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

<u>IP over WDM</u>

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

<u>Packet Optical Transport Platform (P-OTP)</u>

- 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:

Layer	Dominant protocol	Primary function	*Notes*
L3 routing	IP	• Internet routing	• *Necessary for any Internet services*
L2.5 forwarding	MPLS	• Reduce required density for expensive IP layer processing	• *MPLS and Carrier Ethernet considered alternatives; neither is strictly necessary*
L2 switching	Ethernet	• Reduce required density for expensive IP/MPLS processing	
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	

Are there unnecessarily many layers for carrying just IP and TDM?

IP over WDM

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

Layer	Dominant protocols	Primary function	*Notes*
L3 Routing - - - - - - - - - - L2.5 forwarding	IP MPLS	• Internet routing • MPLS forwarding for QoS and packet-layer protection	•*Natural integration of all packet layer functionality*
L1 multiplexing - - - - - - - - - - L0 transport	SDH WDM	• Reduce the required density of delay, jitter, packet loss probability and cost increasing packet switching and processing • Transparent any-protocol transport services (incl. native TDM) • Physical layer performance monitoring and protection • Multiple virtual fibers over single physical fiber	• *Natural integration of all non-packet i.e. TDM and WDM layer functionality*

Clear - but without optimization between packet and transport layers

P-OPT

Integrate L2.5-L0:

Layer	Dominant protocol	Primary function	*Notes*
L3 routing	IP	• Internet routing	• *Keep "as is"*
P-OTP: L2.5/2 forwarding/ switching - - - - - - - - - - L1 multiplexing - - - - - - - - - - L0 Transport	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*

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

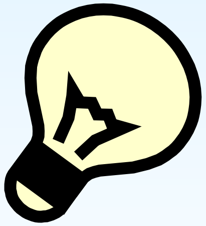
Summa Summarum

Alternative	Advantages	Disadvantages	Conclusions
IP over WDM	+ Clear division of packet and non-packet layers + Simple transport	- Network operator highly dependent on very few IP router vendors - No cross-layer optimization	Mixed bag #1?
P-OPT	+ Flexibility + Minimized IP routing	- Complex integration of multiple L2.5/2/1/0 protocol functions in one platform - Due to complexity, not many vendors have the capabilities to develop, scale and support P-OPT	Mixed bag #2?

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

Transparent packet forwarding over adaptive L1 networks:

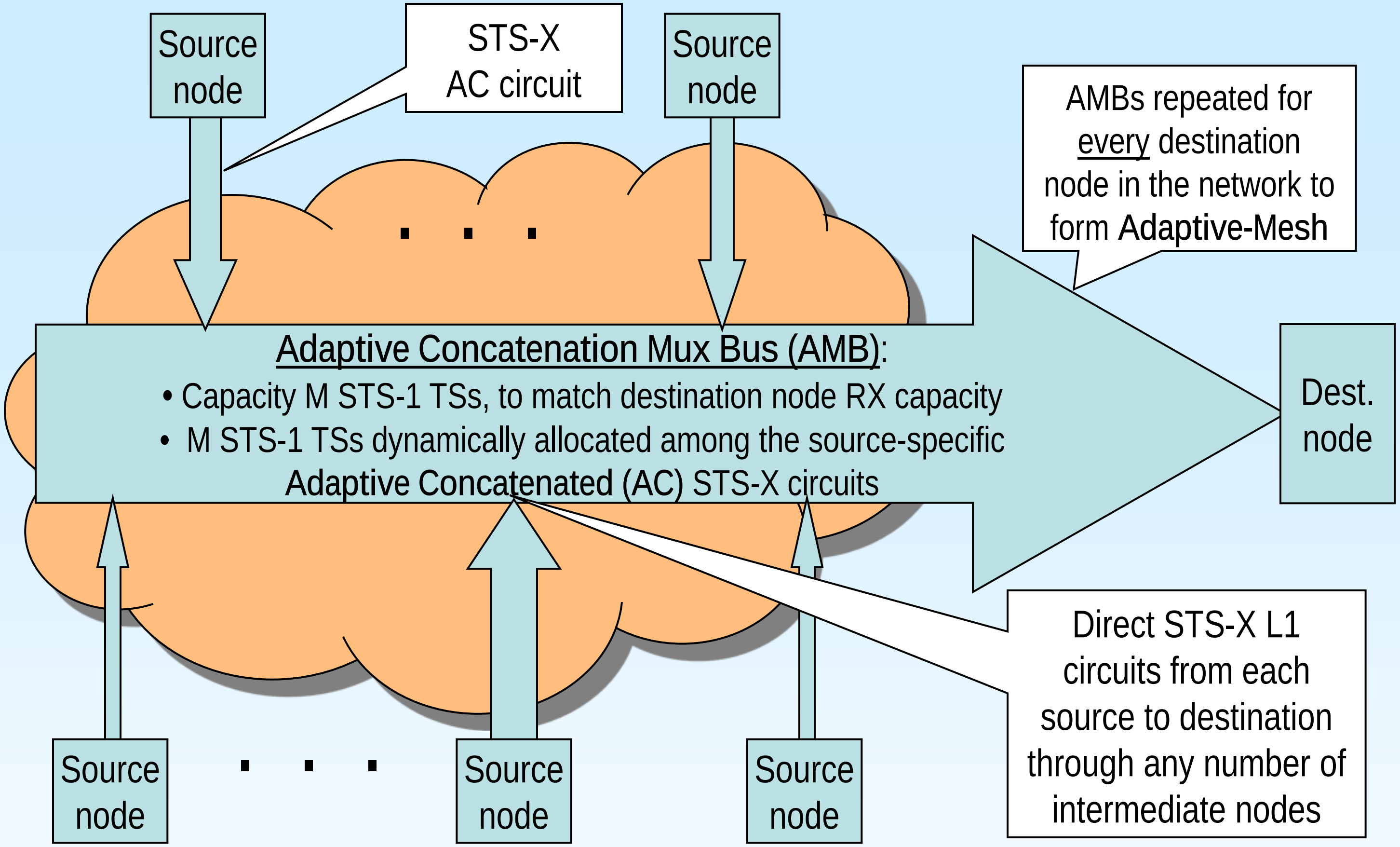
Layer	Dominant protocols	Primary function	*Notes*
L3/2.5 routing/ forwarding - - - - - - - - - - - Transparent optimization layer	IP MPLS Adaptive Conca-tenation	• Internet routing • MPLS forwarding for QoS and packet-layer protection - - - - - - - - - - - • L1 by-pass to minimize the frequency of the delay, jitter, packet loss probability and cost increasing L2/3 processing • Optimized bandwidth allocation among mesh of L1 circuits between a set of routers per realtime traffic load variations	• *Natural integration of all packet layer functionality* • *Dynamic L1 channelization transparently across static L0 WDM*
L0 transport	WDM	• Multiple virtual fibers over single physical fiber	• *Transport as simple as it comes*

Automatic optimization across standard packet and simple transport layers

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 bandwidth L1 delivered:

✓ Maximized bandwidth utilization

AND

✓ Premium QoS based on actual L1 circuit transport:
- Minimized jitter and delay
- Packet loss free transmission

