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New Approaches to Optical Packet Switching in Carrier Networks

Thomas C. McDermott
Chiaro Networks
Richardson, Texas

Outline

- **Introduction, Vision, Problem statement**
- **Approaches to Optical Packet Switching**
  - Optical Cross-connects (& GMPLS)
  - All-optical routing
  - Hybrid Optical routing
- **Key Technologies enabling each approach**
  - Optical switching, optical header processing, synchronization, etc.
- **Advantages & Disadvantages of each approach**
  - Advantages
    - Cost, bandwidth, granularity, scalability, QoS, etc.
  - Disadvantages
    - Unsolved technical & performance
    - Difficult operational issues
- **Key Issues**
- **Conclusions**

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Vision, Problem Statement

- **Vision: Avoid electronic processing at transit packet routing nodes by using fast optical switching.**
  - Data rate independent, format independent.
  - Promise: much simpler packet nodes.
  - But of course, some kind of routing header needs to be understood by each router.
  - Therefore: separate the header from the payload
    - Process the header (electronically?)
    - Don’t touch the data.
- **Problem: no optical RAM**
  - Only fiber delay lines exist: limited time management capability.
  - Leads to all manner of practical problems!
  - Approaches: Flow Switching, Deflection Routing, etc.

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Definition of an Optical Packet

Two basic types of optical packets:

- **Packet over Sonet / SDH.**
  - Industry standard format today.
  - Sometimes overly-eager marketing types call this IP-over-WDM, implying what it is not.
  - Not directly switch-able in an all-optical network
    - Requires extensive electronic processing at each routing point.
- **Optical burst over lambda**
  - No standard format exists, various different researchers have experimented with a variety of formats.
  - Goal is to make it directly switch-able in an all-optical network.
    - Avoid altering the data payload.

