GE Multilin
Lentronics Multiplexers

SONET 101

Aman Mangat

imagination at work

Proprietary & Confidential to GE

Building the future together

What is SONET?

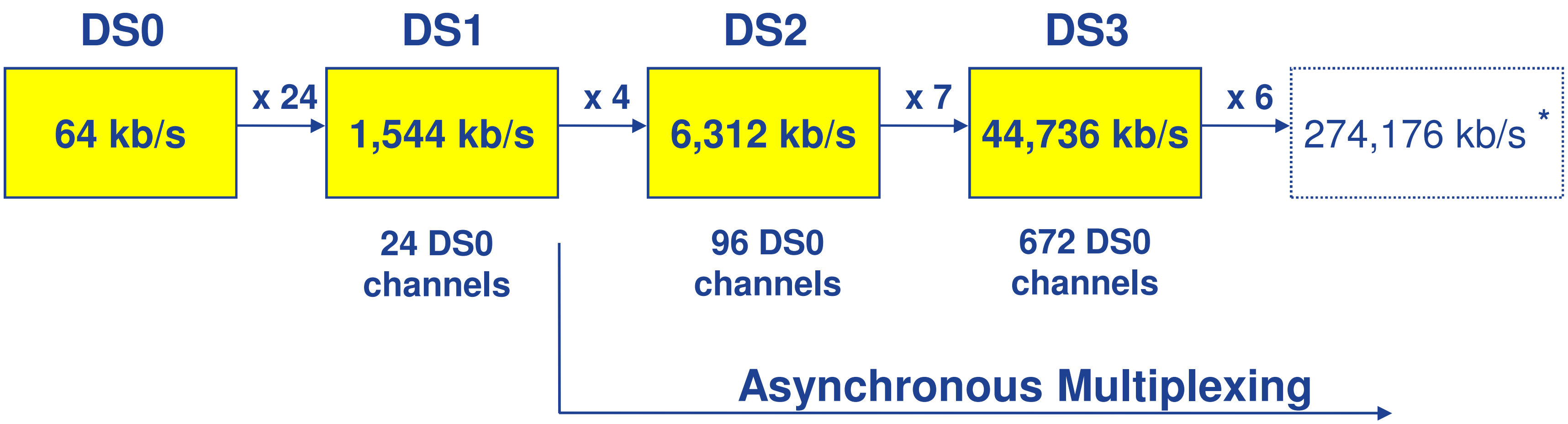
SONET = Synchronous Optical NETwork

- **Optical** = This is a standard for optical telecommunications. (Although some SONET rates can be transported over microwave radio.)
- **Synchronous** = All terminals in a SONET network are normally timed from the same clock source.

What Preceded SONET?

- Prior to SONET, digital transmission systems were generally asynchronous, with each terminal running on its own clock.

North American Asynchronous Digital Transmission Hierarchy (PDH)



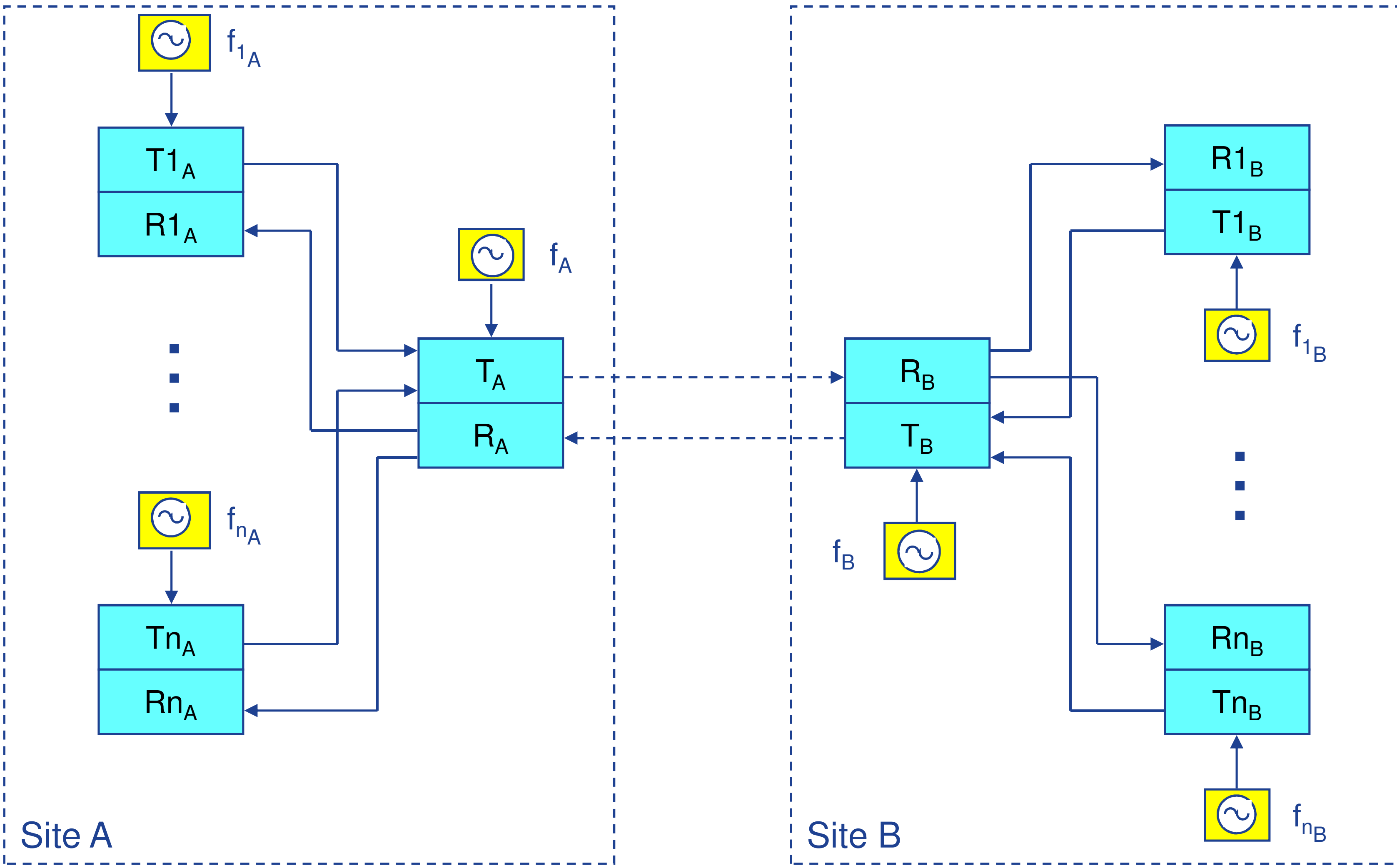
- The bit rates produced by devices running at nominally the same rate could be slightly different (within specified range).

DS1: 1544 kb/s ± 50 ppm (±77 bits/sec)
DS3: 44,736 kb/s ± 20 ppm (± 895 bits/sec)

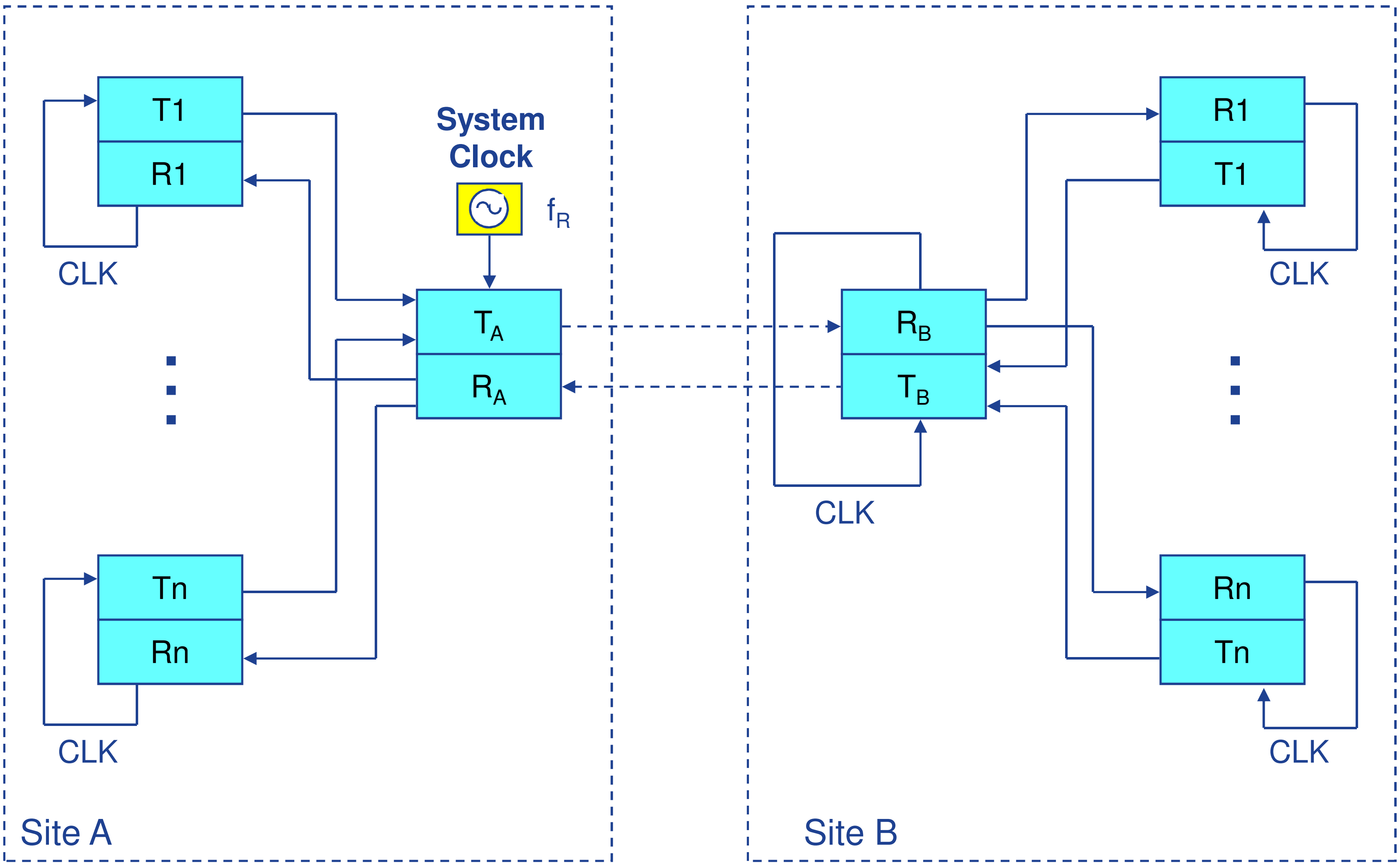
- PDH = Plesiochronous Digital Hierarchy (Plesiochronous = Almost Synchronous)

* Not recognized by ITU-T

Timing in Asynchronous System



Timing in Synchronous System



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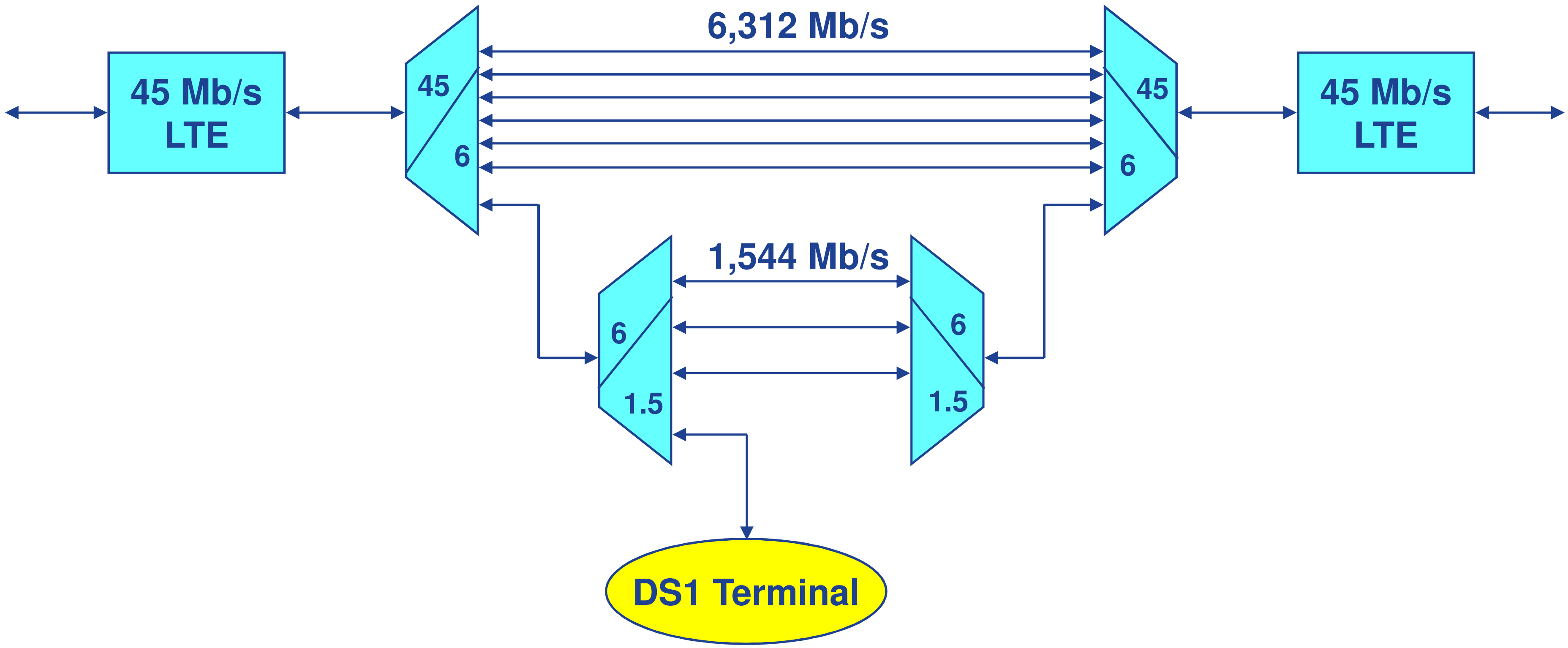
Asynchronous vs. Synchronous

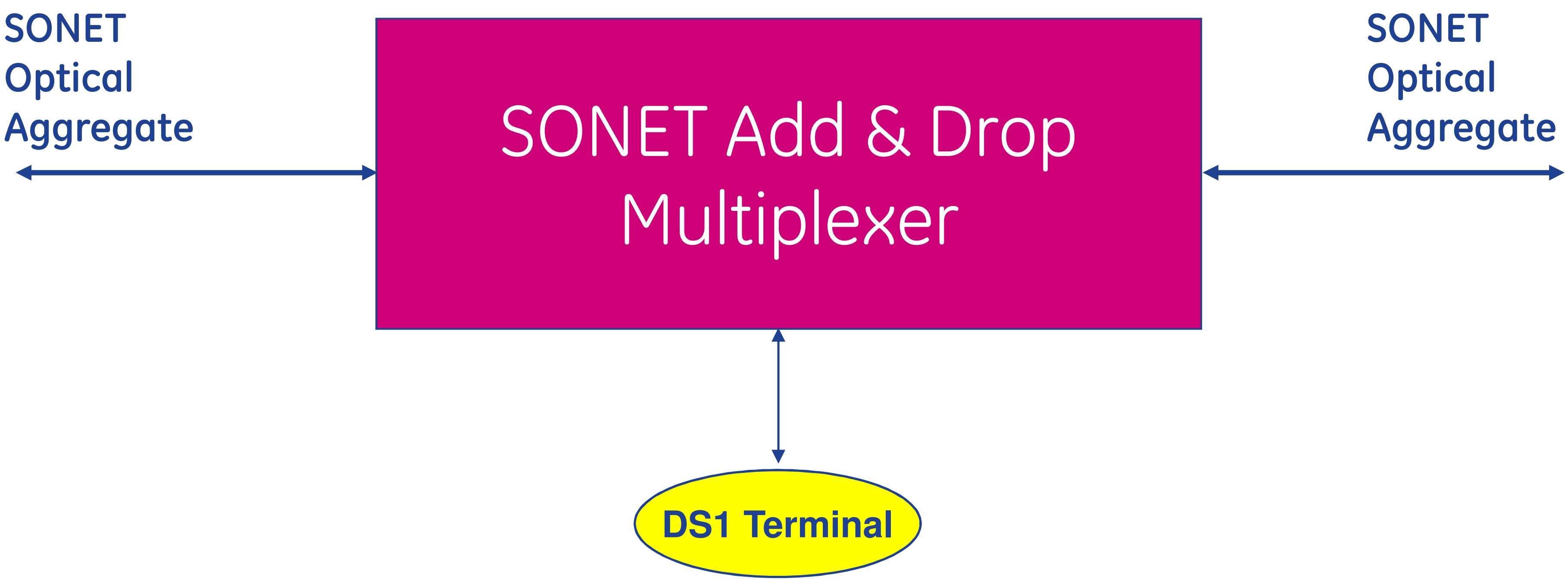
Asynchronous Multiplexing	Synchronous Multiplexing
Bit stuffing. During multiplexing, extra bits are added to account for bit rate variations.	No need for bit stuffing.
No “visibility” of lower order signals in a higher-order multiplex signal.	Full “visibility” of lower order signals in a higher-order multiplex signal.
Lower-order signals cannot be accessed without demultiplexing.	Lower-order signals can be added/dropped without demultiplexing of the higher order signal.

Asynchronous “Drop/Insert”



- Multi-stage multiplexing/demultiplexing
- Multiplex equipment connected back-to-back

Synchronous "Drop/Insert"



- Single-stage multiplexing/demultiplexing
- Complete add/drop functionality provided in one box

SONET Objectives

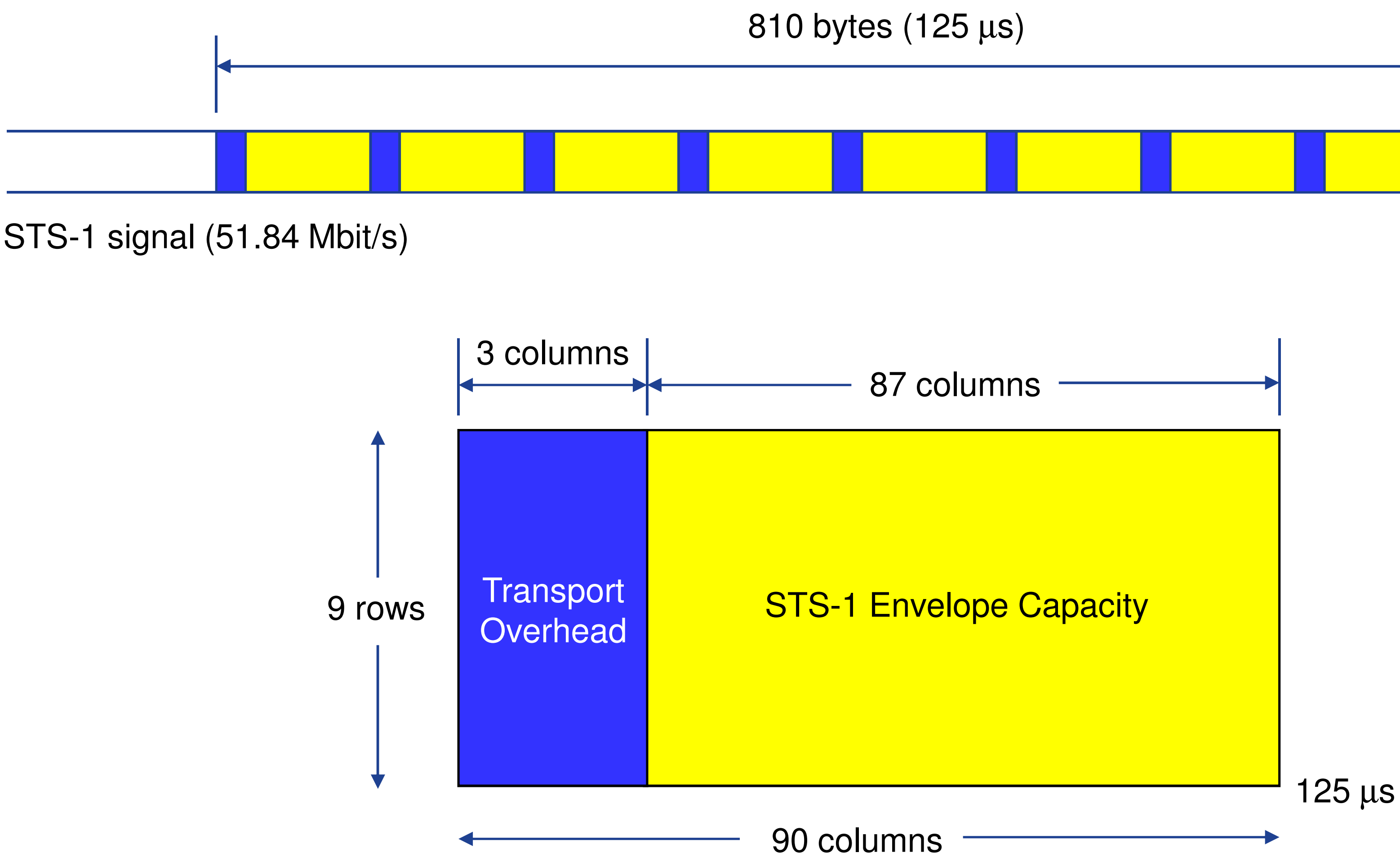
- Eliminate need for multi-stage multiplexing
- Provide optical interconnectivity in multi-vendor environment (“mid-span meet”)
- Enhance Operations, Administration, and Maintenance (OAM)
  - Provide sufficient capacity for transmitting overhead information
  - Create basis for efficient Network Management System
- Come up with a universal multiplex signal structure applicable to all (even future) SONET rates
- Ensure scalability of bandwidth allocations to services
  - Position the network for transport of new services (ATM, IP, Video…)
- Ensure backward compatibility
  - Transparent for legacy PDH transport signals

SONET Signal Hierarchy

STS Level	OC Level	Bit Rate (Mbit/s)	# of DS1s	# of DS0s
STS-1	OC-1	51.84	28	672
STS-3	OC-3	155.52	84	2016
STS-12	OC-12	622.08	336	8064
STS-48	OC-48	2488.32	1344	32,256
STS-192	OC-192	9953.28	5376	129,024

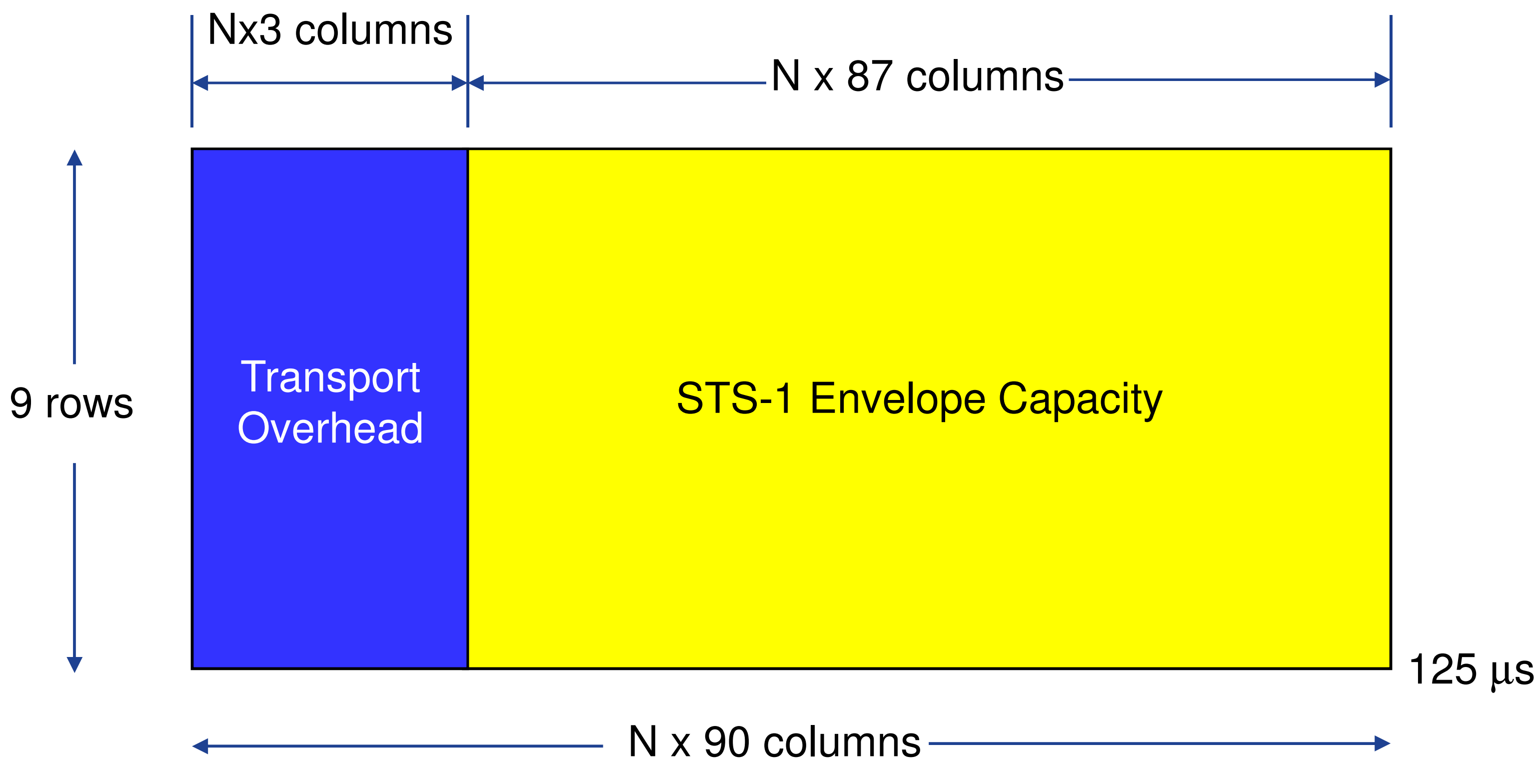
STS = Synchronous Transport Signal
OC = Optical Carrier

STS-1 Frame Format

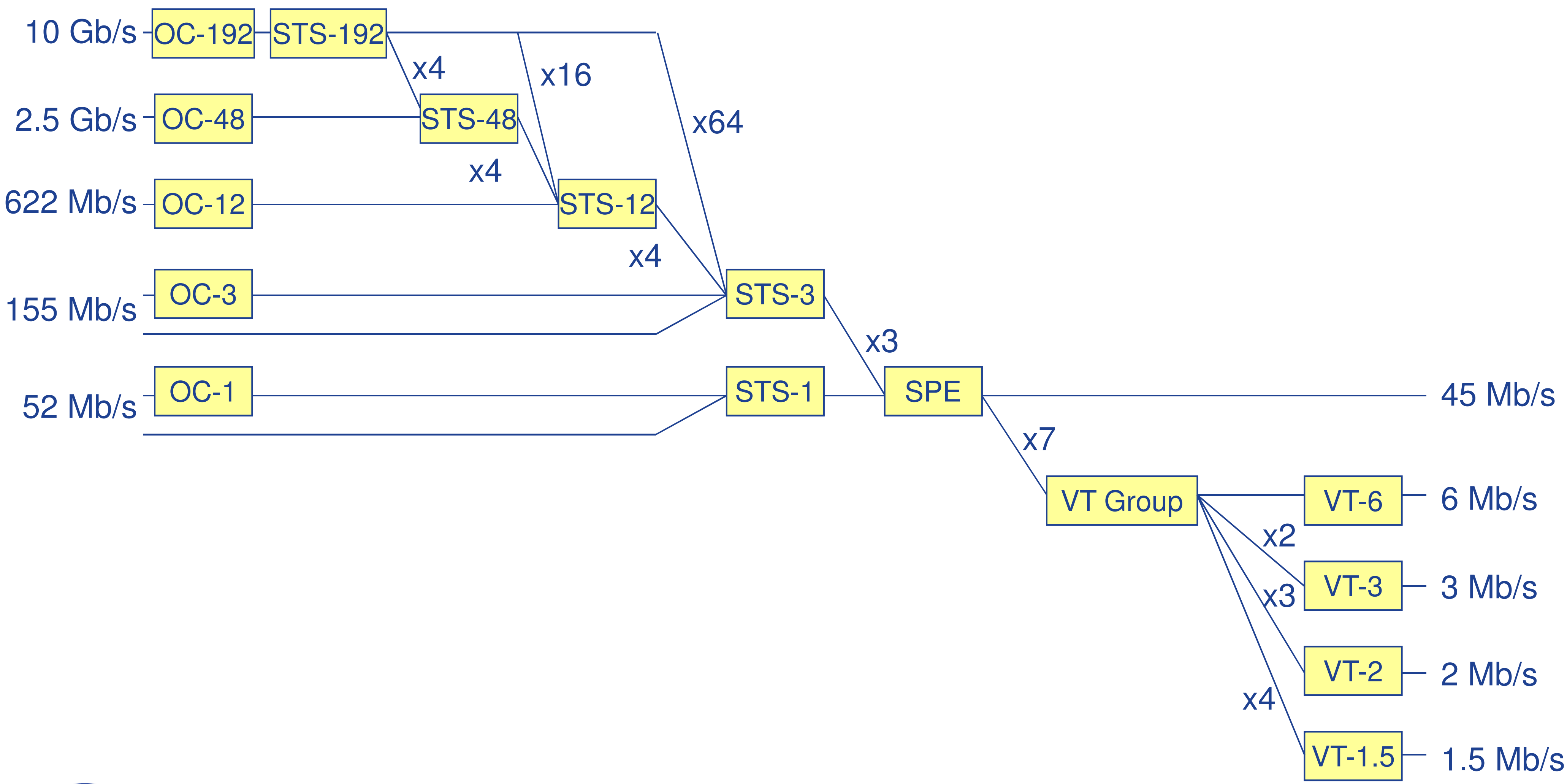


Column width = 1 Byte (8 bits)

STS-N Frame Format



SONET Multiplexing Hierarchy



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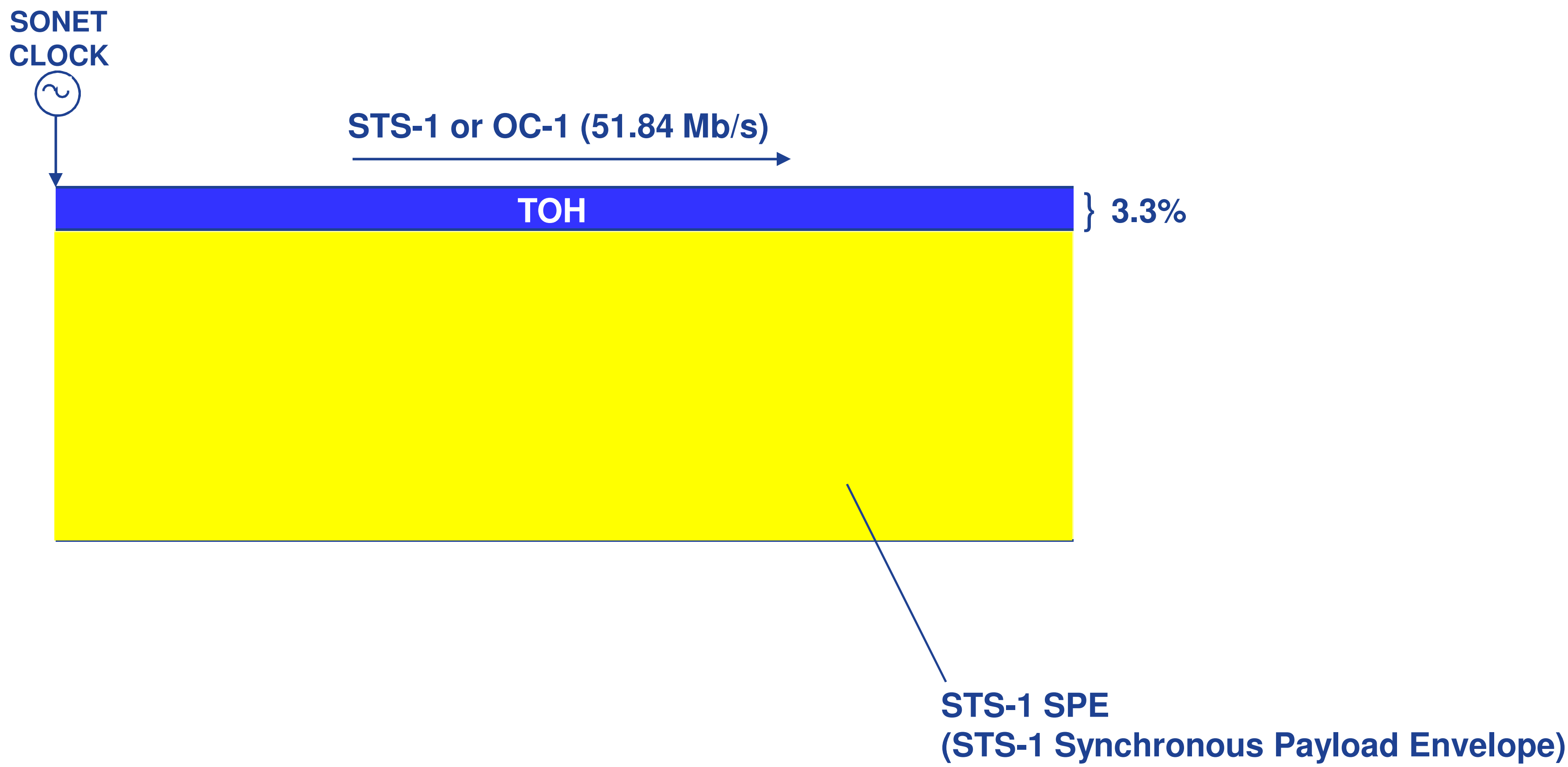
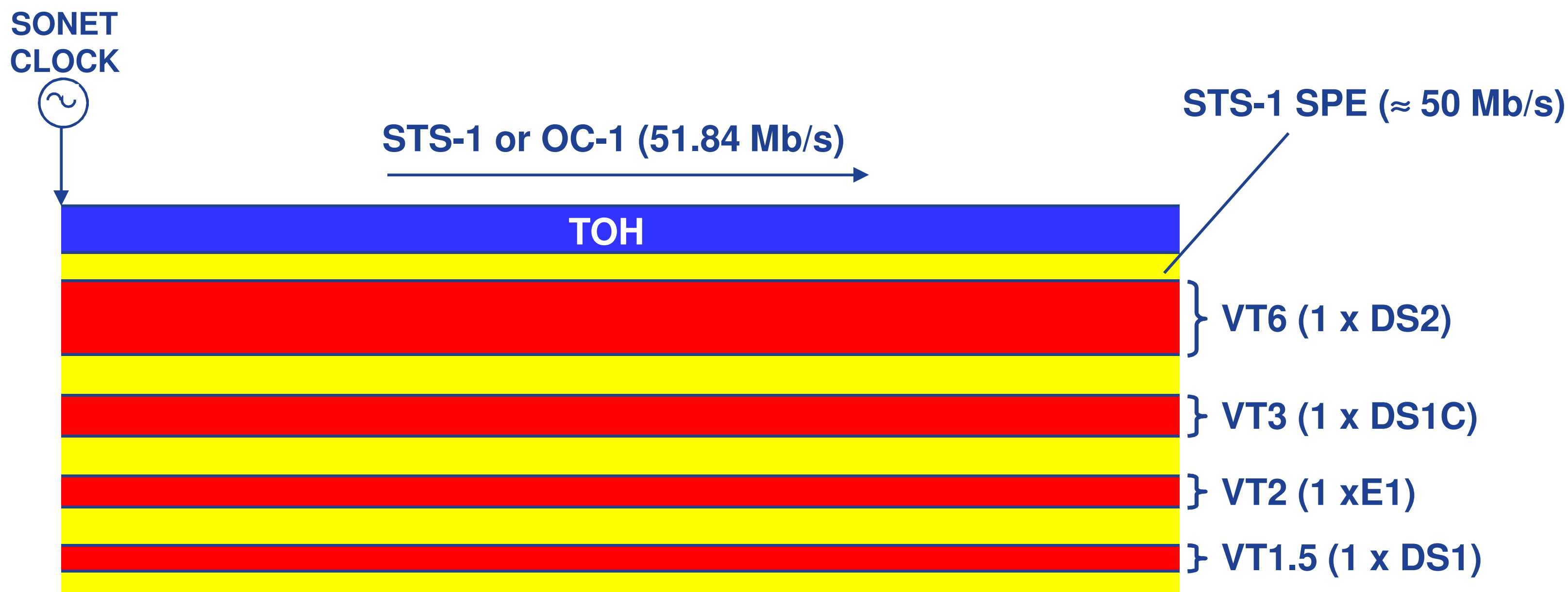
STS-1 Signal Structure



Sub-STS-1 Synchronous Signals



STS-1 SPE =
- 1 x DS3 (or a broadband tributary signal), or
- VT-structured (7 x VT Groups)

