All-Optical Token Technique for Contention Resolution in AWGR-based Optical Interconnects

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Abstract: This paper shows an optical technique for contention resolution in AWGR-based optical interconnects. The technique exploits the saturation effect in SOAs and a polarization-diversity scheme to implement a fully-distributed optical control plane.

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1. Introduction

Optical interconnects have emerged as a promising method to realize high-port count, low-latency, and high-throughput networks in high-performance computing systems and data centers. Several research projects have already proposed architectures for optical interconnects [1-3]. A bottleneck to the scalability of these architectures can arise from the centralized electrical control plane where the maximum number of I/O resources of currently available ASICs can limit the optical switch port count. This paper reports a proof-of-concept demonstration of an all-optical token technique for contention resolution in distributed control plane for arrayed waveguide grating router (AWGR)-based interconnects. The technique exploits the saturation effect [4] in semiconductor optical amplifiers (SOAs), and a polarization-diversity scheme, which keeps the control and data plane separated. To the best of our knowledge, this is the first attempt toward the realization of a fully distributed all-optical control plane.

2. Working principle of the all-optical token technique and architecture

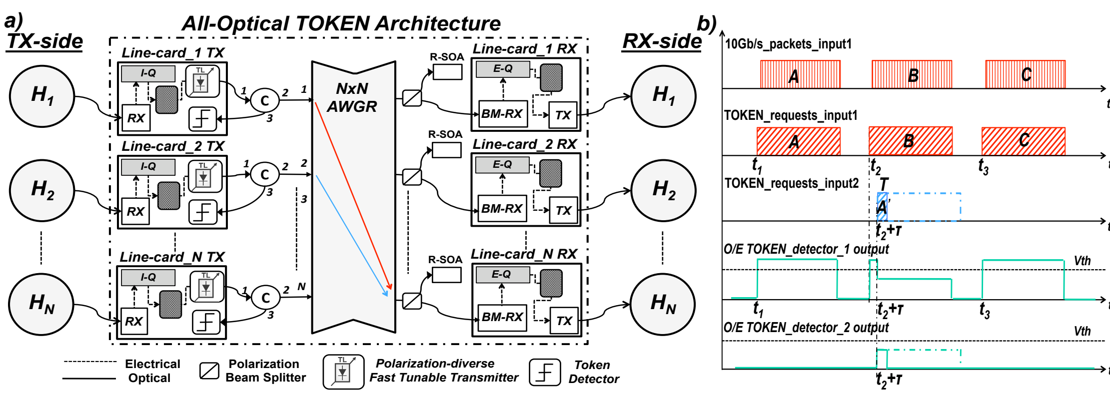
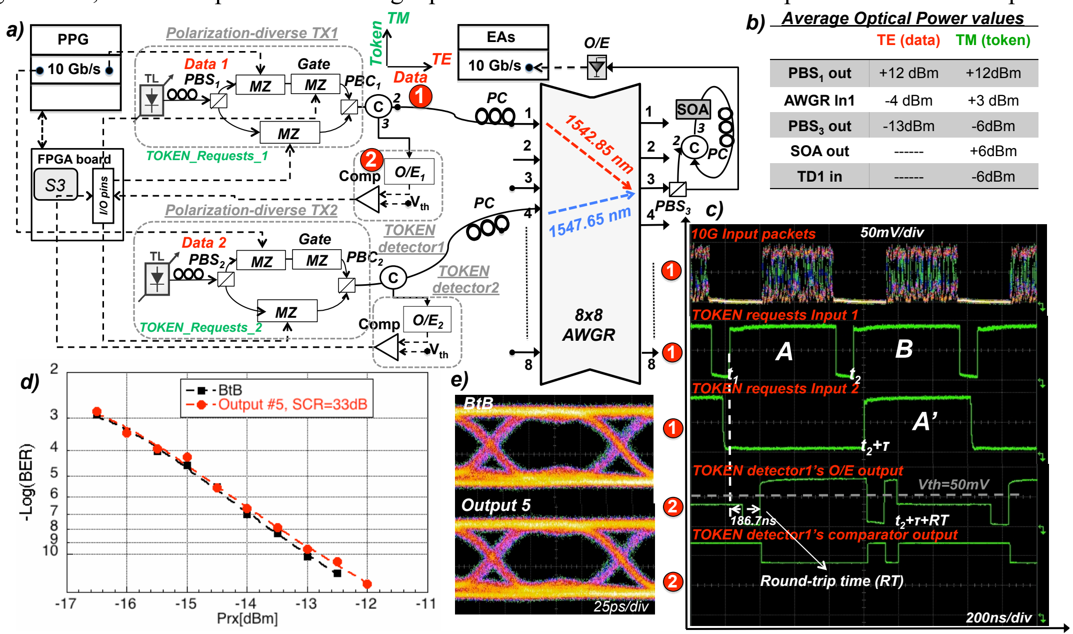


Figure 1. (a) An all-optical token architecture for contention resolution in AWGR-based optical interconnects, and (b) timing diagram.