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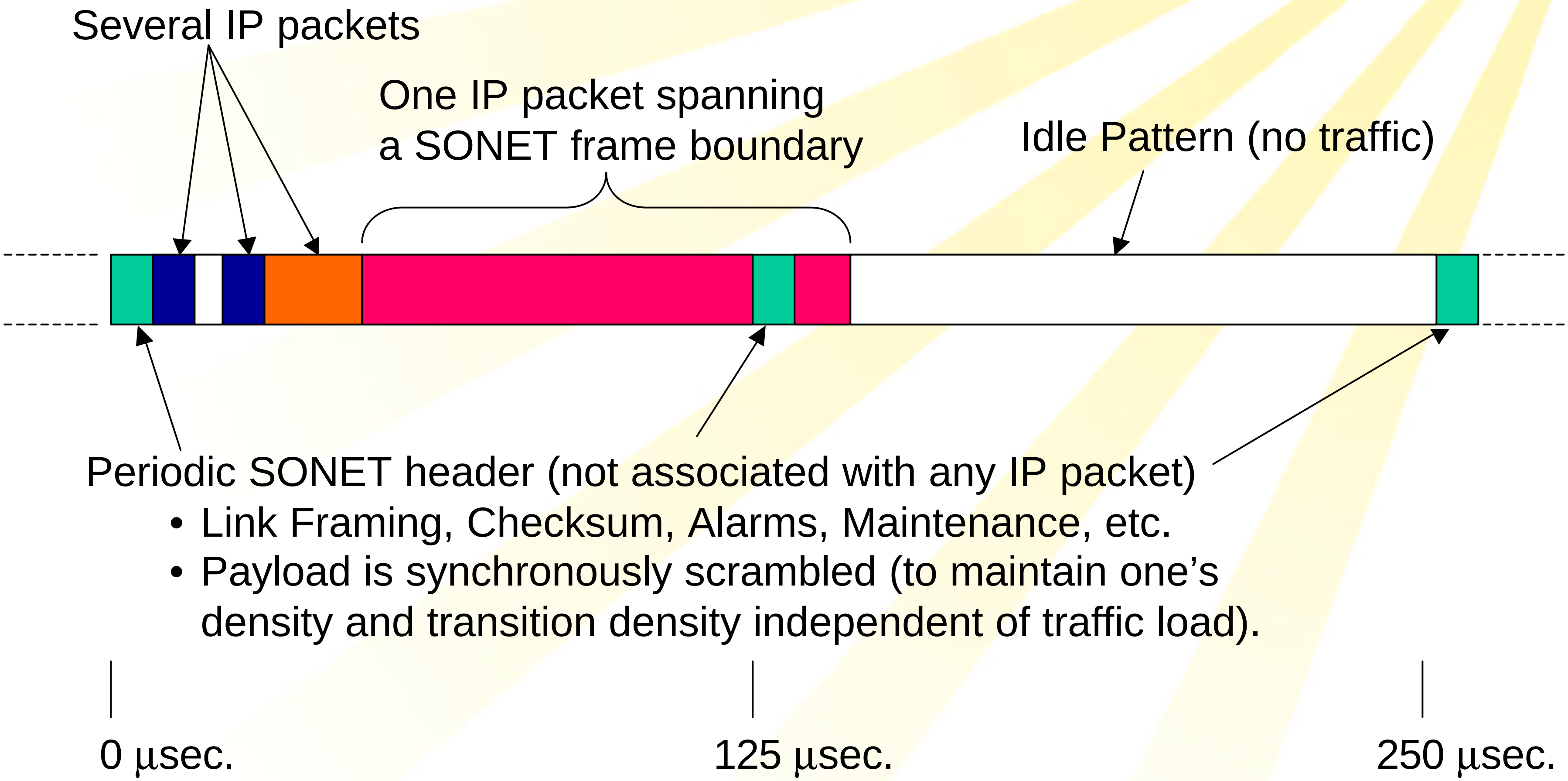
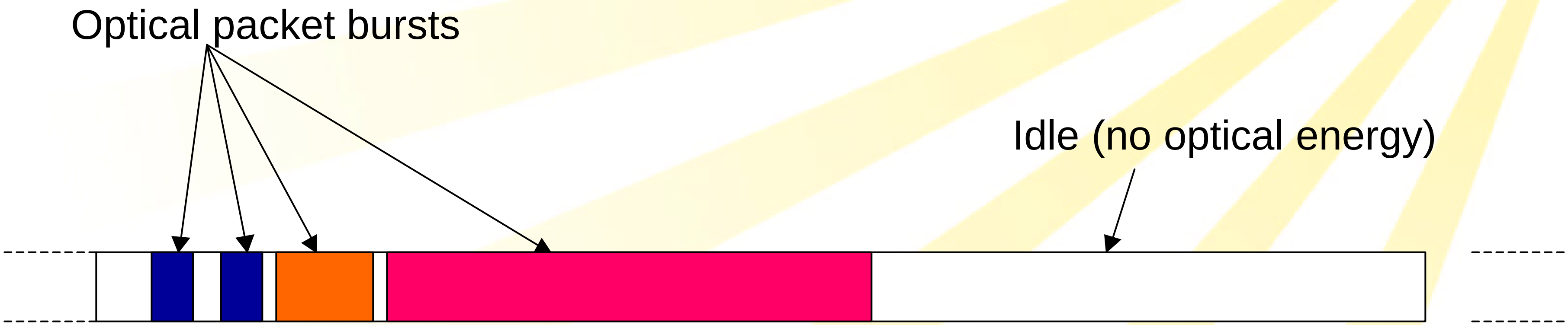
Packet over SONET



Burst over lambda



No link framing, Alarms, Checksum, etc.

- Each Packet is individually identifiable optically
- A minimal gap between bursts is required
- No synchronism between bursts

0 µsec. 125 µsec. 250 µsec.