VT Group
- 1 x VT6, or
- 2 x VT3, or
- 3 x VT2, or
- 4 x VT1.5

STS-1 SPE = 28 VT1.5 = 28 DS1s = 672 DS0 channels

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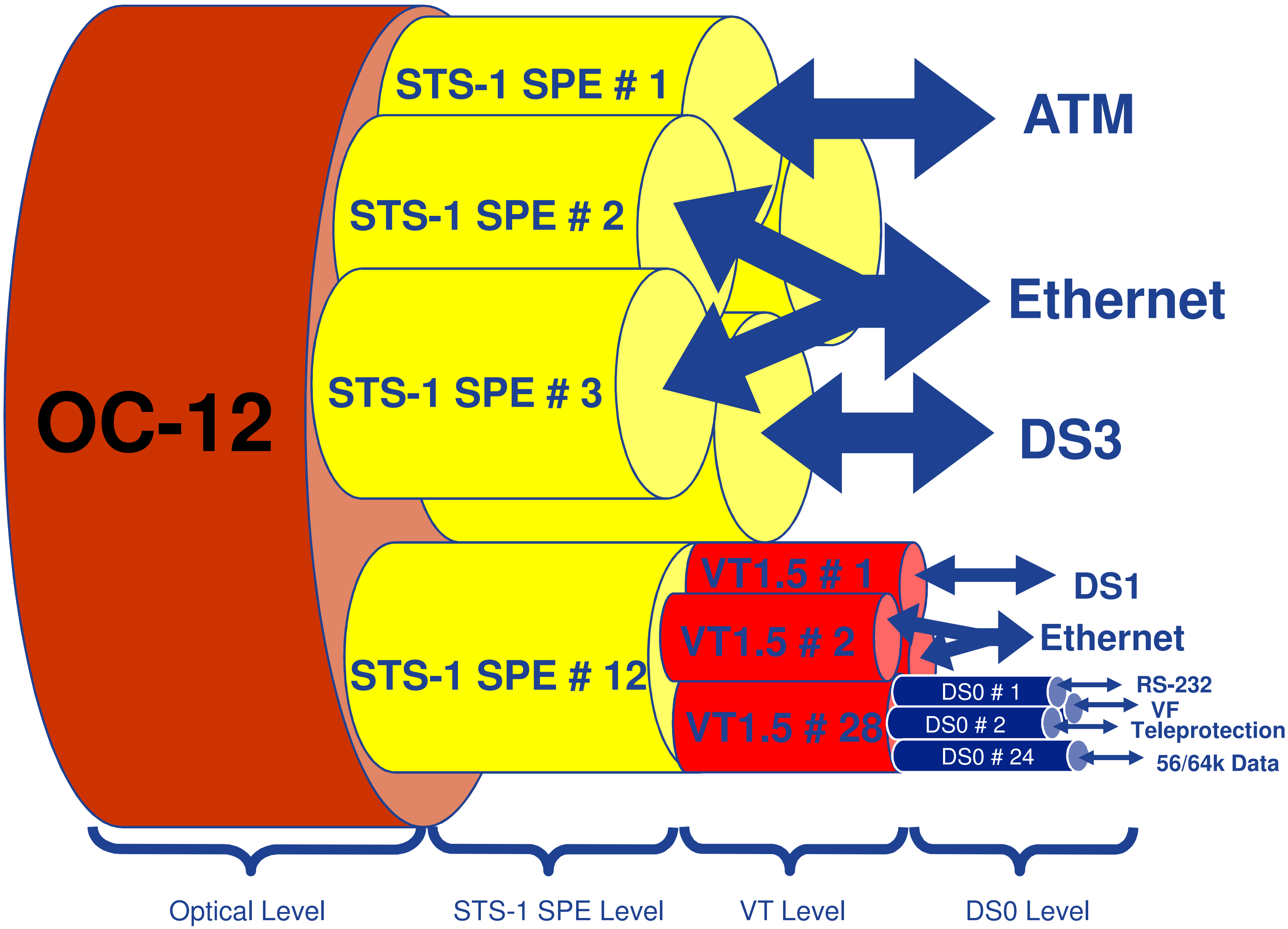
Sub-STS-1 Synchronous Signals



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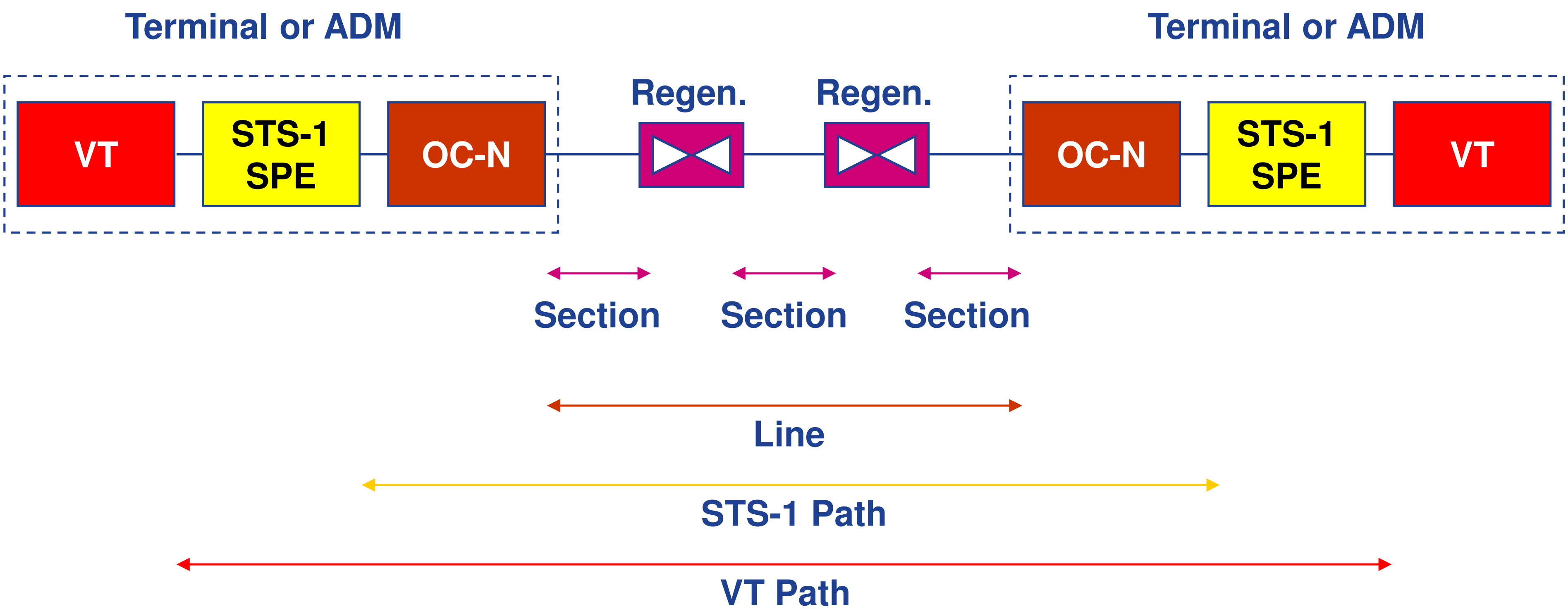
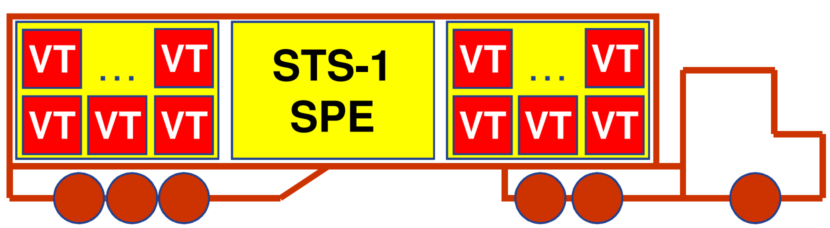
SONET Layers





OC-3/STS-3

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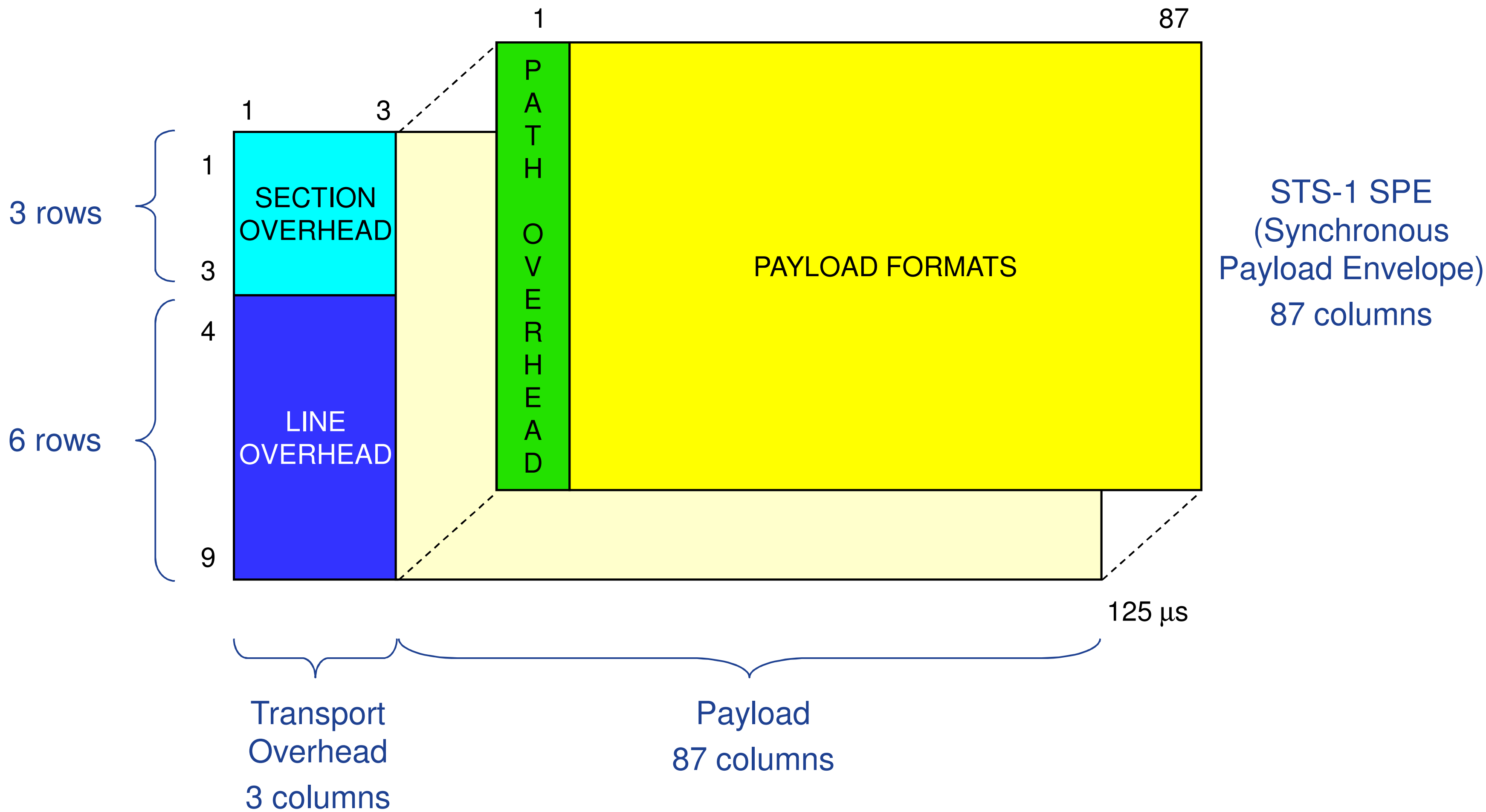
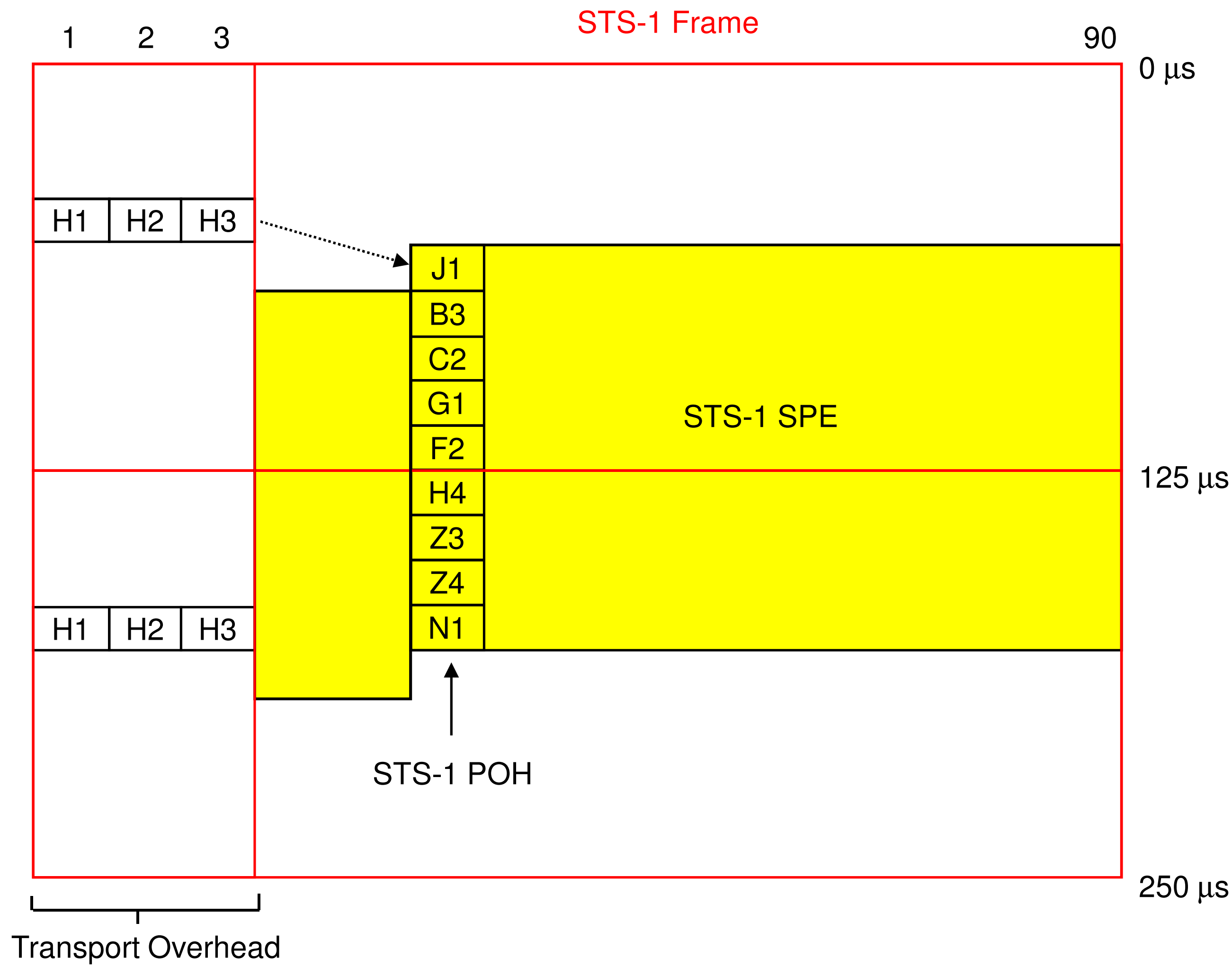
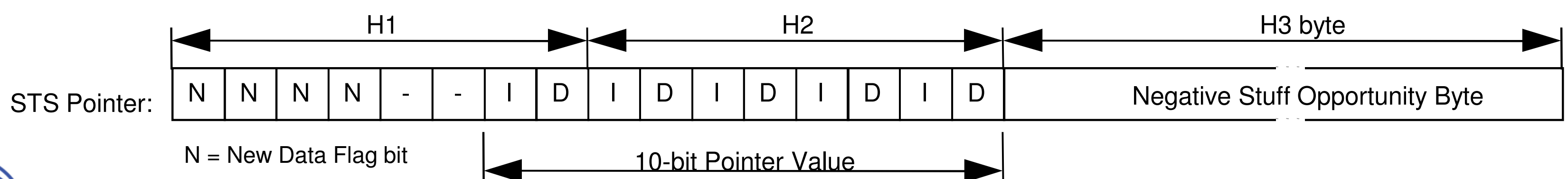
STS-1 Frame Format



STS-1 Pointer





Normal:	0	1	1	0	0	0	Pointer Value (0-782 dec)

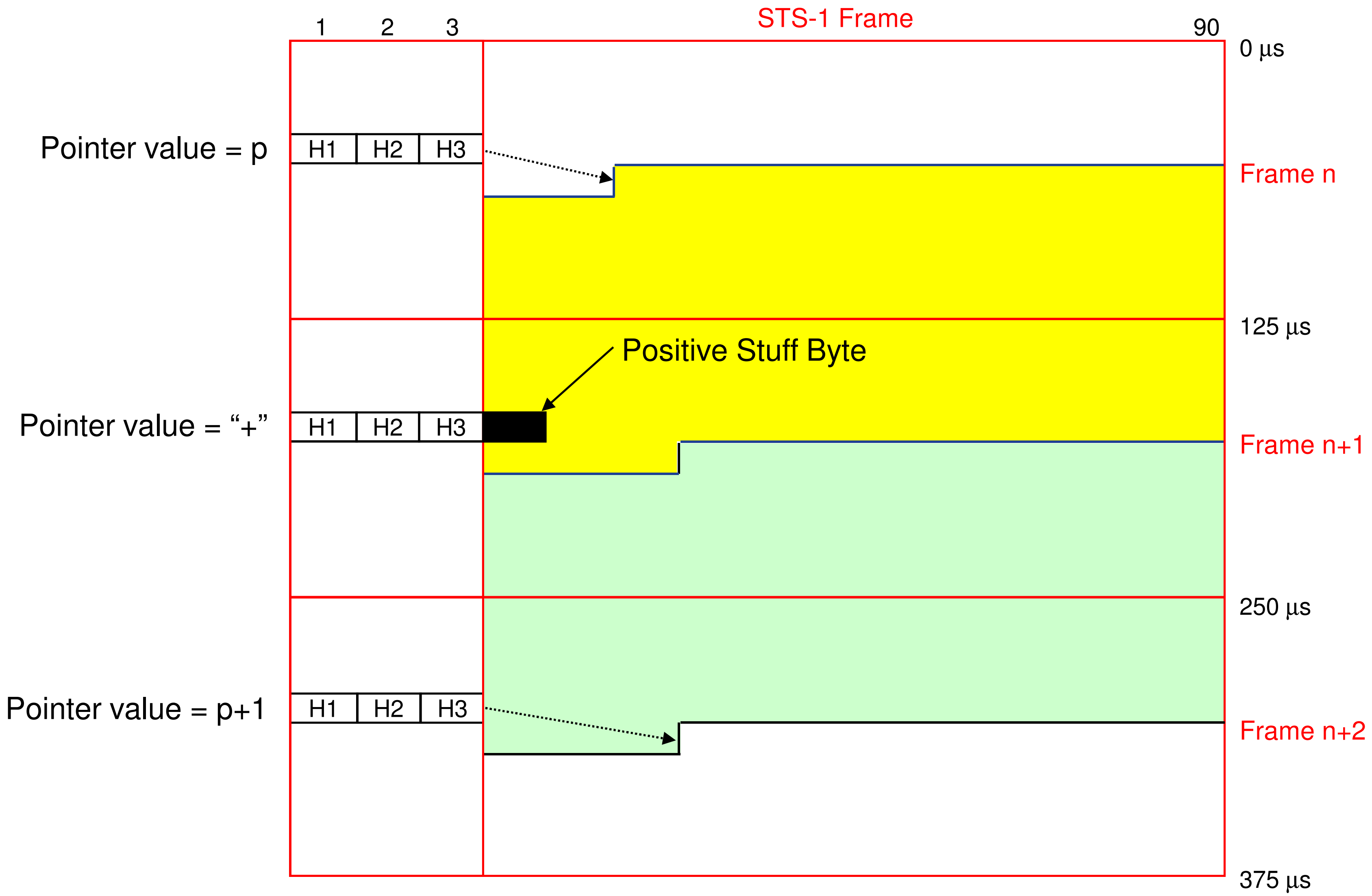
<u>To indicate</u>:

Positive Stuff - Invert 5-I bits

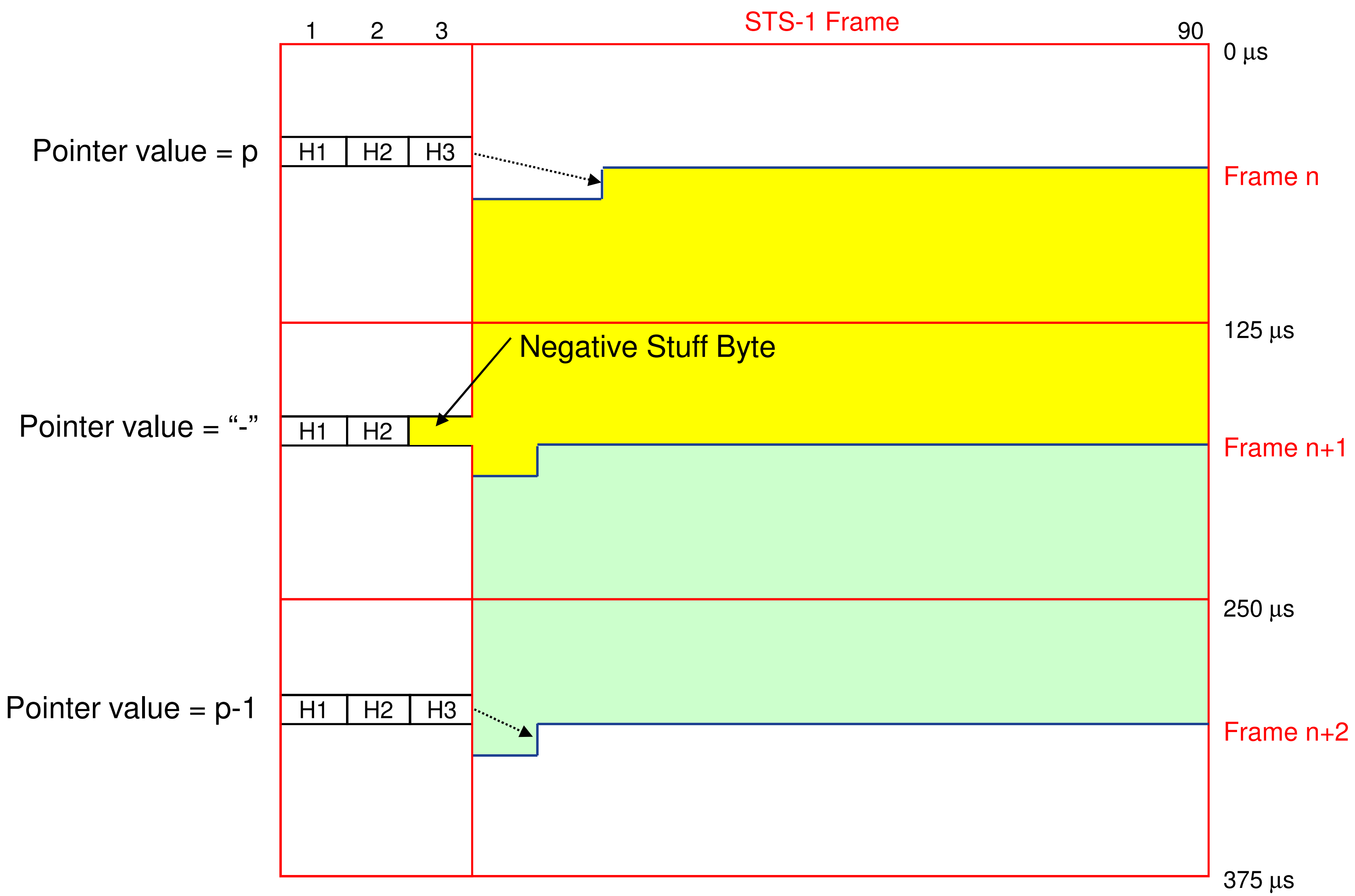
Negative Stuff - Invert 5-D bits

New pointer value - Invert NDF bits

Positive Justification



Negative Justification

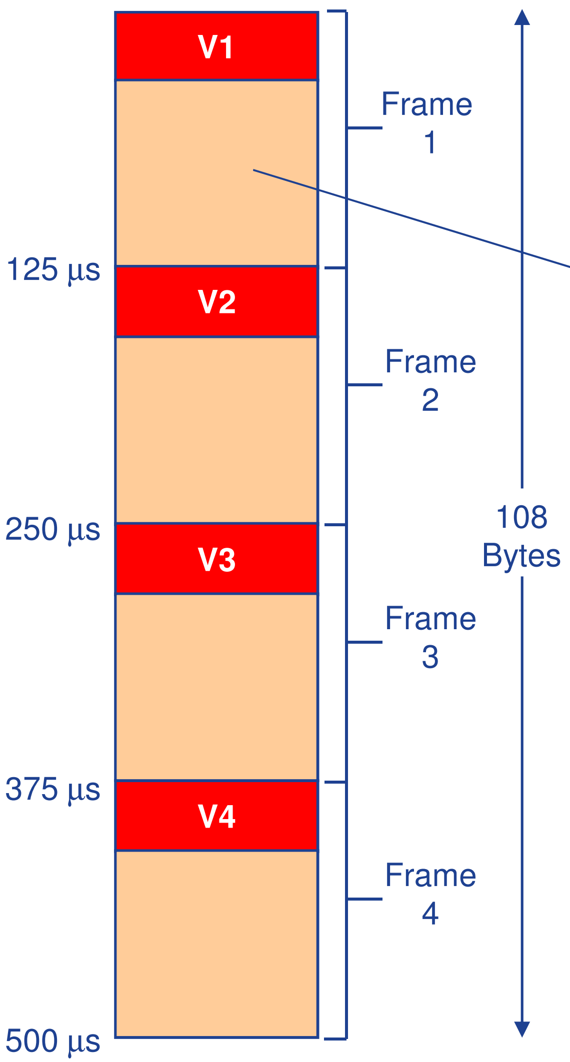


Benefits of Pointer Use

- Dynamic and flexible phase alignment of SPEs
  - Ease of dropping, inserting, and cross-connecting payloads
- Transparent transport of SPEs across network boundaries with plesiochronous timing sources.
- Accommodate transmission signal wander (low frequency jitter).
- Eliminate delays and loss of data associated with use of large (125 μs frame) slip buffers for synchronization.

VT Superframe

VT1.5 Superframe



- **V1, V2** - VT Payload Pointer bytes
- **V3** - VT Pointer Action Byte (Negative Stuff Byte)
- **V4** - Undefined

VT Envelope Capacity
(excludes V1, V2, V3, V4 bytes)

VT SPE floats within VT Envelope Capacity.

VT Payload Pointer (V1 and V2 bytes) points to the start of VT1.5 Payload).

VT POH

- V5 - VT Path Overhead byte 1
- J2 - Reserved for VT Path Trace (future)
- Z6, Z7 - Future use

VT Payload Capacity = VT SPE – VT POH

VT1.5 SPE ("VT Payload")

Asynchronous Mapping of DS1	Byte-Synchronous Mapping of DS1
V5	V5
R R R R R R I R	P1 P0 S1 S2 S3 S4 F R
24 Bytes (192 I bits)	DS0 CHANNELS 1-24
J2	J2
C1 C2 0 0 0 0 I R	P1 P0 S1 S2 S3 S4 F R
24 Bytes (192 I bits)	DS0 CHANNELS 1-24
Z6	Z6
C1 C2 0 0 0 0 I R	P1 P0 S1 S2 S3 S4 F R
24 Bytes (192 I bits)	DS0 CHANNELS 1-24
Z7	Z7
C1 C2 R R R S1 S2 R	P1 P0 S1 S2 S3 S4 F R
24 Bytes (192 I bits)	DS0 CHANNELS 1-24

104 Bytes, 500 µs

- I - Information bit
- R - Fixed stuff bit
- O - Overhead bit
- S - Stuff opportunity bit
- C - Stuff control bit

- P - Sig. Phase Indicator
- S - Signaling bit
- F - DS1 framing bit
- R - Fixed stuff bit

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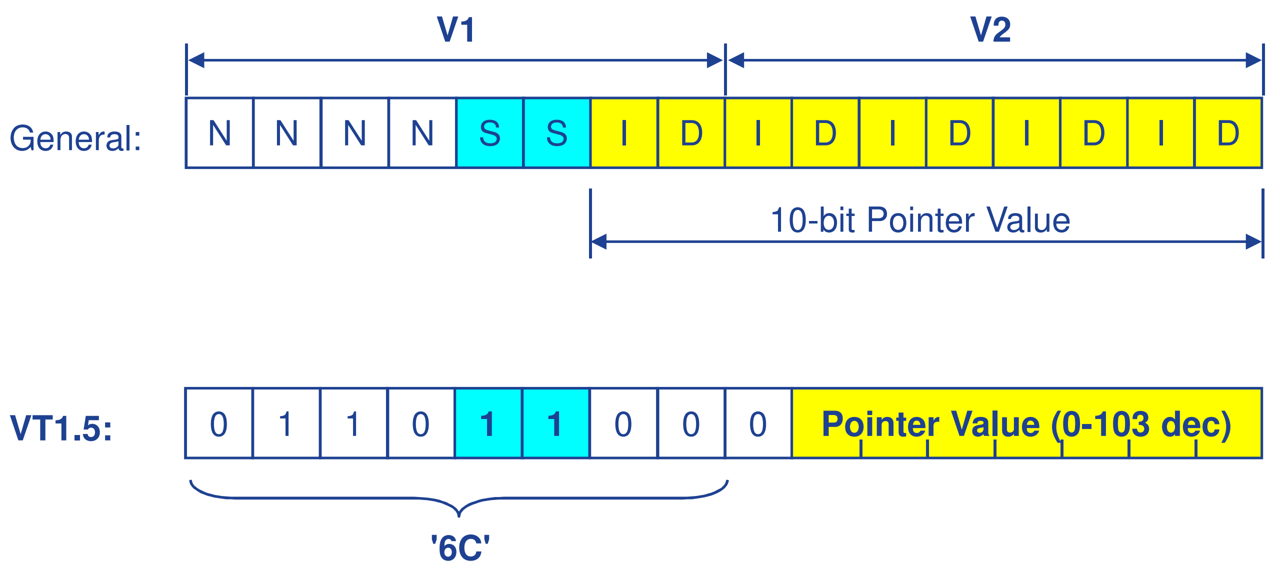
VT Pointer Bytes (V1 and V2)



To indicate:
Positive Stuff - Invert 5-I bits
Negative Stuff - Invert 5-D bits
New Pointer Value - Invert NDF bits

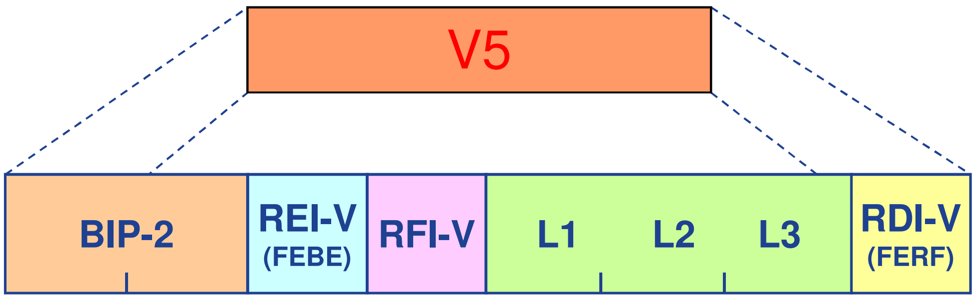
S bits = VT Type (Size) Indication

SS	VT Type	VT Size	VT Pointer Range
00	VT6	428	0 - 427
01	VT3	212	0 - 211
10	VT2	140	0 - 139
11	VT1.5	108	0 - 103

V1, V2, V3, V4

VT SPE Size = VT Envelope Capacity = VT Superframe Size – 4

VT Path Overhead Byte (V5)



Signal label coding:

L1	L2	L3	
0	0	0	**Unequipped (unassigned)**
0	0	1	**Equipped – non-specific**
0	1	0	**Equipped – asynchronous mapping (DS1/E1/DS1C/DS2)**
0	1	1	**Bit-Synchronous Mapping of DS1/E1 (removed from standard)**
1	0	0	**Byte-Synchronous Mapping of DS1/E1**

ACRONYM	NAME	USAGE
BIP-2	**Bit Interleaved Parity**	Error Detection (used to calculate BER at receive end)
REI-V	**VT Path Remote Error Indication**	Info on errors detected in opposite signal direction (so far-end BER can be calculated)
RFI-V	**VT Path Remote Failure Indication**	Used in byte-synchronous DS1 mapping applications only
RDI-V	**VT Path Remote Defect Indication**	Status of signal received at transmit end (opposite signal direction) (1 = ‘VT Yellow Alarm'; 0 = No ‘VT Yellow Alarm')

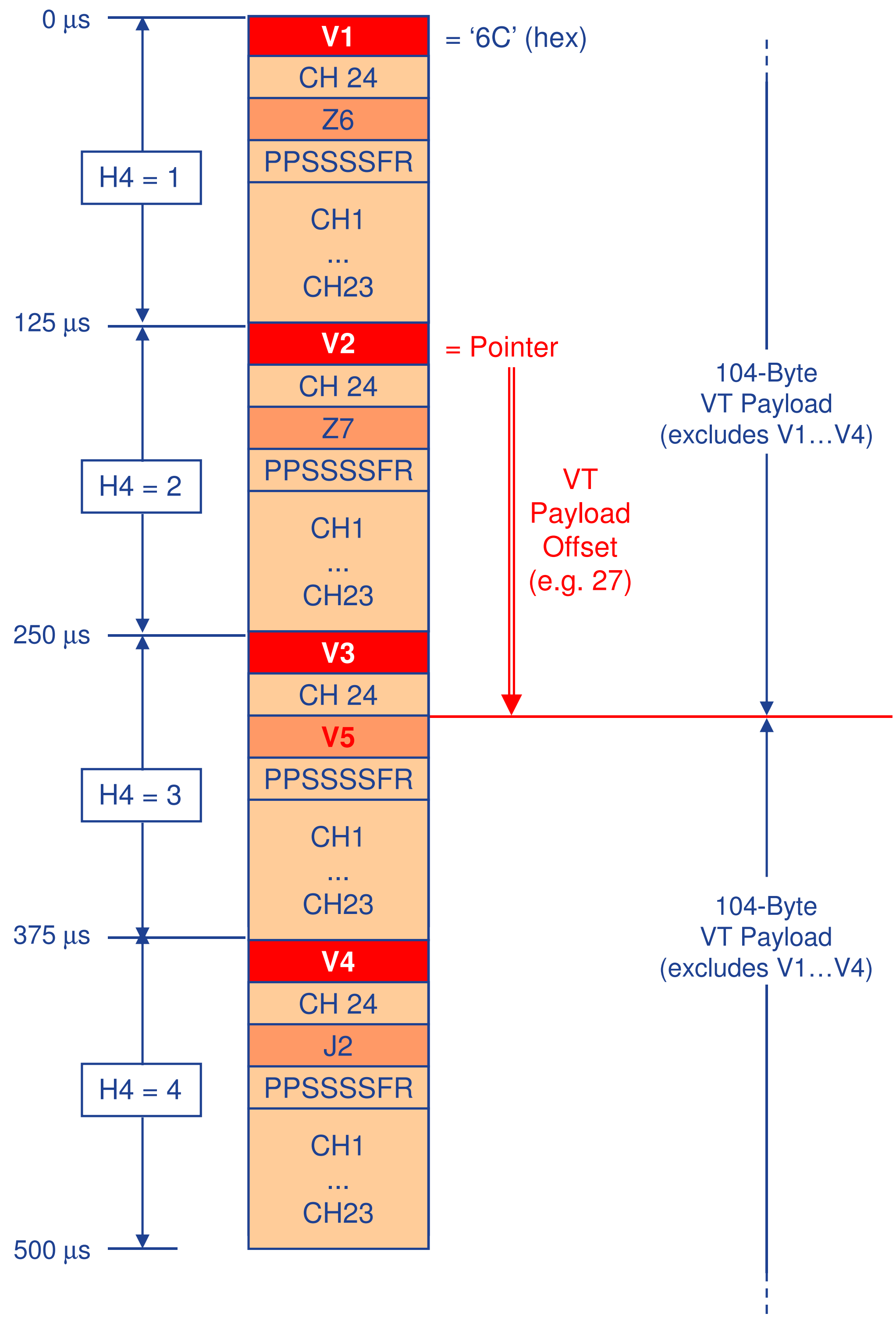
FEBE Far End Block Error
FERF Far End Receive Failure

VT1.5 Superframe

Example with Byte-Synchronously mapped payload capacity

Bit:	1	2	3	4	5	6	7	8	Next Frame
	1	1	1	1	1	1	0	0	1
	1	1	1	1	1	1	0	1	2
	1	1	1	1	1	1	1	0	3
	1	1	1	1	1	1	1	1	4

H4 Byte* Coding Sequence



* H4 Byte is an STS-1 POH Overhead byte.

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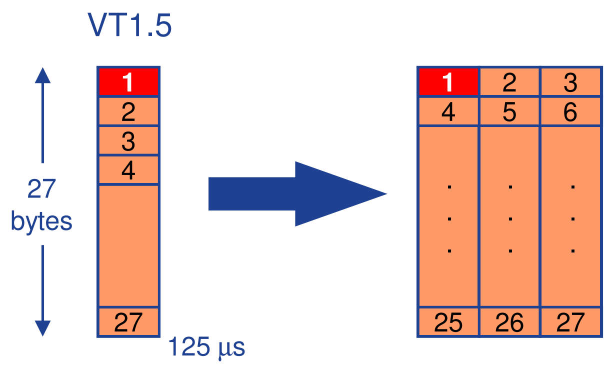
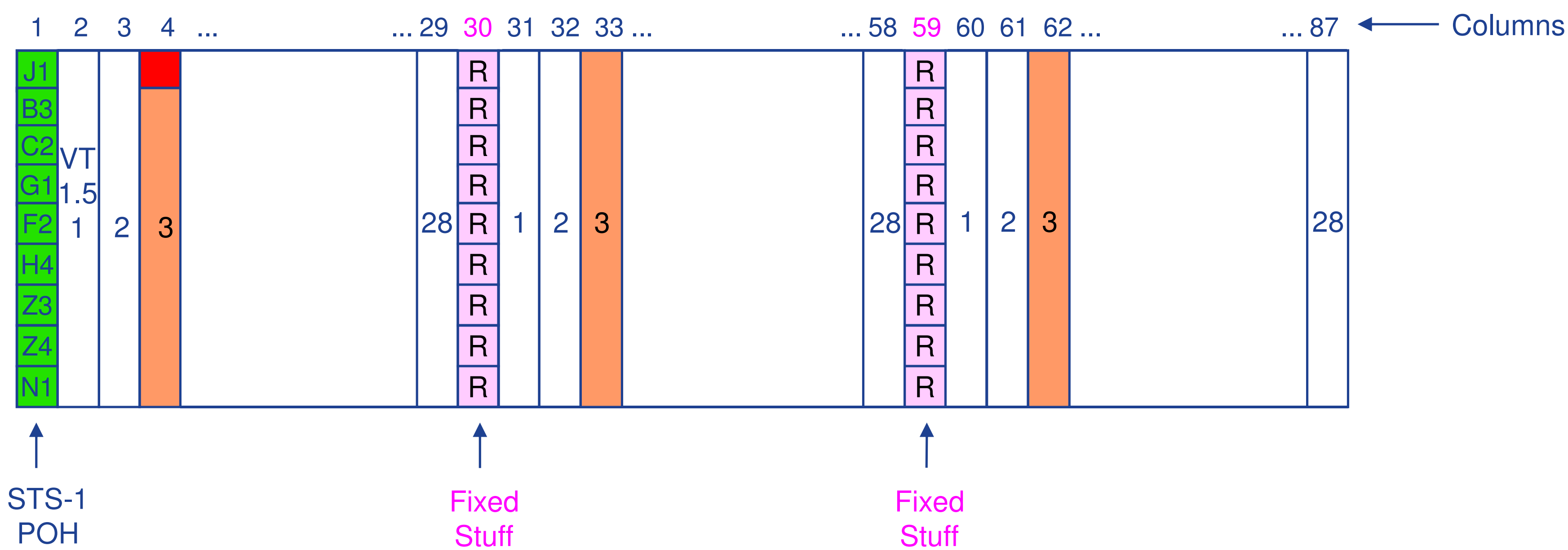
VT1.5 Frame within STS-1 SPE Frame*





