
***Synchronous Digital Hierarchy
Synchronous Optical Network
SDH/SONET***

SDH – Table of Contents

- Introduction
 - Problems of the PDH
 - SDH layering
 - SDH framing
 - Elements of the SDH infrastructure
 - SONET/SDH Physical layer
-

SDH – Introduction

- Started by Bellcore in 1985 as standardisation effort for the US telephone carriers (after AT&T was broken up in 1984),
 - Later joined by CCITT (later: ITU), which formed SDH in 1987
 - Three major goals:
 - Avoid the problems of PDH
 - Achieve higher bit rates (Gbit/s)
 - Better means for Operation, Administration, and Maintenance (OA&M)
 - SDH is THE standard in telecommunication networks now
 - It is designed to transport voice rather than data
 - It covers the lower 2-3 OSI layers
 - SONET/SDH defines only a point-to-point connection in the network
-

SDH - Problems of PDH

- The Plesiochronous Digital Hierarchy had a number of problems:
 - Each multiplexing section has to add overhead bits for justification (higher rate -> more overhead)
 - Each part of the world has its own transmission hierarchy (expensive interconnection equipment)
 - Justification (bit stuffing) spreads data over the frame
 - add-drop-multiplexers are hard to build
 - extract a single voice call -> demultiplex all steps down
 - switching of bundles of calls ($n * 64$ kbit/s) is difficult
 - (every switch has to demultiplex down to DS0 level)
 - The management and monitoring functions were not sufficient in PDH
 - PDH did not define a standard format on the transmission link
 - Every vendor used its own line coding, optical interfaces etc.
 - Very hard to interoperate
-

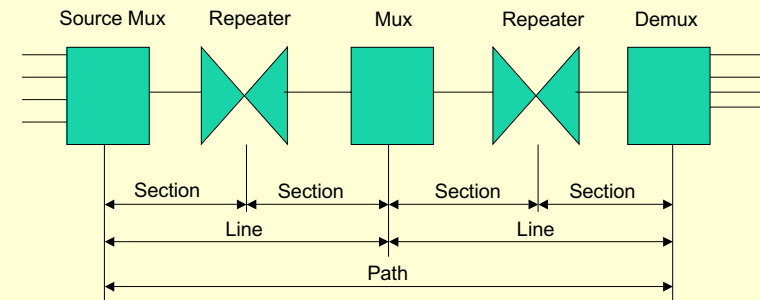
PDH –Data Rates

Table 1: PDH transmission rates in kbs

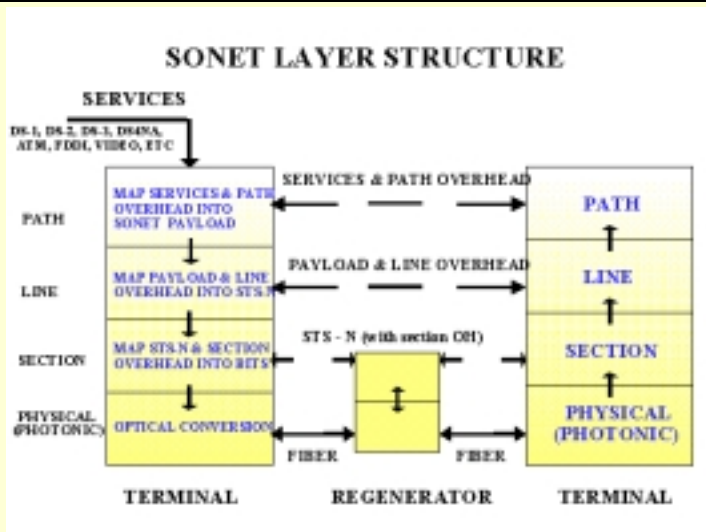
Hierarchical Level	American DS-x	European CEPT-x	Japanese	International
0	64	64	64	64
1	1544	2048	1544	2048
2	6312	8448	6312	6312
3	44736	34368	32064	44736
4	139264	139264	97728	139264

