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Integrating Optical and Wireless Technologies

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Background

- Optical (fiber or free-space) networks
  - high bandwidth (Gbps to Tbps) at low per bit cost (due to low power/heat, small footprint)
  - transparency (i.e., independent of bit rate, protocol and coding format) and low latency
  - going into access (e.g. PON)
- Wireless (RF) technologies
  - mobility and wide coverage (e.g., cellular)
  - limited bandwidth and need interoperability
  - going to metro area (e.g., WiMAX)

Motivation

- Integrated optical and wireless technologies for Fixed and Mobile Convergence
  - reduce both capital and operating cost and
  - provide new bundled services
- Integrated Optical/RF networking research issues
  - Protocol mapping, Joint resource allocation, Dynamic load balance, End-to-End QoS, Handover etc

Vision: A Disappearing Network

- Billions of devices (from tiny sensors to big supercomputers)
- Some are analog and others are digital
- Some are wireless and others are wired
- Some are near by and other are far away
- Can communicate with transparency and low latency *as if* the devices were directly connected, and near-by

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Outline

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- Optical Wireless Systems at Edge
  - OW signals can couple into fibers and then use COTS WDM components and subsystems
  - transparent OW (and fiber-optic) links extend radio range without interference
  - facilitates interoperability among different RF devices (using all-band radios and backhualing different RF signals to a remote processing center)
- Optical Burst Switching (OBS) at Core
  - end-to-end transparency
  - Optical Grids for “pro-sumers” and consumers

Part I: Optical Wireless (Free-Space Optics)

- for inter-chip, first/last mile and space comm
- can take us where fiber-optics can't
- supports broadband (up to Gbps)
- transparent (can carry RF signals along with other digital and analog signals)
- interference free & license free
- can extend RF coverage and improve spectrum reuse
- secure and safe

Early Concepts

- Photophone:
  - Alexander Bell patented the it in 1880 and called it the “greatest invention, greater than the telephone”
  - modulates the light reflected from Sun using a voice signal, and transmits that across free-space
- Smokes, semaphore flags etc.

Gbps Bandwidth

- Backbone can support a few Gbps for every office/home
- But 9 out of ten small business (in US) with 100 employees have has bottleneck in the last/first mile from the office to the backbone.
- DSL, cable etc cannot provide over 1Gbps
- Only laser and millimeter waves can, and the device technology for laser is much more mature than that for millimeter waves.

Truth vs Myth

- Cost
  - Much more cheaper than digging fiber
  - Cheaper than RF wireless (millimeter meters) with comparable bandwidth-distance product
- Safety and security
  - Can use Class I (eye safe low emission power)
  - Others do not have to be eye safe
  - Hard to intercept, and easy to detect eavesdropping

Truth vs Myth

- Alignment
  - Takes trained technicians a few hours to align
  - High-rise building sway is negligibly small (Japan, Germany)
  - Stable alignment possible between a building and a ship in the sea (US Navy)
- Availability/Reliability
  - OWS equipment (transceivers/telescope) very reliable
  - Links longer than 200 meters affected by weather (dense fog/cloud instead of rains which affect RF)
  - Atmospheric attenuation and scintillation
  - Still, 99% availability (though not 99.999%) possible

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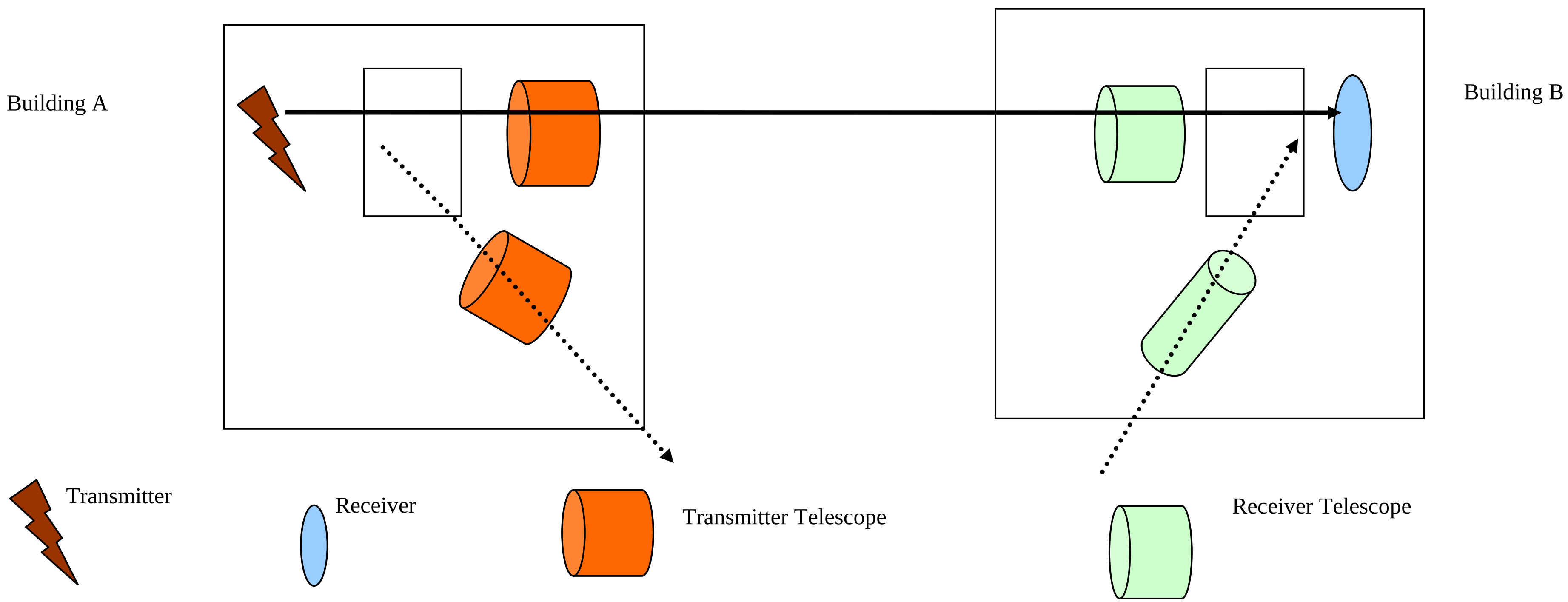
Dynamic Rerouting in OWS Networks



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Integration with Fiber

- Received signals from an OWS link can be directed coupled into a fiber
- Fiber based amplifiers (EDFA or Raman) can be used
- So are fiber based photonic switches and optical regenerators
- Signals can be sent (via a telescope) across the free space to the next node
- Accomplishes transparent switching, routing and transport

Example Usage

- Use OWS links to carry “aggregated” RF wireless signals transparently over a long distance
  - Let a user communicate to a remote wireless device as if it’s nearby and dedicated
  - Enable different wireless signals to be carried to a “central” command & control center for interoperability and coordination
  - Facilitate fast provision of high bandwidth “clear” channels