***Carrying only VT1.5s**

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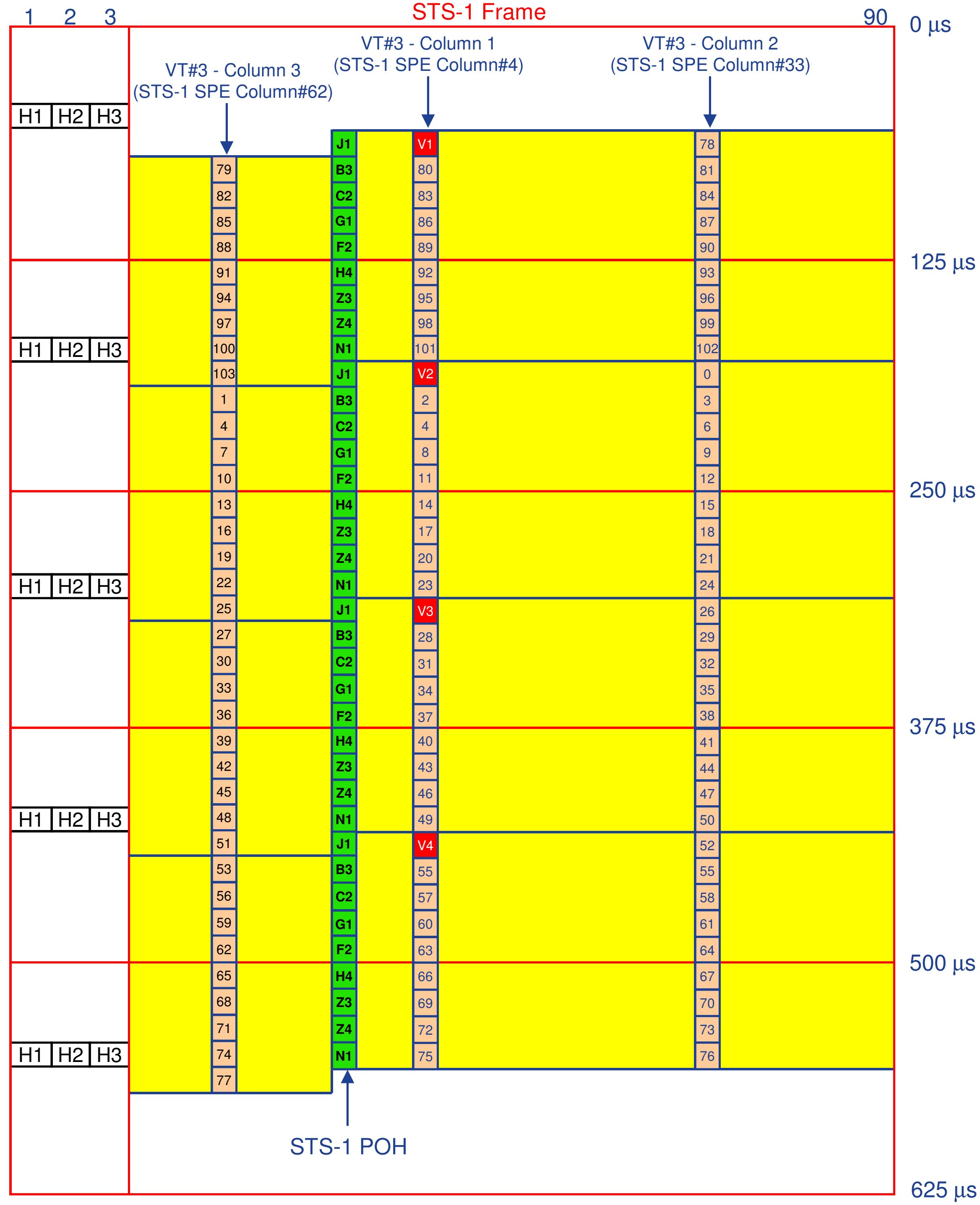
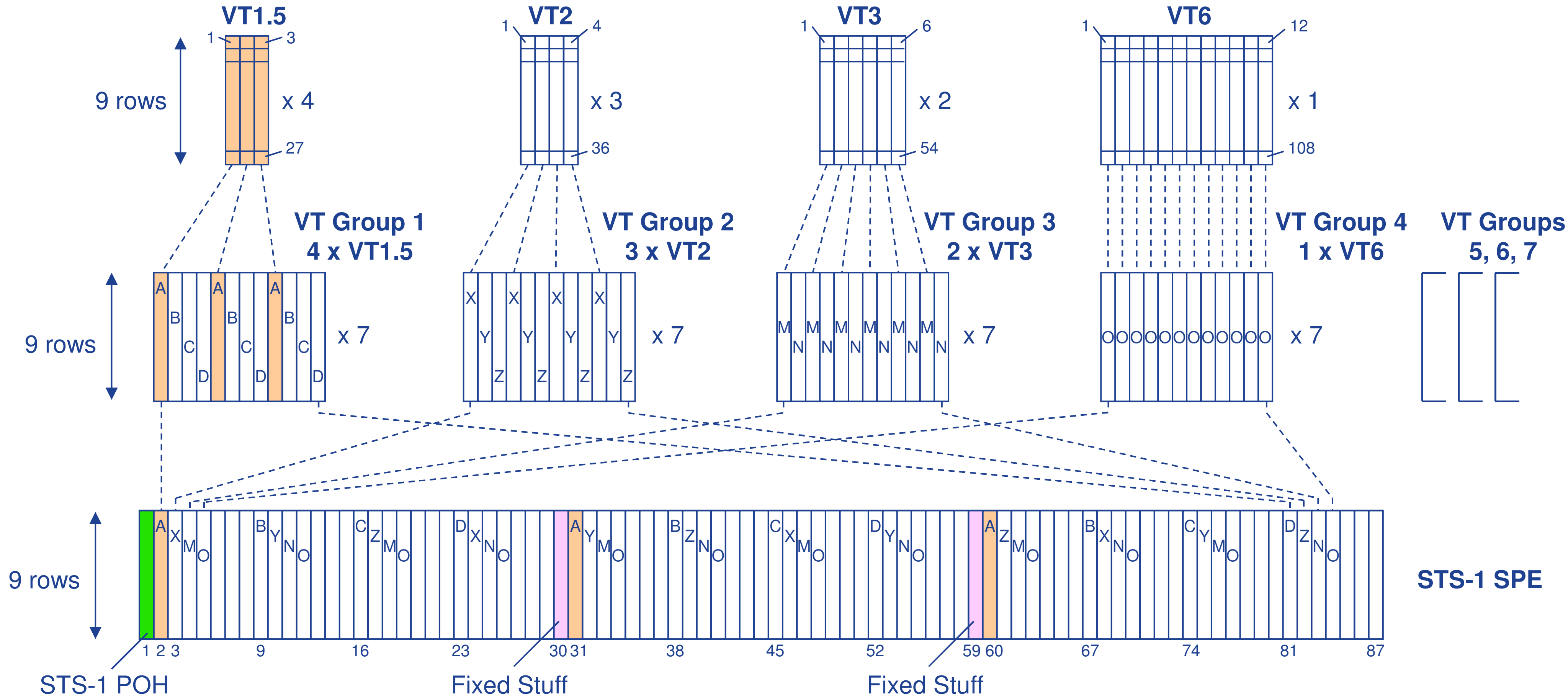
VT1.5 Superframe within STS-1 signal



Multiplexing of VTs into STS-1 SPE



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TOH and STS POH Structure

Transport Overhead (Section Overhead: rows 1–3; Line Overhead: rows 4–9)

Framing A1	Framing A2	Trace J0
BIP-8 B1	Orderwire E1	User F1
Data Com D1	Data Com D2	Data Com D3
Pointer H1	Pointer H2	Ptr Action H3
BIP-8 B2	APS K1	APS K2
Data Com D4	Data Com D5	Data Com D6
Data Com D7	Data Com D8	Data Com D9
Data Com D10	Data Com D11	Data Com D12
Sync S1	REI-L M0	Orderwire E2

STS Path Overhead (STS-1 SPE)

Trace J1
BIP-8 B3
Signal Lab. C2
Path Status G1
User Chan. F2
Multiframe H4
Growth Z3
Growth Z4
Tand.Conn. N1

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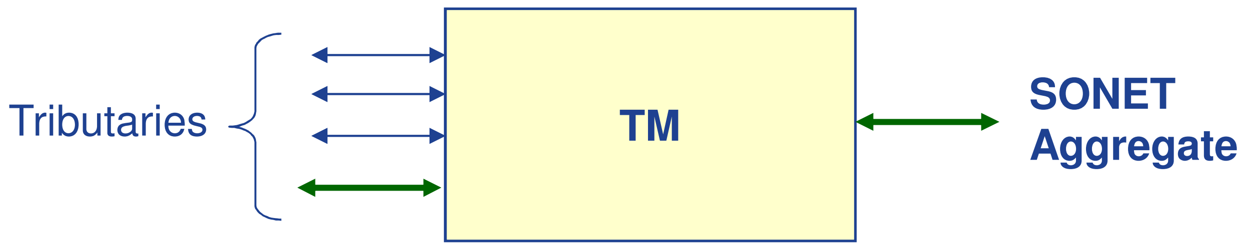
SONET Network Elements

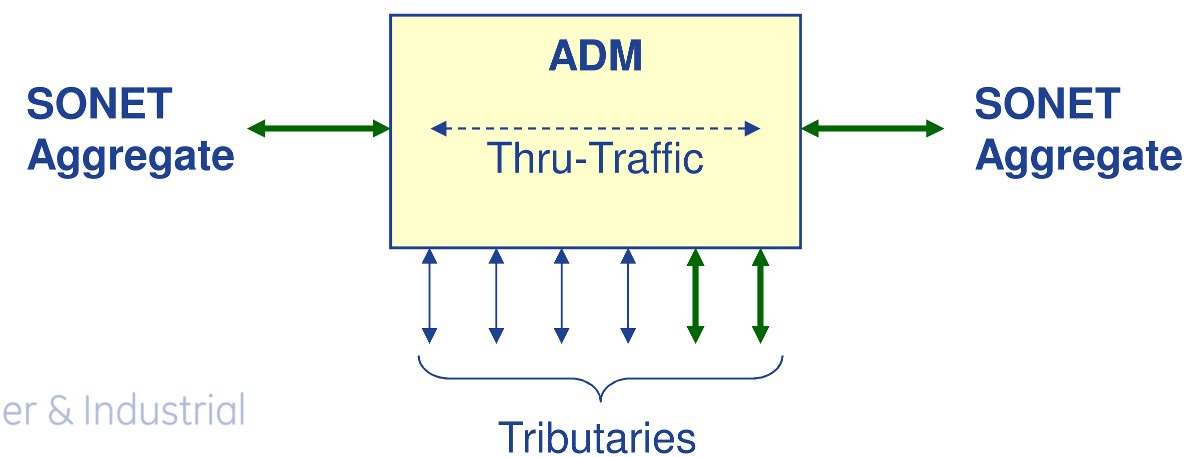
- **Terminal Multiplexer**



SONET Aggregate/Tributary

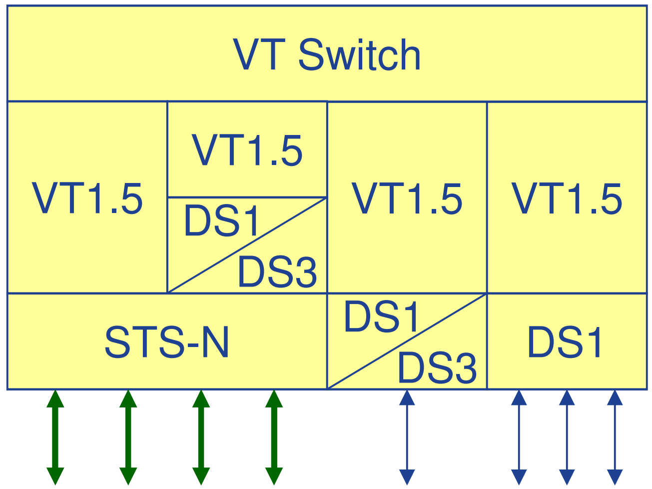
Async (PDH) Tributary or Wide/Broadband Service (Ethernet, ATM etc.)

- **Add/Drop Multiplexer**



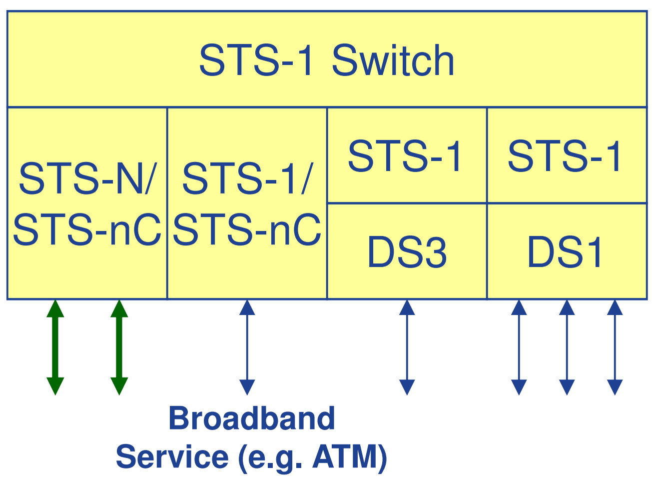
SONET Network Elements

- **Wideband Digital Cross-Connect (W-DCS)**



Cross-Connects at VT level

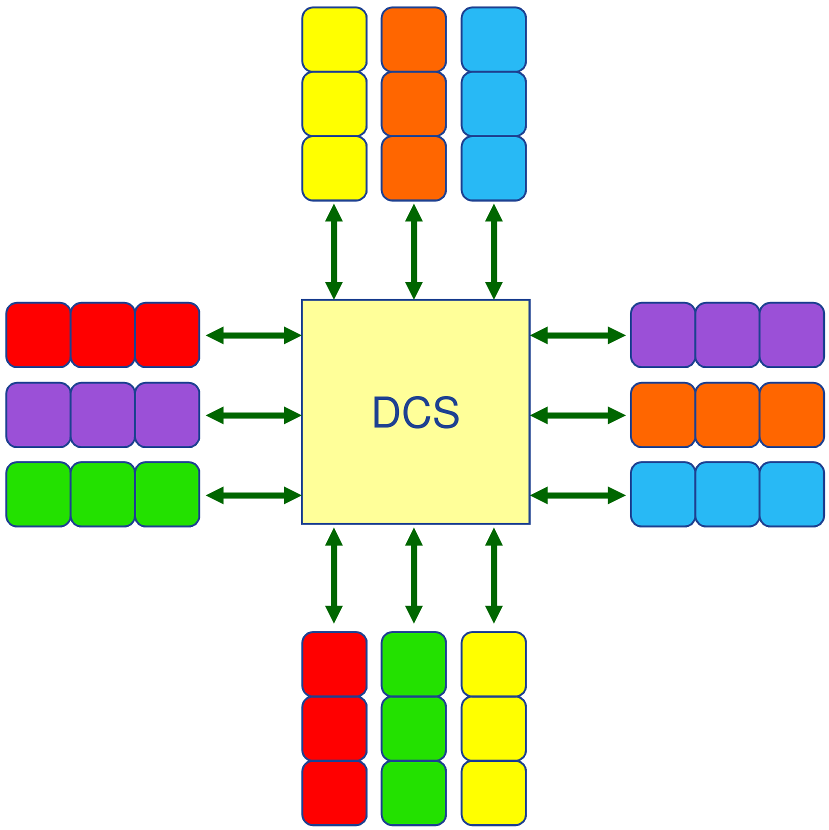
- **Broadband Digital Cross-Connect (B-DCS)**



Cross-Connects at STS-1 level

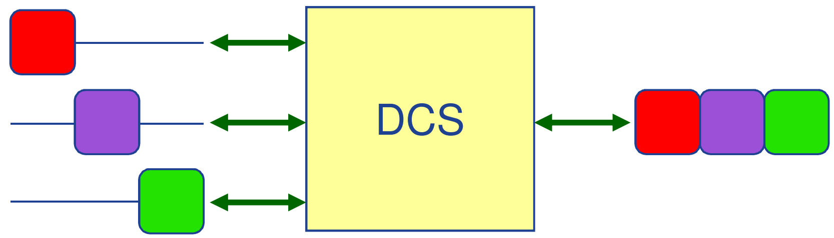
SONET Network Elements

- **Cross-Connect Functions**

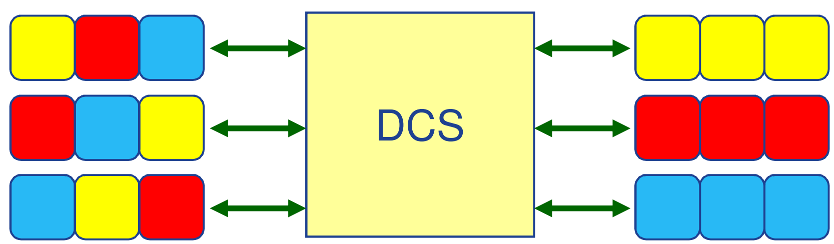


Flexible Routing

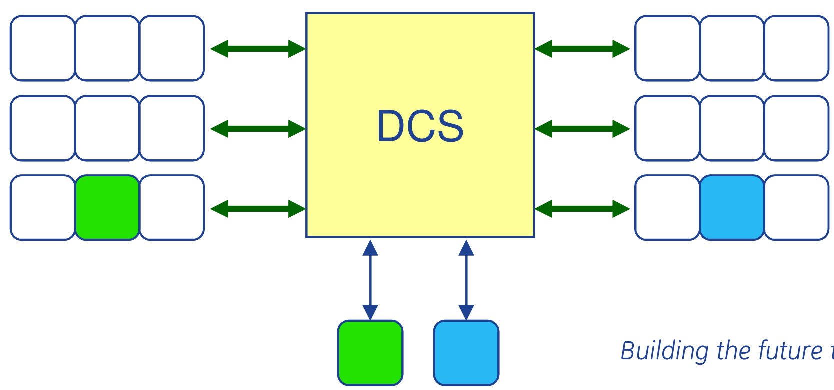
Traffic Consolidation



Traffic Segregation

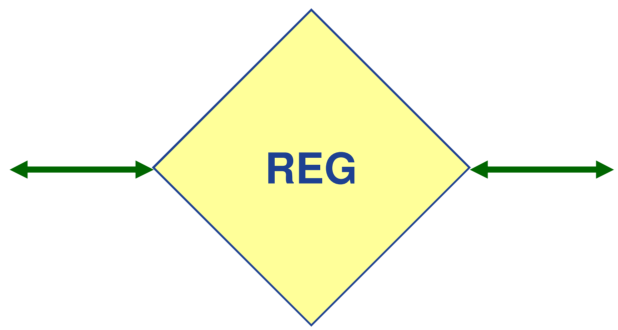


Add/Drop



SONET Network Elements

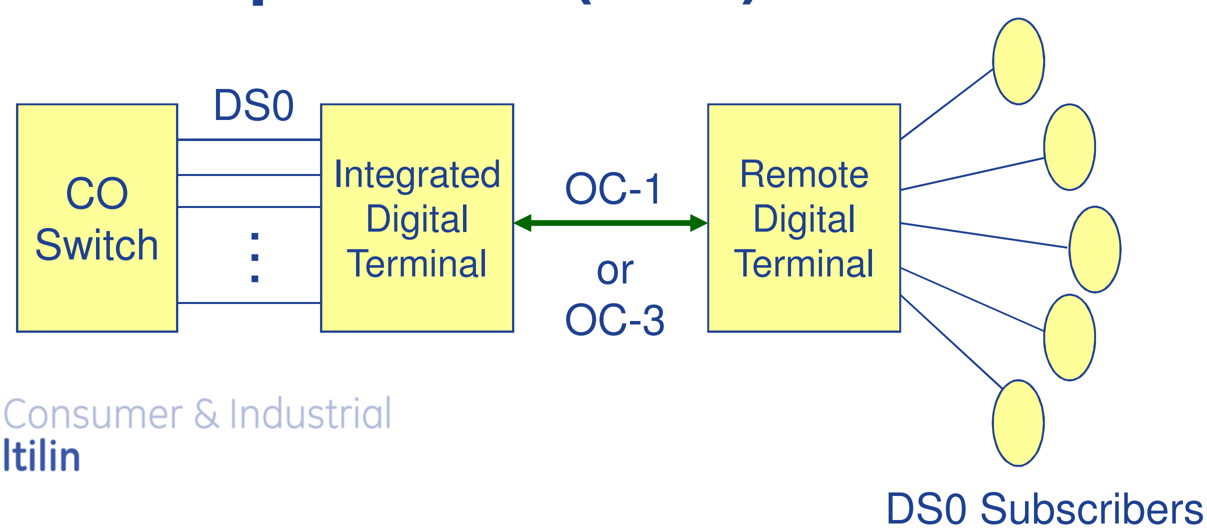
- **Regenerator**



Needed when, due to long fiber distance, the optical signal level becomes too low.