- 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

Impact of L1 Optimization

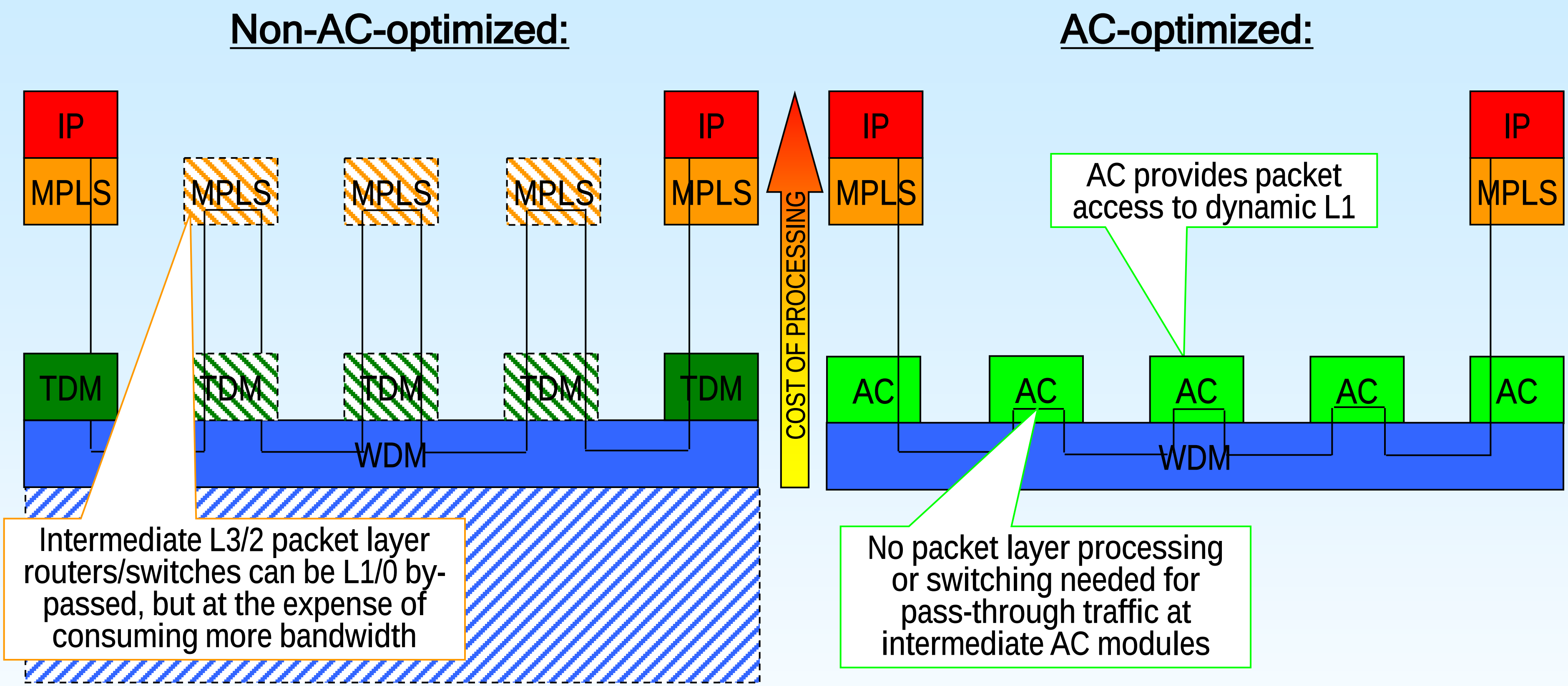
- L1 efficiency affects any service delivered over *any* L2/3+ protocol stacks

→ L1 optimization fundamental to network efficiency and performance

- How does Adaptive-Concatenation (AC) L1 optimized IP over WDM compare against:
  I. Non L1 optimized IP over WDM?
  II. 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