SONET/SDH - Layering

- SONET/SDH system consists of switches, multiplexers and repeaters (and the fiber in between)
- PATH is the connection between source and destination
- LINE runs between two multiplexers (possibly through repeaters)
- SECTION is the connection of any two devices (point-to-point)
- PHOTONIC is the e/o and o/e conversion layer

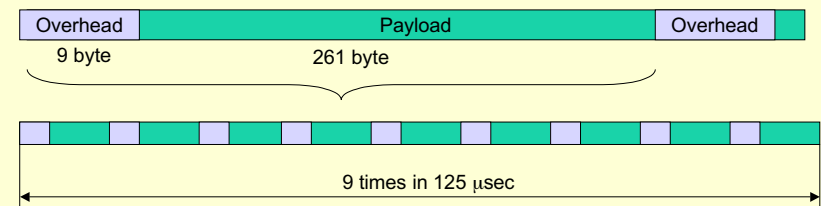


SONET/SDH-Layering (cont.)



SDH - Framing

- Frame format in SDH:



- Sampling rate of a 3400 Hz voice channel -> 8000 Hz
- $8000 \text{ Hz} * 1 \text{ byte} = 64 \text{ kbit/s}$
- $9 * 270 * 8 \text{ bit} * 8000 \text{ Hz} = 155.52 \text{ Mbit/s}$
- Basic data rate in SDH
- STM-1 -> Synchronous Transport Module

SONET - Framing

- Basic signal in SONET is OC-1 (Optical Channel level 1) or electrical equivalent STS-1 (Synchronous Transport Signal level 1)
- Is organized in 9 rows and 90 columns a 1 byte
- This frame is repeated at 8000 Hz -> $9 \times 90 \times 8000 \text{ s}^{-1} \times 8 \text{ bit} = 51.84 \text{ Mbit/s}$
- First three columns are reserved for system management information
 - upper three contain section overhead information
 - lower 6 contain line overhead information
- 87 columns remain for user data and carry the AU
- (Administrative Unit, the Payload Envelope)
- AU begins anywhere in the frame
 - first row of line overhead contains a pointer to the first byte of the AU
- Basic signal in SDH is STM-1 (Synchronous Transport Module level 1)
- Built as if 3 STS-1 signals are byte interleaved

SDH Framing

A1	A1	A1	A2	A2	A2	A3				J1		
B1			E1			F1				B3		
D1			D2			D3				C2		
H1	H1	H1	H2	H2	H2	H3	H3	H3		G1		
B2	B2	B2	K1			K2				F2		
D4			D5			D6				H4		
D7			D8			D9				Z3		
D10			D11			D12				Z4		
Z1	Z1	Z1	Z2	Z2	Z2	E2				Z5		

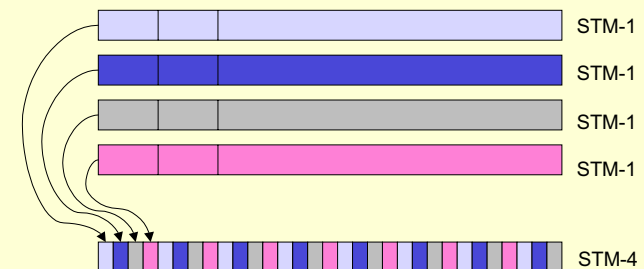
- A1, A2 – Framing
 - H1-H3 – AU (Administrative Unit) Pointers
 - B1, B3 – BIP-8 (Bit interleaved parity)
 - B2 – BIP-24
 - C1, C2 – STM Identifiers
 - D1 to D12 - Data Communication Channels
- Section OH (SOH)
 Line OH (LOH)
 Path OH (POH)

SDH Framing (cont.)