- **Digital Loop Carrier (DLC)**

(For telco's & carriers only)



A concentrator for narrow-band services between subscribers, remote digital terminals and Central Office switches.

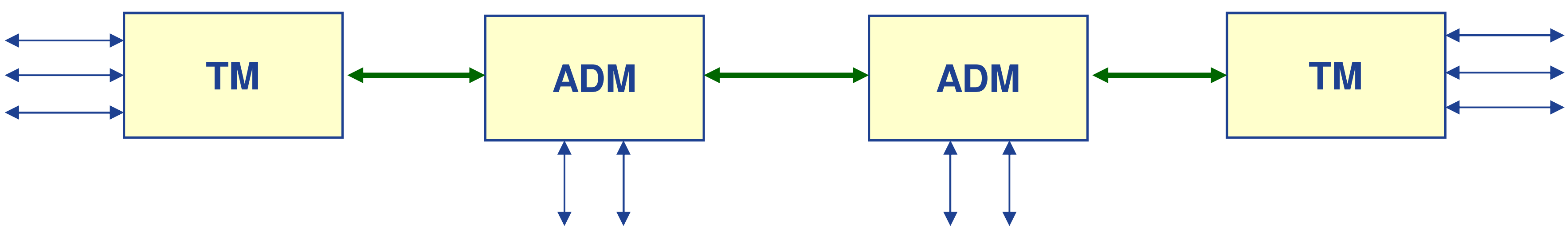
SONET Network Topologies

- **Point-to-Point Topology**

SONET Aggregate
Async (PDH) Tributary

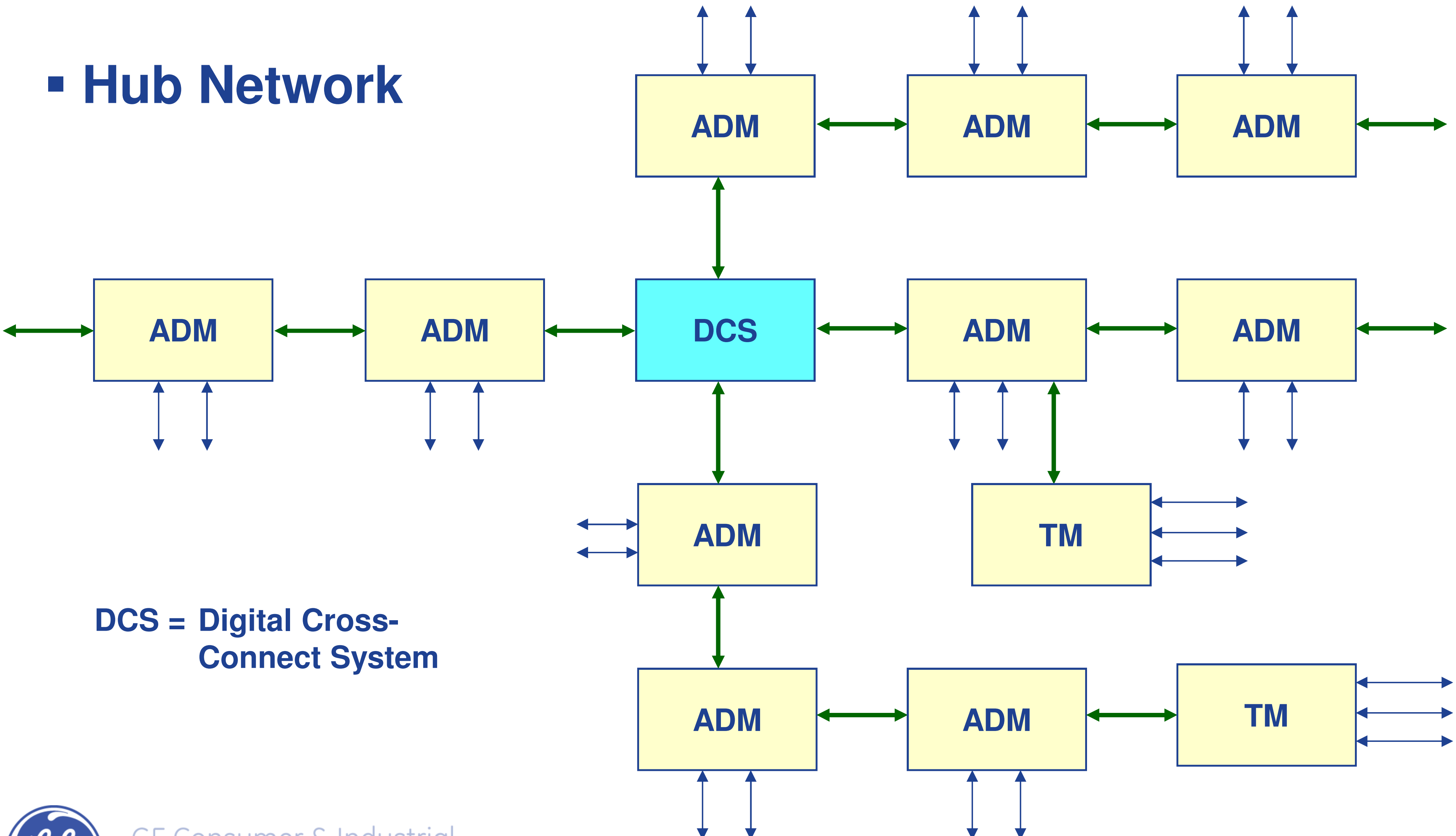
TM Terminal MUX
ADM Add/Drop MUX

- **Linear Add/Drop Topology**



SONET Network Topologies

- **Hub Network**



DCS = Digital Cross-Connect System

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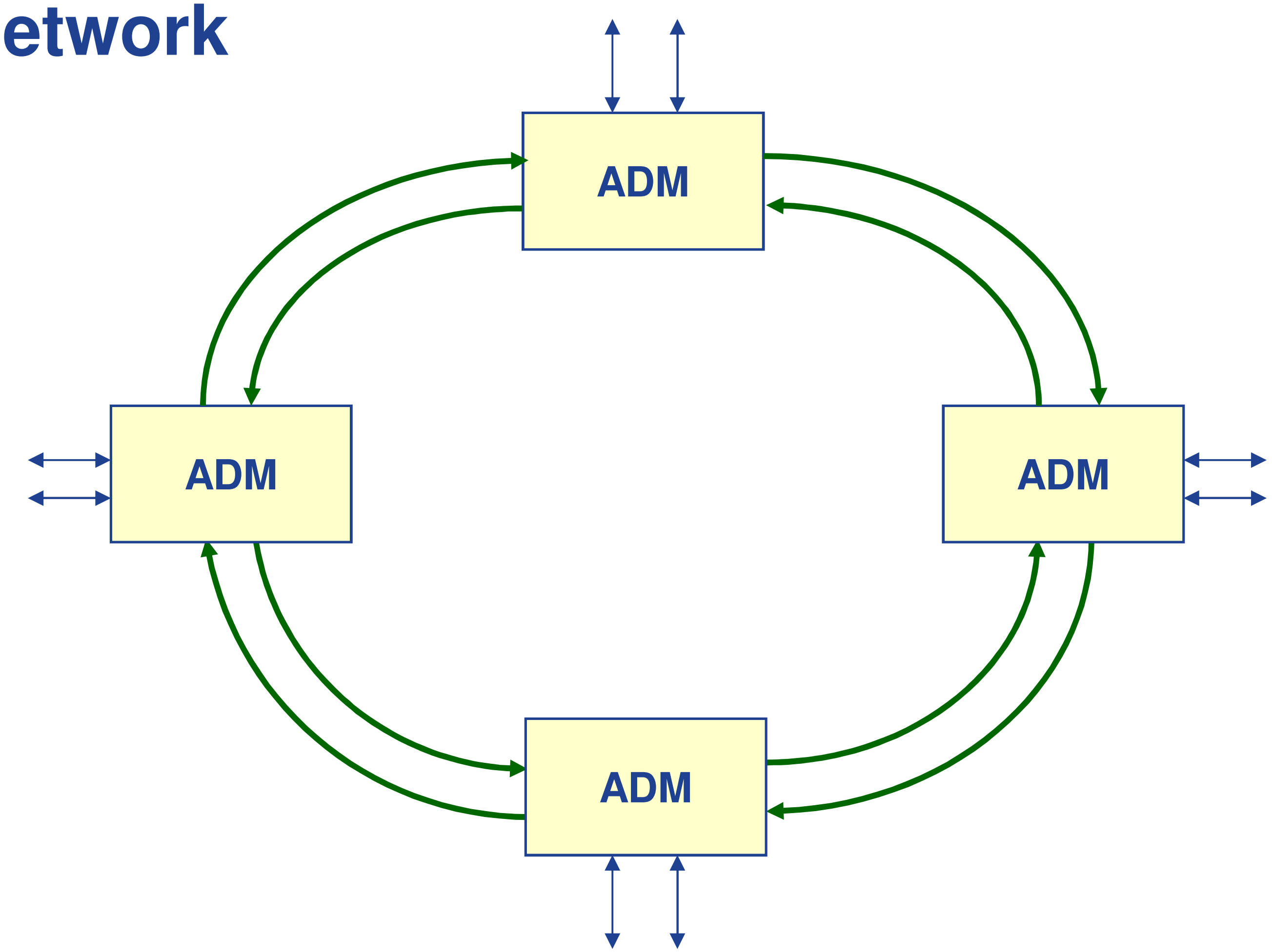
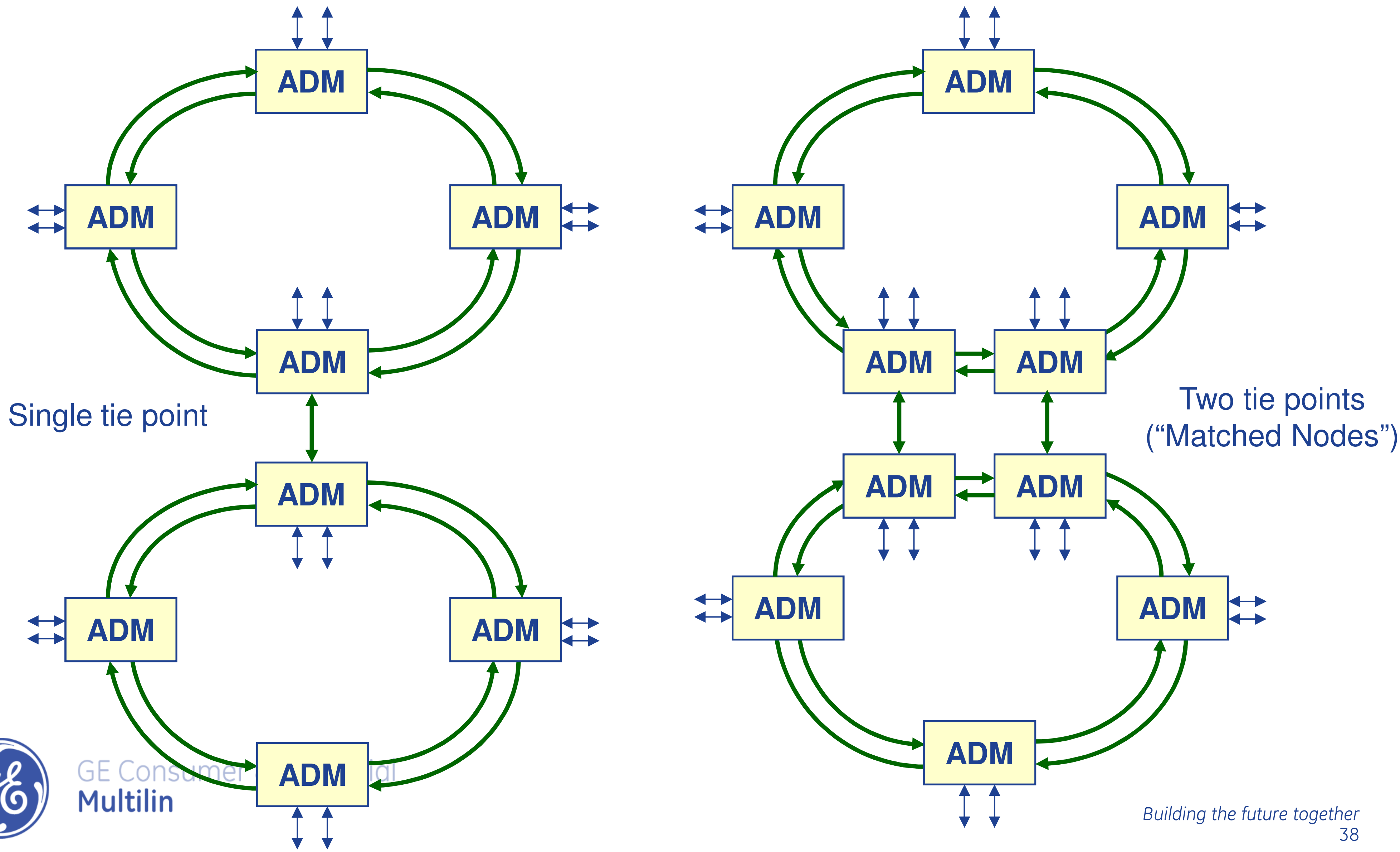
SONET Network Topologies

- **Ring Network**



SONET Network Topologies

- **Multiple Ring Network**



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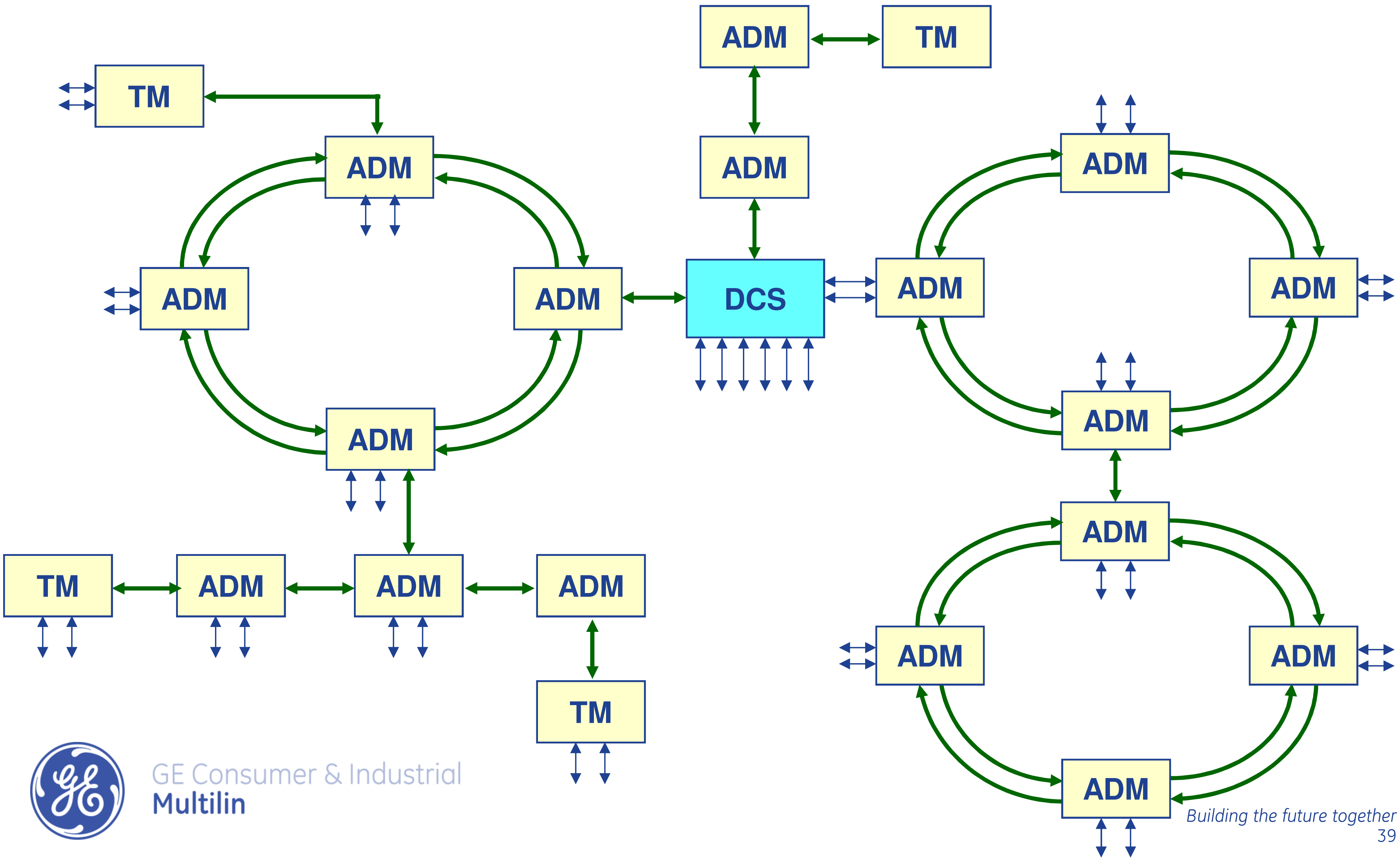
SONET Network Topologies

- "Combined" Network

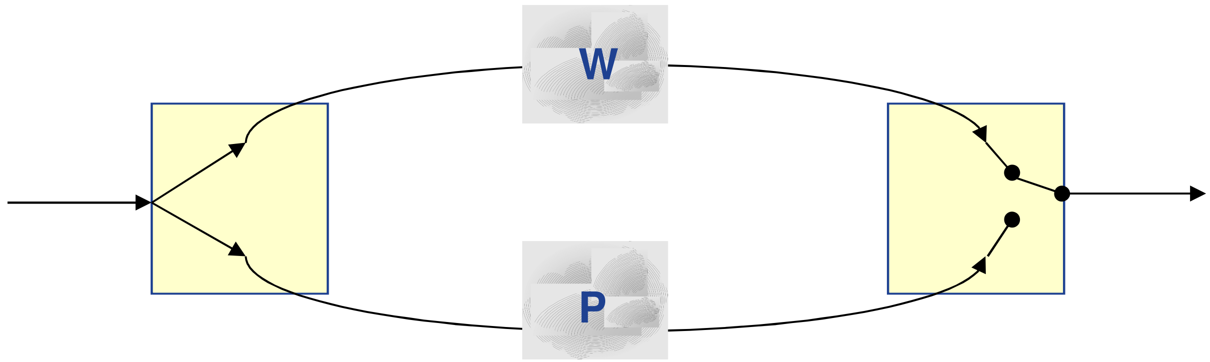


Automatic Protection Switching

- Requires presence of alternate route
- Criteria for making the switching decision include:
  - AIS
  - Loss of pointer
  - Bit-error ratio
  - Path label set to "Unequipped"
    - STS POH: C2 byte
    - VT POH: Bits 5-7 of V5 byte
  - Remote Defect Indication (to prevent asymmetric delays)

