北京郵電大學
BEIJING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

UCDAVIS COMPUTER SCIENCE

Photonic Firewall Oriented All-Optical Binary Pattern Recognition

Speaker: Ying Tang

PhD student, State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications (BUPT), China

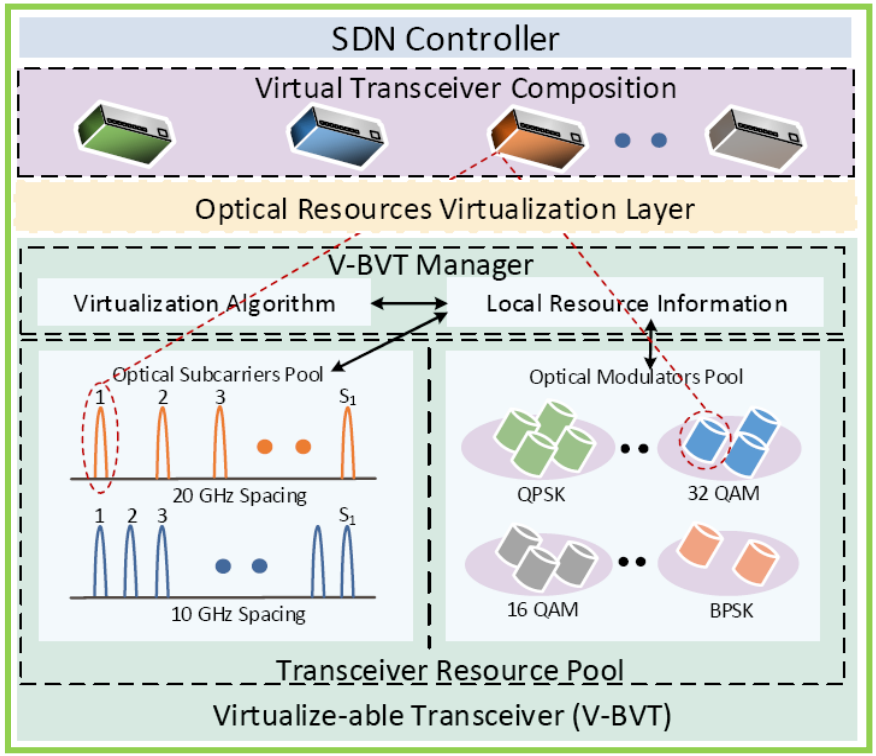
Group Meeting, Friday, October 11th, 2019

Outline

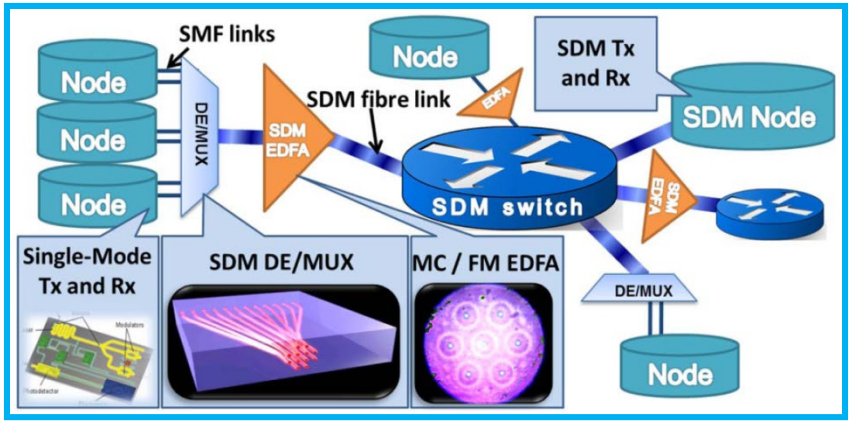
1. Background
2. Applications deployment with photonic firewall
3. All-Optical Binary Pattern Recognition using SOA-MZI
4. Future works

Background of optical networks

Optical networks have been widely used in access, aggregation, backbone transmission, data center interconnection, satellite networking, etc. Currently, they are moving towards ultra-large capacity (time/space/frequency multiplexing), flexible control (SDON) and intelligent optimization (AI).



SDN enables the reconstruction of optical network flexibly and efficiently



SDM increases the transmission capacity

AI enables the traffic, fault, resource management autonomously and is currently developing rapidly!

Security challenges

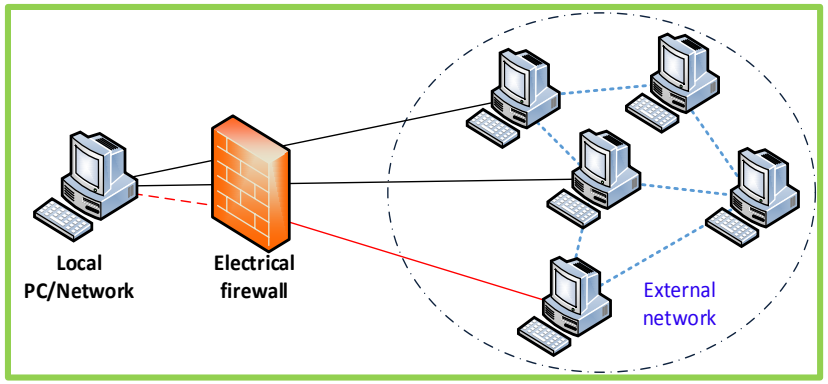
Due to the large amount of transmission information, wide coverage, and QoT sensitivity, optical networks are highly vulnerable to eavesdropping and attacks. And current protection measures for optical networks are weak.

