IP and Optical Networking

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Contents

• Introduction
• Evolution Toward IP Optical Networking
  - Core and edge switches
• IP over SDH/SONET (using ATM, HDLC, SDL)
• IP Directly over WDM Network (point to point, ring or mesh)
• IP over Wavelengths (HSSF, Digital wrapper)
• IP Switching/routing inside Core Network
  - Optical switching control
  - Wavelength-based transmission/switching (OADM, OXC)
  - Optical packet routing/forwarding
• Control and Management
• Network Resilience and Survivability

References

• J. Anderson et al., BLTJ, pp.105-124, Jan. 1999
• T. Bharat et al., BLTJ, pp.63-85, Oct. 1998
**IP Backbone Network**

**Situation:**
- connects multiple regional networks and
- consists of high-capacity backbone IP routers and links

**Situation changes:**
- increase in link capacity: \(\sim \text{Mb/s} \rightarrow \sim \text{Gb/s}\)
- soft-based forwarding \(\rightarrow\) hardware-based forwarding
- ATM is not adequate for high bit rate traffic
- however, SONET is transport inefficiencies due to fixed bandwidth
Optical Transparent Packet Network

LANs and WANs
Interworking unit (IWU)
Edge switch
Optical packet core switch
Optical packet layer
Wavelength adaptation
Transparent optical packet layer
Electrically switched layer
Transparent optical transport layer

OADM - Optical add drop
OXC - Optical cross connect

ACTS project KEOPS
Switched Optical Network Structure

- Electronic island (LANs, Mans, ..)
- Physical links
- Logical links
Long-term Requirements of the Optical Transport Network

- open multi-service platform
- flexibility
- protection and restoration
- scalability
- management and supervision
Evolution Toward IP Optical Networking

In edge switch,
- Classical IP over ATM over SONET
- IP directly over SONET over WDM (using HDLC or SDL)
- IP over optical network

In core switch,
- Wavelength-based transmission and switching
- optical packet-based routing and forwarding
IP over ATM over SONET

- provides flexible bandwidth allocation
- provides robust transmission at 155Mb/s and 622 Mb/s

Transport:
- each IP datagram is encapsulated into an ATM adaptation layer type 5 (AAL-5) frame
- is segmented into 48-byte payloads for ATM cells
- are then mapped into a SONET frame
Classical IP over ATM over SONET

AAL-5 frame

SNAP header

LLC
3 bytes
0xAA-AA-03

OUI
3 bytes
0x00-00-00

PID (Ether type)
2 bytes
0x08-00

Information (IP packet)
with a maximum of 65,527 bytes

Padding
0-47 bytes

AAL-5 CPCS-PDU trailer
8 bytes

Cell 1
48-byte payload

Cell 2
48-byte payload

Cell 3
48-byte payload

Cell N
48-byte payload

5-byte ATM cell overhead

SONET STS-3c frame
per 125 μs

Section and line overhead
9 x 9 bytes

Path OH
1 x 9 bytes

Header Payload Header

STS-3c payload
260 x 9 bytes

9 bytes

270 bytes
IP directly over SONET
- using HDLC
- using SDL

Today's transport infrastructure:
• access network: OC-3 and OC-12 SONET UPSRs
• interoffice and long-haul backbones: OC-48 SONET BLSRs

• IP/ATM/SONET results in an overhead of 18 to 25%
• IP/SONET requires the approximately 4% fixed overhead

A key issue:
How to transport OC-48 signals through deployed SONET infrastructures

To transport gigabit data links
• employing SONET virtual concatenation to transport them through the existing TDM infrastructure
• Upgrading the existing TDM infrastructure to accommodate higher TDM line rates, or \( \rightarrow \) OC-192
• Migrating to a WDM-based optical networking infrastructure \( \rightarrow \) the most feasible candidates at present
IP over SONET using HDLC

- IP datagrams are encapsulated into PPP packets (IETF RFC 1661)
- PPP-encapsulated IP datagrams are framed using HDLC protocol (IETF RFC 1662)
- finally mapped byte aligned into the SONET SPE (synchronous payload envelope)
IP over SONET  
(using SDL)

: provides the high-speed delineation of variable-length datagrams with asynchronous arrival times

SONET STS-3c frame per 125 µs

<table>
<thead>
<tr>
<th>Section and line overhead</th>
<th>Path OH</th>
<th>Payload - length indicator</th>
<th>Header CRC</th>
<th>IP datagram</th>
<th>Payload CRC</th>
</tr>
</thead>
</table>

