A Novel Optical Switching Architecture for Metropolitan Photonic Networks with a brief review of Photonic Switching in Brasil

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Agenda

- What is photonic switching
- Brief historical perspective
- Experiments
- Models & simulations
- Conclusion
what is *photonic switching*?

- Dynamic routing of network traffic in optical networks, without actually leaving the optical domain;
- The time spans of the switching process determine whether it is:
  - Optical packet (OPS) => 10 µs ;
  - Optical burst (OBS) => 100 µs ;
  - Optical circuit (OCS) => 10 ms ;
- OCS applied at WDM trunk/long-haul or metro-core networks;
- OPS & OBS are dynamic processes, very attractive for application in metro-access networks .
Introduction

- Photonic Switching Networks & WDM Networks
  - optical packets (OPS) as a traffic solution for limited area networks high granularity, availability & flexibility;
  - possibility of aggregation in optical burst switching (OBS);
  - WDM networks supporting backbone traffic (OCS);
Metro-access network: *add-drop traffic*

**Optical Packet Switching – Application**

Fibre everywhere...

FTTB/C
fiber to building or curb

FFTA
fiber to area

Optical Packet Switching

**Optical Node**

Nó k

Nó i

Nó j

Add/drop optical packet

Add/drop optical packet

Fibras simples
Fibras duplas
Historical perspective

- **first project sponsored by Ericsson AB**
  - Through Ericsson do Brasil = OCS & OBS at CPqD and Unicamp; Nov.2000-Nov.2002 [total budget ~U$1.5mi]
  - 02 indep. Projects: team and labs;

- **second project sponsored by Funttel (MinCom)**
  - At CPqD -- 2002-2003, (some overlap)
  - OCS was adopted by Giga Project
  - OPS was direct funding [total budget ~R$600 k]

- **third project sponsored by Funttel**
  - At CPqD (direct funding...) 2004-2006

\[New \text{ Federal Govt. in Jan 2003. Revision of Funtel in late 2004.}\]
Experiments
Optical Packet Switching – Characteristics

Manhattan St.
2x2 mesh topology for metro-access netwk

- Frequency Header Optical packets:
  - simple & fast header recognition
  - fast switching (~µs) and low latency
  - asynchronous operation
  - RF in-band low frequency header (1-20 MHz)
  - high-capacity digital payload, transparent to rate & format (1-10 Gb/s)
  - readily available components

packet traffic simulations show that bufferless optical mesh networks have better throughput than ring or star.

FH Opt Pkt

τp=2-6µs (typ.)
Optical Packet Switching & Routing

Node k

In 1 → Optical Switch → Out 1

In 2 → Optical Switch → Out 2

Drop

Header Recognition → Decisions & Actions → Add

Local User

Requirements: **Golden Rules**

- ✓ no buffering in the optical layer;
- ✓ optical switch is blocked when a packet is present;
- ✓ a packet can be deflected but not cut or lost;
- ✓ switching operation is packet-by-packet
Optical Packet Switching – Experiments 1

Experimental Set-up (drop function; 3 freqs.)

- LASER
- Polarization control
- EDFA
- EOM
- Filtro Óptico
- Optical delay line
- Acousto-optic switch 1
- Opt Tap
- Acousto-optic switch 2
- Digital Pattern Generator

Packet generation:

Packet detection & routing:

HRC response (rise & fall times) is 40 ns
Acousto-optic switch response is ~2 µs;
Optical switching (rise & fall times) is ~90 ns;
**Optical Packet Switching – Results 1**

Experimental \(\text{drop function; 3 freqs.}\)

- **Drop f_1**
  - OptSw1
  - outport D

- **Follow f_3**
  - OptSw2
  - outport C

- **Follow All**
  - both Opt Sws \textit{On}

- **Optical signal at tap**
- **Optical signal at output**

- **Drop f_2**
  - OptSw2
  - outport D

- **Optical signal at tap**
- **Optical signal at output**

- **Follow f_3**
  - both Opt Sws \textit{On}

- **Follow All**
  - both Opt Sws \textit{Off}

*The Golden Rules work!!*
Experimental Set-up (deflection routing; 2 freqs.)

- LASER
- polariz.
- control
- EOM
- Filtro Optico
- Digital Pattern Generator
- Optical Switch
- f1, f2, f3
- HRC
- Opt Rx
- OR
- NOR
- J, K
- Clk
- LDC
- Digital Oscilloscope (20 GS)
Experimental (*deflection routing; 2 freqs.*)

Control circuits HRC and LDC **on**

Control circuits HRC and LDC **off**

The Golden Rules still work!!
Experimental Set-up (deflection routing and drop; 3 freqs.)

- Packet generation
- Packet detection, deflection & routing

- LASER
- Polarization control
- EDFA
- EOM
- Optical Filtre
- Digital Pattern Generator
- Optical Switch
- Opt Rx
- HRC
- LDC
- Electrical
- Digital Oscilloscope
- (20 GS)
Optical Packet Switching – Results 3

Experiments (deflection routing, 2 freqs.; and drop 1 freq.)