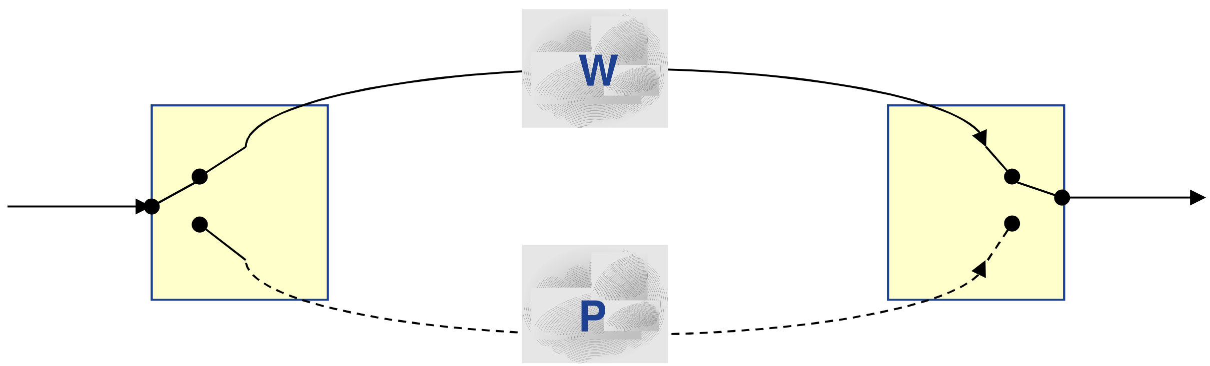
Automatic Protection Switching

- Linear Protection mechanisms
  - 1+1



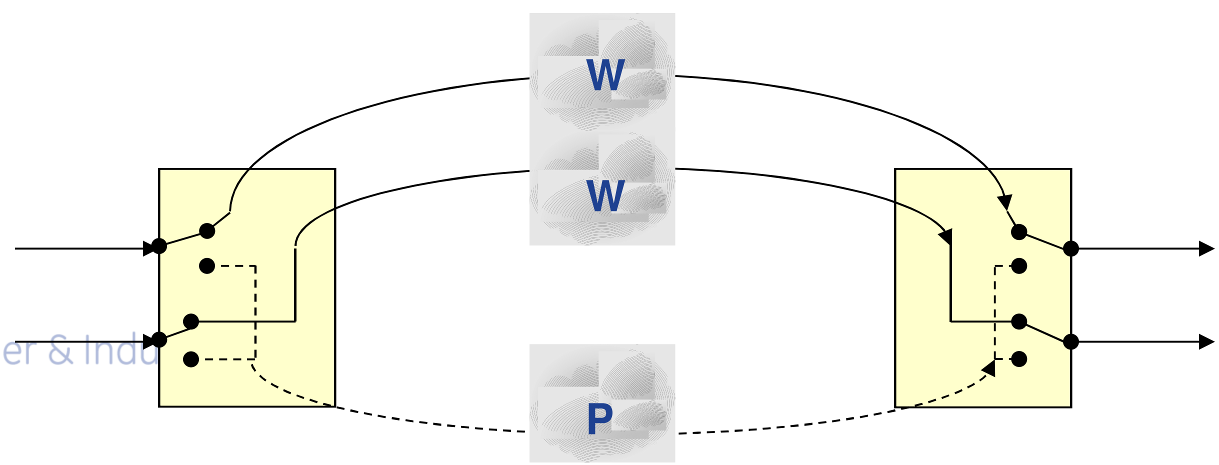
No APS protocol required

  - 1:1



APS protocol required. May carry additional traffic in “P”.

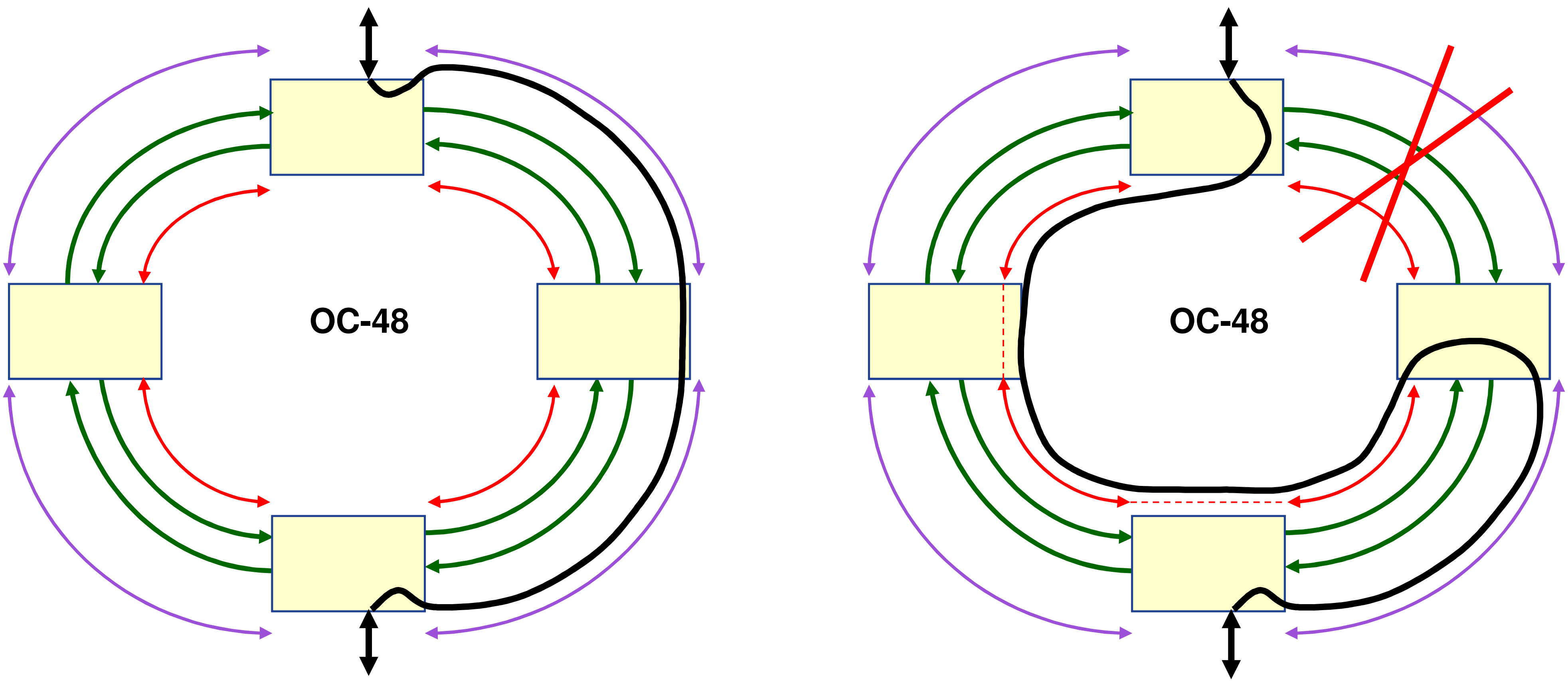
  - 1:N



APS protocol required. May carry additional traffic in “P”.

Automatic Protection Switching

- Bidirectional Line Switched Ring (BLSR)

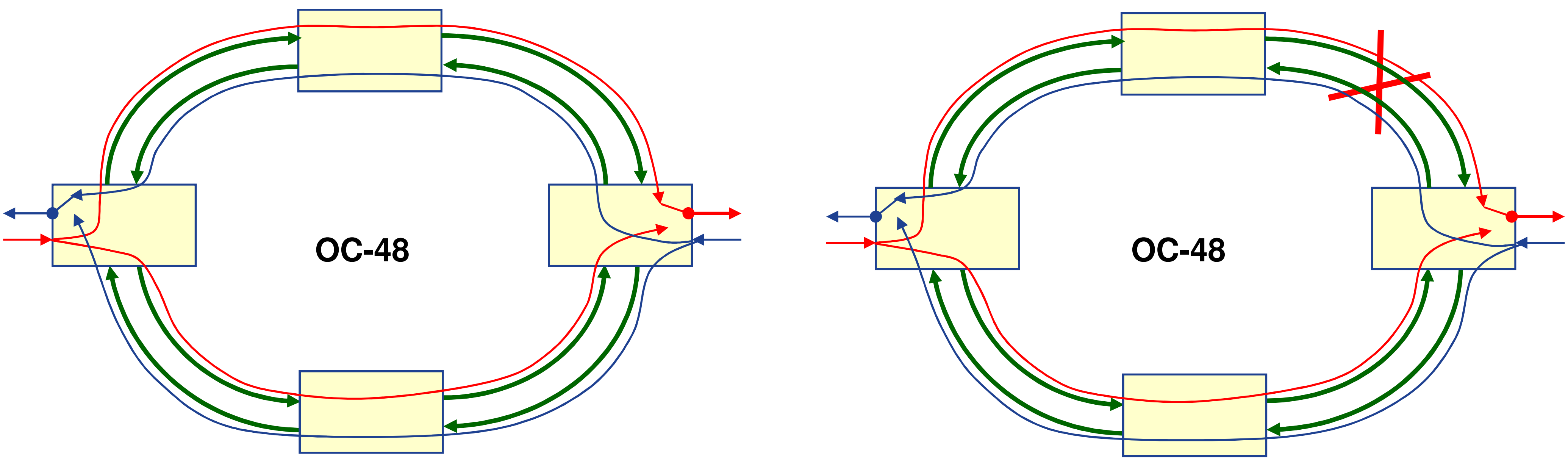


24 Working STS-1 Channels

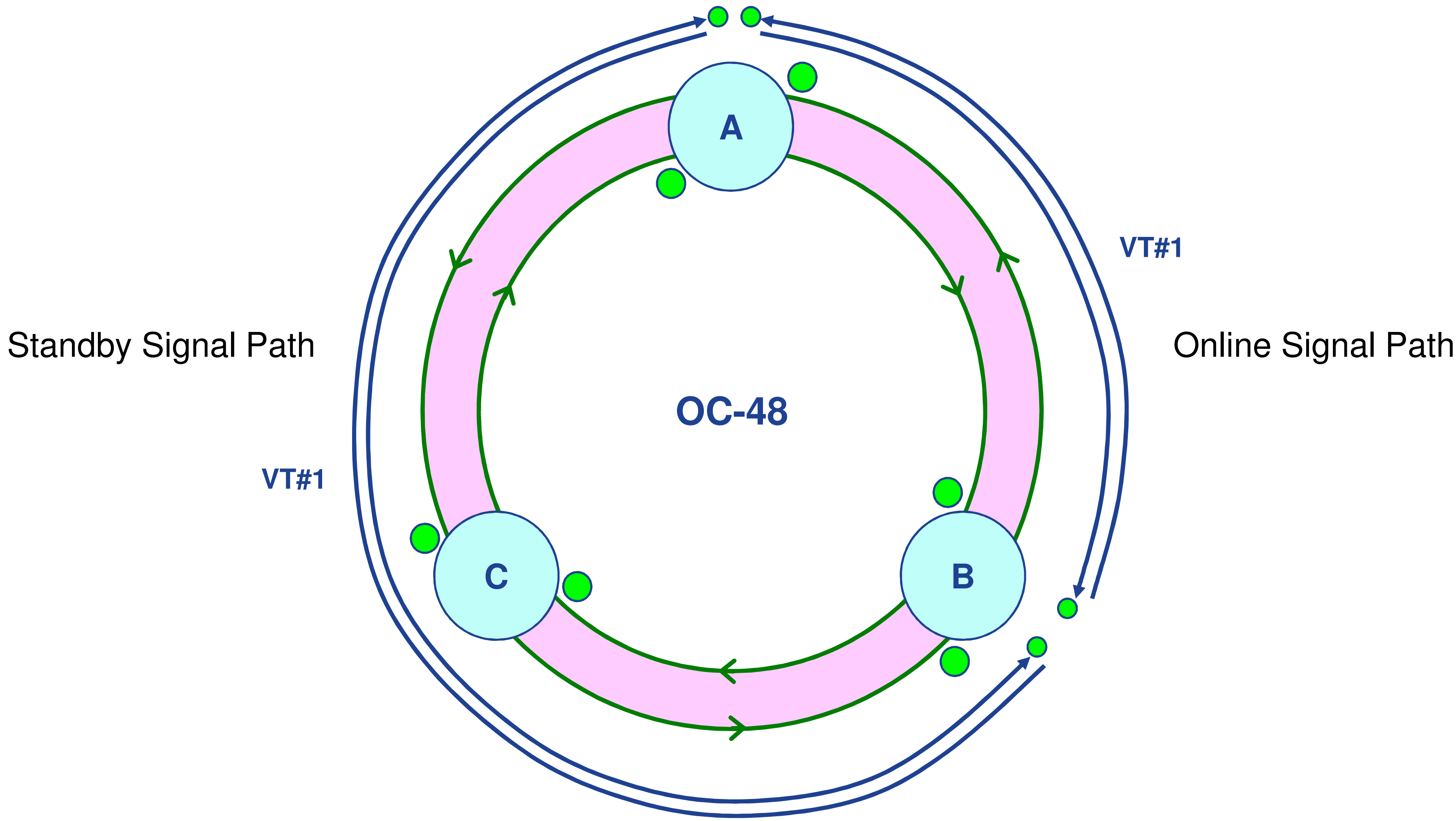
24 Protection STS-1 Channels

Automatic Protection Switching

- Unidirectional Path Switched Ring (UPSR)