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Granularity

- **Coarse granularity**
  - Like a circuit switch: all packets in a stream are going to the same output link, whether they want to or not.
  - Example: MEMs optical switch
    - Millisecond switching time
  - Example: SONET terminal
    - Seconds++ to re-provision channels
- **Fine granularity**
  - Like a router: individual packets can be plucked out of a stream and routed to different output links. New packets can be merged into an output link stream that has idle capacity.

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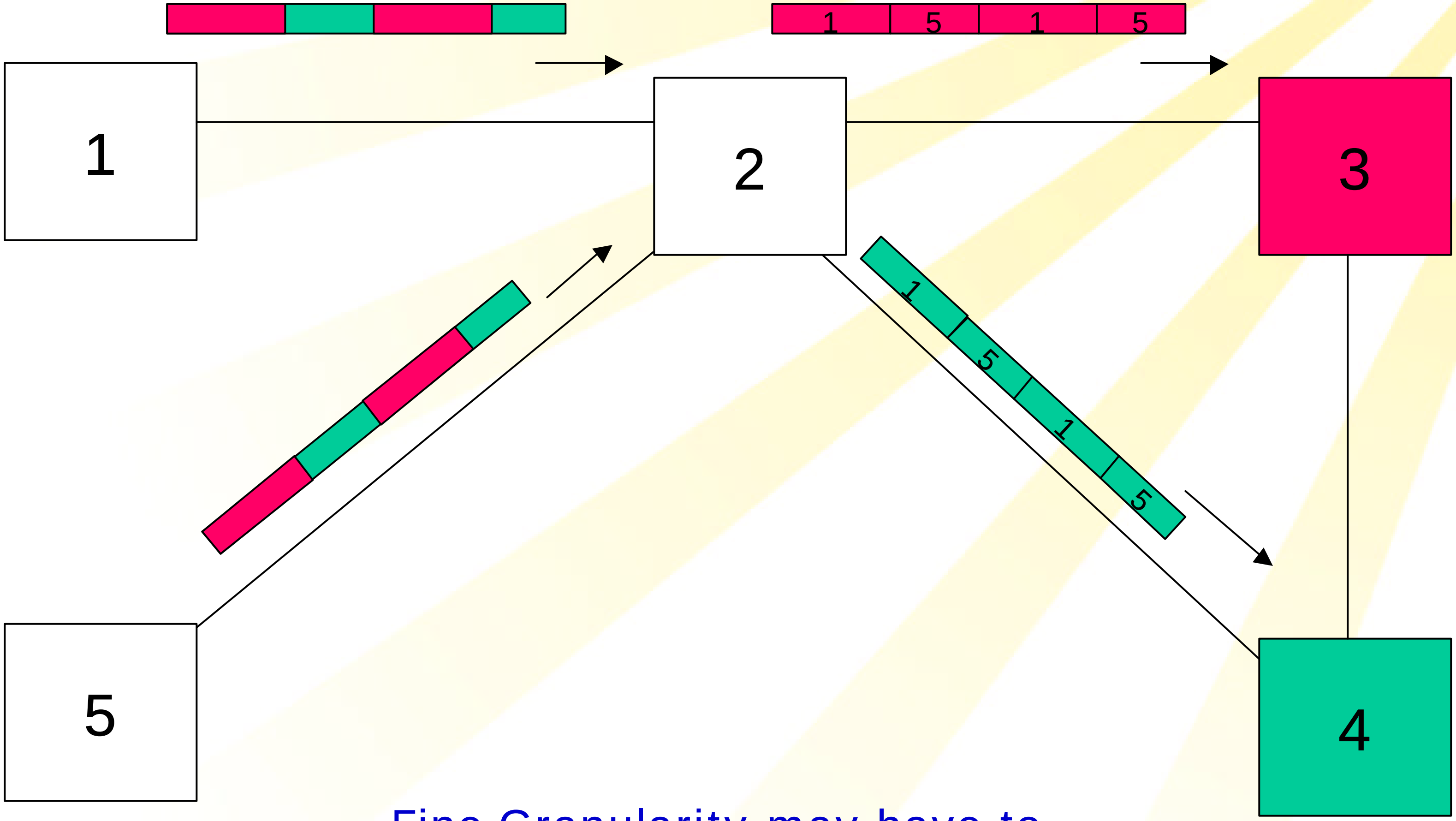
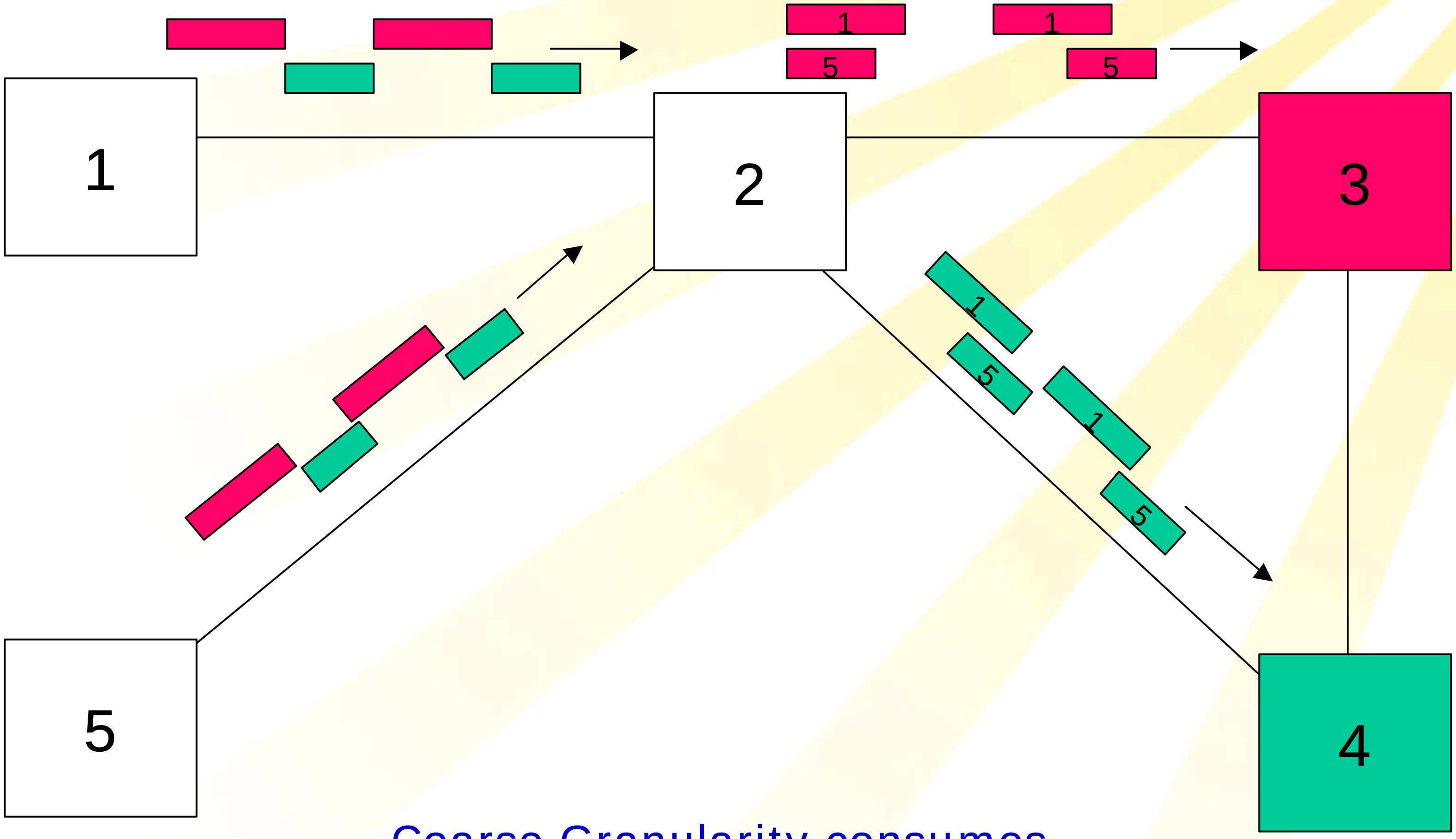
Fine Granularity Example