EternalBlue DROWN Telecom fraud

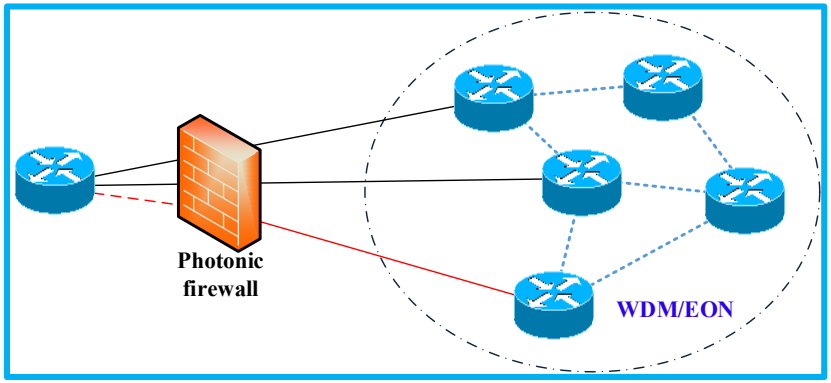
Attacks & research

- Common attacks
  - Aim for optical devices
    - Optical fiber: eavesdropping, in-band interference, signal delays, etc.
    - Optical amplifier: gain competition, modulation effect eavesdropping, etc.
    - Optical cross connector: out-of-band crosstalk, in-band crosstalk, etc.
    - Optical demultiplexer: leakage, etc.
  - Aim for network management
- Main research directions
  - OCDMA, quantum encryption, chaotic encryption
  - Node/link reinforcement, spectrum shifting, attack detection, specific signal analysis, etc.
  - **Photonic firewall**

Photonic firewall VS electrical firewall



Location of electrical firewall



Location of photonic firewall

Main types of electronic firewall

- Packet-filter firewall
- Proxy firewall
- Stateful inspection firewall

⋮

Development direction of photonic firewall

- Packet-filter firewall (current)
- Proxy firewall (near future)
- Stateful inspection firewall (future)

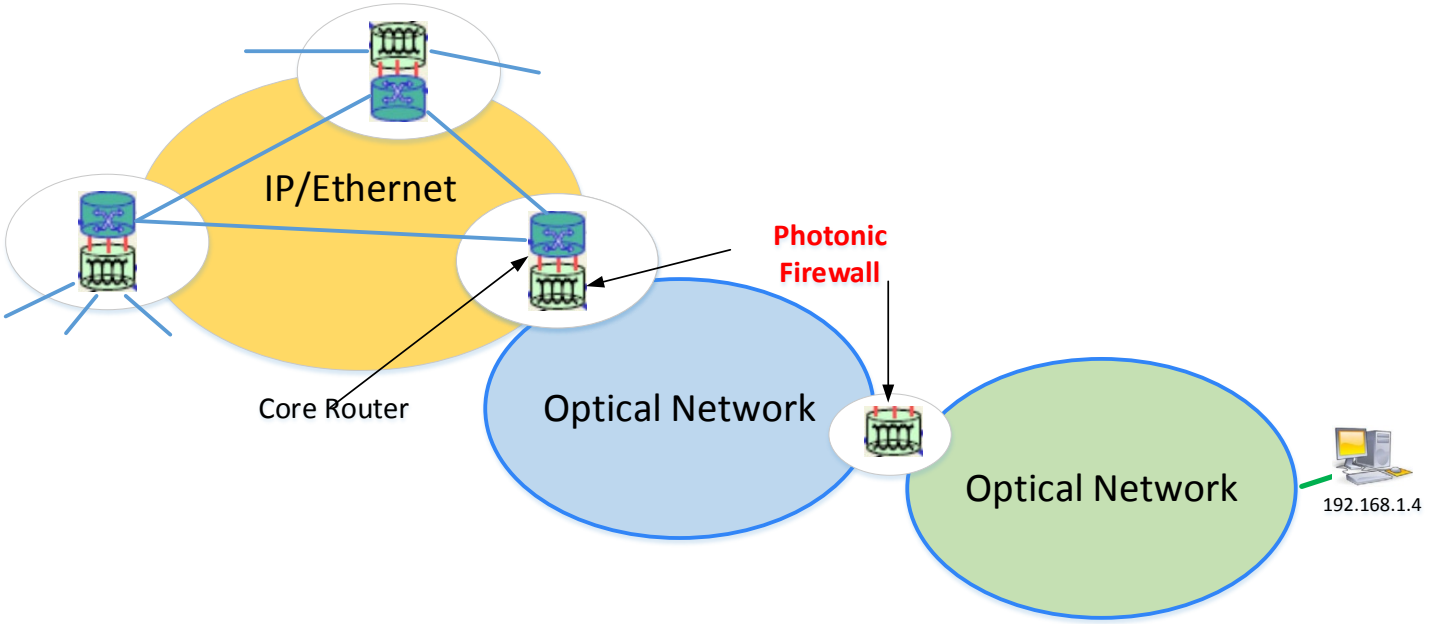
⋮

Photonic firewall VS electrical firewall

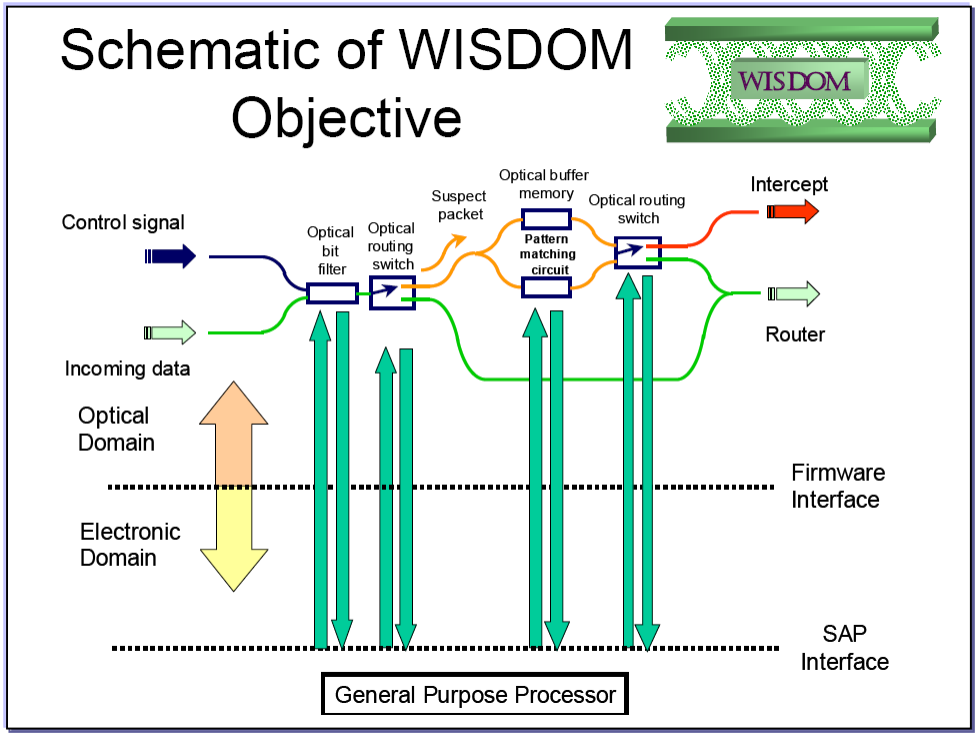
	Electrical firewall	Photonic firewall
Principle	Leveraging electrical logic gates, including electrical AND gate, OR gate, etc. to compose integrated circuits.	Leveraging the non-linear effects of optical devices, including XPM, XGM, FWM, etc.
Energy	Only operate in electric domain. Optical signals need to be converted into electrical signals for pattern recognition, which consumes a lot of energy.	Operate directly in optical domain without O-E-O conversion, which consumes less energy.
Speed	The rate of processed optical signals can not exceed 2.5 Gbps.	Optical signals over 40 Gbps can be processed.
Volume	Take CISCO ASA5515-K9 as an example (maximum throughput is 1.2 Gbps), we needs at least 33 electrical firewalls to process optical data with 40 Gbps.	One photonic firewall is enough for processing optical data with 40 Gbps.