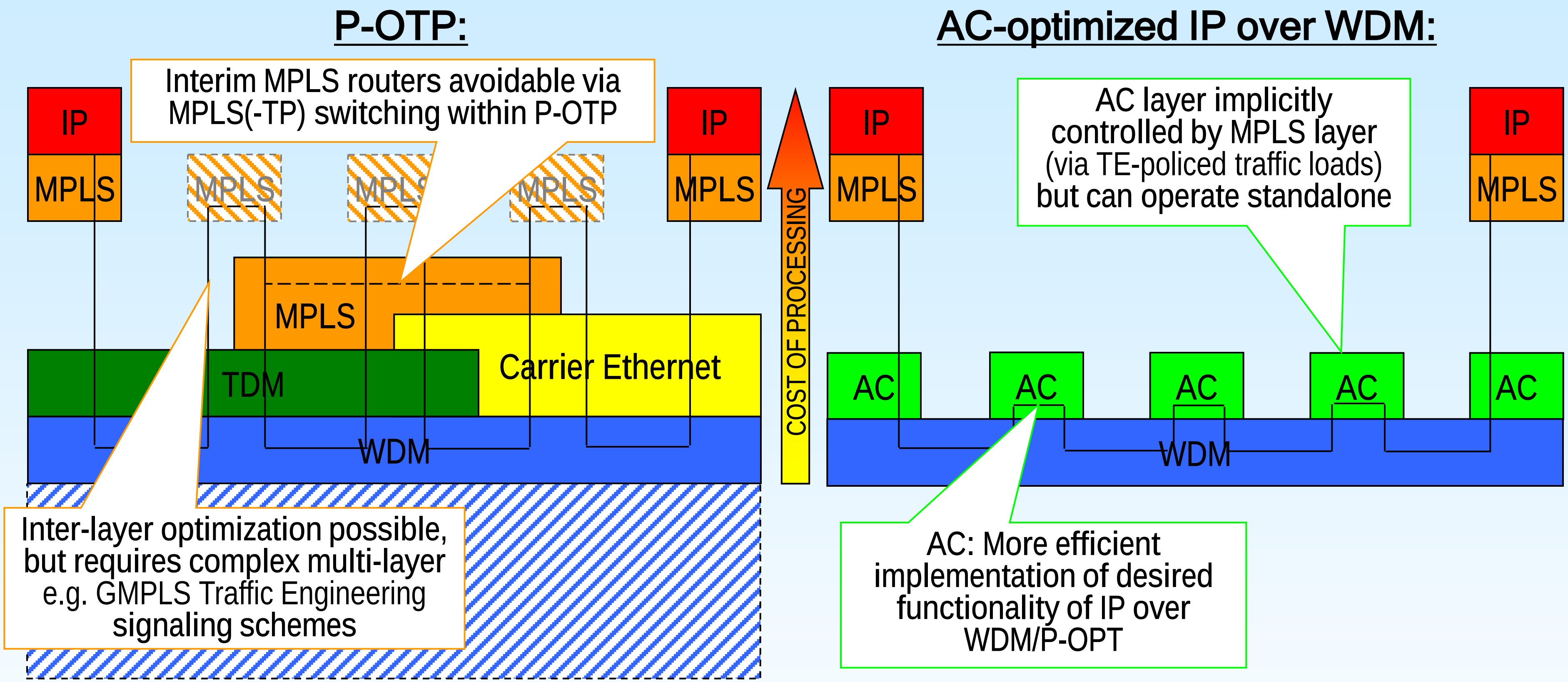


- Requires multiple times more packet hops, or multiple times more WDM wavelengths than AC-optimized