Fine Granularity may have to delay/sequence some packets to prevent contention

Coarse Granularity Example



Coarse Granularity consumes more intra-node resources (wavelengths, fibers, or hops)

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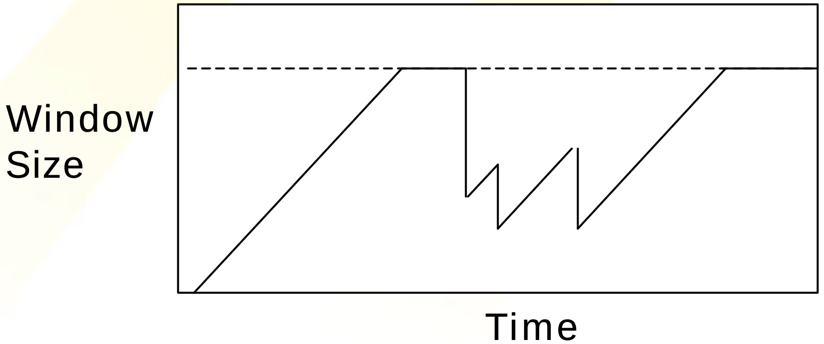
End to End Protocol

- **TCP is a dominant protocol in today's network.**
  - Reliable data transfer on top of an unreliable channel.
  - Congestion detection (missing packets) causes sender to cut the window size in half, then slowly increase it as packets are successfully 'acked'.
  - End to end: transfer managed by state stored in the two endpoints.
    - Time constant = 2 * round trip delay
    - "Slow increase" multiplies the effect of the time constant.
    - Thus reduction of packet loss rate (i.e.: congestion management) at the transit nodes is extremely important to throughput.

➔ <u>Queuing needed at transit nodes</u>



GMPLS & Optical Cross Connect

- **Idea: Optical Cross Connect provides low cost switch-able optical layer.**
  - Mesh optical layer protection is cost effective – minimal O/E/O conversion.
  - Could provision wavelength-on-demand
    - Economics not clear
- **GMPLS extends Internet protocols**
  - To discover network topology
  - To add new types of links
    - Sonet/SDH: 51Mb/s, STS-3, STS-12, etc.
    - Optical wavelength
    - Optical fiber
  - Provides method to setup, teardown, and manage links between routing end points
- **GMPLS not envisioned to be fast enough to dynamically manage flows**
  - It's basically like a circuit switch
  - Approach: over-provision facilities to handle anticipated flows

