

# How Emerging Optical Technologies will affect the Future Internet



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# Emerged (and deployed) Optical Technology

## Well established

- Long-haul optical links
- Short-haul links between sub-systems

## More recently deployed

- Photonic space switches
- Wavelength conversion

Q: Has optical technology affected the current Internet architecture?

# Has optical technology affected the current Internet architecture?

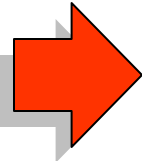
## Opinion #1: Not really.

- IP is oblivious to lower layers.
- IP will exploit any lower layer.
- Optics meant faster links: more of the same.
- Optics changed the numbers, but not the architecture.

## Opinion #2: Yes. Wildly.

- Imagine the Internet without optics.
- Abundant optical growth has transformed: Topology, growth, scalability, usage, applications, and cost.

# Emerging optical technology



1. Faster links
2. Lower cost and lower power
  - Nanophotonics
  - Integration of optics and electronics
    - InP (e.g. single chip optical cross connects)
    - Silicon optics (e.g. SiGe modulators)
3. Optical packet switching
  - Integrated optical processing, switching and wavelength conversion
  - Integrated optical packet buffers

# Are faster optical links interesting?

## Opinion #1: Who cares about links?

- We've moved to a period of abundance.
- Link bandwidth is no longer a constraint.

## Opinion #2

- Is abundance definitely the new order?
  - Operators deliberately over-provision (e.g. fault recovery, and traffic growth; customers hate queues)
  - Operators are losing money.
  - Is abundance sustainable?
- Architecture is not oblivious to lower layers (e.g. wireless)
- Disruptive performance always disrupts the architecture
  - Telephony: switching cost ⇔ long-distance calls
  - Computer systems: Central ⇔ timeshare ⇔ mini ⇔ desktop ⇔ pda

My conclusion:

Faster optical links will affect the Future Internet

# Example of how optics can affect architecture

## Dynamic circuit switching in the backbone

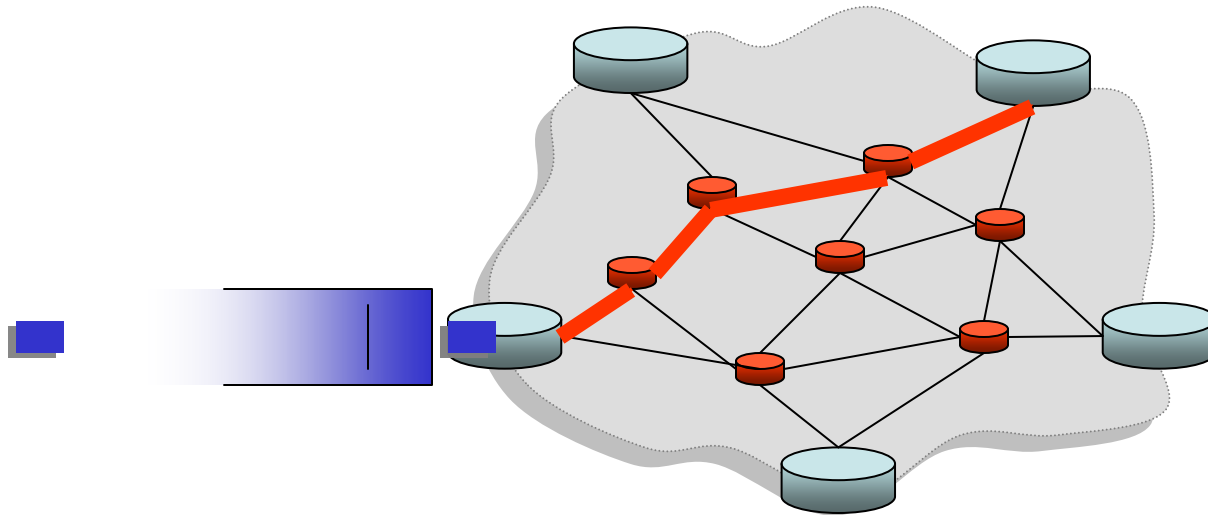
### Advantages of circuit switches

- Well-suited to optics
- Circuit switches are simple
  - “Start with a packet switch and throw most of it away”*
- Higher capacity per unit volume
- Higher capacity per watt
- Lower cost per Gb/s