270 bytes

9 bytes

SONET STS-3c payload

260 x 9 bytes

CRC - Cyclic redundancy check
SDL - Simplified data link
PDU - protocol data unit
How to migrate to a WDM-based optical networking infrastructure

• the first step
  - data links that can be accommodated by the existing TDM network are transported to the SONET transport network using the router node interconnections
  - OC-48 and higher data traffic can be transported using a point-to-point WDM architecture

• new high-capacity data interfaces can be added without additional changes to the transport network

• WDM provides the advantage of being able to transport multiple interface technologies via a single transport infrastructure (IP over SONET, 1000BaseT, and IP over ATM)
Migrating to an IP Optical Networking Backbone (point-to-point WDM)

Access routers/enterprise services → IP backbone node

EMS → IP router → SONET ADM/LT → SONET XC → SONET NMS

ON NMS → WDM LT → Point-to-point WDM transport network

SONET transport network

OC-12/48

[STS-3c/12c] [STS-3c/12c] [STS-48c] [STS-48c]

ADM- Add drop multiplexer
EMS- Element management system
LT- Line terminal
NMS- network management system
XC- Cross connect
ON- Optical network
IP- Internet protocol
STS- nc- Synchronous transport signal n concatenated
WDM- Wavelength division multiplexing
OC- N- Optical carrier digital signal rate of N x 52 Mb/s, SONET
Migrating to an IP Optical Networking Backbone (ring or mesh WDM)

- availability of equipment capable of “networking” optical wavelengths such as OADMs and OXC
- protection switching and restoration in the optical domain

ADM - Add drop multiplexer
SC - Single-channel interface
WDM - Wavelength division multiplexing

• flexible routing of wavelengths
• protection switching
• restoration capabilities
IP over Wavelength

- IP
- ATM
- OC-3
- OC-12
- OC-48
- STS-48
- UXC
- OTU
- DWDM
- OTU
- OTU
- OTU

- HS - High speed
- LS - Low speed
- OC - Optical carrier
- OTU - Optical transponder unit
- STS - Sync. transfer signal
- UXC - Ultra-cross connect
  (SONET multiplexer and OXC)

BLTJ, Oct., 1998
Packet over Wavelength Protocol Architectures

HSSF - High-speed synchronous frame
HSSF

- designed for SONET-like transport for gigabit IP
- eliminate unnecessary SONET functionality (payload pointer) and overhead (stuff bytes)
- make it possible to transport IP directly to WDM optics
- use SONET 125-μs frame
- provides link status indications for link fault and performance management

![Diagram of HSSF frame]

```
A1  A1  ···  A2  A2  ···  signal status  Growth  SDL alignment  Payload for SDL  FEC

← 3 x N  → 3 x N  → 2  → j  → 2  → k  → p  →
```

Octets

FEC - Forward error correction
SDL - Simplified data link
How to cost-effectively manage the increasing number of wavelengths?

- effectively managing wavelengths (or optical channels)
- supporting Och-level Operations, Administration, and Maintenance (OAM) functions
- carrying a wide variety of client signals for optical transparency

↓

Digital Wrapper (Lucent Technologies)

<table>
<thead>
<tr>
<th>IP</th>
<th>SONET/SDH</th>
<th>FDDI</th>
<th>ATM</th>
<th>SDL</th>
<th>GbE, 10xGbE</th>
<th>PDH</th>
</tr>
</thead>
</table>

- Optical Channel (Wavelength) Digital Wrapper
- FEC Data
- Och Payload
- Och OAM
The best way is to effectively decouple optical switching capabilities between transmission/switching and routing/forwarding:

- **Wavelength-based transmission/switching in the optical domain** → OADM or OXC
  - provides high speed switching and full bandwidth in fiber itself
  - however, static utilization → inefficient optical bandwidth usage

- **Optical packet routing/forwarding in the electronic domain**
  - optical transparent packet switching based on fixed-length packet (KEOPS)
    - optical buffering
    - synchronization
  - optical burst switching based on variable-length packet
    - apply separate wavelengths to optical header and payload
    - asynchronous mode

↓

circuit-based switching + virtual path
Optical Switching Control

- Compatible to the existing control plane techniques developed for MPLS traffic engineering
- provide a framework for real-time provisioning of optical channels in automatically switched optical networks
- foster the expedited development and deployment of a new class of versatile OXCs
- allow the use of uniform semantics for network management and operations control in hybrid networks consisting of OXCs and Label switching routers
Configuration of OADM