What is photonic firewall?

Photonic firewall: It leverages the all-optical pattern matching to directly identify the signals in the optical domain, then it can distinguish hidden network intrusions and attacks, and finally selects corresponding defense means according to the set security policy. Thus, it can realize intrusion detection and security protection in the optical domain.



WISDOM



Wirespeed Security Domains using Optical Monitoring, WISDOM

Goal

Developing a new optical processing module for photonic firewalls to achieve secure transmission of optical signals at 40Gbps.

Participant

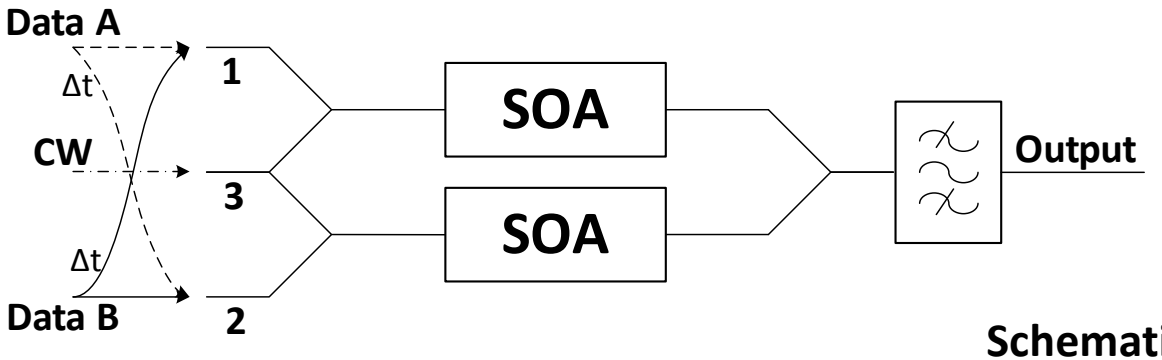
Tyndall (Ireland), FORTH (Greece), CIP (Britain), Avanex (France), BT (Britain)

Period

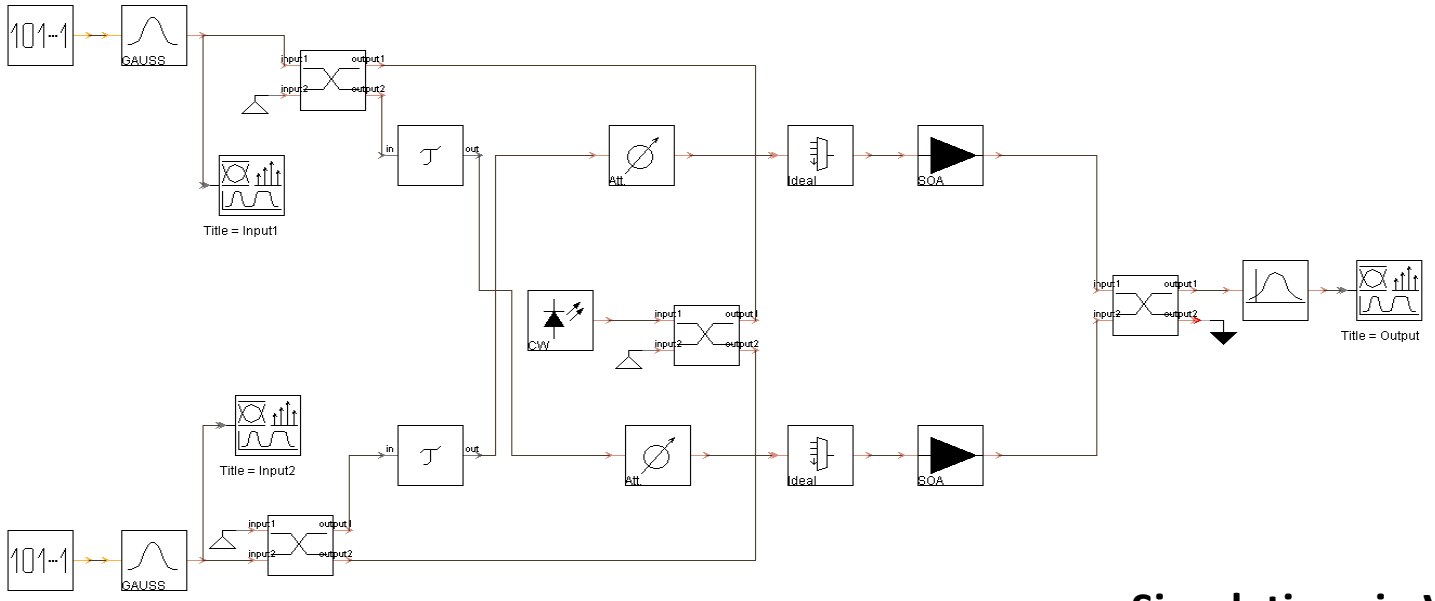
It lasted 3 years from 2006, and spent 1.91 million euros.

WISDOM realized intrusion detection of optical burst data packets of 40 Gbps, and is compatible with two optical signal formats of OOK, i.e., non-return-to-zero and return-to-zero. The optical signal pattern matching circuit supports the length of a target up to 256 bits. However, there is currently no optical layer intrusion detection technology for continuous optical data above 40 Gbps.