Fig.1 explains the working principle of the all-optical token technique and architecture. Fig 1a shows the interconnect architecture. A NxN AWGR is at the core of the system. Each input port is connected to a line-card (*Line-card_i* TX). Each line-card receives packets from a host (H_i) and buffers them in an input queue (I-Q). The packets are then transmitted in the optical domain by means of a transmitter equipped with a fast tunable laser (TL) [5]. A packet transmission is initiated upon the reception of the token by a token detector (TD). A polarization-diversified (PD) scheme can be used to avoid interference between the token-based control plane messages and data packets. An optical circulator (C) is used to extract the counterpropagating token. Each AWGR output is then connected to a polarization beam splitter (PBS) to separate the token and data path. One PBS output connects to a reflective SOA (R-SOA), which is the key component in this token-based contention resolution technique. The PBS data output connects to a linecard (*Line-card_i RX*), which buffers the received packets in an egress queue (E-Q), and transmit them to the destination. Fig.1b explains the working principle of the token technique. At t_2, line-card1 needs to send a packet to output_N and it tunes its TL to λ_{1N} to generate token request B on TM polarization. The RSOA at output N reflects the signal extracted by the PBS, which reaches the *linecard_1* TD with an optical power P_{TO1}. The O/E converter in the TD generates an electrical signal with $V_p = V_{TO1}$. At $t_2 + T$, *line-card_2* has also a packet for *output_N* and it tunes its TL to λ_{2N} to generate the token request A' on TM polarization. RSOA reflects the token request extracted by the PBS, which reaches the *linecard_2* TD with an optical power P_{TO2}. The O/E converter in the TD generates an electrical signal with $V_p = V_{TO2}$. Let us assume that the R-SOA works in the strong saturation regime. At $t = t_2$, $P_{TO1} = X$ dBm and $V_{TO1} > V_{th}$. A comparator in the TD generates a logic "1" and *linecard_1* gains the token and starts transmission on the TE polarization. At $t = t_2 + T$, due to the saturation effect in the R-SOA, we will have P_{TO2}= (X-3) dBm. Then V_{TO2} = V_{TO1}/2 < Vth. The token is not available until *linecard_1* finish to transmit (linecard2 needs to retry with a random backup time). Then *linecard_2* needs to stop the token request A'. Note that the voltage drop in O/E TD1 output at $t = t_2 + T$ can be used to sense whether or not other linecards need to access the same output. This information can be used to release the token and guarantee fairness.

3. Experimental setup and results

Fig.2a shows the testbed used for the experimental demonstration. Two PD TXs are connected to input ports 1 and 4 of a 200GHz-spacing 8x8 AWGR (uniform insertion loss= 8dB). Polarization controllers (PCs) at AWGR inputs align the signal polarization with the PBSs at the AWGR outputs. Alternatively, all PM components could be used. Each PD TX includes a PBS and PBC to polarization multiplex the data and token path. The token arm of the PD-TX includes a Mach Zehnder (MZ) modulator. Two MZs are used in the data arm as data modulator and gate. The gate is controlled by an FPGA and remains open unless the token request is not granted (this is not shown in this paper). The FPGA generates also the token requests, while the 10Gb/s 406.9ns-long packets are generated with a pattern generator, with each packet containing a portion of 2^{31}-1 PRBS. A PBS is placed at AWGR output 3. The



	TE (data)	TM (token)
PBS1 out	+12 dBm	+12dBm
AWGR In1	-4 dBm	+3 dBm
PBS3 out	-13dBm	-6dBm
SOA out	------	+6dBm
TD1 in	------	-6dBm

Figure 2. a) Experimental testbed. b) Optical power values in the testbed. c) Measured traces. d) BER measurements. e) Eye-diagrams.

PBS extracts the token requests, which enter in a R-SOA implemented here with an optical circulator and a SOA. The PC at the SOA output maximizes the optical power going back through the PBS and reaching the TD1. The second PBS output connects to an O/E converter for BER measurements on the data path. Fig.2c shows the measured traces for the packets at AWGR input1, token requests at AWGR input 1,4 and TD1 O/E and comparator output. Note that the comparator output uses negative LVDS logic. Fig. 2d shows BER measurements for the data packets at AWGR output 3. It is important to guarantee a high polarization extinction ratio (PER) at the PBS to minimize the crosstalk from the token path. In this experiment, a signal to crosstalk ratio (SCR) of 33dB is maintained to guarantee negligible penalty due to the coherent crosstalk and incoherent crosstalk from the contending token request. Note that if two or more token requests reach the R-SOA at the same time, with a time difference within the SOA gain response time (which is in the order of 100ps) none of the requests will be granted.

4. Conclusions

We reported a first-time demonstration of an all-optical token technique for contention resolution in an AWGR-based optical interconnects. The technique eliminates the need of any centralized electrical control plane, making use of a fully-distributed token-based contention resolution scheme based on the saturation effect in SOAs.

5. References

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