OWC Networking Research

- Meshed access network design
- Routing (in addition to RF backup) for fault-tolerance and load balancing
- TCP Performance over OW links (high bandwidth and high BER)
- End-to-end QoS Performance in integrated networks with WiMAX and fiber-optic links

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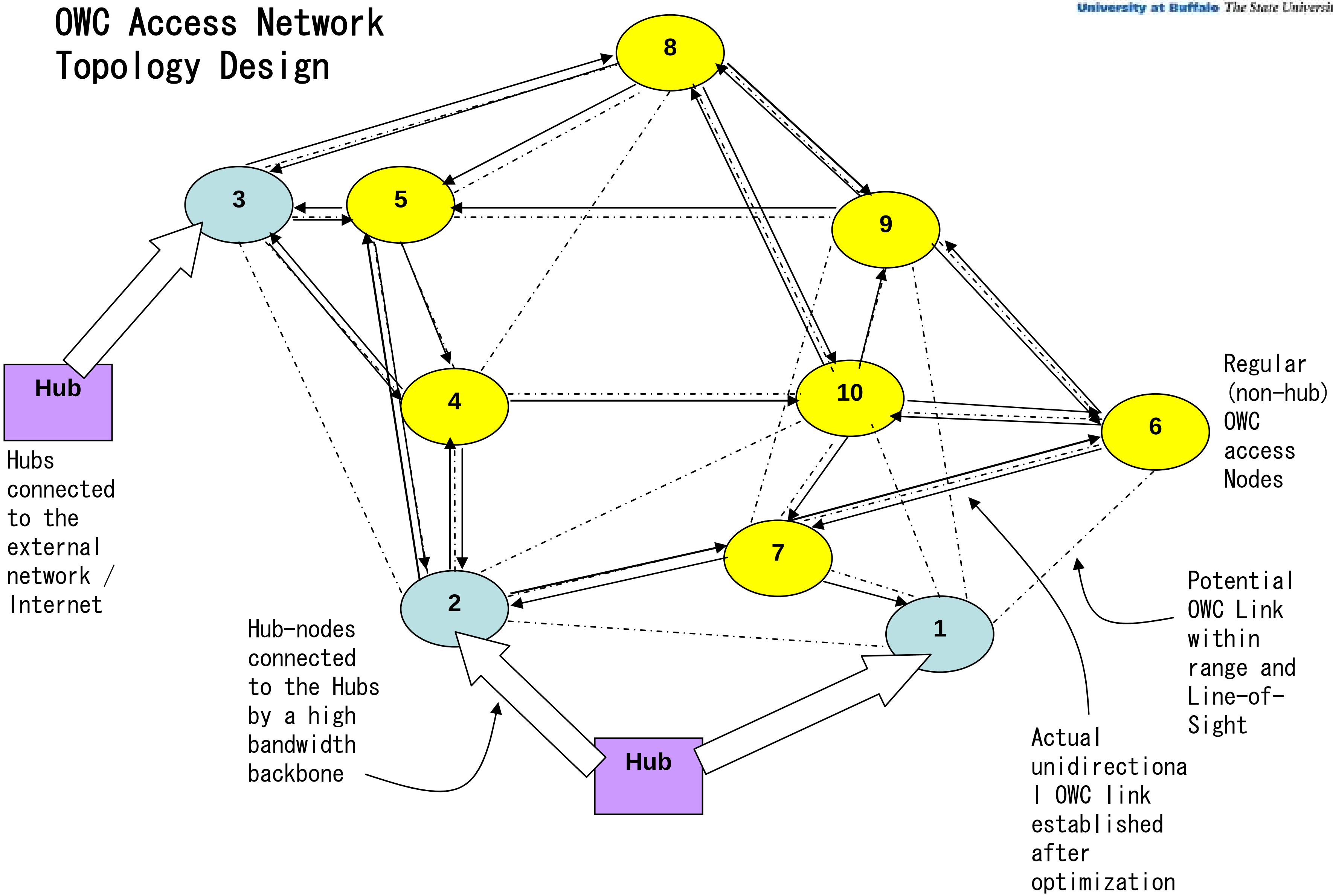
OWC Access Network Topology Design



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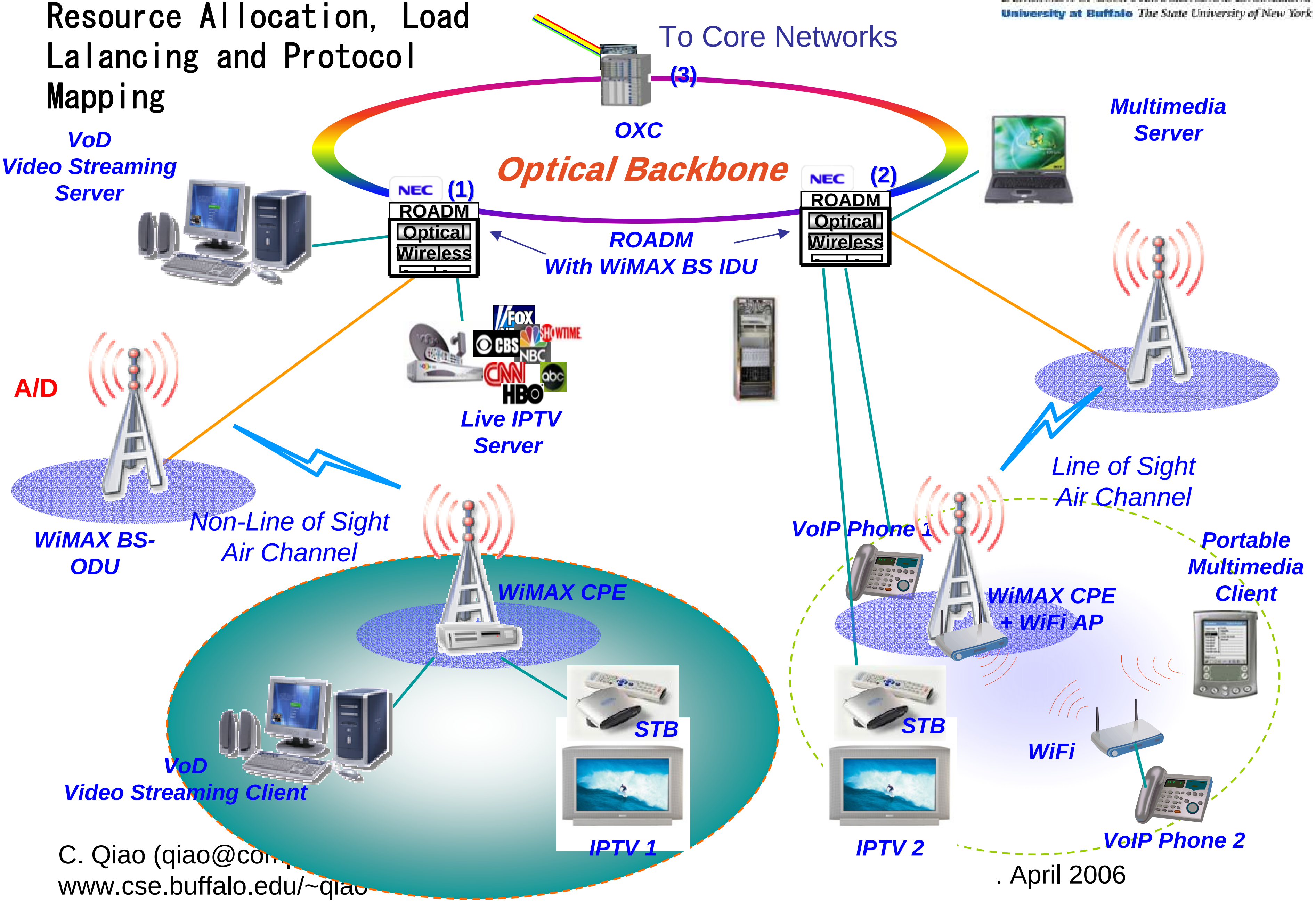
Resource Allocation, Load Lalancing and Protocol Mapping



