Optical Networks

Circuit switched, Burst switched, Packet switched

Electronic vs. Optical Switching

• Data is transmitted optically (in WANs, MANs and even some LANs)
• Electronic switching: uses digital (electronic) switching fabrics; converts data from Optical to Electronic for switching, and then from Electronic to Optical for transmission.
• Optical (photonic) switching: uses optical switching fabrics; keeps data in the optical domain
All Optical Switching (OOO)

• Pros:
  • low-cost (no OEO), and high-capacity
  • transparency (bit-rate, format, protocol)
  • synergetic to optical transmission and future-proof

• Caveats
  • opaque (OEO) switches are more mature/reliable
  • still need some electronic processing/control
  • optical 3R (Reliability, Robustness, and Resiliency)
    performance monitoring are hard

Optical Circuit Switching

• Long circuit set-up (a 2-way process with Req and Ack): $RTT = \text{tens of } ms$
  • 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)

• setting up a lightpath ($\lambda$ path) is like setting up a circuit.
  $\lambda$-path specific pros and cons:
  • very coarse granularity (OC-48 and above)
  • limited # of wavelengths (thus # of lightpaths)
  • no aggregation (merge of $\lambda$s) inside the core
    – traffic grooming at edge can be complex/inflexible
  • mature OXC technology ($msec$ switching time)
Opical Core

- five src/dest pairs
  - circuit-switching (wavelength routing)
    - 3 λs if without λ—conversion
    - only 2 λs otherwise
  - if data is periodic
    - packet-switching
      - only 1 λ needed with statistical muxing
      - λ conversion helps too

Packet Core

- optical access/metro networks (LAN/MAN)
  - optical buses, passive star couplers (Ethernet)
  - SONET/WDM rings (token rings)
  - switched networks? (Gigabit Ethernet)
- optical core (WAN)
  - λ-routed virtual topology (circuits/leased lines)
  - dynamic λ provisioning (circuits on-demand)
  - optical burst (packet/flow) switching (IP)

Packet Core: explosive traffic growth, bursty traffic pattern, bandwidth efficiency, flexible core, simplify network control & management
Self-Similar (or Bursty) Traffic

• Left:
  • Poisson traffic (voice)
  • smooth at large time scales and mux degrees
• Right:
  • data (IP) traffic
  • bursty at all time scales and large mux degrees
  • circuit-switching not efficient \((max >> avg)\)

Optical Packet Switching

• No.1 problem: lack of optical buffer (RAM)
• Fiber delay lines (FDLs) are bulky and provide only limited & deterministic delays
  • store-n-forward (with feed-back FDLs) leads to fixed packet length and synchronous switching
• tight coupling of header and payload
  • requires stringent synchronization, and fast processing and switching \((ns or less)\)
Packet (a) vs. Burst (b) Switching

Multiple data channels share one control channel. Data bursts remain in optical domain while CPs go through O/E/O conversions.
Optical Packet Switching Node

All-optical processing is not practical yet (will be ever competitive?), Need O/E/O conversion of header on every $\lambda$ (hundreds of them in each fiber). Also not scalable and cost-effective.

OEO approach

All traffic goes through O/E/O conversions (for sub-$\lambda$ granularity) However, as transmission speed goes higher, this approach is neither scalable nor cost-effective (heat, power, footprint)
Optical Circuit Switching (Wavelength Routing) node

Bandwidth is assigned at the wavelength ($\lambda$) granularity after lightpath is set up. No statistical multiplexing gain and high overhead for bursty traffic.

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 ($\lambda_{\text{control}}$)
  - reserves BW ($\lambda_{\text{data}}$) and configures switches
- A burst is sent after an offset time
  - arrives at a switch after it has been configured so no buffering needed

Optical Burst Switching (OBS) Networks

- Shift control complexity from optical to electrical layer
- Lower the switching granularity
- Dynamic bandwidth efficient
- All-optical bufferless
OBS Network Architecture

- Edge Node
  - Burst Assembly
  - Routing
- Core Node
  - Signaling
  - Scheduling

Burst Switching – Time Line

- Burst Switching For Digital Voice
- Resv Just-In-Time (RIT) Protocol
- Tell-and Wait (TAW)
- Tell-and-Go (TAG)
- Just-Enough-Time (JET) for OBS

Burst Signaling for TDM Networks

- Tell-and-Wait (TAW) = Connect-Confirmation (CC)
  - Send REQ first to make reservation; Transmit the burst after ACK is received (hop-by-hop distributed control)
- Reservation Just-In-Time (RIT)
  - Similar to TAW/CC; But switching fabric configured just before burst arrival; Burst transmitted at a time specified by ACK (centralized control or with global knowledge/synchronization)
- Tell-and-Go (TAG)
  - Send REQ and then burst (before receiving ACK); Delay burst at intermediate nodes to wait for REQ processing and switch configuration (hop-by-hop distributed control)

