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 <u>will</u> 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

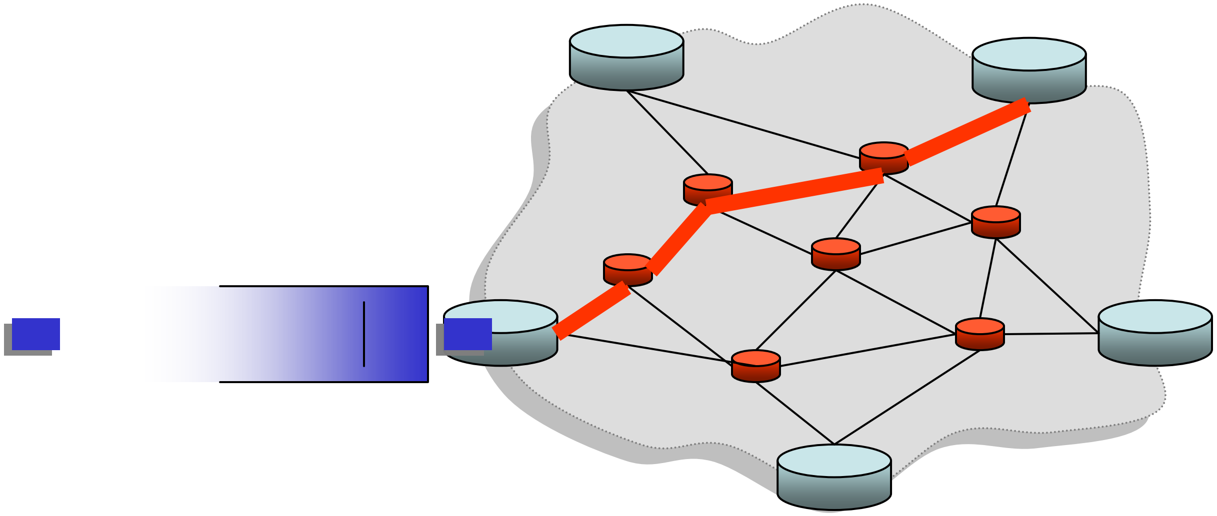
  "Start with a packet switch and throw most of it away"

- 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

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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

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Optical Packet Switching

Conventional wisdom

"A packet switch must...

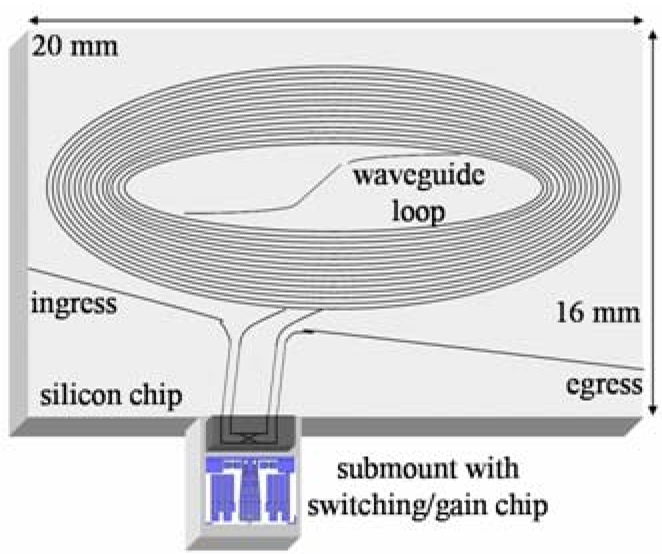
1. **Process headers,**
2. **Switch packet-by-packet, and**
3. **Buffer packets during times of congestion.**

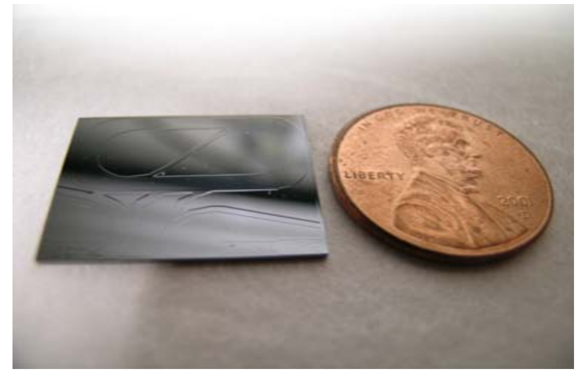
Optics suck at all three."

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

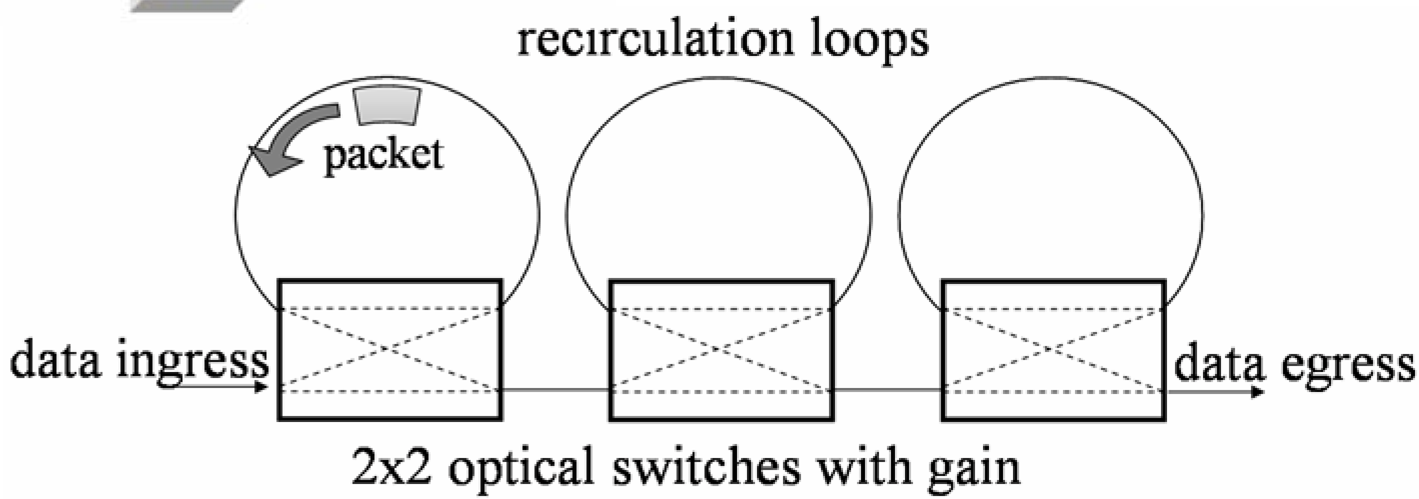
1. **Process headers**: Carry headers slower; process electronically.
2. **Switch packets**: Valiant Load Balancing (VLB) avoids packet-by-packet switching [Sigcomm 03]
3. **Buffer packets**: 20-50 packets might be enough in the backbone [CCR 05]; will be feasible with integrated optics [Bowers 05]

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