Is it IP over

WDM or Packet Optical Transport Platform?

And are these the best available approaches?

Perspective by

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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?

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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?

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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

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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

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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?

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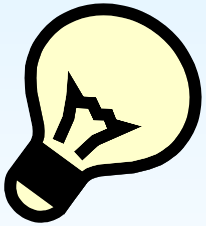
Observations

- 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?

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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

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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

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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

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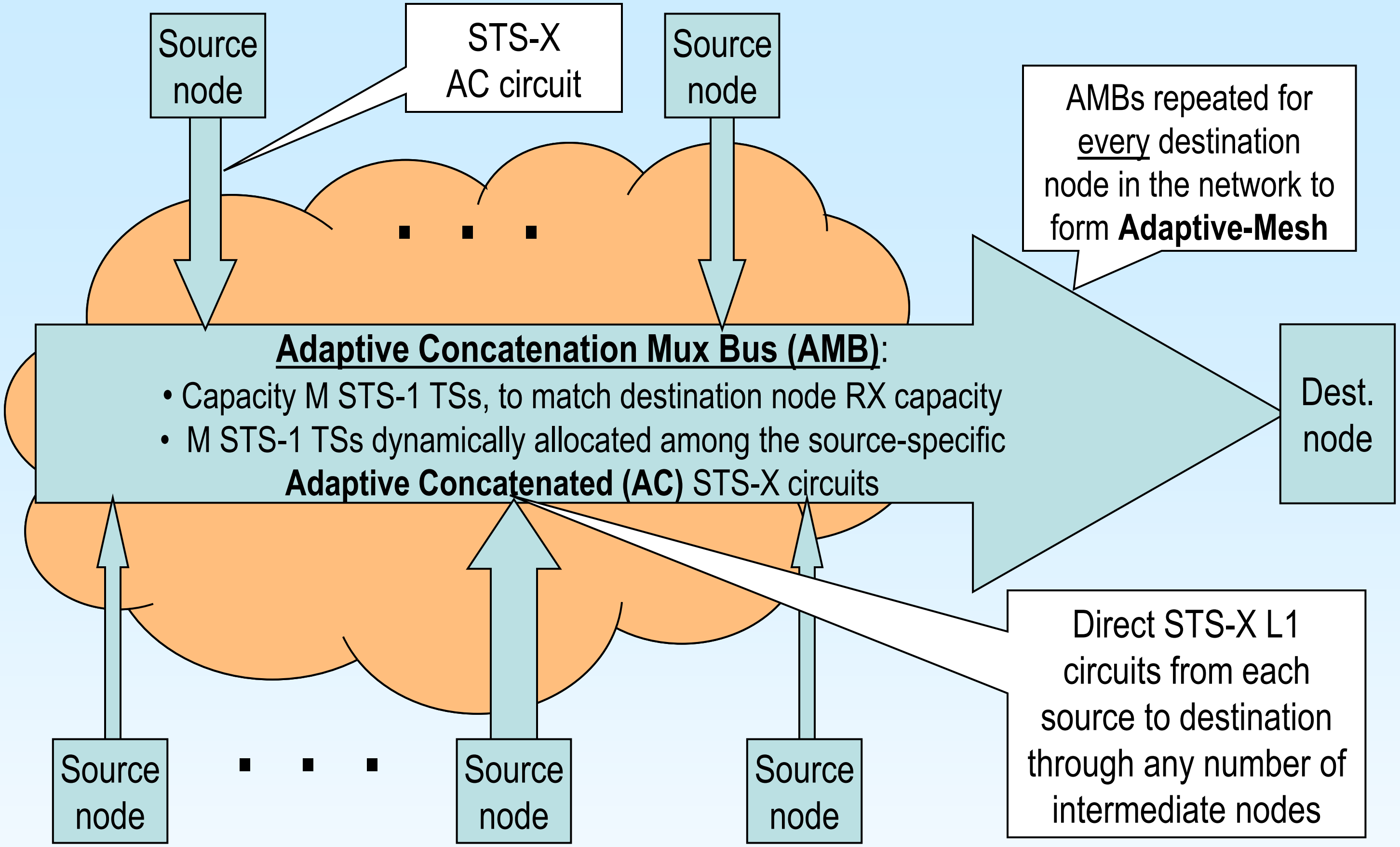