### Disadvantages

- They are unfashionable

# DCS: Capacity on demand between border routers



## Rule of thumb

Predict the need for capacity by monitoring how quickly new flows are created, rather than waiting for the buffer to fill

# My conclusion on dynamic circuit switching

Compelling to operator

- Cost, reliability, management, predictability

Scalable with optical circuit switching

Users can't tell the difference

**Prediction:** The backbone will use some optical DCS in 10 years time

# Emerging optical technology

1. Faster links

2. Lower cost, and lower power

➤ Nanophotonics

➤ Integration of optics and electronics

- InP (e.g. single chip optical cross connects)

- Silicon optics (e.g. SiGe modulators)

3. Optical packet switching

➤ Integrated optical processing, switching and wavelength conversion

➤ Integrated optical packet buffers

# Integration of optics and electronics: Lower cost and lower power.

## Effect on architecture of the last mile

- Very low-cost manageable optical switches on every pole-top [Sandy Fraser].

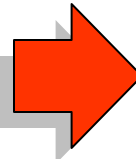
## Effect on architecture of routers

- Optical interconnects between chips, cards, shelves and racks
- Higher bandwidth per unit volume
- Higher bandwidth per watt

## General effect

- Integrated optics in 2005 are where integrated circuits were in 1965
- We can't even imagine how optics will evolve

# Emerging optical technology

1. Faster bit-pipes
2. Lower cost and lower power
  - Nanophotonics
  - Integration of optics and electronics
    - InP (e.g. single chip optical cross connects)
    - Silicon optics (e.g. SiGe modulators)
-  3. Optical packet switching
  - Integrated optical processing, switching and wavelength conversion
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# Optical Packet Switching

## Conventional wisdom

“A packet switch must...

1. **Process headers,**
2. **Switch packet-by-packet, and**
3. **Buffer packets during times of congestion.**

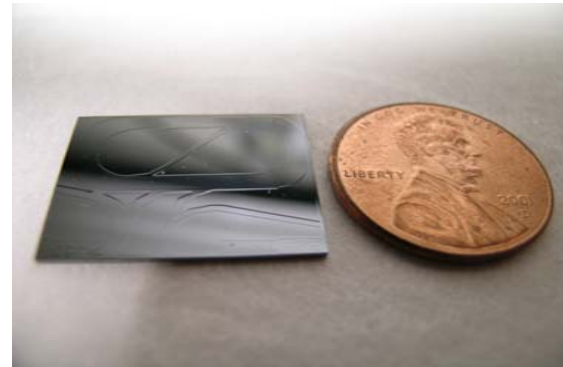
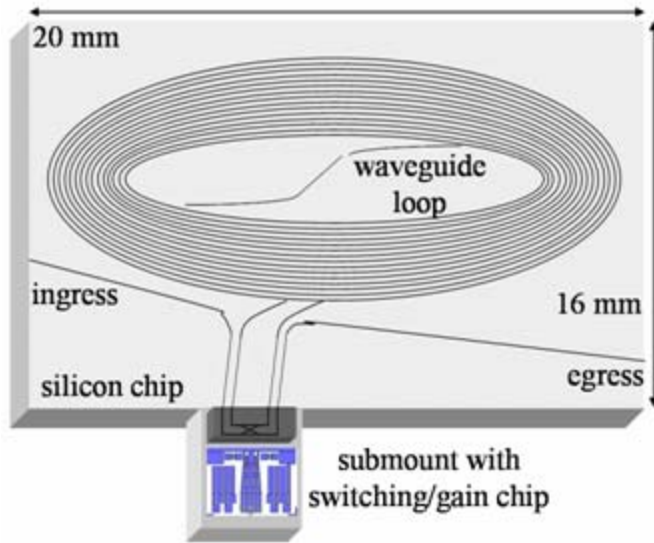
Optics suck at all three.”