Function : Add and Drop of Optical Signal, Optical Protection

- Large scale optical matrix SW
- Optical pass-band narrowing

SW Type

AOTF Type

- Simple configuration
- Need of tunable laser
- Easy upgrading of number of λ
Routing/Switching – II
(WDM-based OXC)

- Each OXC has a unique IP address

- Demux and mux: arrayed waveguide grating, coupler & grating
- M x M switches: cascaded thermo-optic, mechanical 2 x 2 switches
- Possible number of waves: 16 ~ 32 (present), 128 (near future)
Optical Interworking at the Edge Node

Edge Node
- IP address detection
- forwarding
- Look up table
- DAL-1
- DAL-2
- DAL-n
- Packet mux/demux
- Packet mux/demux
- Wavelength allocation

WDM Network
- DAL-n : Data Adaptation Layer-n

WDM Routing/ Switching
- IP backbone router w/ Optical interworking unit
- • insert IP packets onto the payload of the new frame structures
- • define optical packet for packet-based photonic switching
- • fixed and dynamic wavelength routing using optical add drop multiplexer
- • wavelength routing and switching using WDM optical cross connect
Optical Packet Format

- Fixed length was proposed by KEOPS because of the transition time of the ATM cell (e.g., 42 ns at 10 Gbit/s)
  - the use of the same infrastructure whatever the user bit rate
  - scalability of the link speed

- Packet format (header, payload, and guard times)
Transport IP to Optical Packet (time domain)

- gather IP packets directed to the same remote IP network in optical packets
- it provides improved utilization of network capacity and better network flexibility

- incoming signals (from other NEs)
  - PDH frame
  - SDH(2.5/10Gbps)
  - Gbit Ethernet (IP packet)

- client signal generation
  - PDH path signal
  - SDH VCs
  - ATM cell stream
  - PPP frames

- client signal mapping to Optical Containers

- optical packet size – network efficiency
  - minimum overhead
- guard time between optical packets
- transit and switching delay

Ref. OFC’99, S. Okamoto
Optical Transparent Packet Network Switch Architecture

Input interface:
- Demux
- Synchronizer
- O/E
- Header delineation
- Header recovery
- Payload position
- Local clock

Switching fabric:
- Switch control unit

Output interface:
- Synchronizer and signal regeneration
- O/E
- Payload delineation
- Header updating

Electrical blocks
Optical Burst Switching Architecture
(Ordered IP Router)

Forwarding table lookup
Matrix control and link scheduler
BCP rewrite

BCP detect

Inlet FDLs
Wavelength translation
FDLs for buffering
Space switch
Wavelength translation

FDL: Fiber Delay Line
BCP: Burst Control Packet

F. Callegati
Control and Management in the Optical Domain

- There exist a lot of redundancies in transporting IP traffic using conventional protocols.
- The best way is to remove the redundancy in transporting IP including maintenance or protection switching

→ IP over DWDM

Network Design:

- wavelength allocation
- topology and architecture for asymmetric packet traffic and wavelength reuse
- design for restoration versus reconfiguration versus congestion control
- availability of wavelength conversion
- effect of multi-fiber WDM networks on topologies and architectures for survivability

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Network Performance Monitoring, Fault Detection, and Fault management
Network resilience and Survivability

Network management system

1 + 1OMSP
1 + 1 SNCP
1:1 OMSP, OMS/SPRINGS

Mesh- based pre- computed restoration with centralized pre- computation
Mesh- based distributed restoration with distributed pre- computation

OMS- Optical multiplex section
OMSP- Optical multiplex section protection
SNCP- Subnetwork connection protection
SPRINGS- Shared protection rings
Conclusions

- Now, IP encapsulated into continuous frame structure → Future, IP into optical packets
- Now, IP routing/switching by way of WDM-based optical ADM or cross connect system → Future, IP by way of optical packet switching
- Now, wavelength allocation to same destination groups → Future, wavelength allocation to IP packets

Pre-requisites

- More efficient and compatible protocol and frame structure
- Secure wavelengths enough to allocate to each IP packet (> 100 waves)
- Wavelength conversion → virtual wavelength path and wavelength reuse
- Wideband optical amplifier (more than 70nm)
- High speed, cheap, and compact (or integrated) optical switch
- High density optical MUX with low insertion loss
- Optical signal monitoring techniques and related devices
- Optical 3R
- Wavelength management