Adaptive bandwidth L1 delivered:

✓ 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

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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*

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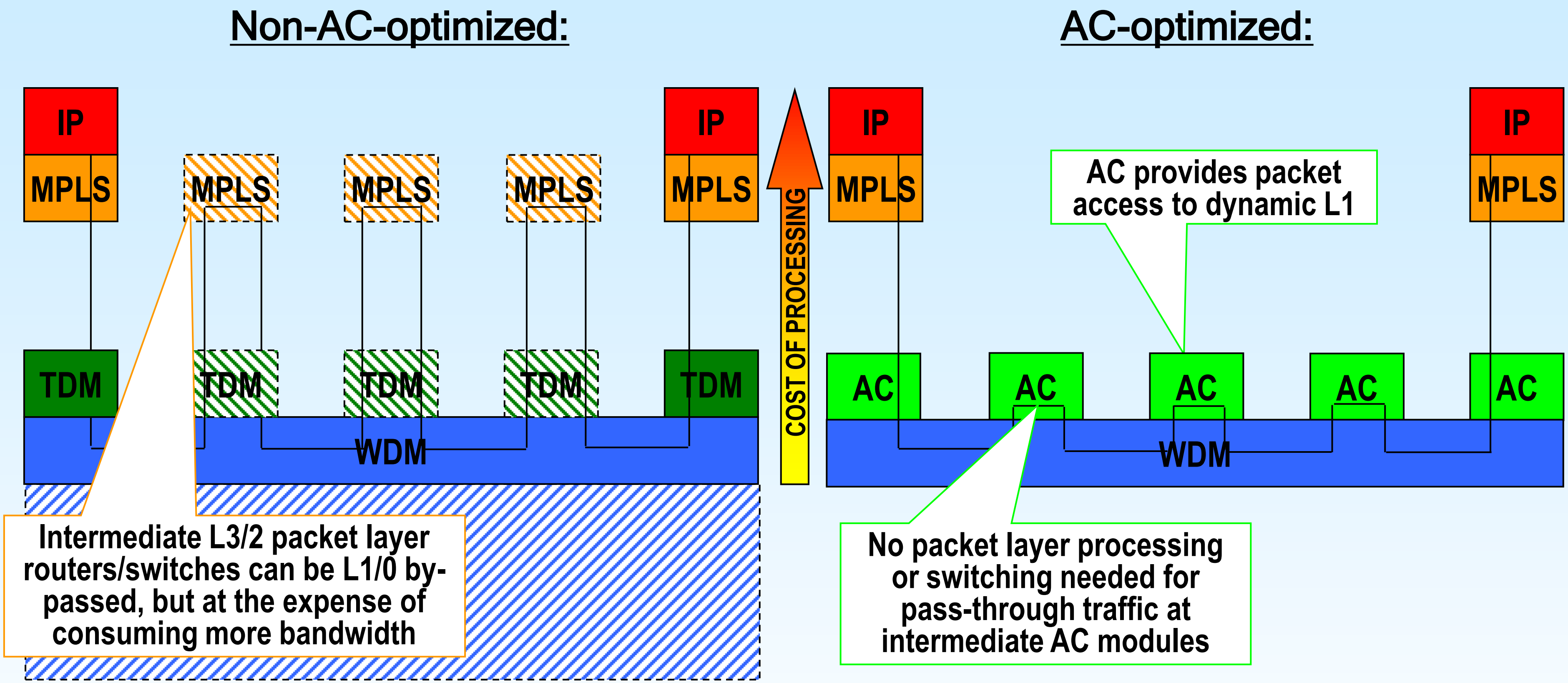
I.) Non-optimized vs. AC-optimized IP-over-WDM