✓ 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



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

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

AC: Simplicity wins

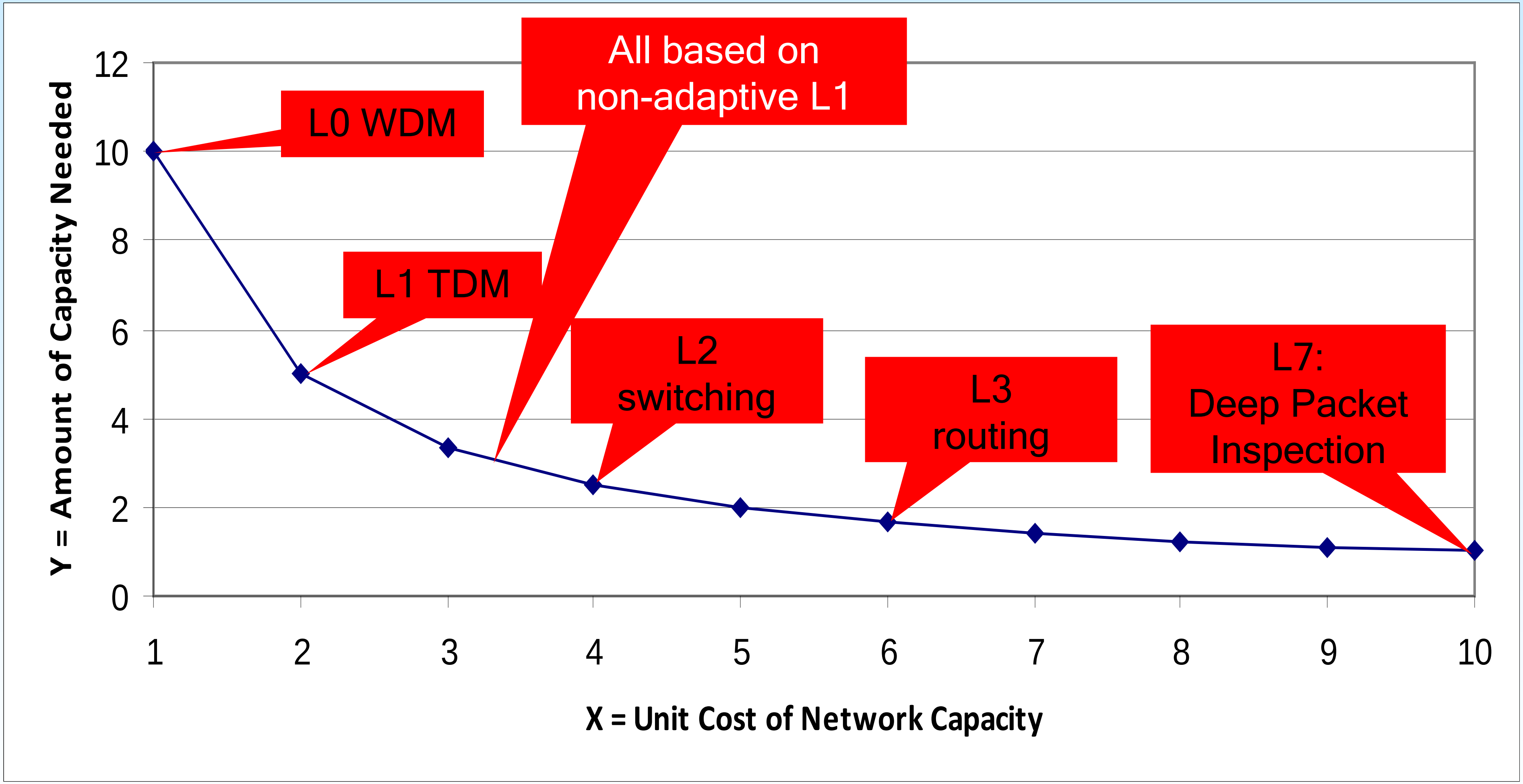
Further Observations

- 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*

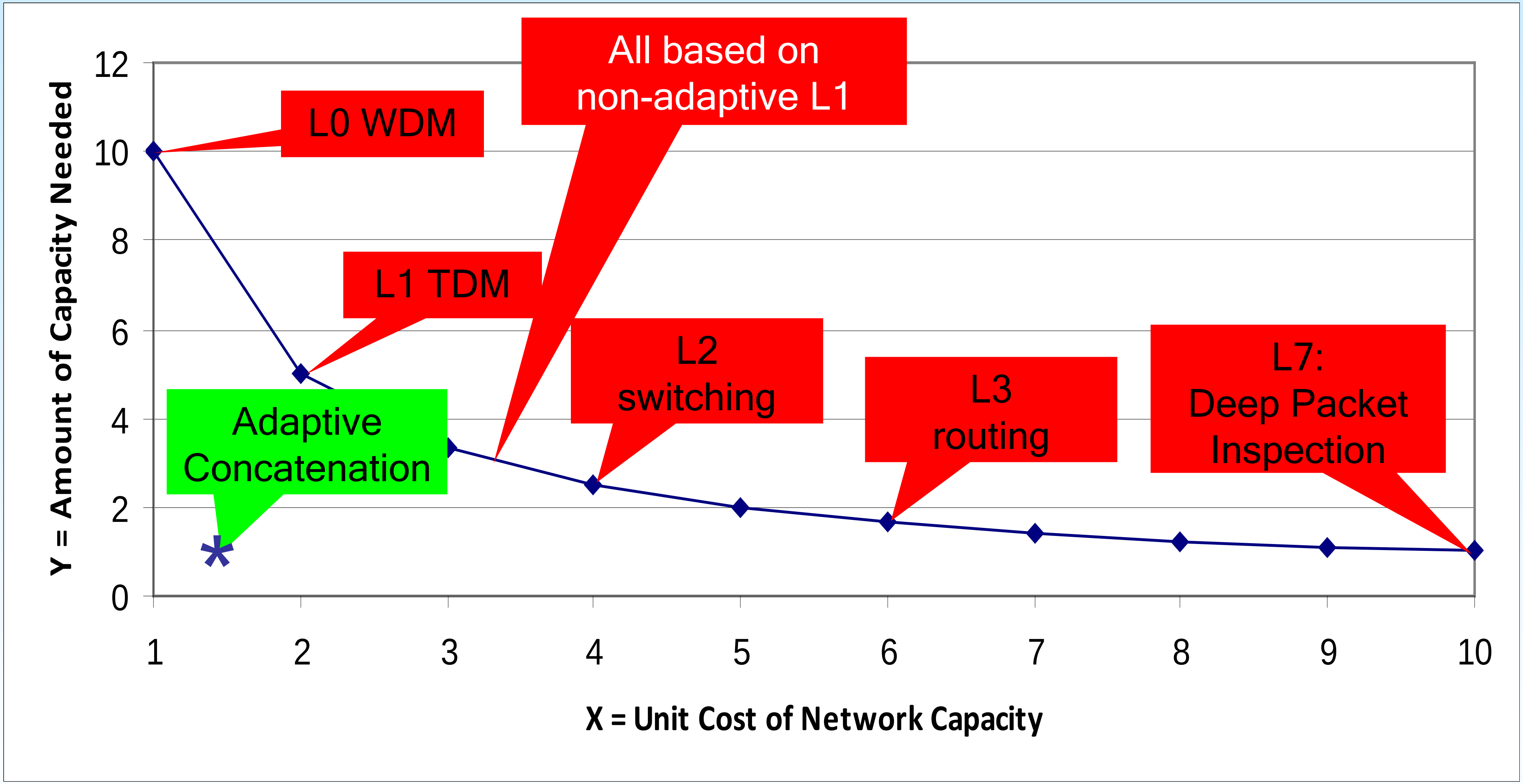
AC - True optimization at expense of none

No-Win Network Cost-efficiency Curve



- <u>Cost = X times Y ~ Constant</u>
- 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

→ <u>To be of value, dynamic control plane needs to operate at data plane packet rate</u>

AC vs. Conventional Dynamic L1/0 Techniques (#3)

<u>Adaptive Concatenation:</u>

- STS-1 row (86 bytes) capacity allocation unit sufficient; close to minimum L2 packet length
- 9 (STS rows/frame) x 8000 (STS frames/second) = <u>72000 optimization cycles / second</u>
- AC provides L1 bandwidth allocation granularity of 50Mbps/72000 i.e. finer than 1 kb/s

<u>Conventional techniques:</u>

- Involve software processes (*non-synchronous* to data plane) on several nodes that take seconds to complete
- <u>Are thousands of times too slow to be effective</u> (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

→ <u>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</u>

Adaptive Concatenation - *Always* optimized

Optimum Communications Services, Inc.

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