XOR based on SOA-MZI

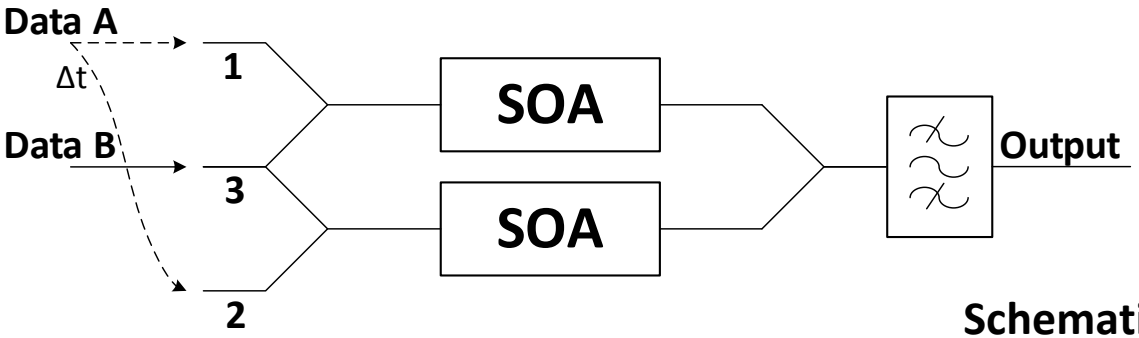


Schematic

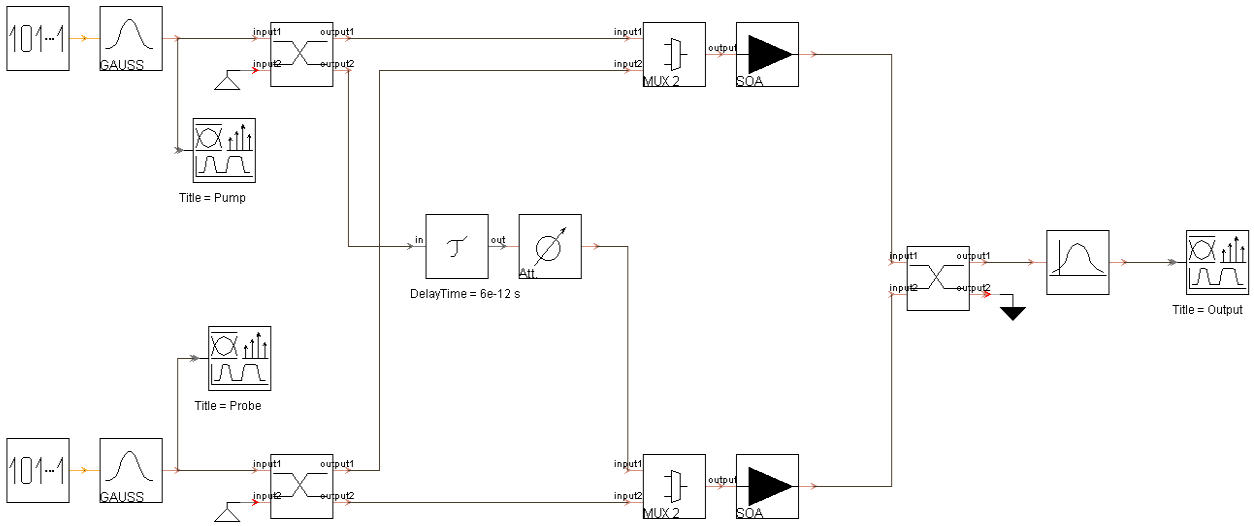


Simulations in VPI

AND based on SOA-MZI

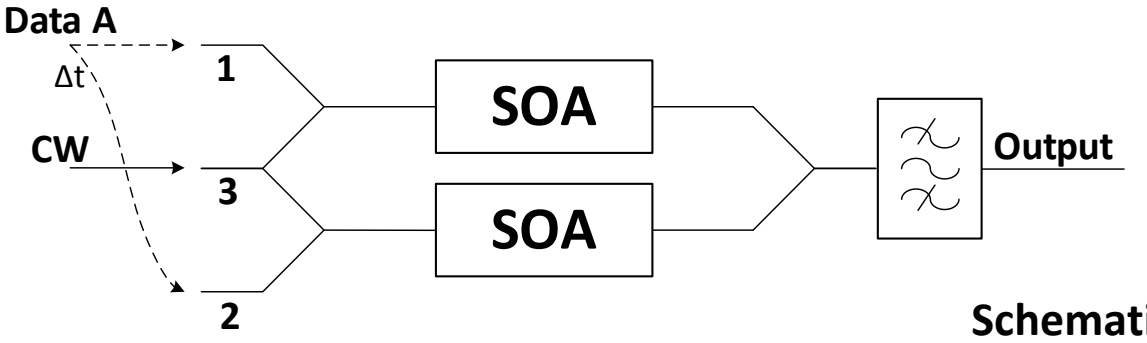


Schematic