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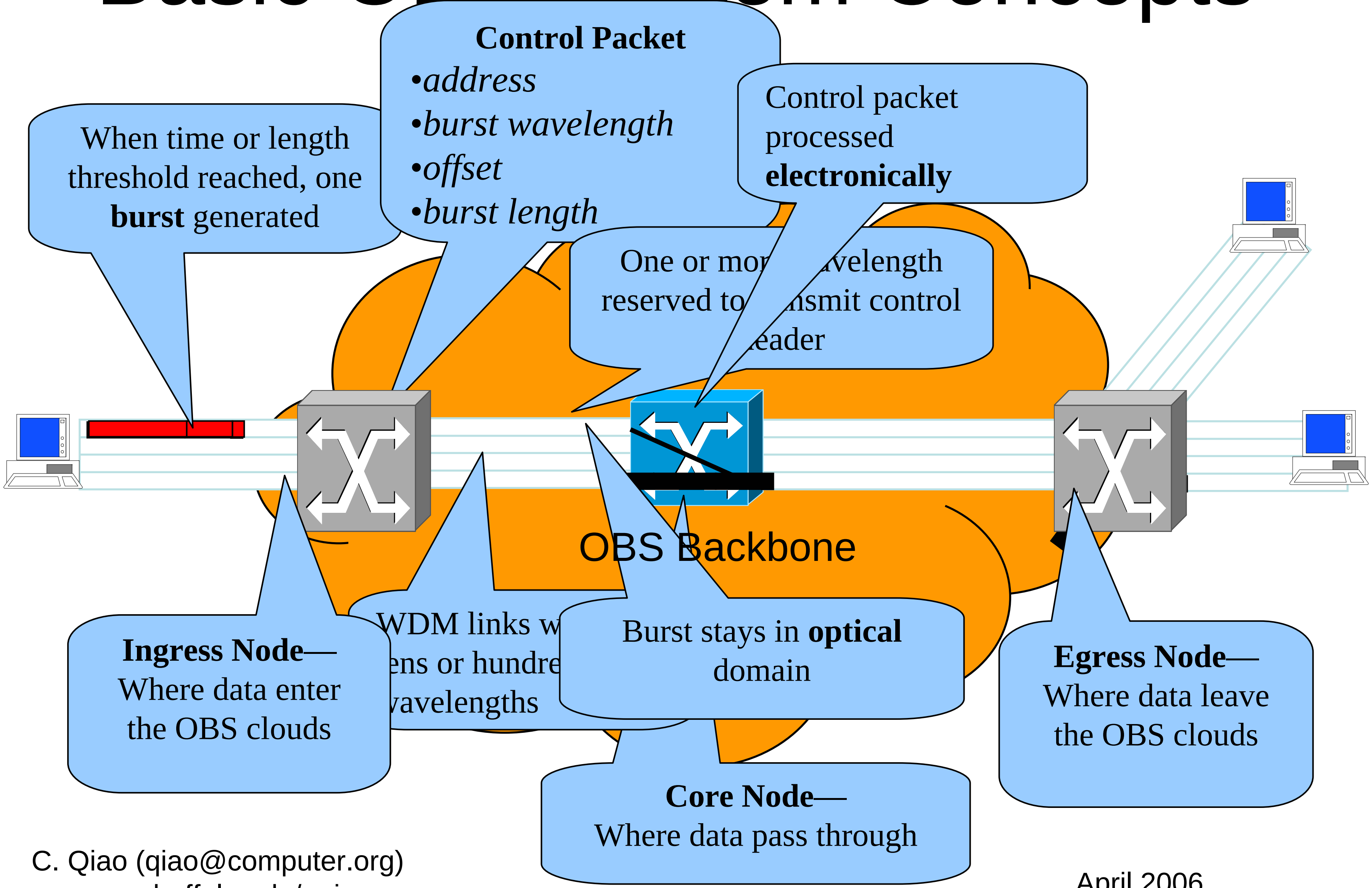
Part II: Optical Burst Switching (OBS): Roles and Issues

- Provides transparency and
  - takes advantage of electronics for control processing
  - is amendable to traffic engineering and QoS with label switching and priority schemes
  - is more scalable due to statistical multiplexing
- Reduces latency and
  - enables dynamic reconfiguration and on demand resource allocation
  - achieves high-speed and high throughput

Optical Burst Switching (OBS)

- A burst has a long, variable length payload
  – low amortized overhead, no fragmentation
- A control packet is sent out-of-band ($\lambda_{control}$)
  – reserves BW (λ_{data}) and configures switches
- A burst is sent after an offset time
  – arrives at a switch after it has been configured so no buffering or FDL is needed

Basic OBS System Concepts



Circuit Switching

- Long circuit set-up delay (a 2-way process with Req and Ack): *RTT* = tens of *ms*
- Pros: good for smooth traffic and QoS guarantee due to *fixed* BW reservation;
- Cons: BW inefficient for bursty (data) traffic
  - either wasted BW during off/low-traffic periods
  - or too much overhead (e.g., delay) due to frequent set-up/release (for every burst)

Wavelength Routing (WR)

- Setting up a lightpath (or l path) is like setting up a circuit (same pros and cons)
- λ-path specific pros and cons:
  - very coarse granularity (OC-48 and above)
  - limited # of wavelengths (thus # of lightpaths)
  - no aggregation (merge of λs) inside the core
    - traffic grooming at edge can be complex/inflexible
  - mature OXC technology (*msec* switching time)
  - Packet level granularity supported at the IP layer.