Opt Sw 1 - HRC & LDC on
Opt Sw 2 - HRC off

Opt Sw 1 - HRC & LDC on
Opt Sw 2 - HRC on (drop)
Publications


Patents

- Ericsson – 2002; spread header solution
  - FRBarbosa, ACSachs, MTFurtado;
- CPqD – 2004; field-header solution
  - FRBarbosa, ACSachs, LPezzolo.
Simulations
packet traffic simulations show that bufferless optical mesh networks have better throughput than ring (or star).
Ring Topology
Anel 16 nós
Conditions:
- Deflection routing
- No optical buffers
- Optical packets block optical switches;
- Single packet buffering at node ingress
Modelo para cálculo de vazão e atraso

Manhattan street (9 nodes)

⇒ Traffic originates at any node and arrives at node 1;
=> Any other node is equivalent.

Matriz de Tráfego:

Traffic Analysis

Network capacity
(aggregate throughput)

\[ C = \frac{2 \cdot N \cdot S}{H} \]

Node user capacity

Total

\[ R = \frac{C}{N \cdot (N - 1)} \]

Effective

\[ R_e = R \cdot L \]

Packet loss fraction

\[ PLF = \frac{p}{p + r} \]

\( p = \) packets sent
\( r = \) packets received

\( L = 0-100 \% \) link usage
Network throughput

![Network throughput graph](image)

- Manhattan Street
- Anel

**Links with 1 Gb/s & 10 km**

**OBS.: Anel de 4 nós e MS de 4 nós são a mesma topologia**
NS Simulation Scenario

- MS topology with 16 nodes
- Bandwidth of 2.5 Gb/s
- Packet size of 650 bytes
- Optical links length of 2 km (10 µs)
- UDP protocol in the transport layer to avoid packet retransmission
- CPVI traffic
- These simulations were performed using Network Simulator (NS-2)
Results

Performance comparison of a MS-16 network with –
deflection routing (DR) and
without deflection routing (NDR)

=> Notice that for ntwk loads above 40%,
everything is lost anyway.
Results (2)

Performance comparison of a MS-16 network with deflection routing and single packet optical buffer.
Summary Simulation

- Mesh architecture demonstrated to provide better and easier network performance;
- Natural matching to the physical layer of fiber radio networks;
- Modified Manhattan Street topology to avoid congestion and improve the overall capacity of the optical access network.
- Analytic Simulation with excellent results and efficient timing!
- Results compatible with experiments;
- Simtime “minutes”; SW -- MatLab (vectors & matrices) and Origin graphs
**Publications**


Optical Burst Switching

Client Network

IP, Ethernet
or IP/MPLS

Optical Nodes

Other client network

IP, Ethernet
or IP/MPLS
Optical Node Architecture

a bidirectional diagram

Client IP Netwk

Router

Control Plane

Operação e controle

Burst Assembler

Hardware Proprietary

Operação e controle

λ_{data}

Sinal do plano controle

Plano controle

λ_{cont}

FDL

Photonic Switching
- Optical packet switching Ring network operating in burst mode
- Electronic Buffering at client side, *not* at optical ntwk layer;
- controlled by the use of tokens issued by the control plane;
- Fast switching process (tens µs) based on very fast (tens ns) optical (photonic) switching architecture;
- Ethernet compatible, transparent to rate; moderately opaque.
To summarize:

- Solutions for optimized transport in Innovative Optical Networks, based on OPS, OBS (and OCS) have been proposed and demonstrated;
- All are transparent to rate & format (within reasonable limits...)
- Optical bufferless node architectures have been implemented, with add-drop functionalities, based on fast switching times (<2 µs), and very low network latency;
- Optical packets have a frequency header and a high-capacity digital payload;
- Optical bursts are controlled by a controlplane, and share fast OPS;
- OCS is controlled by (different) controlplane and use “slow” WDM optical switches;
- Optical grade transmission allows for BER<10^{-12} and node links 20km; multi-hop deflection paths in excess of 60km.

&...
Photonic Switching – Conclusion 2/2

Last, but not least …

- WDM as ‘longitudinal slicing’ of fibers; Optical Packets & Bursts as ‘transverse slicing’…
- Increase of granularity in transparent WDM networks, with the resource of optical packets (single & burst);
- More effective use of available bandwidth; reduced latency and increased network throughput; ($$, ROI, user QoS)
- Application in Optical Metro-Access Networks: Techno-economic appeal: attractive cost p/ bit through
  - reduction of equipment in the optical network,
  - simple infra-e, and high reliability.
- Mesh topologies required in most cases.
Photonic Switching – Major players

Felipe Rudge Barbosa
Edson Moschim
Luis Bonani
Antonio C. Sachs
Decio Maia Jr.
Leonardo Pezzolo
Marcos Salvador
Eduardo Mobilon
Mario Furtado
Alberto Paradisi
Obrigado!

Thanks for coming!

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Não sou conformista.
O Homem só não consegue
o que não deseja.

Zeferino Vaz

foundation year = 1969