- 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

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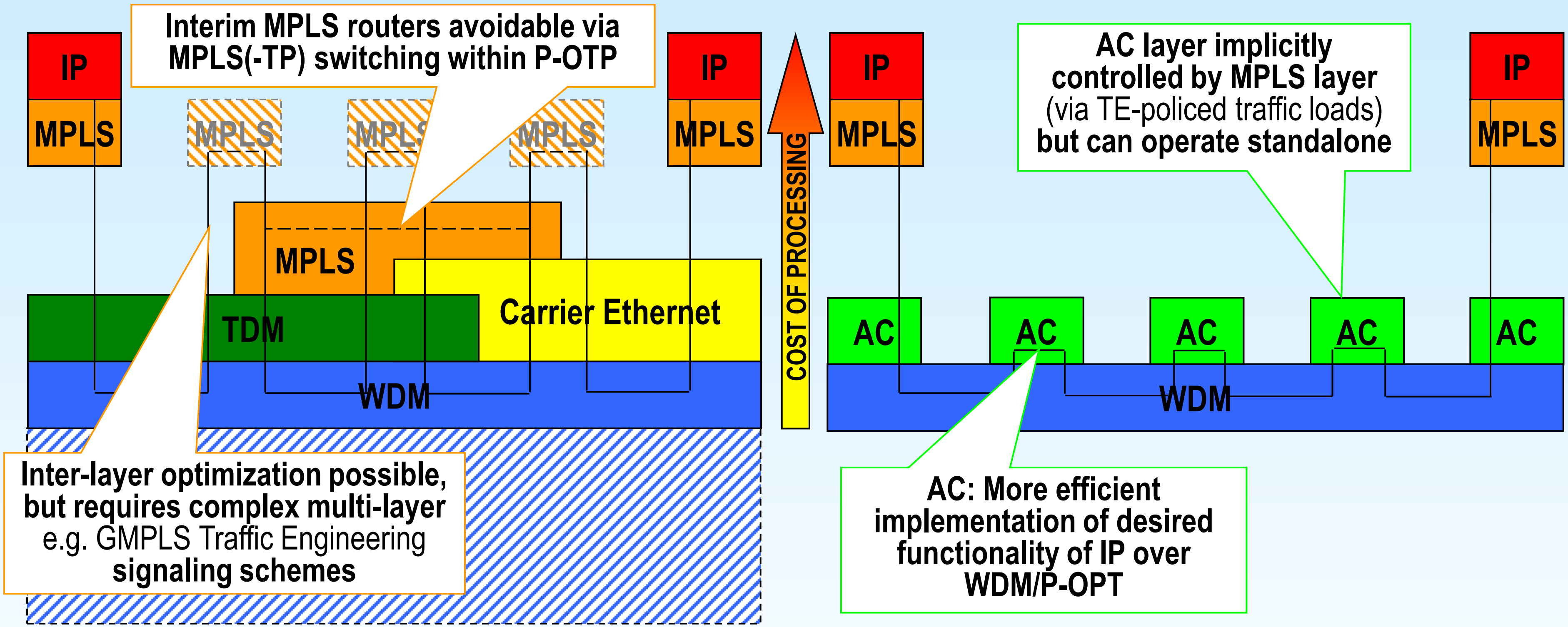
II.) P-OTP vs. AC-optimized IP-over-WDM

P-OTP: | **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

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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

