Is it IP over WDM or Packet Optical Transport Platform?

And are these the best existing approaches?

Perspective by
Optimum Communications Services, Inc.
Key Issues

IP over WDM
- Simple architecture
  - All intelligence at IP routing layer
  - One complex (IP), one simple layer (WDM)
- No optimization between packet and transport layers

Packet Optical Transport Platform (P-OTP)
- Flexible architecture
  - Intent to minimize the required density of IP layer traffic processing
  - Two complex layers: IP and P-OTP
- Possibility for optimization across packet and transport layers

Is either one clearly better than the other?
### How Did We Get to These Alternatives?

**Current norm:**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Dominant protocol</th>
<th>Primary function</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3 routing</td>
<td>IP</td>
<td>• Internet routing</td>
<td>• Necessary for any Internet services</td>
</tr>
<tr>
<td>L2.5 forwarding</td>
<td>MPLS</td>
<td>• Reduce required density for expensive IP layer processing</td>
<td>• MPLS and Carrier Ethernet considered alternatives; neither is strictly necessary</td>
</tr>
<tr>
<td>L2 switching</td>
<td>Ethernet</td>
<td>• Reduce required density for expensive IP/MPLS processing</td>
<td></td>
</tr>
</tbody>
</table>
| L1 multiplexing | SDH               | • Reduce the required density of delay, jitter, packet loss probability and cost increasing L2/3 processing  
|              |                   | • Transparent any-protocol transport services (incl. native TDM)  
|              |                   | • Physical layer performance monitoring and protection                           | • Physical layer necessary for any communications                       |
| L0 transport | WDM               | • Multiple virtual fibers over single physical fiber                             |                                                                      |
## IP over WDM

### Division of network elements for packet and non-packet layer elements:

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<td>L3 Routing</td>
<td>IP</td>
<td>• Internet routing</td>
<td>• Natural integration of all packet layer functionality</td>
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<td>L2.5 forwarding</td>
<td>MPLS</td>
<td>• MPLS forwarding for QoS and packet-layer protection</td>
<td></td>
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<td>L1 multiplexing</td>
<td>SDH</td>
<td>• Reduce the required density of delay, jitter, packet loss probability and cost increasing packet switching and processing</td>
<td>• Natural integration of all non-packet i.e. TDM and WDM layer functionality</td>
</tr>
<tr>
<td>L0 transport</td>
<td>WDM</td>
<td>• Transparent any-protocol transport services (incl. native TDM)</td>
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<td></td>
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Clear - but without optimization between packet and transport layers
**P-OPT**

**Integrate L2.5-L0:**

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<td>L3 routing</td>
<td>IP</td>
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<td>• Keep “as is”</td>
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</table>
| P-OTP: L2.5/2 forwarding/switching | MPLS, Ethernet, SDH, WDM | • L2.5/L2 to reduce required density of IP layer processing  
• L1/L0 by-pass options to reduce the required density of delay, jitter and packet loss probability increasing L2/3 processing  
• Transparent any-protocol transport services (incl. native TDM)  
• Physical layer performance monitoring and protection  
• Multiple virtual fibers over single physical fiber | • Flexibly mix/match MPLS, Ethernet and TDM traffic  
• P-OTP systems will unavoidably be more complex, costly and less scalable than the plain L1/0 transport layer of IP over WDM |
| L1 multiplexing        |                   |                                                                                  |                                                 |
| L0 Transport           |                   |                                                                                  |                                                 |

Minimizes need for IP routing -- but at expense of more complex transport
## Summa Summarum

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Conclusions</th>
</tr>
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<tbody>
<tr>
<td>IP over WDM</td>
<td>+ Clear division of packet and non-packet layers</td>
<td>- Network operator highly dependent on very few IP router vendors</td>
<td>Mixed bag #1?</td>
</tr>
<tr>
<td></td>
<td>+ Simple transport</td>
<td>- No cross-layer optimization</td>
<td></td>
</tr>
<tr>
<td>P-OPT</td>
<td>+ Flexibility</td>
<td>- Complex integration of multiple L2.5/2/1/0 protocol functions in one platform</td>
<td>Mixed bag #2?</td>
</tr>
<tr>
<td></td>
<td>+ Minimized IP routing</td>
<td>- Due to complexity, not many vendors have the capabilities to develop, scale and support P-OPT</td>
<td></td>
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Choice between two differently mixed bags of goods and bads?
Observations

• Do these alternatives offer much more than mechanical integration of different combinations of Layers 3-0?
• Is there any architectural optimization?
• Is there any actual innovation?