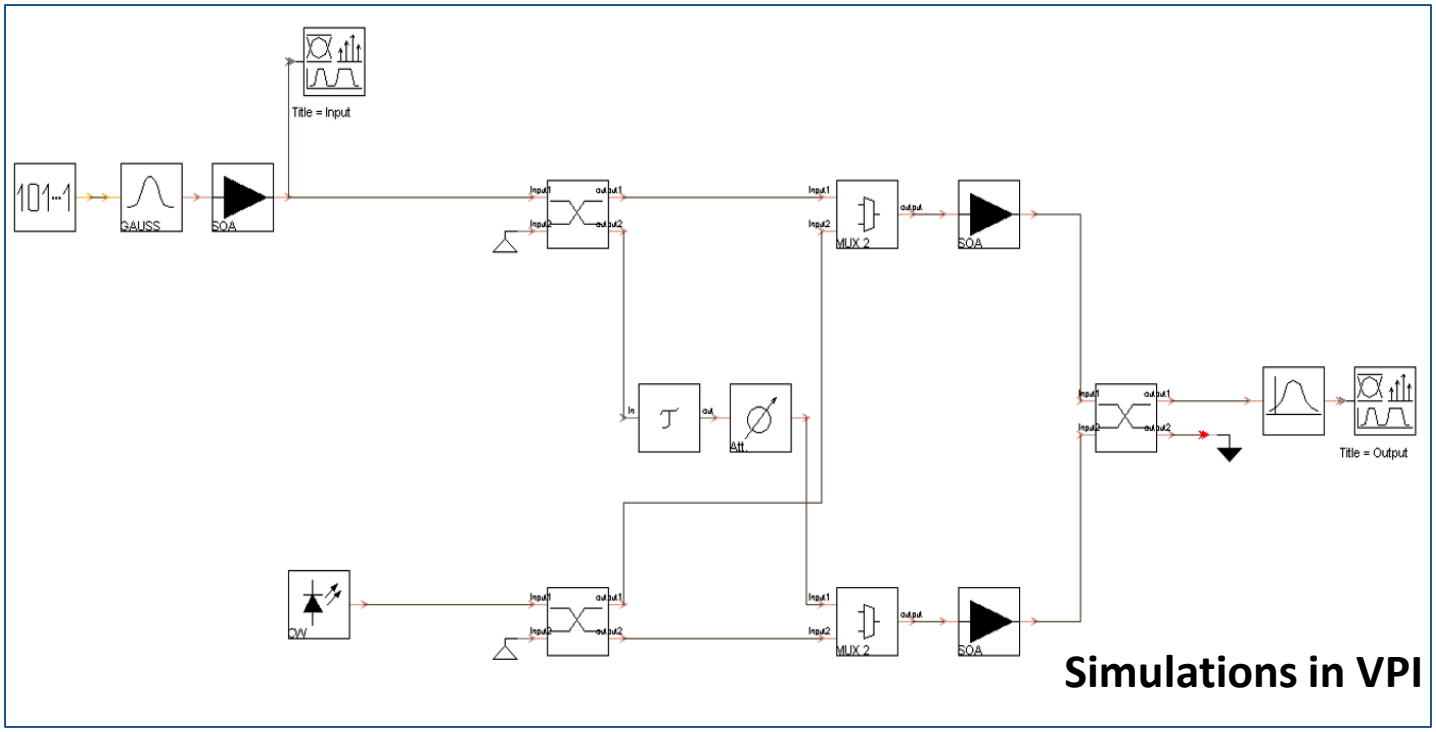


Simulations in VPI

Regenerator based on SOA-MZI

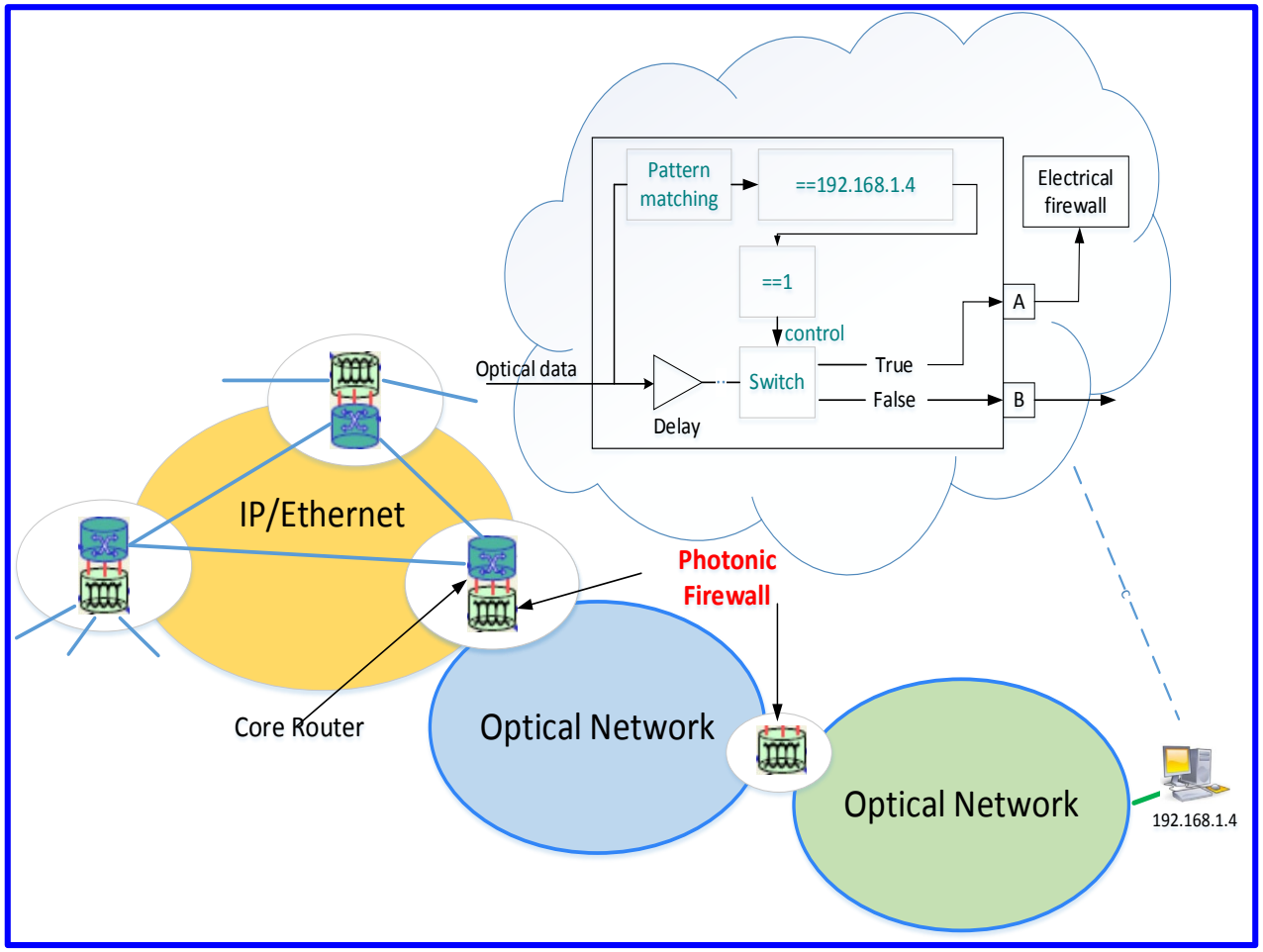


Schematic



Simulations in VPI

Technical principle



Basic principle of photonic firewall

Types of target:

1. IP address
2. Port number
3. Specific sequence
4. …

Basic process:

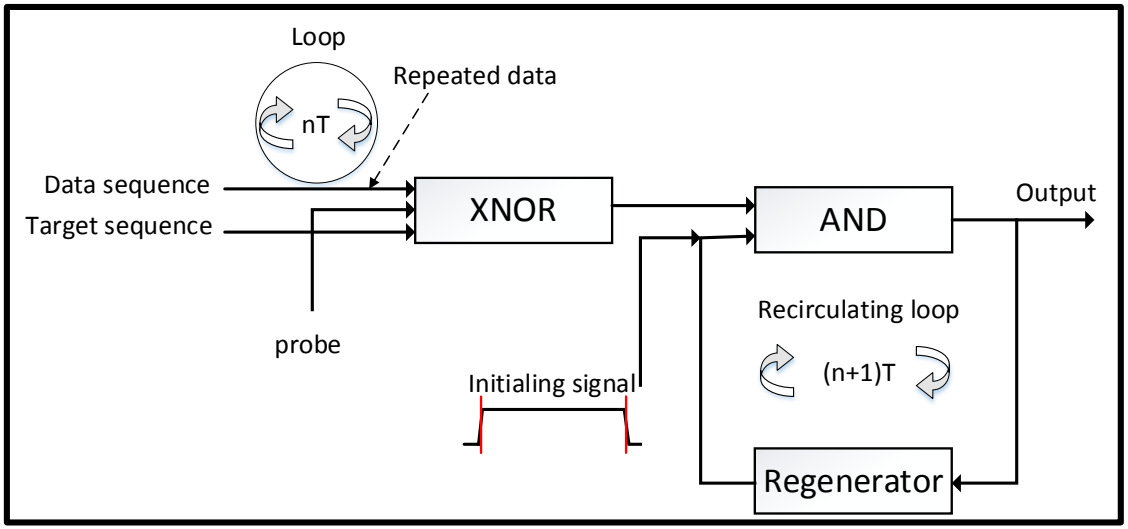
1. Splitting
2. Pattern matching
3. Safe handling

Main application:

1. Gateway node
2. Core node
3. Access node

Delay: offset the time consumed by pattern matching.

Technical principle



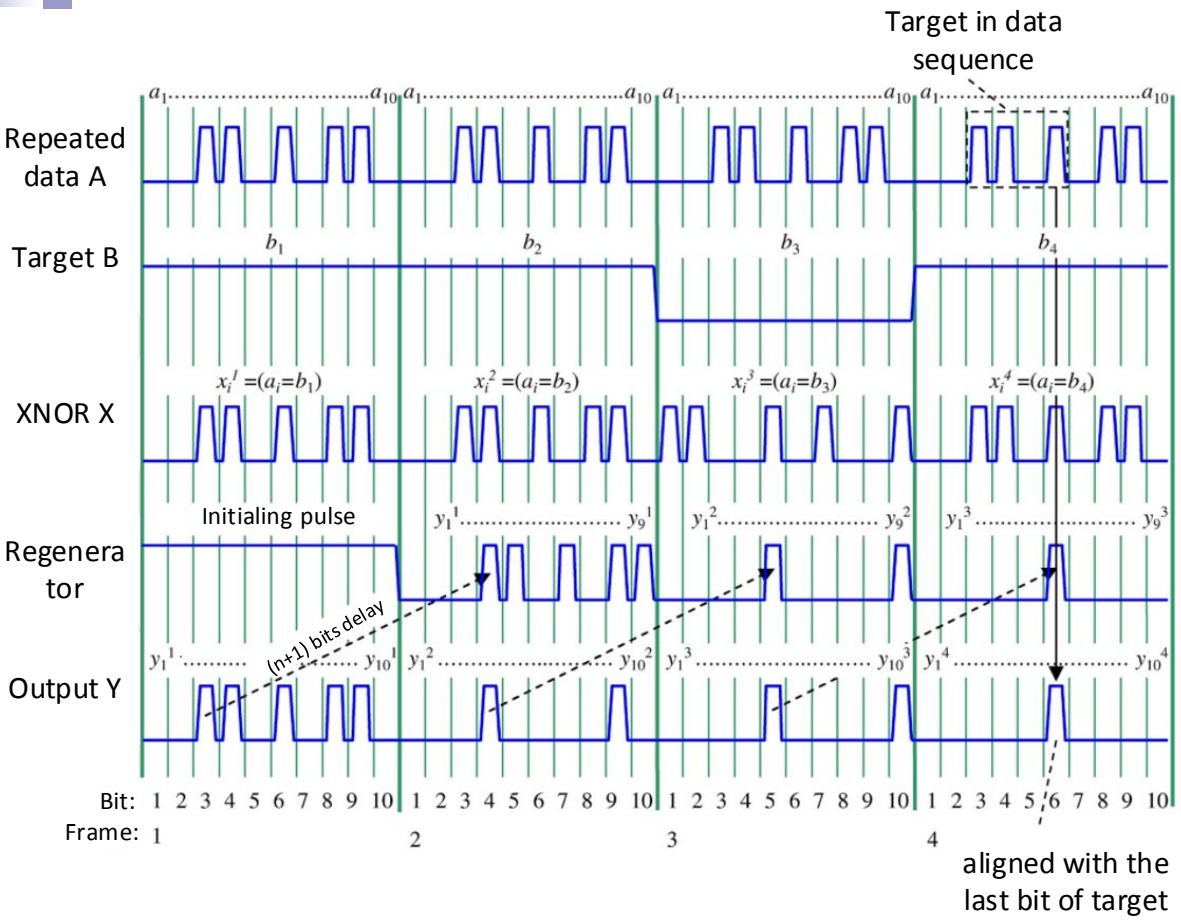
The module of pattern matching consists of:

1. XNOR gate
2. AND gate
3. Regenerator（for delay）

Cycle period： n*T

- The input data first compare with the target using XNOR, then the output enters the AND gate.
- A part of output of AND gate enters the regenerator with a delay of (n+1)T, and then, it compares with the output of XNOR using the AND gate.