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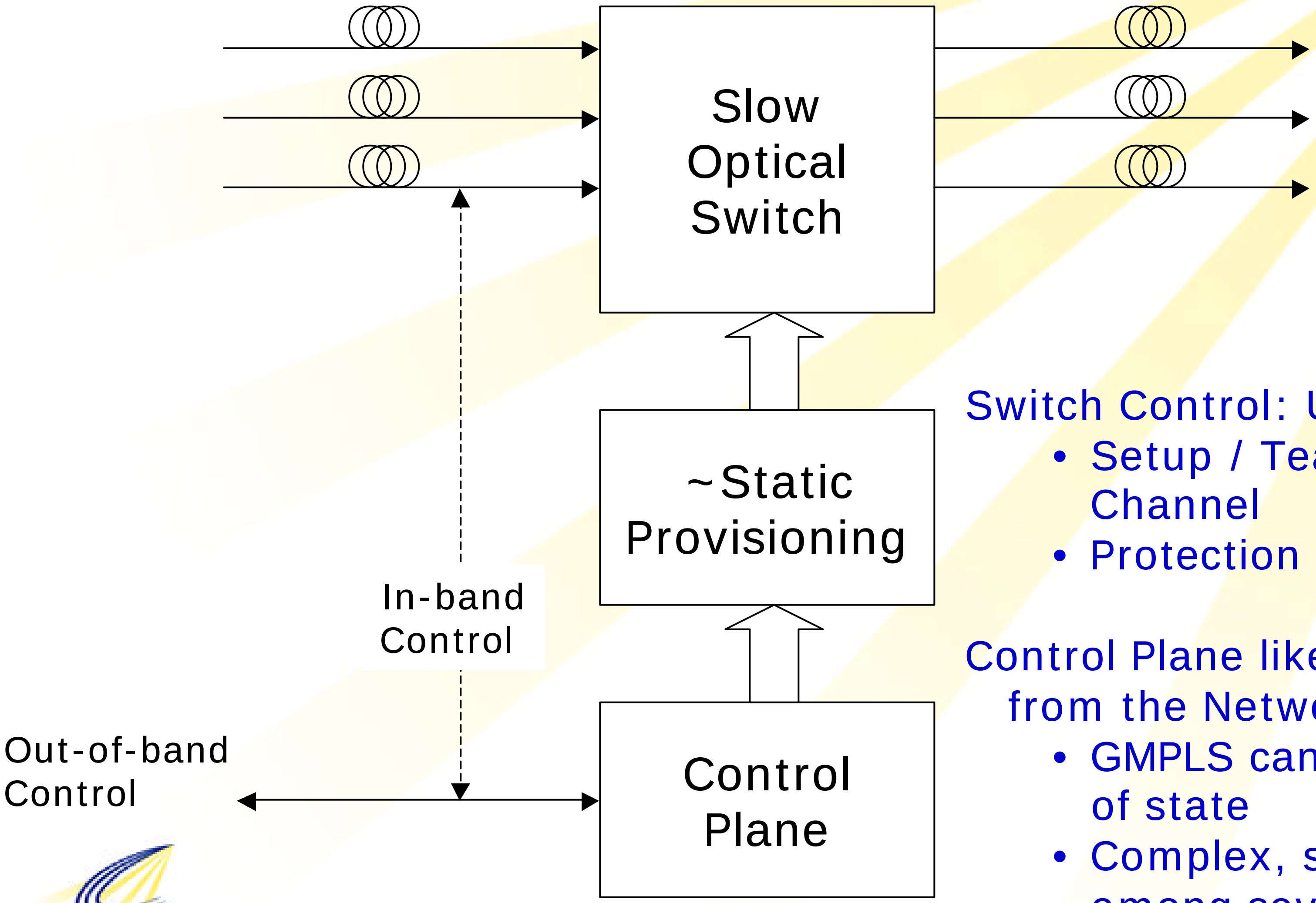
Block Diagram – OXC/GMPLS node



Switch Control: UNI 1.0 / 2.0
- Setup / Teardown Channel
- Protection Options

Control Plane likely separate from the Network Element
- GMPLS can have a lot of state
- Complex, shared among several NE's

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All Optical Routing

- **Idea: fast optical switching is capable of routing individual IP packets without electronic conversion.**
- **Various techniques proposed for independently communicating header information to each router.**
  - Separate control wavelength, subcarrier, others.
  - Headers usually handled electronically.
    - Data plane is all optical, but control plane is not
- **Problem: synchronization**
  - Packets from different sources arrive at any node non-time-aligned
  - Either time-align and switch synchronously, or switch asynchronously.
- **Problem: contention**
  - Packets may contend simultaneously for the same router output
  - Solving contention requires large degree of storage (both size and resolution) to achieve an acceptable Packet Loss Rate (PLR).