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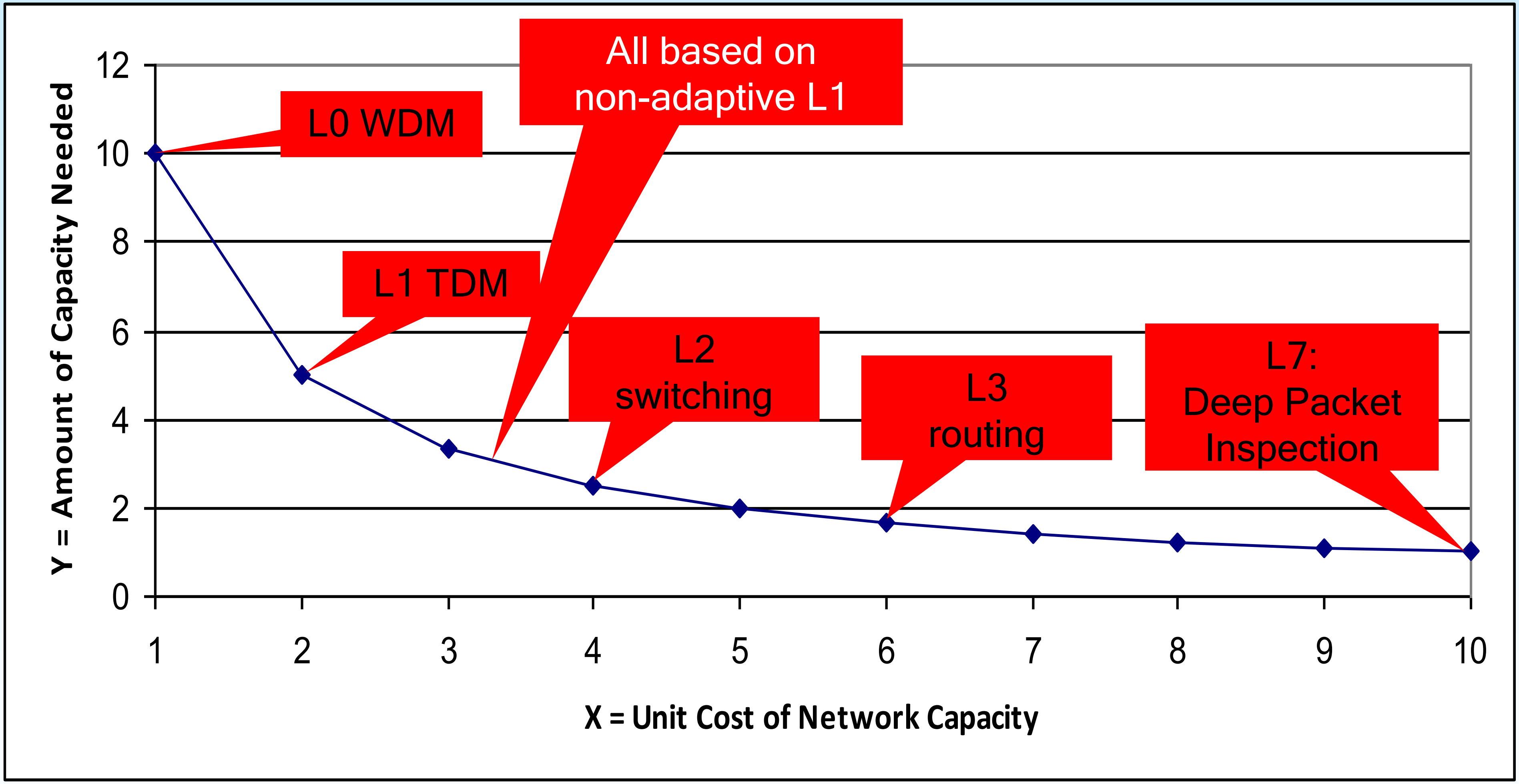
No-Win Network Cost-efficiency Curve



- <u>Cost = X times Y ~ Constant</u>
- The less expensive unit capacity, the more capacity needed
- Service cost base roughly equal whatever the implementation