Example Usage: Optical Grids

- From Internet, to Web, to Grid
- Grid would allow for sharing of processing power, software/programs, storage (memory and disk), data, instruments (including sensors) and communication capabilities
- Lambda Grid (based on OCS) is mainly for "professional"-strength grid applications involving supercomputers at fixed, known locations, and pre-scheduled times
- OBS Grid can be used for consumer and/or "pro-sumer" applications.

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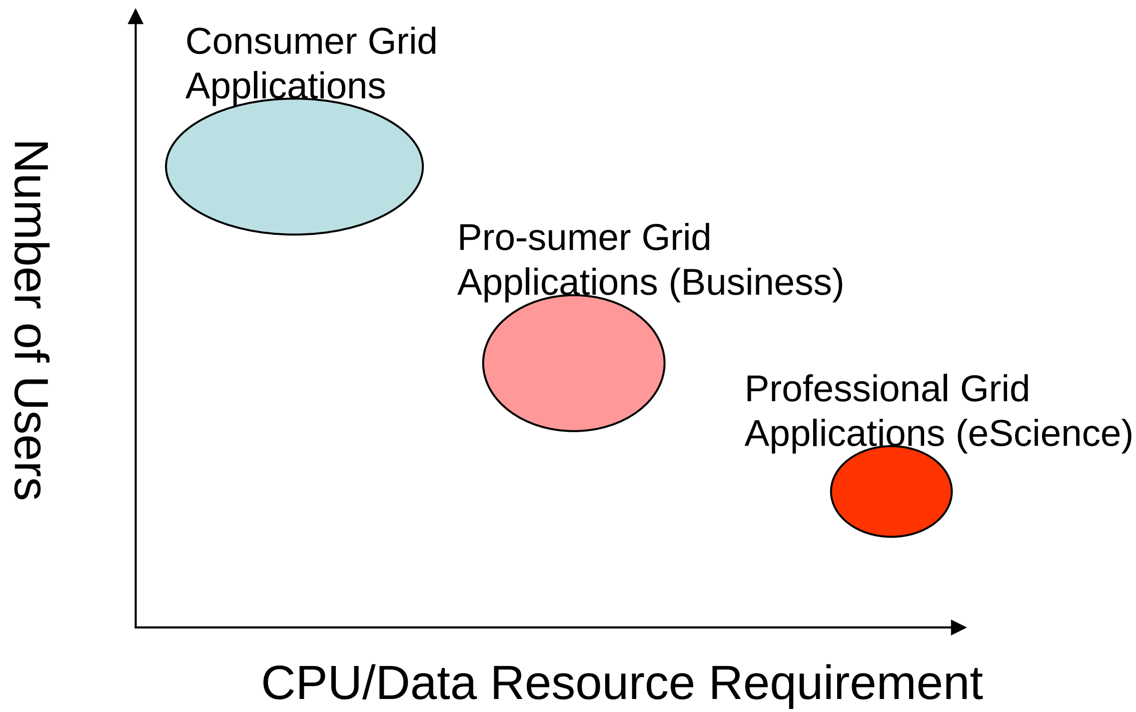
Number of Users
vs
Resource Requirement



OBS – A Future Proof Solution

Optical switching paradigms	Bandwidth Utilization	Latency (setup)	Optical Buffer	Proc./Sync. Overhead (per unit data)	Adaptivity (traffic & fault) and Routing Flexibility
Circuit	**Low**	**High**	**Not required**	**Low**	**Low**
Packet/Cell	**High**	**Low**	**Required**	**High**	**High**
OBS	**High**	**Low**	**Not required**	**Low**	**High**

OBS combines the best of the two while avoiding their shortcomings

Potential Use of OBS

- Sending service notification, registration and discovery, as well as job description/request, (possibly using multicast and/or anycast)
- Applications with no pre-determined destinations, or requiring application initiated, dynamic resource allocation and job migration
- Applications requiring mixed and flexible granularity (small to large) and signaling schemes (one or two way)
- Current λ–Grid infrastructure based on OCS alone is inefficient

Grid over OBS

- Request burst (& response burst)
- No explicit destination
  - Anycast (with no or soft destination) or Multicast
- Do not tolerate too much delay
  - Request burst contains data (if any)
  - Relayed by resource brokers (if any)
- Flexibility of OBS Grids
  - deflection routing to deal with contention
  - dynamic job migration for efficiency or fault-recovery

Polymorphous, Agile and Transparent Optical Networks (PATON)

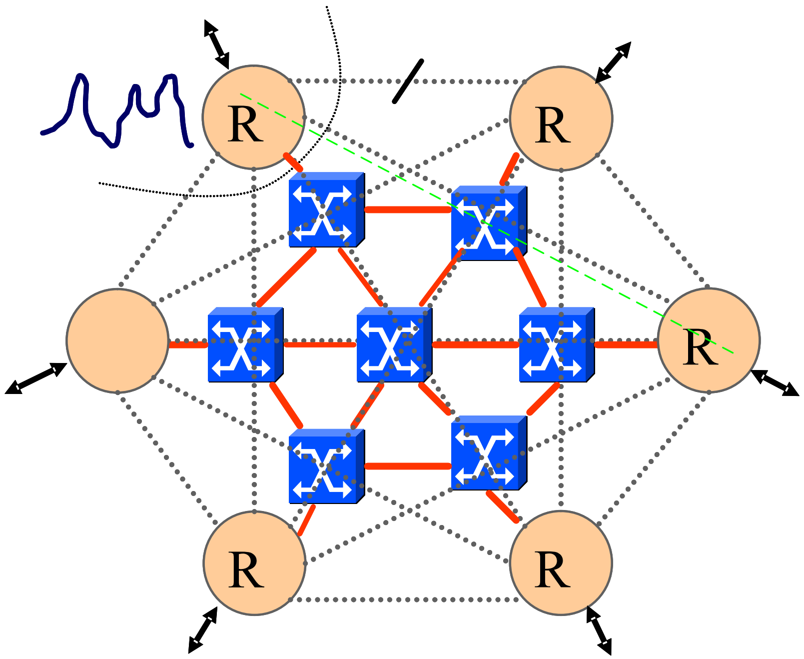
- A single integrated network to support
  - multiple wavelengths, a single wavelength, or sub-wavelength granularity.
  - zero loss guarantee (using a circuit or physical leased line), a statistical guarantee (using a virtual circuit or virtual leased line) , or no guarantee (using best-effort forwarding).
  - delayed (or scheduled) transmissions (e.g, for data backup), transmissions following an instant confirmation, or just opportunistic transmissions.
  - data transparency through all-optical switching

Background and Motivation

- Increasingly high and dynamic traffic demands
  - 100's of Tb/s to Petabits/s in the Metro-Core and Core
  - E-Science, SAN, and other gov'n, military, business and consumer Grid, P2P, video (e.g., IPTV and VoD) and multimedia streaming applications.
- Different bandwidth granularities, QoS guarantees and traffic characteristics, Different scheduling
- Multiple types of networks and equipments (IP packets, SONET/GE/MPEG/Wireless frames etc)
- Various switching and control protocols (GMPLS, OCS/OFS wavelength routing, OBS, OPS, etc).