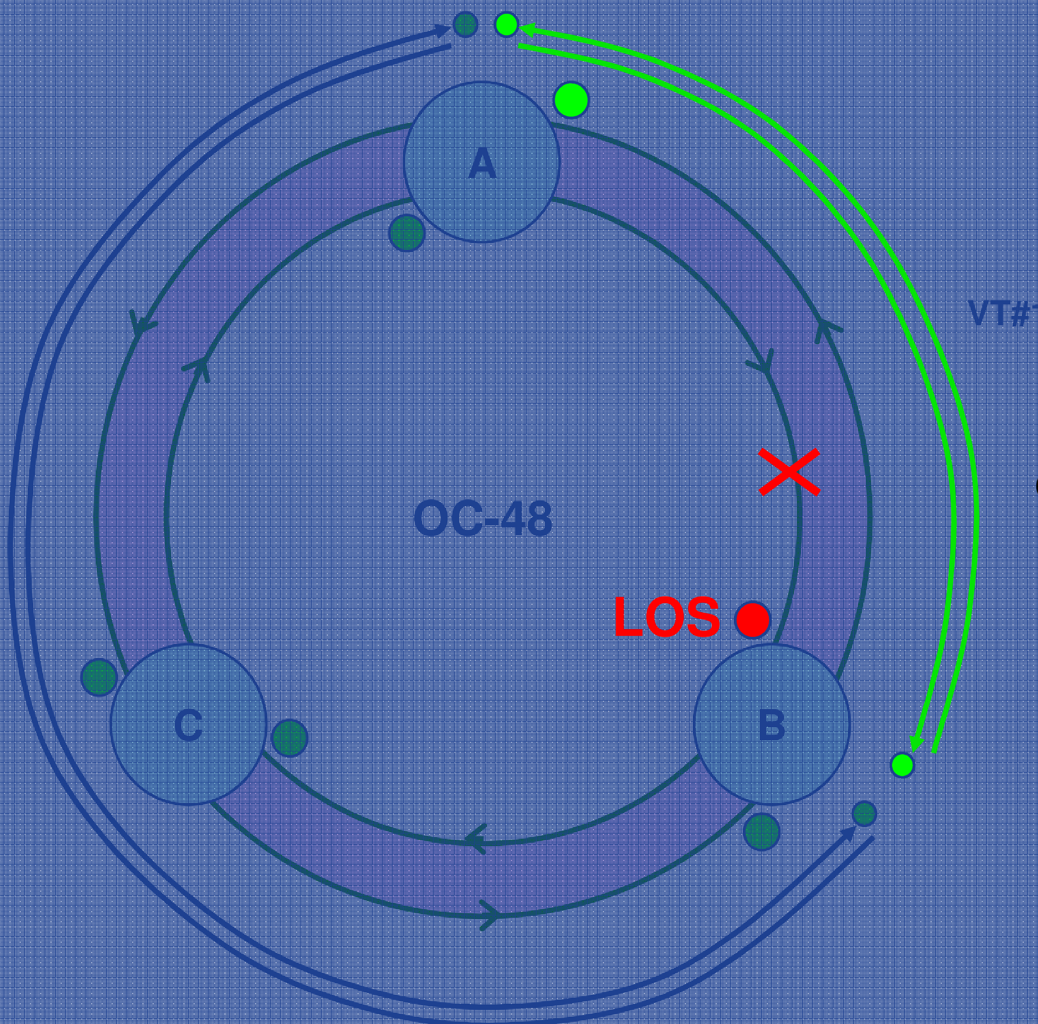
RDI: Remote Defect Indication



C

RDI: Remote Defect Indication

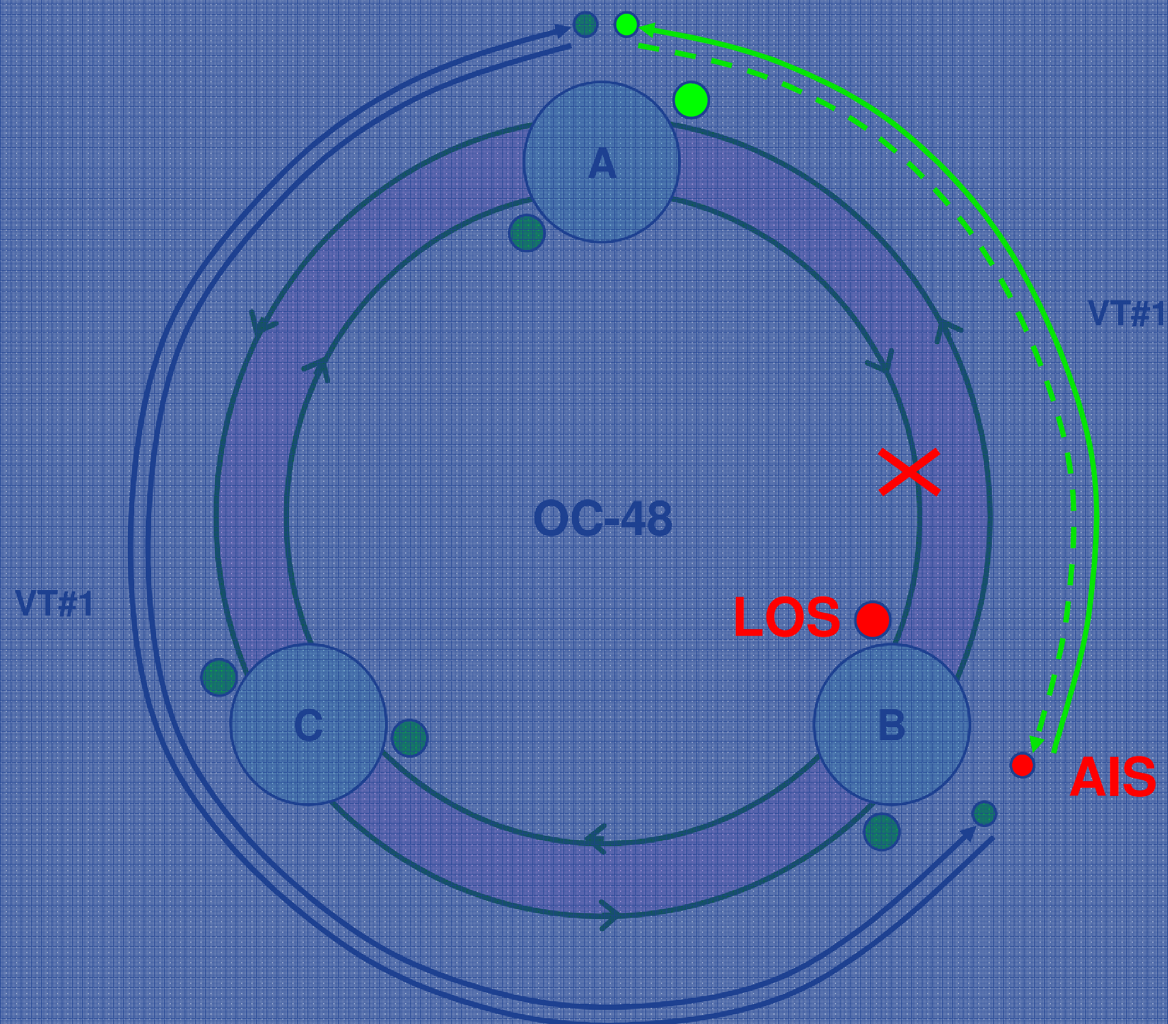
Symmetrical
Standby Signal Path



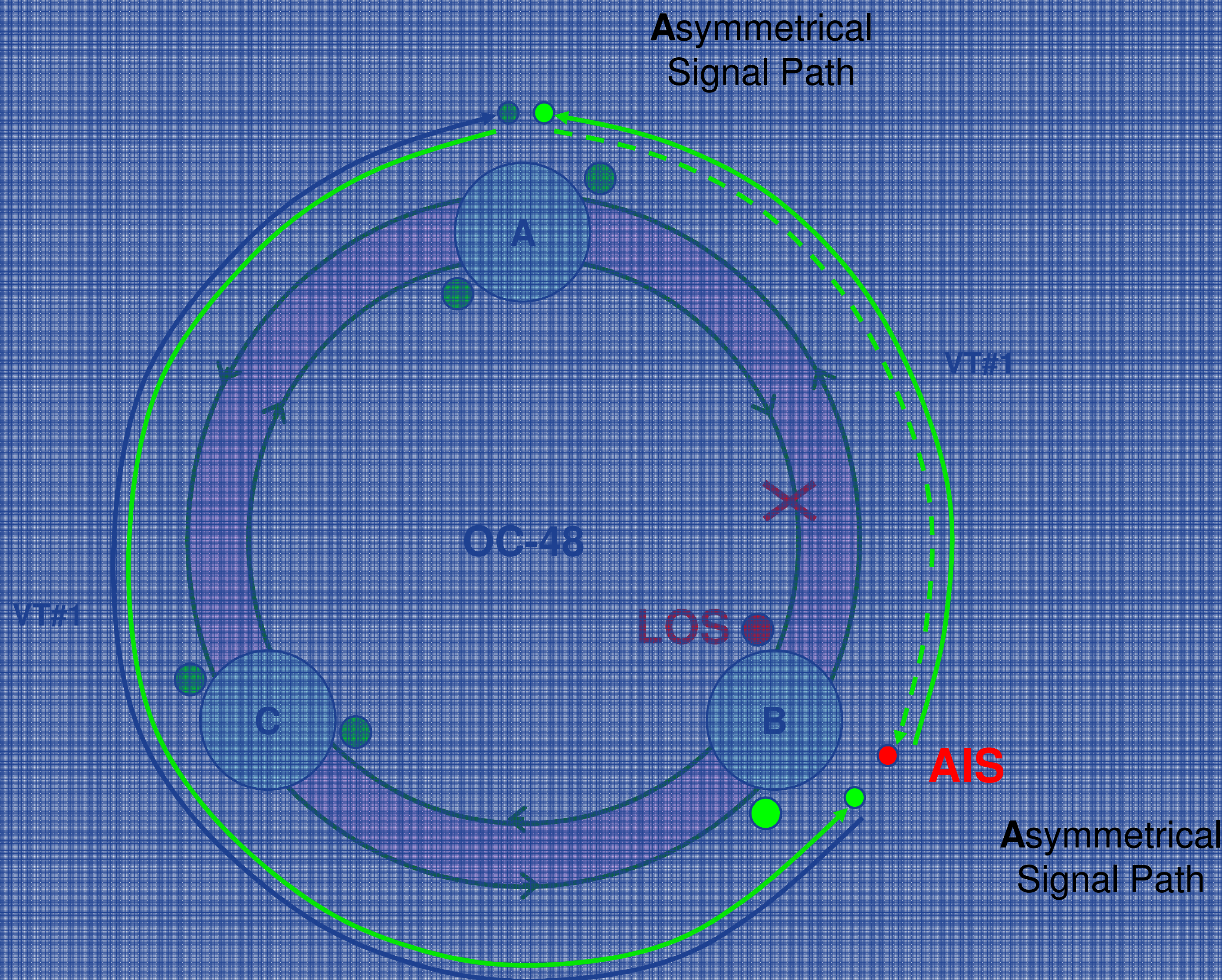
Symmetrical
Online Signal Path

C

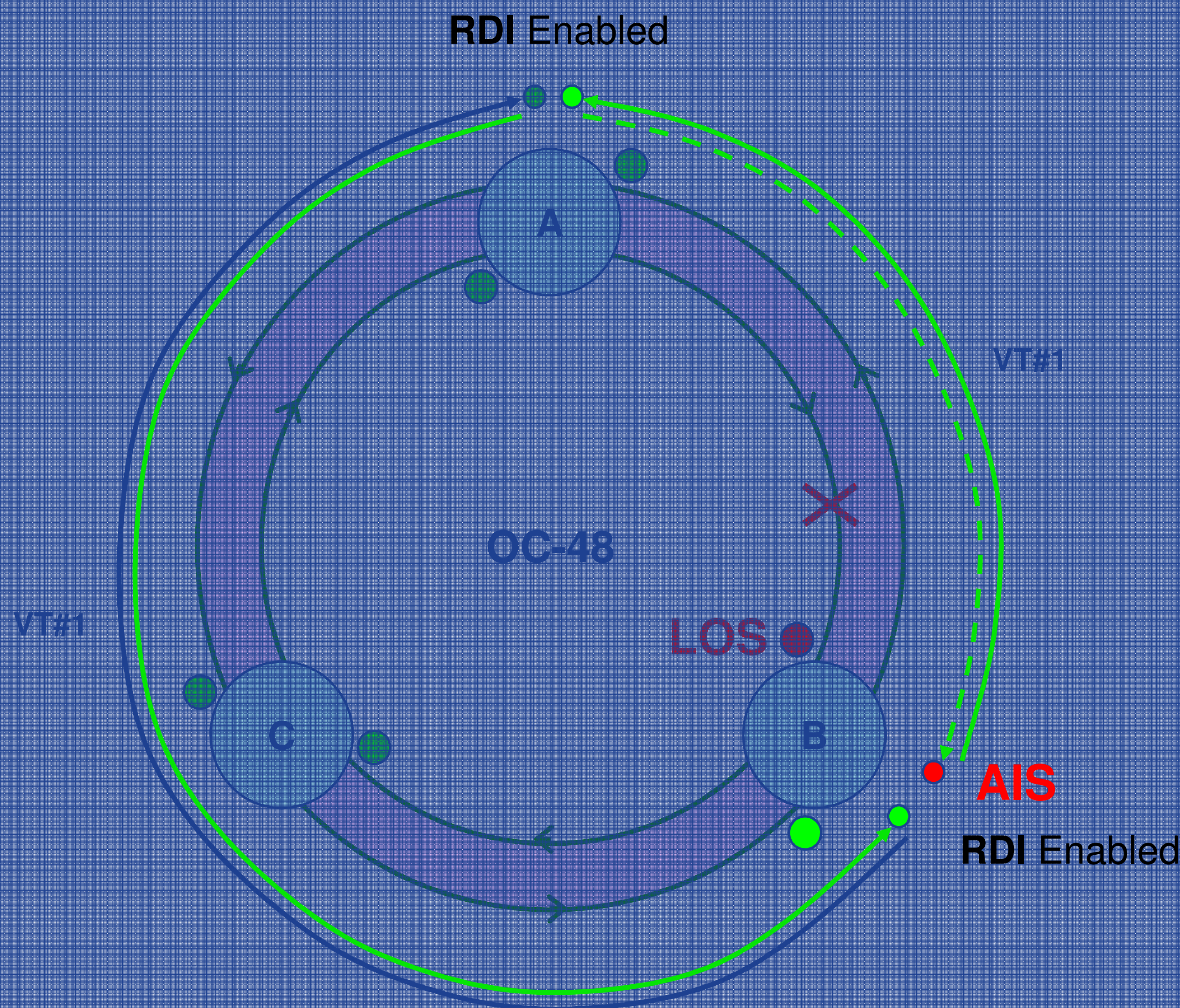
RDI: Remote Defect Indication



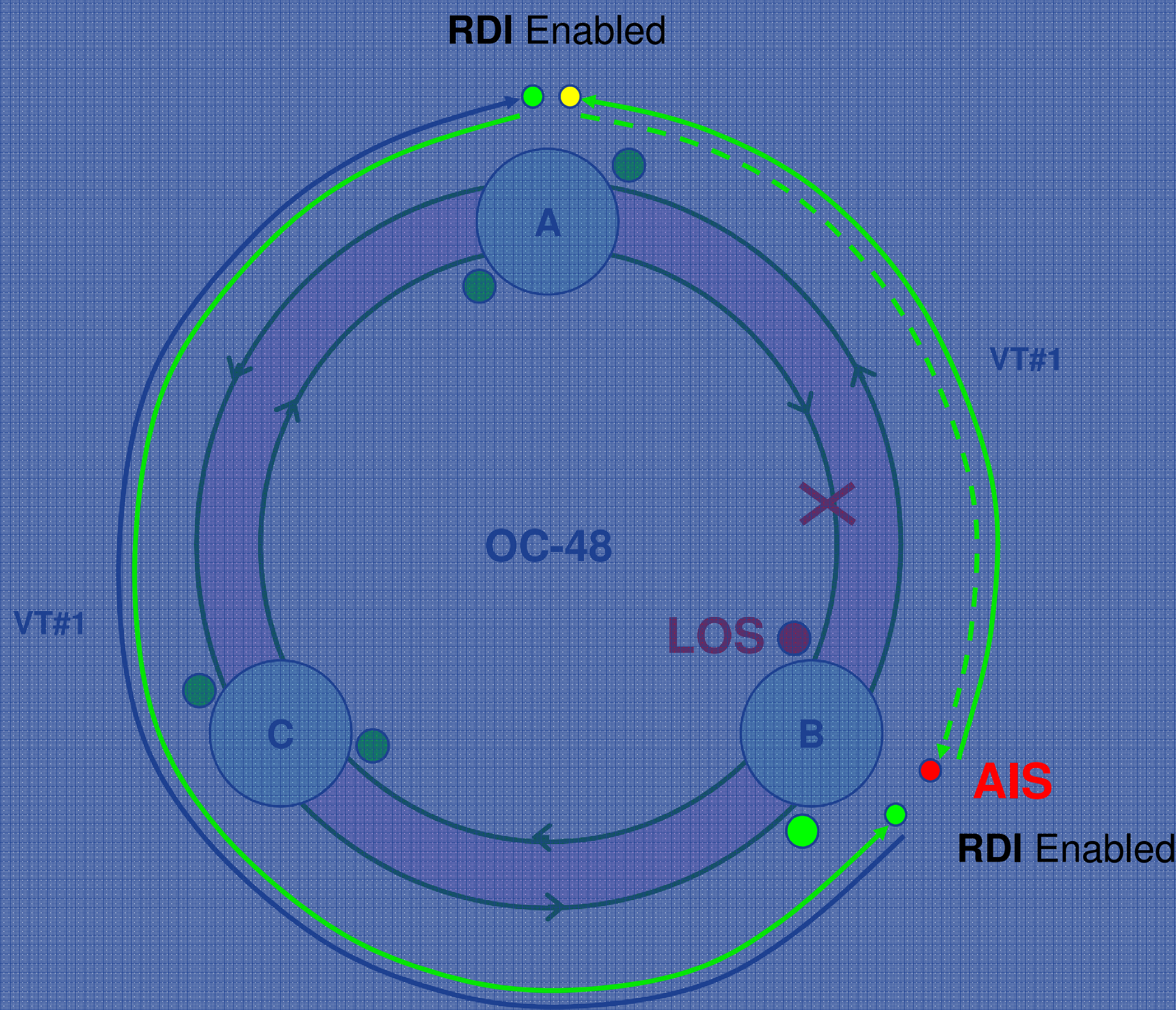
RDI: Remote Defect Indication



RDI: Remote Defect Indication



RDI: Remote Defect Indication



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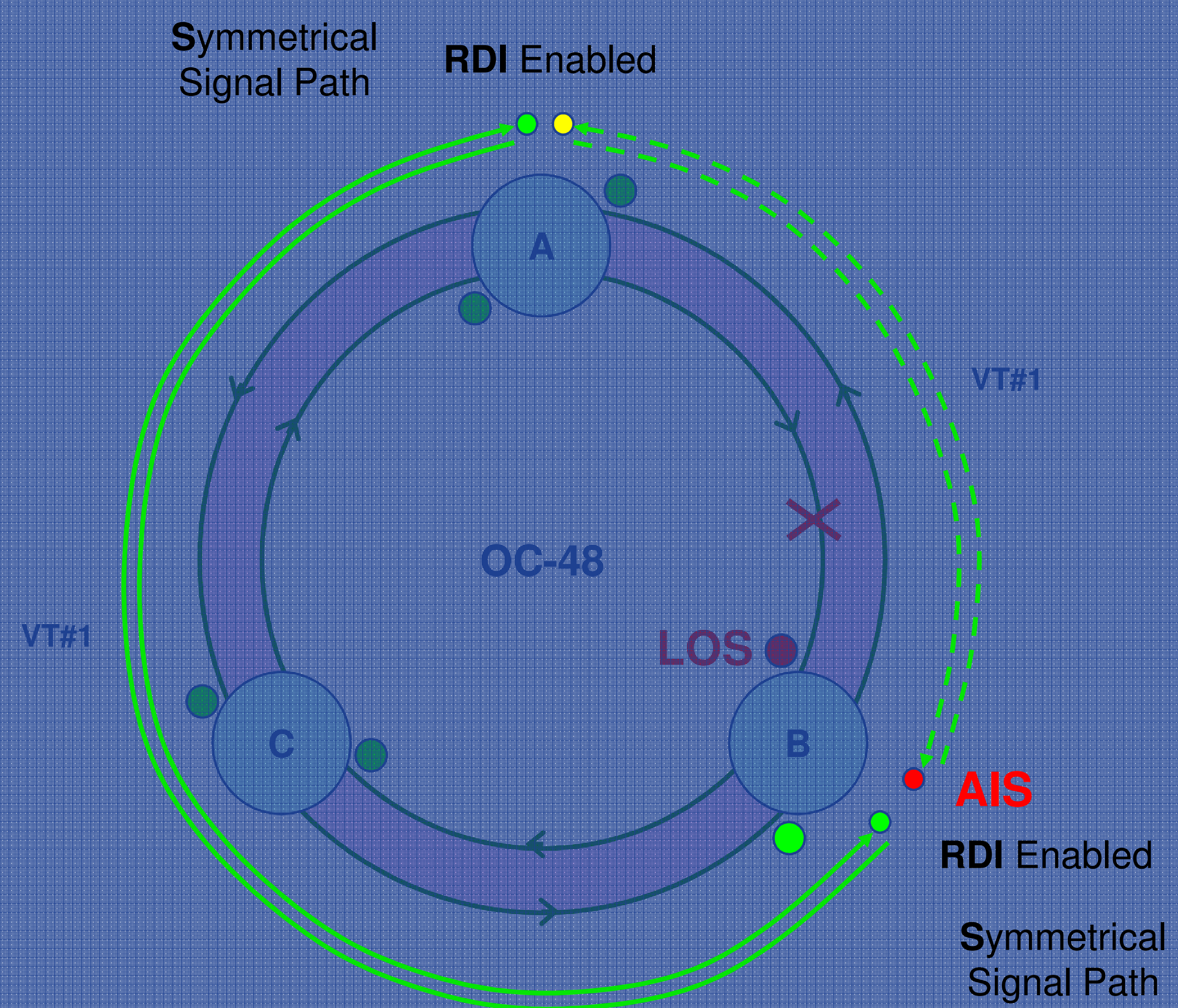

Automatic Protection Switching

	BLSR	UPSR
Main Characteristics	One half of each hop's capacity is used for working traffic; other half for protection. Only working path for each bidirect. circuit is provisioned.	Each tributary signal mapped is sent both ways around the ring. At the demapping point, the better of the two receive paths is chosen.
Type of switching	Line layer (revertive or non-revertive). Both directions are switched simultaneously.	Path layer (revertive or non-revertive). Each direction is switched independently.
APS protocol	Yes (K1 & K2 bytes). Rather complex protection switching mechanism limits the number of nodes to 16.	No. (Simple implementation.)
Switch completion time (in addition to problem detect time of max 10 ms)	Close to 50 ms.	Typically less than 10ms.
Cost	Generally less expensive than UPSR.	Generally more expensive than BLSR (more hardware).
Maximum total amount of traffic in ring	Depends on traffic matrix. Generally higher than in UPSR rings.	Does not depend on traffic matrix. Limited to "hop capacity".
Potential for asymmetric delay	No	Yes, but can be addressed by use of "Switch on RDI" function.
Able to carry additional* traffic?	Yes	No (Not/Applicable)
Typical use	Core networks	Access networks and some core networks.

* Additional traffic is lost in case of any hop failure.

SONET Benefits

- Single-stage multiplexing
  - No need for back-to-back multiplexing
  - Simple add/drop functionality
  - Simple implementation of linear and ring configurations
- Scalability of bandwidth allocation to various services.
- Reduced end-to-end delays (thanks to pointers)
- Traffic grooming (consolidation/segregation)
  - More efficient use of facilities
- Ability to interconnect different vendors' equipment optically ("mid-span meet")
- Powerful Network Management System

Are all SONET products acceptable for utilities?

- Can it operate in harsh environment?
- Does it implement a fast enough protection switching mechanism? (Important for mission critical applications.)
- Can the protection switching mechanism ensure the same delay for both directions of a bidirectional circuit regardless of the ring failure type? (Some relays are sensitive to “asymmetric” delays.)
- Does the overall solution provide acceptable end-to-end delays for mission critical applications?
- Is the implemented redundancy and related system availability acceptable?
- Does NMS cover all equipment in the system? (May be an issue if multiple vendor equipment is used, if “access” and “transport” are separated etc.)
- Can it support switching to alternate traffic routing for backup control center implementations (if required)?