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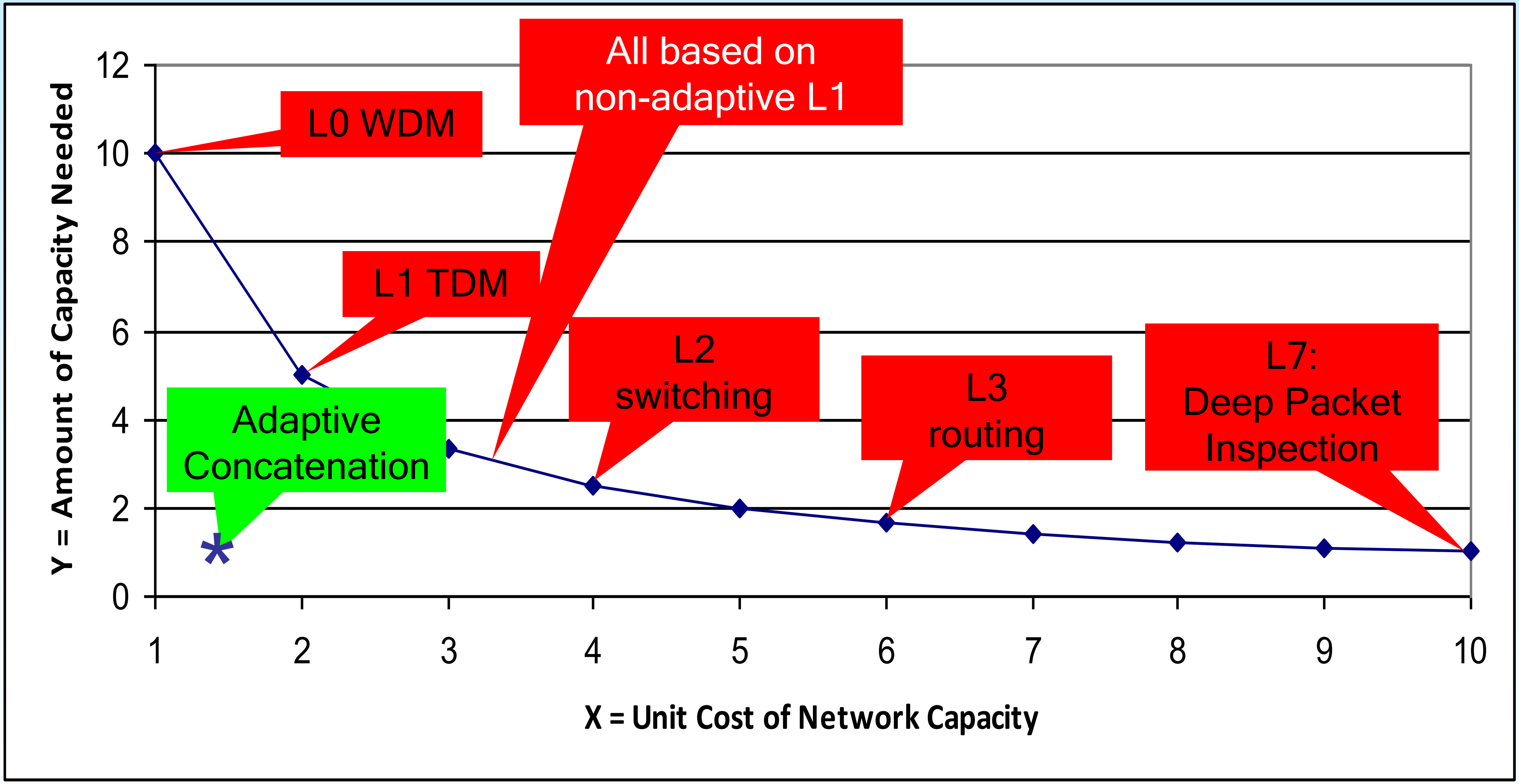
AC: New Standard for Cost-efficiency



- 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

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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

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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>

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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 (STS rows/frame) x 8000 (STS frames/second) = 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

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