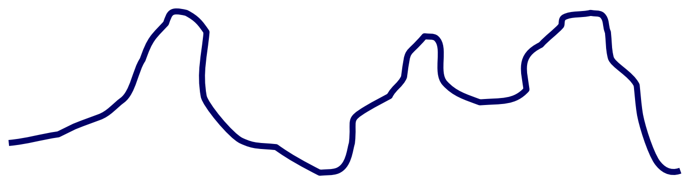
Existing Approach 1 --SHALL (Single-Hop All-to-All Routing)

- Traffic from one router to another follows a dedicated lightpath between the two routers.
- If every router pair has some traffic, the number of lightpaths needed is at least *N(N-1).*



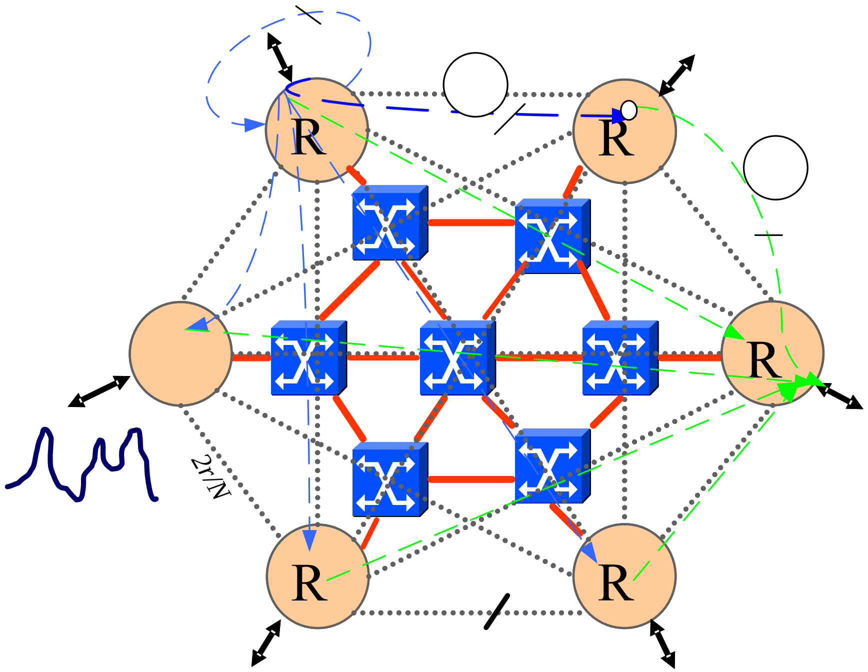
The amount of traffic between two routers is extremely difficult to predict
- non-uniform (space domain)
- bursty (time domain)

Dynamic reconfiguration and time-slotted circuits will help but
- still not very bandwidth efficient
- too slow for some applications
- implementation difficulties



Existing Approach 2 – THALL (Two-Hop All-to-All)

- Assume: max. traffic going out (or coming in) to each router is *r*
- Allocate: B/W in the amount of *2r/N* between any two routers.
- Valiant Load-Balancing: Stage 1: evenly distribute packets from each source; Stage 2: route packets directly to destinations.



Shortcomings:
- non-transparency
- inefficient use of optical network resources
- inefficient use of router resources
- additional propagation and L3 processing delay
- out of order packet arrivals

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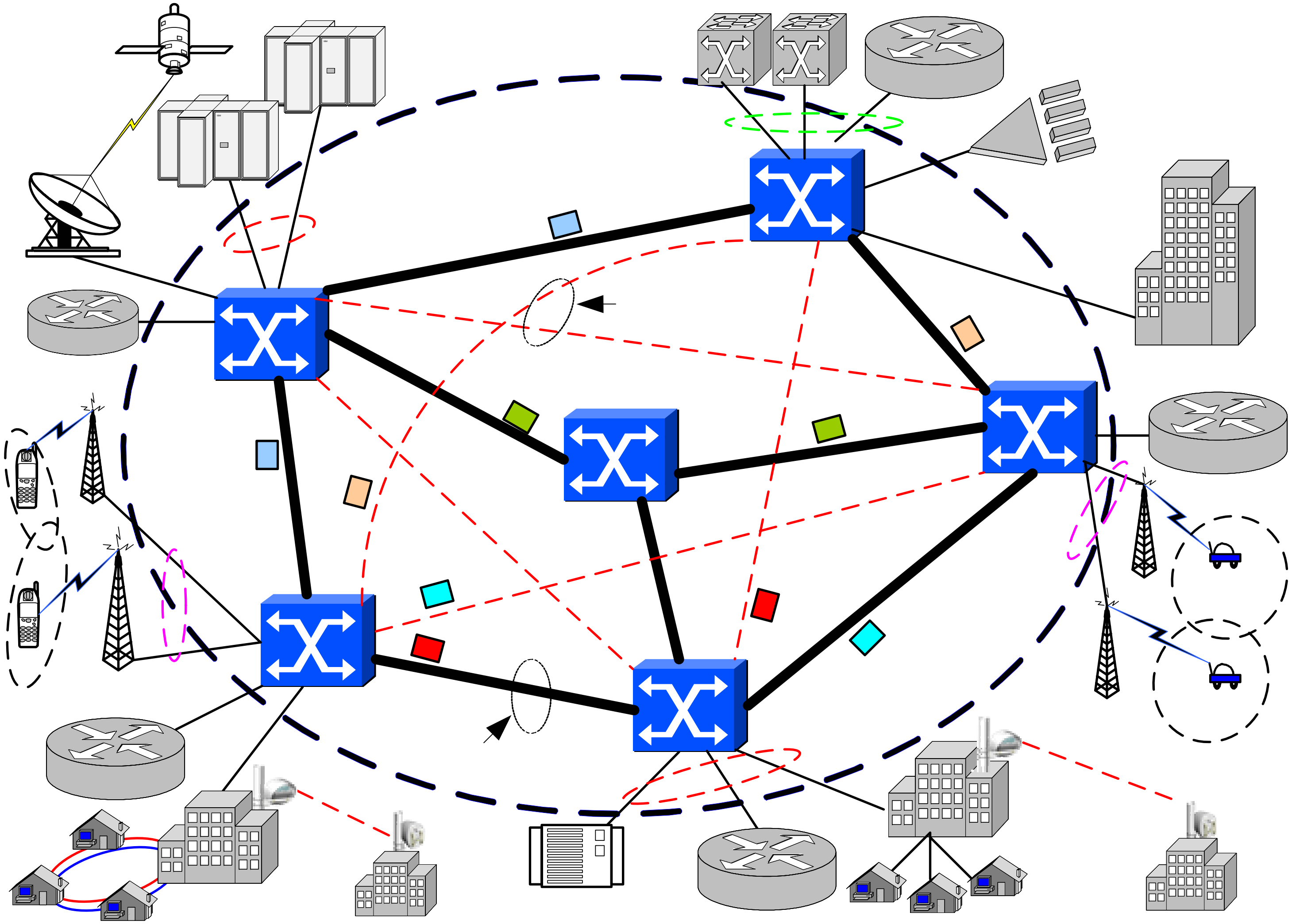
PATON Based on Polymorphous OBS