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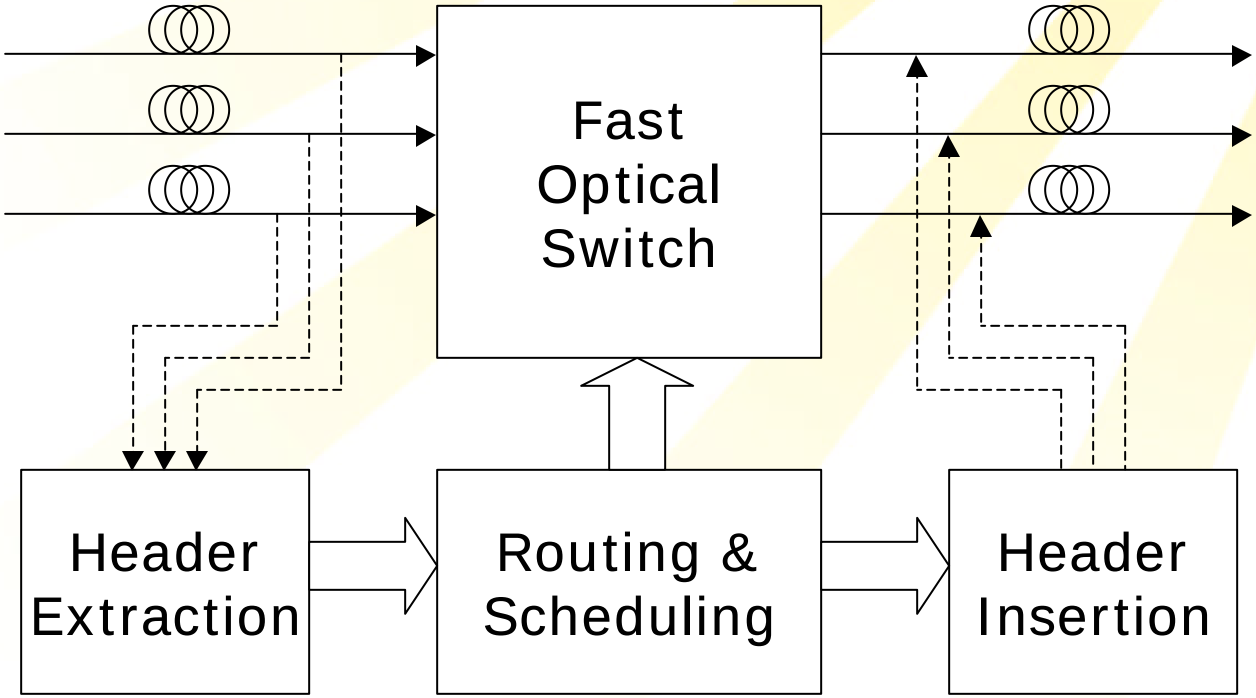
Block Diagram – All optical router

Important Optical Properties of the Switch:
- Gain / Loss
- Dispersion
- Regeneration
- Wavelength Conversion
- WDM



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Hybrid Optical Routing

- **Idea: electronics is better for manipulating & buffering data, optics is better for switching and transporting data**
- **Many different approaches proposed**
- **One approach: use optical switch in the core of the router**
  - To solve contention:
    - Provide signaling and arbitration outside the optical domain
    - Provide electronic storage and header processing outside the optical domain
  - Commercially available

