-nonlinear effect. A world-record repeater-less transmission distance of 265km SMF-28 is achieved with minimum signal degradations. We have also experimentally demonstrated bi-directional transmission of DPSK signal by using SOA as in-line amplifier for the first time. The SOA is a promising candidate for metro and access networks because of its wide amplification bandwidth and potential low cost. Bi-directional transmission can utilize efficiently the optical fiber transmission bandwidth and reduce the complexity and cost of optical transmission systems and networks. The use of SOAs as in-line amplifiers is very suitable for bi-directional transmission systems and networks because SOAs do not need any optical isolators as often used in erbium doped fiber amplifiers (EDFAs). However, gain saturation and cross gain modulation (XGM) in SOAs can degrade the transmission performance when regular modulation format like on-off keying (OOK) modulation is employed. Since the intensity of differential phase shift keying (DPSK) signals are constant, cross-gain modulation (XGM) and gain saturation in SOAs can be overcome. Recently, experiments show that DPSK modulation format can realize long distance and high-spectral efficiency signal transmission by using SOA in-line amplification. In our experiment we have successfully realized bi-directional transmission of 8×10 Gb/s signals using an in-line SOA over 80km SMF-28 with matching DCF. Six papers have been accepted by conferences or journals.

B.2 Enabling Technology of Optical Components

B.2.1 Advanced Wavelength Conversion Components and Techniques
Original goals: advanced wavelength conversion components and techniques.
Progress: we have investigated all-optical wavelength conversion for modified duobinary signal and differential phase shifted keying signal by using high-nonlinear optical fiber or semiconductor optical amplifier. The converted signal has high signal-to-noise ratio and large conversion wavelength range. Two papers has been published or submitted.

B.2.2 Advanced Optical Components and Subsystem Technologies
Original goals: Investigation advanced optical components and optical label switching technique.
Progress:
1) Optical components.
We focused our research on chip-to-chip optoelectronics SOP on organic boards or packages. We have demonstrated compatibility of hybrid, large-scale integration of both active and passive devices and components onto standard printed wiring boards in order to address mixed signal system-on-package (SOP)-based systems and applications. Fabrication, integration and characterization of high density passive components are presented, which includes the first time fabrication on FR-4 boards of a polymer buffer layer with nano scale local smoothness, blazed polymer surface relief gratings recorded by incoherent illumination, arrays of polymer micro lenses, and embedded bare die commercial p-i-n photo-detectors. Two papers have been published in journals.

2) Optical label switching technique.
We have invented a method named after optical carrier suppression and separation to generate optical label and payload. Novel and advanced methods for optical label swapping have also been demonstrated. Our method for label generation has some advantages, such as low bandwidth requirement for RF, electrical and optical components, no ER limitation, flexible label insertion at variable bit rates, no crosstalk for generating and multiplexing payload and label, and narrow separation required between label and payload for better spectral efficiency. In an optical package switching network, one of the critical components is the optical packet router. Buffers are often required in these routers to temporarily store packets for synchronization or for contention

resolution and they are designed to be all-optical in order to achieve high-speed operation while being transparent to bit rates and modulation formats. Since no equivalent of the electronic random access memory in the optical domain has been successfully developed, these buffers are implemented using fiber delay lines. But if long delay time is required, the physical size of the buffer becomes very large. We propose a new type of traveling-wave buffer design. By using a folded-path design and SOA gates, this dynamically reconfigurable buffer is more compact than other traveling-wave designs. Experimental results show that the architecture is scalable, thus enabling more choices and flexibility when selecting the range and granularity of delays. Twelve papers have been accepted or published in the conferences or journals.

Description of any intellectual property invented as a result of the innovations grant

A novel method for optical label generation has been proposed and experimentally demonstrated.