## DARPA DOD-N Program revisiting assumptions (IRIS and LASOR projects)

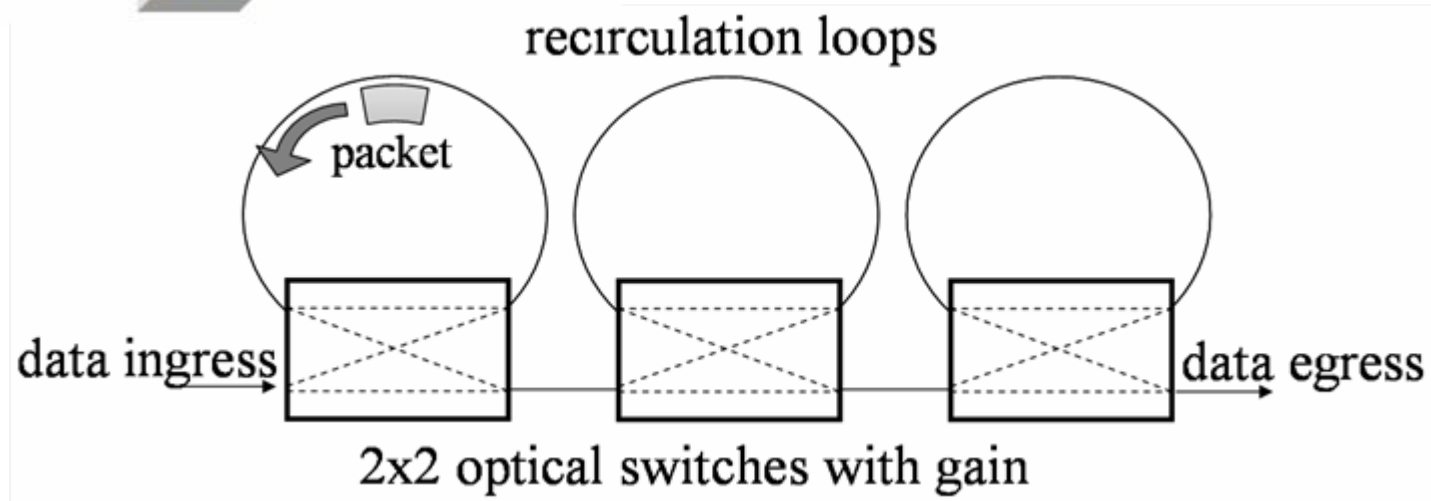
1. **Process headers:** Carry headers slower; process electronically.
2. **Switch packets:** Valiant Load Balancing (VLB) avoids packet-by-packet switching [Sigcomm 03]
3. **Buffer packets:** 20-50 packets might be enough in the backbone [CCR 05]; will be feasible with integrated optics [Bowers 05]

# Integrated optical buffers

[Burmeister and Bowers, UCSB]



**Think: 10-50 packets on a chip**



# Why we have big buffers today

- Packet switching
  - Long haul links are expensive
  - Statistical multiplexing allows efficient sharing of long haul links
- Packet switching requires buffers
- Packet loss is bad
- Use big buffers
- Luckily, big electronic buffers are cheap

# Why bigger is not better

- Network users don't like buffers
- Network operators don't like buffers
- Router architects don't like buffers
- Optical buffers are very expensive
  - Electronics: Cheap buffers, expensive links
  - Optics: Expensive buffers, cheap links
- We don't need big buffers

# packets  
at 10Gb/s

1,000,000

10,000

20

$$2T \times C \xrightarrow{(1)} \frac{2T \times C}{\sqrt{n}} \xrightarrow{(2)} O(\log W)$$

# Flexibility and Choice

Will it be optical DCS or optical packet switching?

- Technically, both seem feasible
- Perhaps we shouldn't care
- Both are unfashionable
- Both should be on the table
- A new architecture should allow both...
- ...but should presuppose neither

These are just examples.

We should architect under the assumption that both will be superseded