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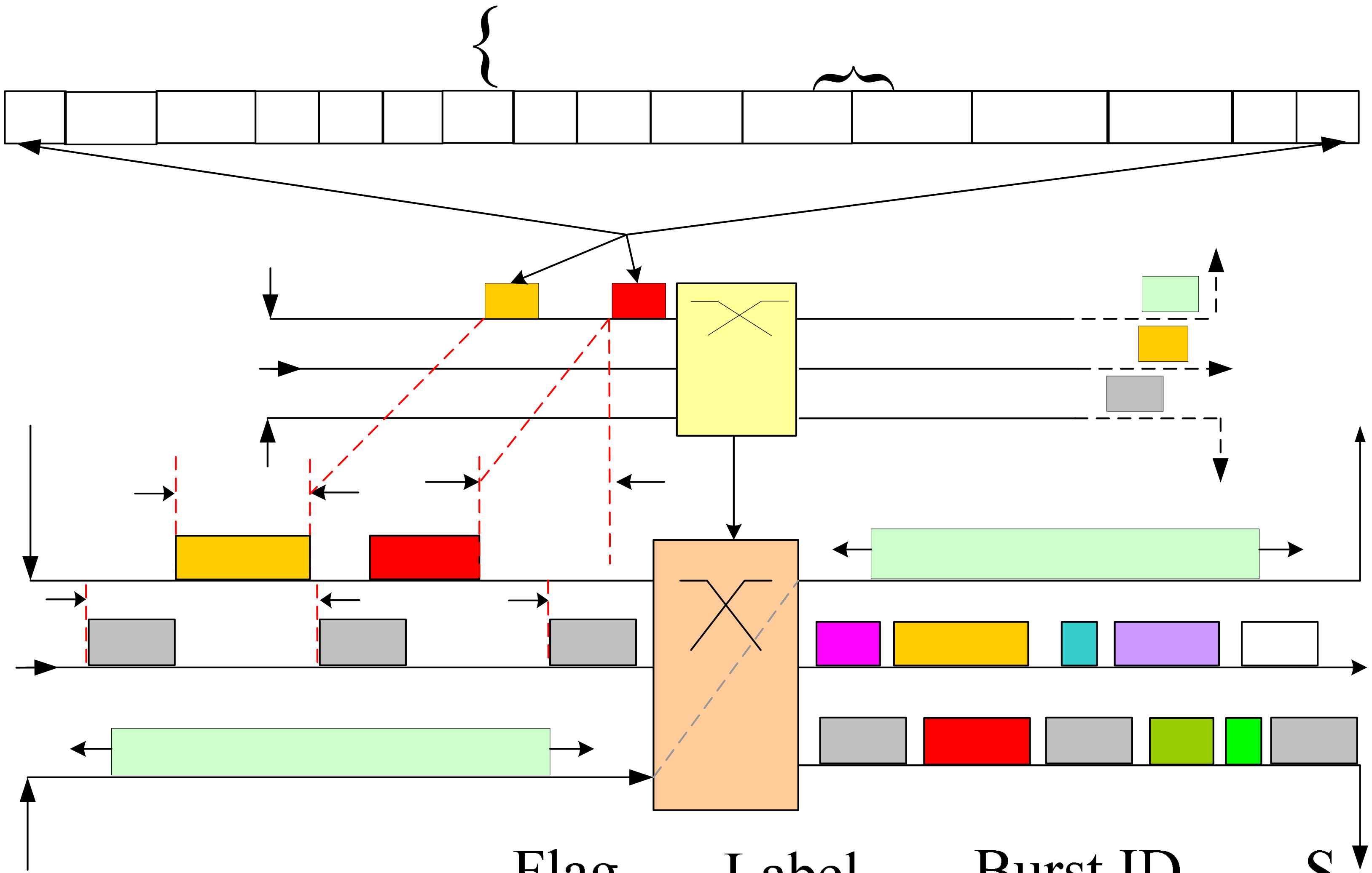
Polymorphous OBS (POBS)



Flag (8b) Label (32b) Burst ID (32b) S (32b) D (32b) T (

Benefits and Cost Saving

- Transparency and low-latency
  - only control wavelengths go through OEO conversion; data (e.g. bursts) does not go through intermediate L3 processing/forwarding.
- Capable of providing physical leased-line service
  - Better than existing GMPLS as GMPLS can't handle delayed/scheduled transmissions
  - Neither GMPLS "soft-state" or "explicit release" is as efficient as automatic release based on Just-Enough-Time.
- Capable of providing virtual leased-line services
  - Can use traffic engineering, QoS differentiation and contention resolution strategies proposed for OBS
  - Can further reduce burst loss by using a few lightpaths between certain router pairs (e.g., those far apart) to effectively reduce contention
- Reduce CAPEX (wavelengths, transponders, router ports) and OPEX, compared to SHALL and THALL.