Technical principle



Principle of pattern matching

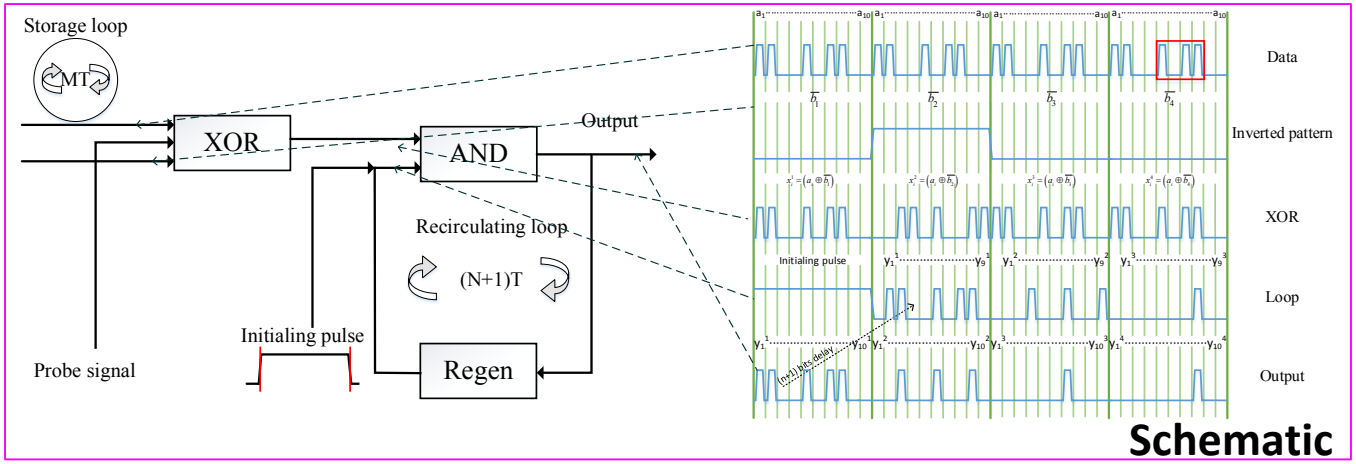
Step 1: XNOR compares all bits in data with the first bit of target, giving the output of X_1, then an initialing pulse and X_1 enter the AND gate and get the first frame of output Y_1 .

Step 2: XNOR compares all bits in data with the second bit of target, giving the output of X_2, then the (n+1) bits delay of Y_1 and X_2 enter the AND gate and get the second frame of output Y_2 .

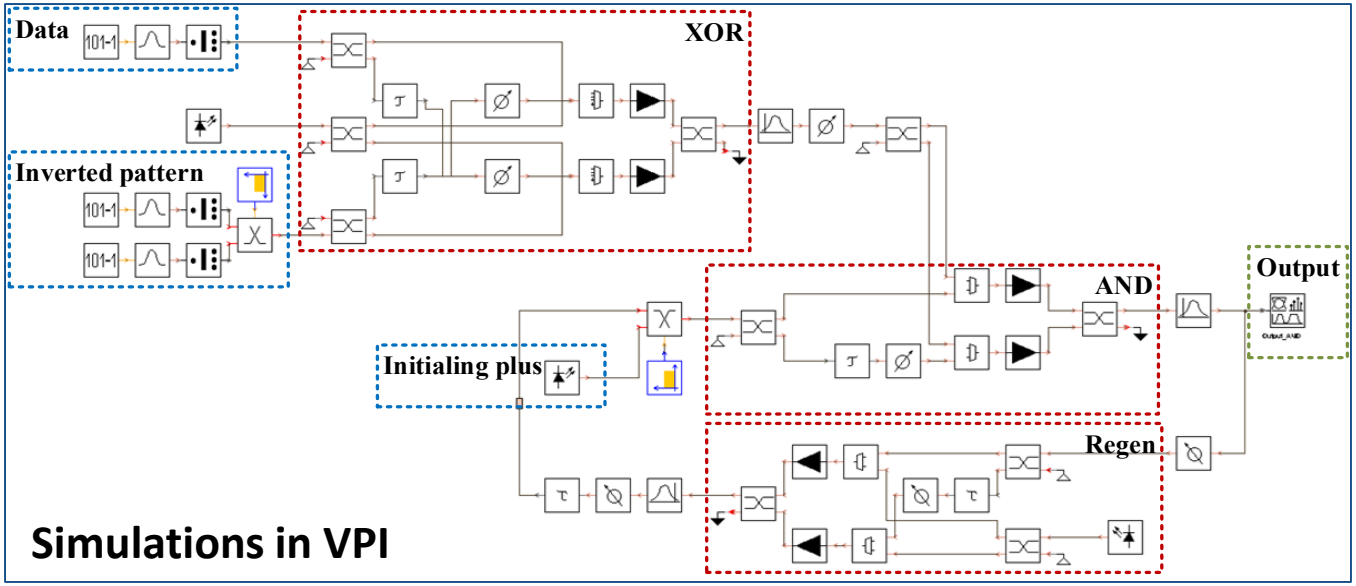
⋮

If a target exists in the data sequence, a 1-bit wide pulse will appear in the final output. In addition, the position of the pulse also indicate the location of target.