Optical label switching (OLS) is a promising approach to switch and route packets at ultra-high bit rates in the optical layer. Up to now, there are three important techniques to generate the optical label and payload: (i) optical subcarrier multiplexing, (ii) fixed rate serial or optical time multiplexing, (iii) orthogonal modulation using combined amplitude shift keying (ASK) and differential phase-shift keying (DPSK) or combining ASK and frequency shift keying (FSK). The traditional subcarrier multiplexed label is inherently a simple configuration [1-3]. However, the subcarrier multiplexing has the main two drawbacks: (i) The way that the payload and label are generated leads to interference between the label and payload with the dense WDM networks, which cannot be avoided. (ii) the two sidebands of the label will interfere with each other after the label is detected by a square law device. When a bit-serial label is used, the label is placed at the start of packet, which is buffered by an optical guard-band that facilitates label removal and reinsertion. However, fixed rate serial label requires strict synchronization between the payload and label, which is very difficult to achieve in actual optical data routing networks. In the orthogonal modulation scheme, one main defect is that the extinction ratio (ER) of the payload and label can not be too high; otherwise the payload and label can not be effectively separated in the receiver. Small ER definitely limits the signal transmission distance.

We propose and experimentally demonstrate a novel technique to generate optical label and payload of a packet based on optical carrier suppression and separation (OCSS). The generated label and payload achieve high ER while requiring only small-bandwidth and low-cost RF, optical, and electrical components.

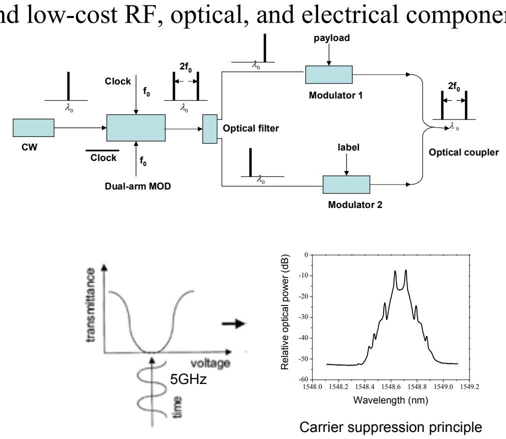

Fig.1. Principle of optical label generation.

Fig. 1 shows the principle of our proposed technique. A sinusoid clock and its complimentary signal are amplified and used to drive a push-pull LiNbO3 modulator (LN-MOD) biased at the minimum-intensity output point. Two symmetrical beat longitudinal modes are generated and the original carrier is suppressed. The spacing between the two new modes is equal to the double frequency of the modulated sinusoid clock. As an example, we insert an optical spectrum in Fig.1 when the modulated frequency is 5GHz. The resolution for this optical spectrum and all spectra in this paper is 0.01nm. It is clearly seen that the wavelength spacing of the two modes is 0.08nm and the carrier is suppressed. We use optical filtering to separate the two modes and obtain two optical modes with fixed wavelength spacing. The two separated intensity external modulators are then used to generate the label and payload separately.

We believe that the technique has the following advantages: (i) The bandwidths of all components used here are less than the maximum repetitive frequency of the payload bit rate. This is in contrast to subcarrier multiplexing method that needs high frequency RF signal; (ii) There is no ER limitation for generating payload or label; this is the main drawback of orthogonal modulation technique; (iii) The label can be chosen to operate at any bit rate, as long as the label bit rate is smaller than or equal to the two times of sinusoid frequency for generation of carrier suppression and the label and payload are not overlapped in the frequency domain; (iv) This technique can be easily used for high-speed label and payload generation, e.g. for ≥ 40Gbit/s per channel. The label and payload is much easily separated using optical filtering because wavelength spacing of the two modes is wider at high bit rates; (v) The payload and label can be separately generated and then combined by optical multiplexing, there is minimum or no crosstalk between the payload and label. This is in contrast of the traditional subcarrier multiplexing having significant crosstalk because the label and payload can not be separately generated; (vi) Narrow bandwidth for transporting both the label and payload is realized and thereby allowing better spectral efficiency. Traditional subcarrier multiplexing requires a wide bandwidth.

List of publications/presentations submitted or planned as a result of the Grant

1. Jianjun Yu, Haris Muhammad, John Barry and Gee-Kung Chang, "A low-cost, novel method for 40Gbit/s modified duobinary RZ signal generation", OECC/COIN 2004, July 2004, Paciico Yokoham, 13P-34.
2. Jianjun Yu, G. K. Chang, J. Barry and Y. Su, "40Gbit/s modified duobinary RZ signal generation, wavelength conversion and transmission", 30th European Conference on Optical Communication, Stockholm, Sweden, 2004: We. 2. 4. 4.
3. Jianjun Yu, G. K. Chang, H. Muhammad and J. Barry, "10Gbit/s repeaterless transmission over 265km SMF-28: using a modified duobinary RZ signal generated by one dual-drive LiNbO3 modulator", Optics Commun. Vol. 239, Issue 1-3, 2004: 99-101.
4. Jianjun Yu, "Generation of modified duobinary RZ signals by using one single dual-arm LiNbO3 modulator", IEEE Photon. Technol. Lett., Vol. 15, No. 10, 2003: 1455-1457.
5. Jianjun Yu, Yong-Kee Yeo, Oladeji Akanbi and Gee Kung Chang, "bi-directional transmission of 8x10Gb/s DPSK signals over 80km of SMF-28 fiber using in-line semiconductor optical amplifier", IEEE LEOS 2004 annual meeting, 2004: ThE3.
6. Muhammad Faisal Khan, Gee-Kung Chang, Jianjun Yu, et al., "Multistage Linear Add/Drop (LAD) Architecture for WDM Based high Capacity Broad-Band Passive Optical Networks", submitted to OFC 2005.
7. G. K. Chang et al., "Chip-to-chip optoelectronics SOP on organic boards or packages", IEEE Transactions on advanced packaging, Vol. 27, No.2, 2004: 386-397.
8. R. R. Tummala, M. Swaminahan, M. M. Tentzeirs, J. Laskar, G. K. Chang, et al., "The SOP for miniarturized, mixed-signal computing, communication, and consumer systems of the next decade", IEEE Transactions on advanced packaging, Vol. 27, No.2, 2004: 250-267.
9. Y. K. Yeo, J. Yu and G. K. Chang, "A dynamically recongfigurable folded-path time delay buffer for optical packet switching", IEEE Photon. Technol. Lett., Vol. 16, No. 11, 2004: 2559-2561.
10. G. K. Chang, J. Yu and J. Long, "Scaleable optical label generation, switching and control for packet routing in DWDM networks", APOC 2004, 5626-12, Beijing **(Invited)**
11. Jianjun Yu and G. K. Chang, "Spectral Efficient DWDM Optical Label Switching Technologies", IEEE LEOS 2004 annual meeting, 2004: ThM1 **(invited).**
12. Jianjun Yu, G. K. Chang, Y. Yeo, K. Lee, "Cascaded optical label swapping in a 40Gbit/s optical switched network with three hops and two core nodes", 30th European Conference on Optical Communication, Stockholm, Sweden, 2004: Th 3.6.4.
13. Jianjun Yu, "Spectral efficient DWDM optical label generation and transport for next generation internet", CLEO/Pacific Rim 2003, Taipei, Taiwan, W2A-(13)-1 **(invited).**
14. G. K. Chang and Jianjun Yu, " Multi-rate payload switching using a swappable optical carrier suppressed label in a packet switched DWDM optical network", OFC 2004, **post deadline paper** PDP5.
15. Jianjun Yu, G. K. Chang and Q. Yang, "Optical label swapping in a packet switched optical network using optical carrier suppression, separation, and wavelength conversion", IEEE Photon. Technol. Lett., Vol. 16, No. 9, 2004: 2156-2158.
16. G. K. Chang and Jianjun Yu, "40Gbit/s payload and 2.5Gbit/s label generation using optical carrier suppression and separation", Electron. Lett., Vol. 40, No. 7, 2004: 442-443.

17. Jianjun Yu, G. K. Chang, A. Chowdhury and J. L. Long, "Spectral efficient DWDM optical label/payload generation and transport for next generation internet", IEEE/OSA Journal of Lightwave Technology, 2004, vol. 22, no. 11.
18. Jianjun Yu, G. K. Chang, "All-optical wavelength conversion for optically multiplexed 40-Gbit/s payload and 2.5-Gbit/s label in an optical-label-switched network", J. of Optical Network, Vol. 3, No. 10, 2004: 722-726.
19. Jianjun Yu and G. K. Chang, "Generation and transmission of eight-channel DWDM signals with 10Gbit/s payloads and 2.5Gbit/s labels over 200km SMF-28", Electron. Lett., Vol. 40, No. 2, 2004: 135-136.
20. Jianjun Yu and G. K. Chang, "A novel technique for optical label and payload generation and multiplexing using optical carrier suppression and separation", IEEE Photon. Technol. Lett., Vol. 16, No. 1, 2004: 320-322.