Have we found the best alternatives yet?
A Way Forward?

- Is it possible:
  - ✓ to achieve optimization between packet and transport layers..
  - ✓ while minimizing the need for IP routing..
  - ✓ and while keeping the transport layer SIMPLE?
- How would the network layer stack look like then?

Achievable with integration of intelligent L1 with L2 forwarding
## Optimization of Packet and Simple Transport Layers

### Automatic optimization across standard packet and simple transport layers

### Transparent packet forwarding over adaptive L1 networks:

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<td>• Natural integration of all packet layer functionality</td>
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<td>Transparent optimization layer</td>
<td>Adaptive Concatenation</td>
<td>• L1 by-pass to minimize the frequency of the delay, jitter, packet loss probability and cost increasing L2/3 processing&lt;br&gt;• Optimized bandwidth allocation among mesh of L1 circuits between a set of routers per realtime traffic load variations</td>
<td>• Dynamic L1 channelization transparently across static L0 WDM</td>
</tr>
<tr>
<td>L0 transport</td>
<td>WDM</td>
<td>• Multiple virtual fibers over single physical fiber</td>
<td>• Transport as simple as it comes</td>
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Adaptive Concatenation

• Adaptive-Concatenation (AC) - next step from SDH Virtual Concatenation:
  ✓ L1 capacity allocation optimization according to traffic load variations
  ✓ realtime-dynamic
  ✓ automatic
  ✓ transparent
  ✓ overhead-free

• Implemented by Optimum Communications Services, Inc.

• Demonstrably achieves:
  ✓ maximized bandwidth efficiency
  ✓ QoS of direct circuit: minimized delay, jitter, no packet loss for priority traffic
  ✓ architecturally minimized packet processing requirements via L1 by-pass

Variable bandwidth transport for variable bandwidth packet traffic flows
Adaptive Concatenation Mux Bus (AMB):
- Capacity M STS-1 TSs, to match destination node RX capacity
- M STS-1 TSs dynamically allocated among the source-specific Adaptive Concatenated (AC) STS-X circuits

- Allocation of STS-1 TSs among the AMB sources optimized for every new STS row based on byte inflows from the sources to the destination of the AMB:
  - 72000 optimization cycles per second
  - Capacity allocation unit 86 byte timeslots; roughly the size of min. length L2 packet
  - Continuously optimized L1 bandwidth allocation on individual packet / STS-1 row timeslot basis

- AMBs continuously maximize network throughput, within the constraints of their destination (customer) node RX capacities (e.g. STS-192 AMB for 10Gbps destination RX port):
  - AMBs consume minimum network capacity sufficient to fully utilize each network egress interface

Dest. node

Adaptive bandwth L1 delivered:
- Maximized bandwidth utilization
- Premium QoS based on actual L1 circuit transport:
  - Minimized jitter and delay
  - Packet loss free transmission
Impact of L1 Optimization

- L1 efficiency affects any service delivered over *any* L2/3+ protocol stacks
- L1 optimization fundamental to network efficiency and performance
- How does Adaptive-Concatenation (AC) L1 optimized IP over WDM compare against:
  1. Non L1 optimized IP over WDM?
  2. P-OTP?
- Let’s analyze the cost, complexity and performance of network by studying a flow of packets between an IP source and destination
  - Factors impacting cost -- *should be minimized*
    - Number and complexity of packet-layer processing, switching instances and layers
    - Amount of WDM capacity consumed
  - Factors impacting performance -- *should be minimized*
    - Number of packet-layer processing, switching instances and layers traversed

→ *See next two slides for analysis on cost of carrying packet flow across alternative implementations of the given required network connectivity*
I.) Non-optimized vs. AC-optimized IP-over-WDM

**Non-AC-optimized:**
- Requires multiple times more packet hops, or multiple times more WDM wavelengths than AC-optimized