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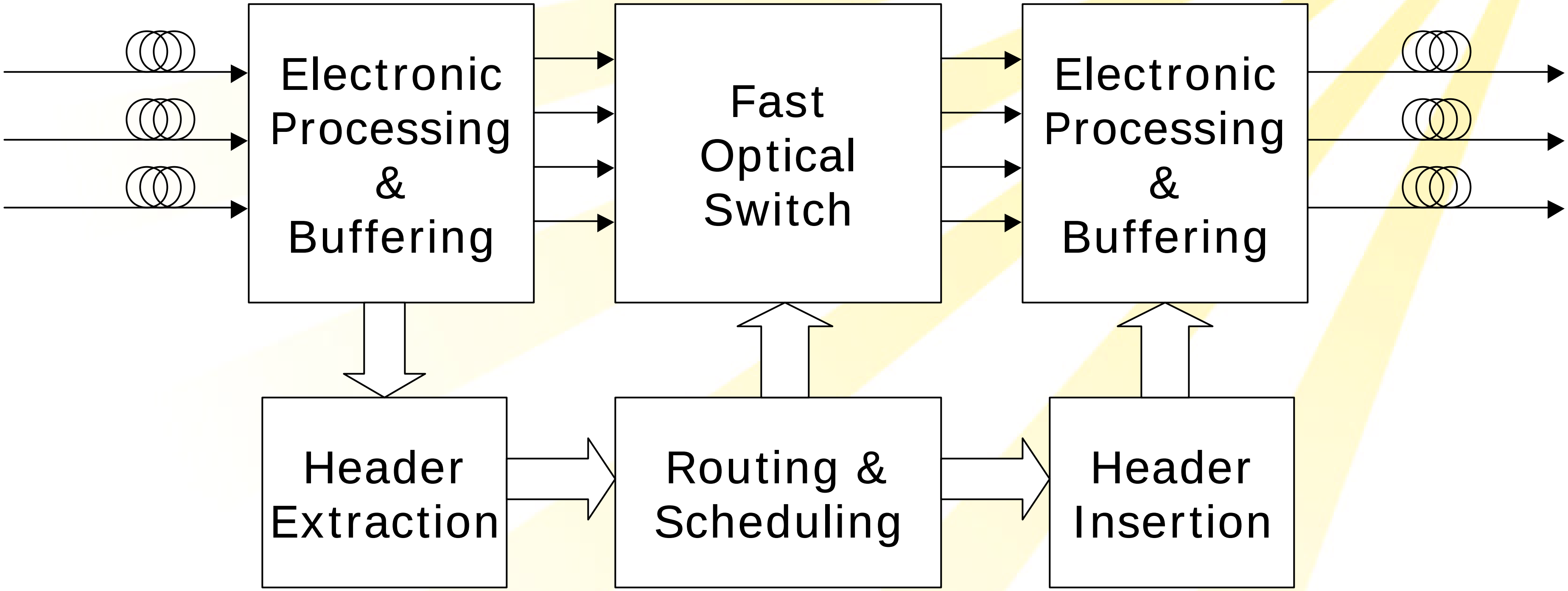
Block Diagram – Hybrid optical node



Electronic Processing & Buffering:

- Map To/From SONET, SDH, Ethernet
- Extract / Insert IP Control Packets
- Buffer & Preferentially Queue
- Alter Content of Packets
- 3R function implicit

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Key Technologies

- **Optical Switch**
  - MEMS: large scale, low optical loss, low dispersion. Cannot directly switch packets due to slow speed.
  - Phased array: large scale, very fast switching speeds (nanoseconds). Not optically transparent – higher loss, polarization-dependent.
- **Wavelength Conversion**
  - Allows re-use of empty wavelength slots.
  - Today: complex and not sufficiently transparent
- **Optical 2R / 3R regeneration**
  - Required in all-optical packet networks of large scale.
  - Dispersion reset vs. dispersion management?
- **Burst-mode Receiver**
  - Easy in theory, more difficult in practice
  - Issues: packet-to-packet amplitude variation, DC balance and empty slots, dispersion, noise and crosstalk.

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Conclusions

- **All Optical routing is still a dream**
  - Contention at the transit node needs much more research:
    - Locally-resolved scheduling and deflection approaches
    - Globally-resolved approaches involving new end-point protocols.
  - Dispersion, other analog distortions need better solutions.
- **OXC / GMPLS is practical, but does not address the routing issue well.**
  - Trades higher consumption of network resources to resolve slow flow response.
- **Hybrid techniques are the focus of much work**
  - Pragmatic approach to contention, header processing, optical signal degradation.
  - Lots of very different approaches possible.

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