Fair Comparison of OBS and OCS

- They are for different applications
- Yet, heated debates require quantitative comparisons
- No comprehensive studies so far
  - Not done in electronic networks
  - Difficult to compare an orange and an apple
  - Connection request blocking rate (in OCS) is not directly comparable with burst loss rate (in OBS)

Building a Fair Model

- Same performance metrics: *data packet loss* rate in both cases
- Same input traffic: packet flows with Poisson arrivals
  - packets in a flow could be Poisson or self-similar
  - packets may have delay constraints
- Same network model and topology, and similar operations
  - a node may have a limited amount of electronic buffer
  - similar control and signaling capability

Operations

- In OCS
  - Each packet flow allocated a CBR connection of at least the *average* bandwidth requirement
  - Multiple flows (CBR connections) are groomed onto a lightpath
  - When a request is blocked, a limited number of retries is allowed
  - Some packets may be dropped when their deadline expire or the input buffer overflows
- In OBS
  - When a control packet is blocked, a limited number of retries is also allowed
  - Same causes for packet loss

Important Factors

- Traffic intensity, delay budget, buffer size
- End-to-end propagation delay vs flow duration
- Number of nodes (not just the total number of flows)
- How connection request packets are handled
  - Distributed signaling
  - Average vs peak bandwidth reservation

Possible Cases

- Unlimited packet delay and unlimited buffer (UDUB)
- Unlimited packet delay and limited buffer (UDLB)
- Limited packet delay and unlimited buffer (LDUB)
- Limited packet delay and limited buffer (LDLB)

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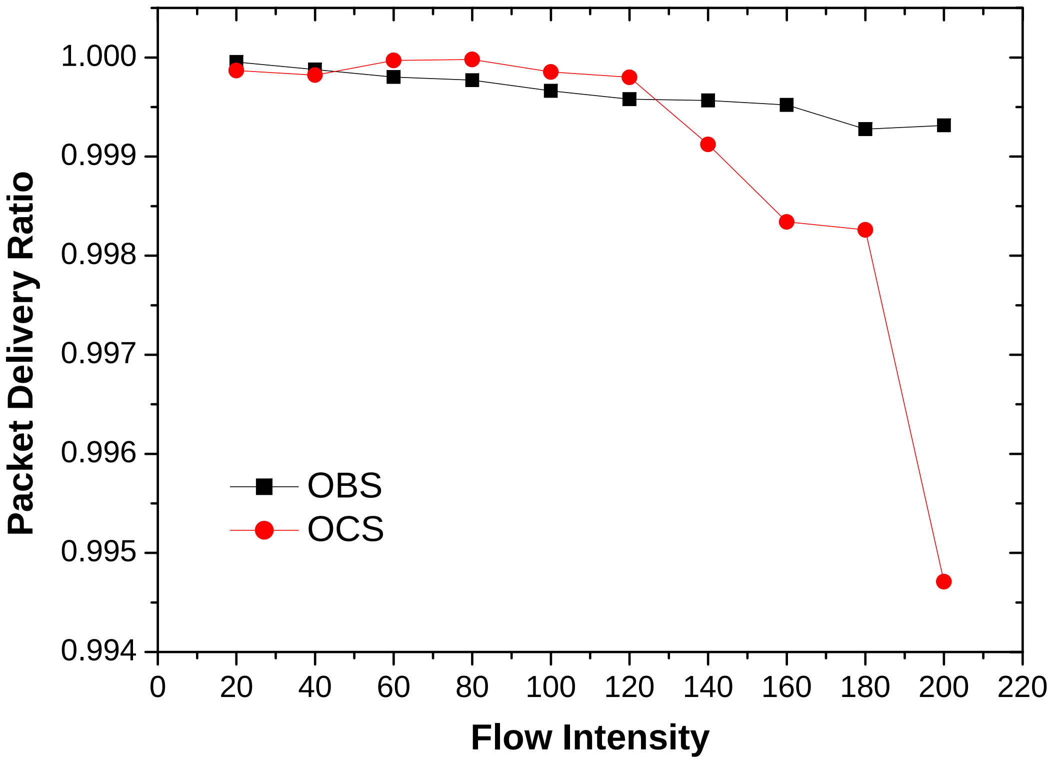
unlimited packet delay unlimited buffer (UDUP)

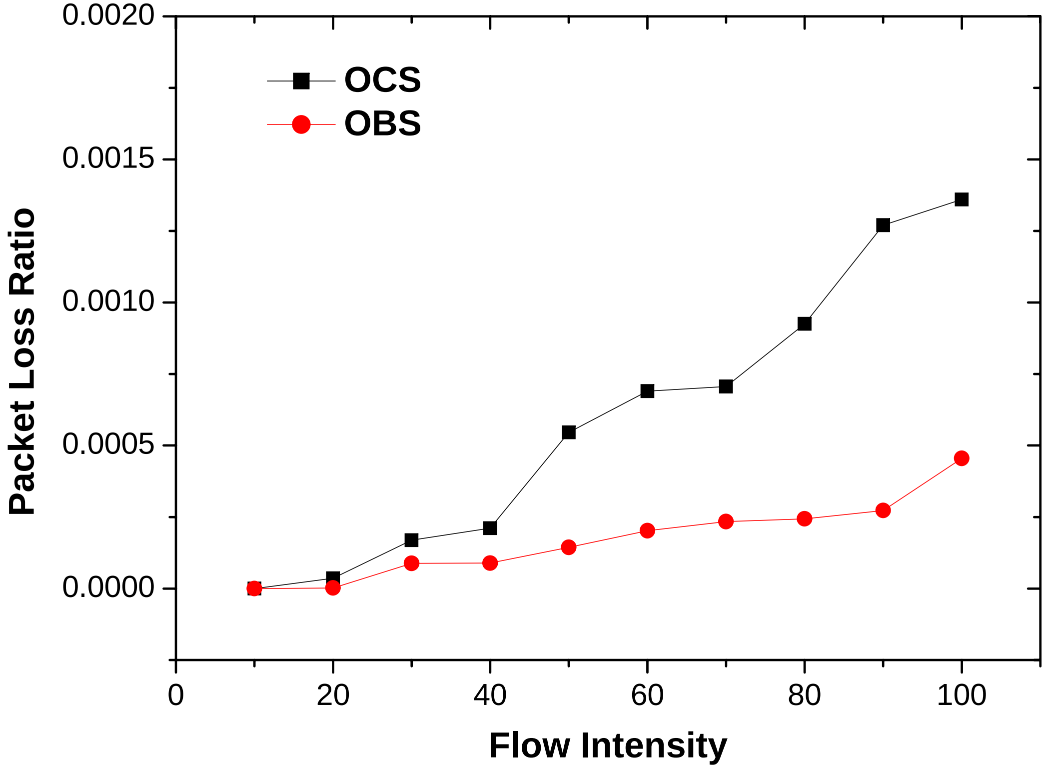


Packet delivery ratio vs flow intensity

unlimited packet delay unlimited buffer (UDUP)

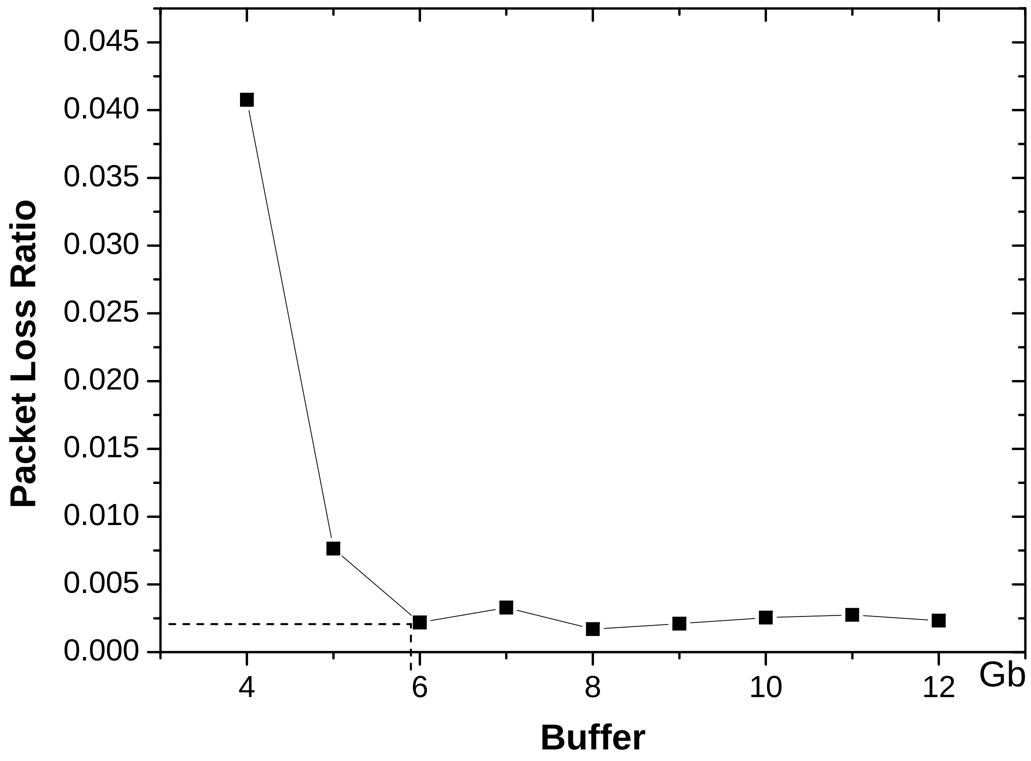
- Packet delivery ratios in the OCS and OBS networks decrease with the flow intensity.
- More packets have to wait in the buffer in OCS for connections to be established, while OBS can send out more packets within the same amount of time due to its shorter signaling delay, and smaller granularity which facilitates statistical multiplexing.

limited packet delay unlimited buffer (LDUB)



Packet loss ratio vs flow intensity

limited packet delay limited buffer (OCS)



Packet loss ratio vs buffer size at edge

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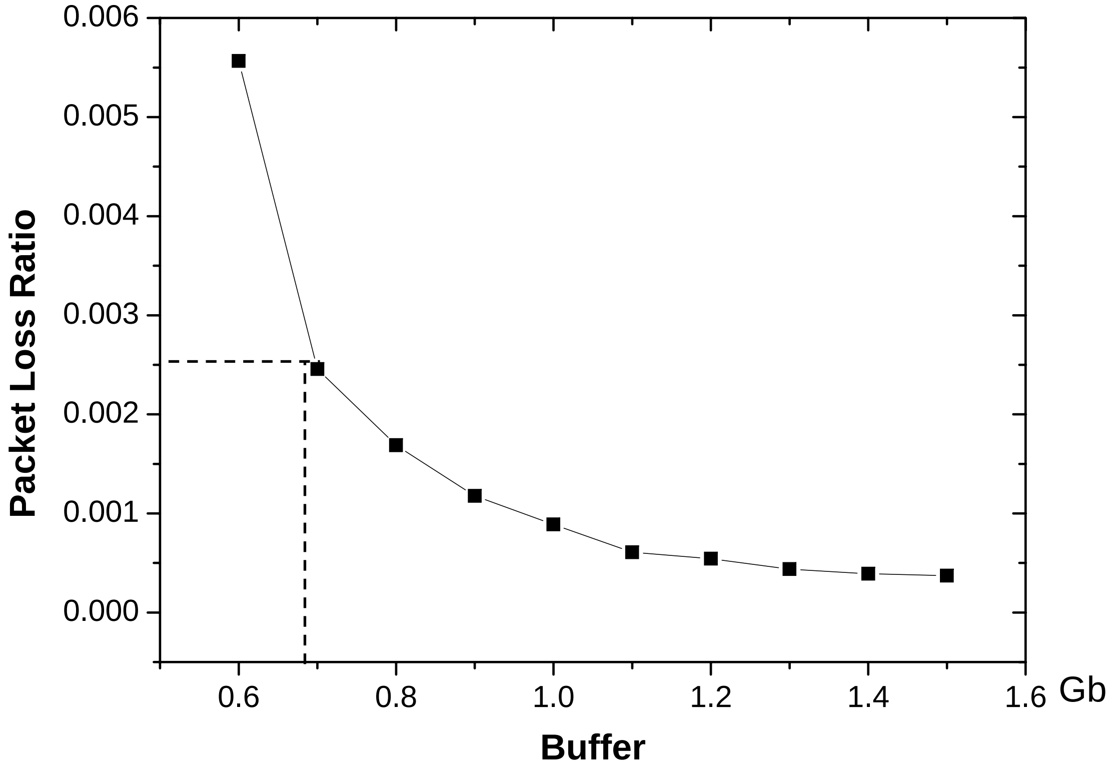
limited packet delay limited buffer (OBS)



OBS requires a smaller buffer to achieve the same packet loss ratio

LDLB and UDLB

- Packet loss ratios in OCS and OBS decrease sharply when the buffer size of each node increases but then stabilize when the buffer size is large enough.
- Beyond these threshold buffer sizes, the case resembles that of LDUB in that the packet loss ratios are largely due to limited delay, *which are around 0.2% in OCS and 0.04% in OBS.*
- The results for the case of UDLB are similar to LDLB when the buffer is small except
  - Both OCS and OBS have a lower packet loss rate
  - Both require a larger threshold buffer size
  - Identical to UDUB (when the buffer size is large enough)

Concluding Remarks (I)

- Transparency and Low Latency
  - Useful for ubiquitous wireless access and computing, and for optical grids applications
- Integrated Optical and RF Technologies
  - Fiber-optic, Optical Wireless, WiMAX at access and metro for reduced cost and emerging applications
- OCS and OBS
  - Both are useful but for different applications
  - Fair numerical comparisons between the two needed

Concluding Remarks (II)

- PATON is an integrated network capable of providing converged services (e.g., wired and wireless voice, video and data)
- PATON is flexible, efficient and scalable to support increasingly high, unpredictable and bursty traffic demands
- Being transparent and future-proof will enable faster and easier application development and service deployment and result in long-term reduction of CAPEX and OPEX.

To Probe Further

- A recent tutorial on OWS in OSA's JON
- OBS Forum www.obsforum.org (where you can many links to OBS workshops as well)
- IETF draft-ggf-ghpn-GOBS (and other IETF GGF Forum and GHPN Working Group documents)

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Thank You!

Questions and Suggestions ?