**AC-optimized:**
- Minimized packet hop density
- Minimized packet processing costs
- Minimized WDM capacity costs

**AC: Premium QoS with minimized equipment, bandwidth & operating costs**
II.) P-OTP vs. AC-optimized IP-over-WDM

**P-OTP:**
- Interim MPLS routers avoidable via MPLS(-TP) switching within P-OTP
- Inter-layer optimization possible, but requires complex multi-layer e.g. GMPLS Traffic Engineering signaling schemes

**AC-optimized IP over WDM:**
- AC layer implicitly controlled by MPLS layer (via TE-policed traffic loads) but can operate standalone
- AC: More efficient implementation of desired functionality of IP over WDM/P-OPT

- Minimized L3/2 packet hop counts
- Minimized packet processing costs
- Minimized WDM capacity costs

**AC: Simplicity wins**

- Plenty of flexibility, but
  - with increased complexity
  - based on trade-offs
Further Observations

• Conventional architectures cause trade-offs:
  - EITHER minimize higher layer processing ('extreme’ WDM view) to minimize cost per unit of capacity provided -- **BUT this requires most overall capacity**, 
  - OR provide most sophisticated application layer processing ('extreme’ DPI view) to maximize capacity utilization i.e. minimize amount of capacity required -- **BUT this makes unit of capacity most expensive**, 
  - OR provide flexibility ('moderate’ P-OTP view) -- **BUT is this merely a hybrid of the above categorical extremes rather than a new level of efficiency?**

• Optimization should not be done for one objective at expense of others, but it should reach a new standard of efficiency

• AC based L1 optimization can maximize capacity utilization efficiency while keeping capacity simplicity and cost-efficiency at level of WDM
  → **See diagrams on the following two slides**

AC - True optimization at expense of none
No-Win Network Cost-efficiency Curve

- Cost = X times Y ~ Constant
- The less expensive unit capacity, the more capacity needed
- Service cost base roughly equal whatever the implementation
AC: New Standard for Cost-efficiency

- AC reduces capacity requirements by ~10X, while simplifying networks i.e. reducing capacity unit cost
  ⇒ Service cost w/ AC in the order of ~1/10 of any non-adaptive L1 based alternative
AC vs. Conventional Dynamic L1/0 Techniques (#1)

- Conventional techniques for dynamic L1/0 capacity allocation include SDH Virtual Concatenation w/ Link Capacity Adjustment Scheme and Optical Burst Switching.

- *Unlike Adaptive Concatenation (AC), conventional dynamic L1/0 techniques:* 
  - *do not support downtime-free capacity reallocation*
  - do require signaling overhead
  - cannot adapt L1/0 bandwidth allocation according to realtime traffic loads variations, even closely to individual packet byte load granularity
  - complicate system implementation
  - due to complexity, limit systems scalability
  - increase system cost vs. static L1/0
AC vs. Conventional Dynamic L1/0 Techniques (#2)

- With conventional dynamic L1/0, the more frequently capacity is reallocated, the greater the portion of network airtime that has to be taken out-of-service (while being reallocated), decreasing the overall available network bandwidth.

- There thus is a limit for how much value such non-downtime-free reallocation techniques can add, as the more dynamic the network would need to be, the greater the portion of network airtime will be unusable (while under reallocation).

→ *To be effective, how dynamic would network capacity allocation need to be?*

- Capacity needs to be reallocated at the time and transport capacity granularity equal to how packets (each providing a burst of data) can arrive to the network.

→ *To be of value, dynamic control plane needs to operate at data plane packet rate*.
AC vs. Conventional Dynamic L1/0 Techniques (#3)

Adaptive Concatenation:
- STS-1 row (86 bytes) capacity allocation unit sufficient; close to minimum L2 packet length
- $9 \times 8000 = 72000$ optimization cycles / second
- AC provides L1 bandwidth allocation granularity of 50Mbps/72000 i.e. finer than 1 kb/s

Conventional techniques:
- Involve software processes (*non*-synchronous to data plane) on several nodes that take seconds to complete
- Are thousands of times too slow to be effective (i.e. to be able react to bursts caused by arrival of packets)
- Even at 1 second capacity allocation time scale with 10Gbps wavelength switching unit, conventional granularity would be 10Gb/s

→ Data plane synchronous embedded control plane of AC provides in the order of 10Gb/s:1kb/s i.e. ten-million-times more accurate capacity allocation optimization

Adaptive Concatenation - *Always* optimized
Optimum Communications Services, Inc.

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