Optical Burst Switching (OBS) Protocols for WDM Networks

- Just-Enough-Time (JET)
  - Qiao, Yoo, 08/97 (IEEE/LEOS, NSF Proposal, DARPA Workshop), SPIE’98, JHSN’99, JSAC’00
- Terabit Burst Switching (based on TAG)
  - J. S. Turner, 12/97 (Tech. Rep), 1999 (JHSN)
- Just-In-Time (hop-by-hop RIT)
  - Wei, Tsai, McFarland et, al., SPIE’98, IFIP’00
  - Xu et al. IEEE ComMag’01, Baldine et al ComMag’02
- Wavelength Routed-OBS (centralized TAW/RIT)
  - Düser and Bayvel, JLT’02
OBS Basic Concepts

- Burst Assembly (and Disassembly) at Edge
  - Client data (e.g., IP packets) assembled into bursts

- Burst Switching/Reservation Protocol
  - Control packet (CP) sent an offset time \( t \) ahead of burst
  - Dedicated control channel (out-of-band signaling) for CP
  - No fiber delay lines (FDLs) nor O/E/O conversions for burst at any intermediate (core) nodes

- Photonic Burst Switching Fabric inside Core
  - Leverages the best of optics (for burst switching) and electronics (for CP processing and fabric control)

Burst Assembly

- Time or length threshold is reached
- Assembly queues for different egress nodes
- ATM Cell
- IP Packet
- SONET Frame

Control channel

Data channel
Assembly queues for different egress nodes

A CP is generated and sent out

Control channel

Data channel

ATM Cell

IP Packet

SONET Frame

Burst Assembly Node

Burst Assembly Node

Burst Assembly

Burst Assembly
Fiber Delay Line (FDLs)

- Feed-forward (above) or Feed-backward (Loop)
- No optical RAM for store-and-forward
- FDLs provide only limited delay and cannot perform most of useful buffer functions
- FDL units are bulky, affect signal quality etc.

Just-Enough-Time (JET)

- An offset time between CP and burst
  - No fiber delay line (FDL) required to delay the burst when CP is processed and switch fabric is configured.
- CP carries the burst length information
  - Facilitates delayed reservation (DR) for intelligent, efficient allocation of BW and FDL (if any), including look-ahead scheduling.
  - Later adopted by TBS, JIT and others (OPS)
JET with Offset Time $T$

Offset = $T$

CP arrives the OEO node at time $t_1$

CP goes through O/E conversion and configure switch fabric
CP goes through E/O conversion and leaves O/E/O node at time $t_1 + \delta$

When burst arrives at the intermediate node, the switch fabric is already configured.
Without any delay, the burst goes through the optical switch fabric.

Reduce Offset Time and Tolerate Switch Setting Delay (better than packet switching)

- control packet can leave right after $\delta = \Delta - s$ ($s$ is the switch setting time)
Delayed Reservation (DR)

DR leads to efficient allocation of BW and any available FDLs (though not shown). Without DR, 2nd burst will be dropped in both cases (and FDLs will be wasted in Case 2).

Burst scheduling

- Which output channel to use?
  - If none is available, which FDL (if any) to use?
- Two categories of scheduling algorithms
  - Without void (closed interval) filling
    - Only use open interval (also called Horizon/LAUC) [Turner'99]
  - With void filling
    - Can minimizes the starting void (Min-SV or LAUC-VF) or the ending void (Min-EV) etc. [Xu et.al. Infocom'03]
Scheduling Algorithms

Min-SV [Infocom'03] achieves the best performance in terms of computational complexity and the bandwidth utilization.

Statistical Multiplexing in OBS

Burst level transmission granularity and delayed reservation makes statistical multiplexing possible in OBS network.
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Sub-\(\lambda\) Switching Capability

By-pass traffic is treated the same as add/drop traffic and both are switched all-optically.
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Burst Contention and Resolution Solutions

- When multiple bursts compete for the same output channel, how to avoid/reduce burst loss?
- Three major strategies
  - Deflection in space, time and wavelength
  - Preemption of an existing reservation
  - Segmentation of a burst into smaller pieces
Contestation Resolution

- Deflection [Yoo, Qiao, Dixit, SPIE’00]
  - Space domain: applying deflection routing
  - Wavelength domain: use a different wavelength via wavelength conversion
  - Time domain: wait using a fiber delay line
- Segmentation
  - Drops, deflects or preempts one or more segments instead of an entire burst [Qiao NSF’97, Deti et al ’02 and Vokkarane & Jue ‘02]

Performance Measurement in OBS

- Burst loss
  - Due to burst contentions at intermediate nodes

![Diagram of Burst Contention]

- Burst delay
  - Burst assembly delay
  - Offset time
  - One-way propagation delay