- E1, E2 - Order Wire
- F1, F2 – User defined
- G1 – Path status
- J1 – Path trace
- K1, K2 – Automatic protection Switching
- Z1 to Z5 – Growth (reserved space)

SDH – Multiplexing

- No overhead bits needed for justification
- higher speed link is formed by byte-interleaving data from lower speed links
- exact multiples of lower speed data rates (OC-12 contains 12 byte interleaved OC-1 frames)
- OC-12c or STM-4c means „concatenated“ payload, these containers are not multiplexed



SDH- Data Rates

Level	US	Europe, Japan	Data rate (gross)	Data rate (SPE)	Data rate (user)
1	OC-1	-	51.84	50.112	49.536
2	OC-3	STM-1	155.52	150.336	148.608
3	OC-9	STM-3	466.56	451.008	445.824
4	OC-12	STM-4	622.08	601.344	594.824
5	OC-18	STM-6	933.12	902.12	891.648
6	OC-24	STM-8	1244.16	1202.688	1188.864
8	OC-36	STM-12	1866.24	1804.032	1783.296
9	OC-48	STM-16	2488.32	2405.376	2377.728
10	OC-192	STM-64	9953.28	9621.504	9510.912

- SPE – Synchronous Payload Envelope = AU in SDH
- In development: STM-256 with 40 Gbit/s
- In the lab: STM-1024 with 160 Gbit/s (HHI and others)
- STM-4096 with 640 Gbit/s

SDH – Payload Mapping

- Adaptation of the old (and still working) PDH tributaries into SDH format
- How many tributaries fit into one STM-1 Payload frame?

Number	Name	Capacity	Sum
1	C4	140 Mbit/s	140 Mbit/s
3	C3	34 Mbit/s 45 Mbit/s	102 Mbit/s 135 Mbit/s
63	C12	2.048 Mbit/s	126 Mbit/s

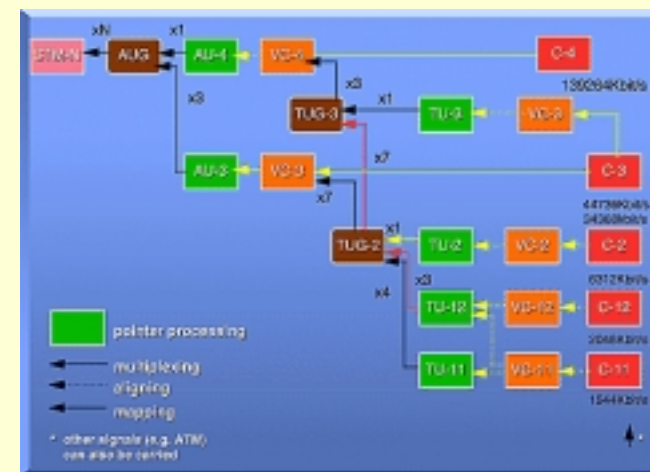
- Or any combinations thereof
- Unused payload capacity (up to 150.336 Mbit/s) is used for additional Path Overhead (POH)
- Path Overhead + Container = Virtual Container (VC)
- Example:
 - (30+2) ISDN channels are mapped into C12 (2.048 Mbit/s) signal
 - STM-1 holds 30*63=1890 telephone calls, STM-64 -> 120960 calls

SDH – Payload Mapping (cont.)

- Higher Order Virtual Container (HVC)
 - Two sizes of HVCs:
 - VC-3:
 - Used only in North America (in SONET)
 - Total capacity of 48960 kbit/s
 - VC-4:
 - Used elsewhere (SDH)
 - Total capacity of 150336 kbit/s
 - Mapped into Administrative Units (AU)
 - AU-Pointer + HVC = AU
 - Referred to as AU-3 or AU-4
- Many sizes of Lower Order Virtual Containers (LVC)
 - VC-12 (VC-1), VC-2, VC-3
 - VC-3 can be HVC (in SONET) or LVC (SDH)
 - Mapped into Tributary Units (TU or VT (Virtual Tributary)) in SONET
 - TU-Pointer + LVC = TU

SDH – Payload Mapping (cont.)

- