Integration of photonic components and impacts on 5G optical networking

Binh[*], Le and Wang[*] Tao, Thomas

Abstract— ***Current demands on ultra-high capacity reaching Peta- or even Exa-bits/s throughput in data centers and 5G PPP wireless networks have exerted tremendous efforts in low cost transmission and networking sub-systems. It is thus inevitable that the integration of both electronic digital processors and photonic processing systems would offer this probability. Si integrated phonics in association with other photonic technologies are necessary for such platform. We thus present an outlook on the impacts of the integration of photonic components on Si as well as electronic counterparts for future optical transmission systems and networks. In particular we stress the critical impacts of semiconductor grown-on-Si laser sources on detection techniques. Hence future coherent only optical transmission systems coupled with optical switching networks. A structure of cloud data center employing a novel photonic kernel is proposed for Pbps data switching and transport.***

Index Terms—*Si integrated photonics, Quantum Dot lasers, coherent/ incoherent optical systems and networks.*

1. INTRODUCTION

OVER the last decades tremendous developments have been demonstrated on the installation of 100G DWDM throughout several global optical networks. Furthermore higher aggregate bit rates employing higher order modulation such as M-QAM to achieve 400G and even Tbps multi-superchannel transmission links in long haul optical networks. Coherent transmission techniques plus digital signal processors (DSP) with high sampling rate analog to digital converters (ADC) and DAC (digital to analog converters) enable the recovery and equalization of distorted signals as well as pre-emphasis of data information [1].

On the other hand tremendous efforts have also pushed the 5th generation of wireless networking towards information consumers [2]. Under the 5G network environment emerging technologies such as cloud radio access (CRAN) networks, mobile high performance computing (HPC) etc. Thus several data centers (DC) will be required in the access, thus metropolitan, areas as shown in Figure 1. Coupling with such likely ultra-high capacity transmission and networking via several DCs in distributed or centralized topologies, the drive for low-cost optical components and systems has put tremendous pressures on equipment manufacturers (EM) and telecommunications carriers (TC) as well as information service providers (ISP).

Si integrated photonic technologies have been explored and exploited by research communities over the last decade, especially the demonstration of ultra-high bandwidth optical modulators [3]. Although it is observed that several research reported on the employment of modulation formats to lowering the costs, they used direct detection techniques [4]. Demands on low cost and high sensitive detection so as to minimize the uses of optical amplifying devices would lead to seeking the high sensitive coherent detection and transmitting technologies in the optical domain provided such agile photonic processing capability would be available.

This paper thus presents an overview on the technological development and research on the integration of several photonic components on a single Si photonic integrated circuit (Si-IPC) serving as transmission links and routing functionalities for optical networking. Furthermore we propose the structure of cloud DC for 5G networks composing of a photonic kernel and a cloud of servers so as to transport and switching optical channels into and from such DC.

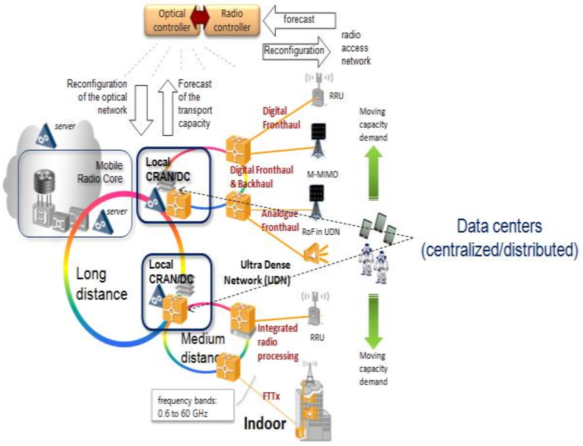

Figure 1 A 5G network structure.

2. QDL AS LASER SOURCES ON SI PHOTONIC CIRCUITS

In order for complete integration in Si photonic circuits, integrated laser sources must be semiconductor sources into Si-IPC has been reported but facing difficulties and hence high cost [5, 6]. Recently quantum dot lasers (QDL) have been successfully directly deposited on Group IV SC substrate [7] allowing us serious considerations of a complete integration of such sources in Si-IPC for both 1310nm and 1550nm spectral regions for silica fiber-based transmission systems which are considered either as minimum dispersion or low loss.

2.1 QDL

QDL is considered to be almost insensitive to temperature fluctuation, hence offering tremendous advantage for uses as un-cooled sources in access low energy consuming environment such as in the optical phase distribution for MIMO (multi-input Multi-output) antennae for 5G wireless networks operating in the micro- or mm- wave regions. Such transponder is shown in *Figure 2* under direct detection.

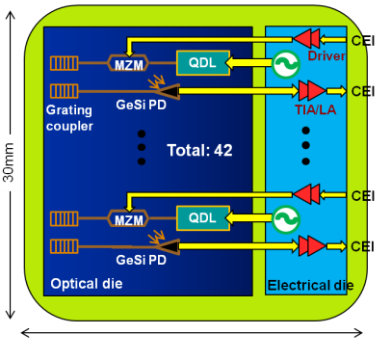

Figure 2 Integration of QDL on Si-IP optical transponder.

2.2 QDL for coherent reception

If such QDL can be grown in SI-IP they can be employed as a local oscillator laser source for mixing with the coming signals which can be from optical transmission fiber distant away from the antenna site to be decoded and the phases of individual elements to be distributed to the MIMO antenna.

The power output from QDLs can be as high as 25 dBm and can be split to share between the transmitter and reception sub-systems in an optical transponder. Coherent reception is well known for enhancing the receiver sensitivity and recovery of the phases of the receiving signals which are particularly important for MIMO wireless antenna systems.

Such MIMO systems with total number of elements of 16x16, each carrying 10Gb/s information would result in 2.6Tb/s to be transported to local access network. In this case it is very likely that data centers would act as the service providing point. Hence routing of information channels must be carried in the photonic domain to reduce severe distortion effects if conversion back to the electronic domain is done. A proposed block diagram is shown in Figure 3.

3. *SI MODULATORS AND PHOTONIC PROCESSORS*

2.3 Optical modulators

Optical signals to be delivered to 5G MIMO antennae systems carry both the phase information to each antenna element in association with the data channels. Sites of antennae can be formed into array can be employed this techniques in order to stir the access point by manipulating the phases of each antenna site system. The phase information can be delivered as shown in Figure 3 in which the optical signals, transmitted from a DC, can be optically mixed with a local oscillator which is derived partially from a QDL.

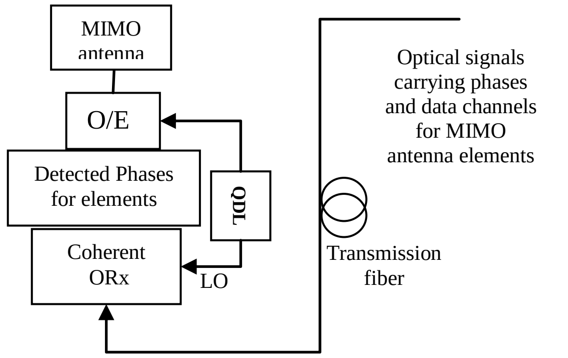

Figure 3: Delivering phase and data info to MIMO antennae for 5G wireless networks.

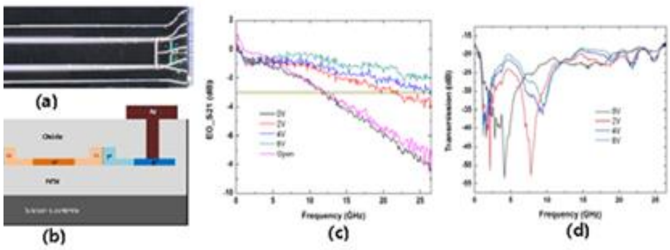

Figure 4 (b) an optical MZI modulator implemented on Si-IP (a) Microscope image of the silicon MZM. (b) Cross-sectional view of the silicon MZM with single-drive push-pull electrode design. (c) Electro-optical (EO) S_{21} response of the travelling wave electrodes at various bias voltage. (d) Electrical return loss S_{11} at different bias voltage

These electrical phases can then be fed to the antenna elements.

On the other hand how can the optical signals be transported from the DC to the MIMO antenna site? Obviously optical modulators can be integrated with QDL. Such an external modulator of Mach Zehnder interferometric structure implanted on Si is shown in Figure 4. Electrode resonant modulator can be formed whose RF frequency can be centered at the RF carrier frequencies can be fabricated to tailor for the operating RF carriers for different MIMO antennae. However in this paper we show here only the broadband operation of such MZ optical modulators whose bandwidth is too broad to a 3dB corner frequency of about 35GHz. Figure 4 shows the S_{21} and S_{11} transfer characteristics of the modulator.

IF multi-site MIMO are required then the RF carrier frequency can be assigned such as in the mm-wave or microwave as shown in Figure 5. The optical modulator in SI-IP should then be narrow band resonant modulation characteristics whose center passband frequency located at the assigned RF band with a 3dB passband of about 6GHz as possibly standardized for European bands [8].

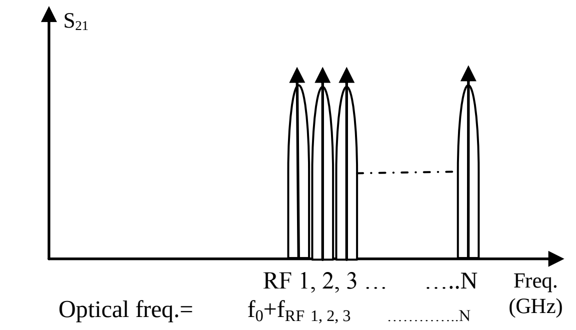

Figure 5: RF frequency spectra and equivalent resonant optical frequency responses for optical modulators for several MIMO antennae systems. f_0 = 193.51 THZ (1550nm or equivalent for 1310nm).

2.4 Photonic processors or data centers in 5G networks

When massive data channels arrive or to be transmitted to appropriate channels, they must be routed in the optical domain in order to achieve fast and transparent. They can be going through optical compensating phase or pre-distortion processing. Thus if DC operating in a centralized struature then a photonic kernel must be formed to conduct all those functions of routing, pre-distortion, post compensating, demultiplexing etc. Figure 6 proposes the structure of a photonic kernel for data centers of such 5G networks. Photonic processors carry out the post-compensation of chromatic dispersion (CD) or pre-distortion in optical domain. These processors would be implemented by Si_3N_4 or SiON integrated optical technology due to its low waveguide propagation loss and well-established fabrication methods. Optical switching matrix can be very large size, but shown in Figure 6 only a 16x16 matrix size is use, possibly using InP switch types. In Si-IP cross switch can be designed to a size of 1.5x1.5 μm^2 leading to a 256x256 matrix size of about 1mm^2. The structure of such switching matrix on SOI is shown in Figure 7 in which each individual cross switch can be formed by Si ridge waveguide and highly doped with impurity in the cross section. The switching can be done by altering the refractive index, hence the refractive index and guiding section, to redirecting the guided region to perform switching.

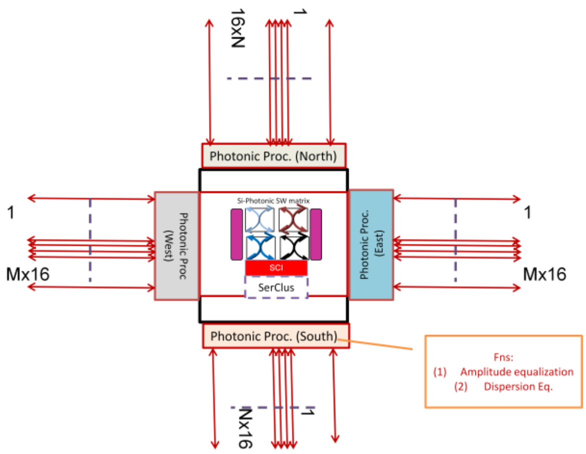

Figure 6: Structure of a photonic kernel of DC in 5G networks.

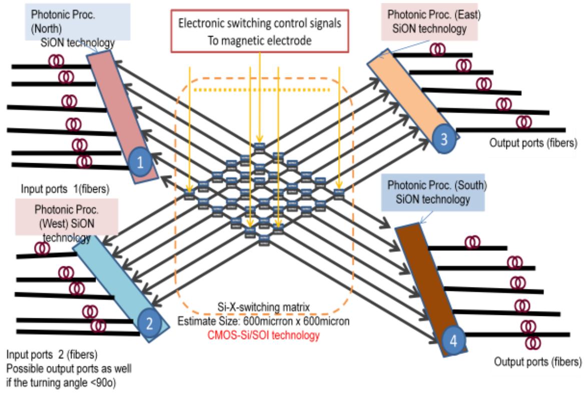

Figure 7: Photonic switching matrix

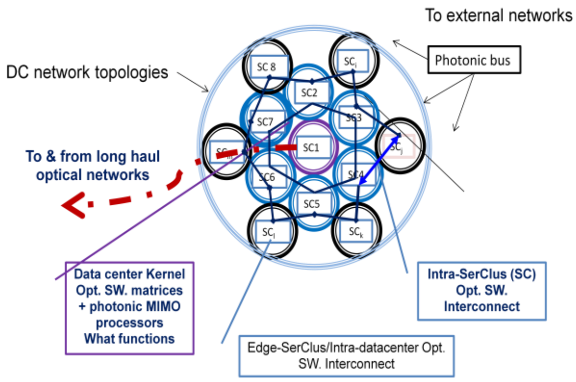

Figure 8: DC structure with a photonic kernel at the center and satellites of clusters of servers.

The photonic kernel shown in Figure 6 is propsed as the central photonic switching server to distribute the incoming optical signals and delivery of data channels via electrical to optical converters embedded in the optical interfaces between the kernel and cluster of servers.

4. Conclusion

In summary the 5G wireless networks demand ultra-agile optical networking with low cost technology. The probability of generating such sources under un-cooled and high performance QDL would permit the employment of coherent transmission techniques o offer high sensitive optical receptions. Furthermore optical switching and photonic processors can offer compensations of impairments such as CD etc. High speed modulation and switching in Si-IP would facilitate the increasing bit rates of transmission and interconnections as well as routing in the optical domain. Thus integration of Si on insulator (SOI), Si3N4 or Silica on Silicon and hybrid integration with CMOS processing systems (for DSP-coherent reception) will the challenges for low cost 5G networks.

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