All-optical binary pattern recognition system



Schematic

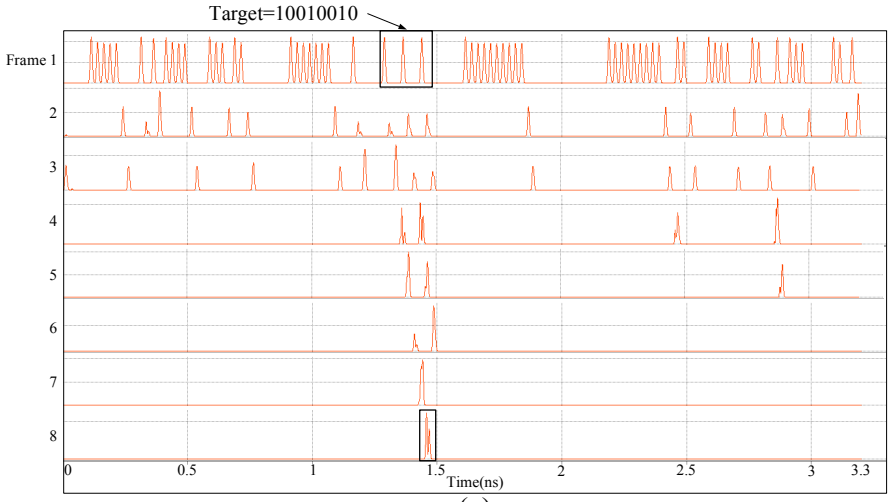


Simulations in VPI

Simulation results

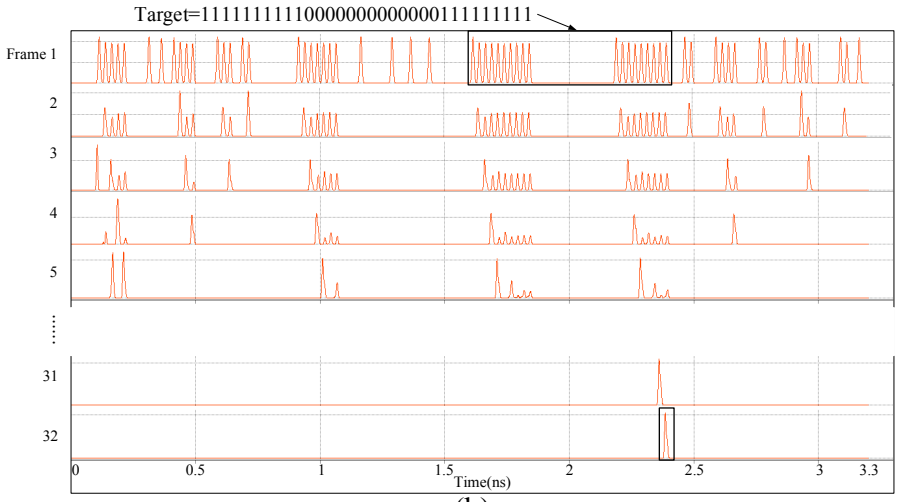
Performance of the system

- The transmission rate of optical signal can reach 40 Gbps.
- 32-bits target can be correctly recognize in a data with a length of 128-bits.



(a)

The output of the system with 8-bits target and 128-bits data pattern at 40Gb/s.

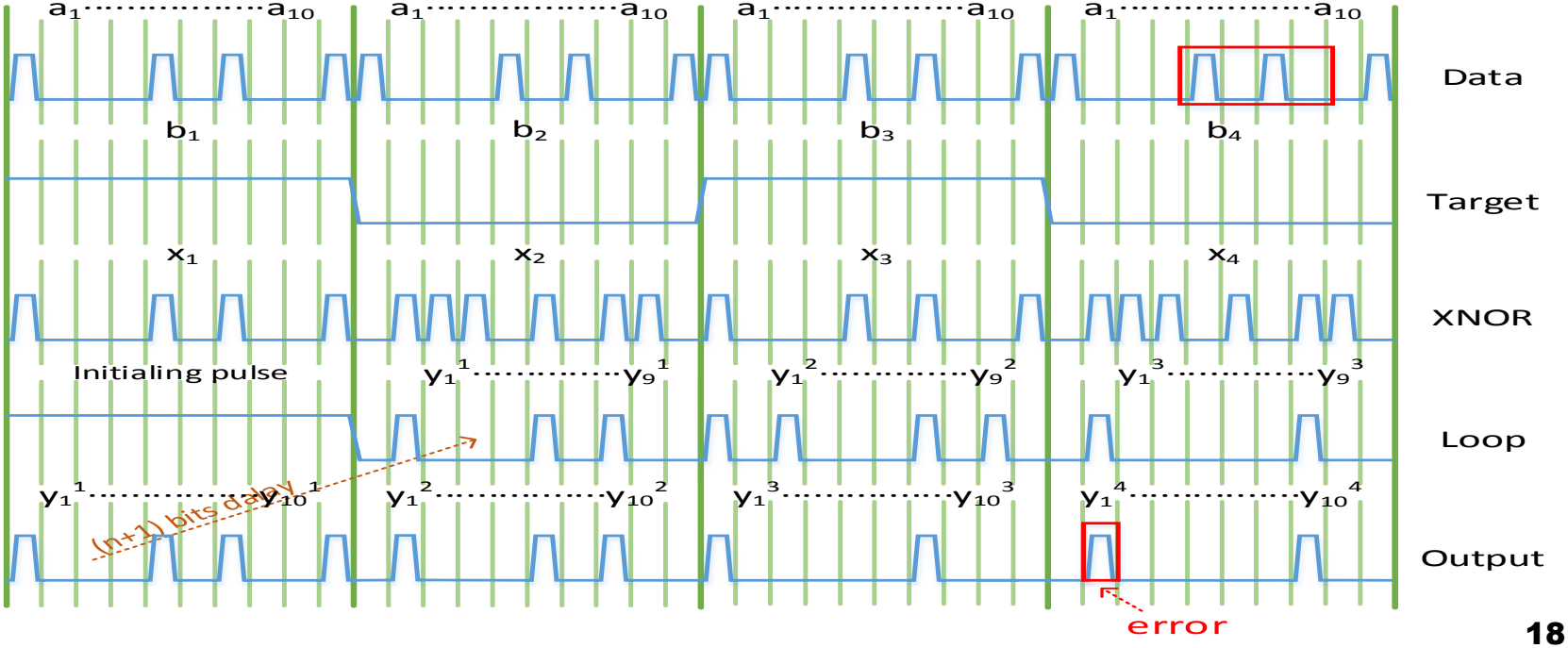


(b)

The output of the system with 32-bits target and 128-bits data pattern at 40Gb/s.

Drawbacks

- **Relatively low matching efficiency**
  - The data sequence needs to loop N times to get the results.
  - SOA-based schemes have limited operation rate (hardly exceed 40Gbps) due to the slow carrier recovery time.
- **Errors occur in extreme cases**



Future works

- **Construct logic gate based on HNLF**
  - HNLF-based schemes are more desirable because of femtosecond response time of fiber nonlinearity.
- **Design and build the system that support data with high modulation format**
  - The data transmitted in existing optical networks is not modulated by OOK. It usually modulated by high modulation format, such as QPSK and 16QAM.
- **How to avoid errors in the output?**
  - Neglect the first few bits of the output?
  - Design a new architecture that can avoid the error?

Thank you for your attention!

Speaker: Ying Tang

Group Meeting, Friday, October 11th, 2019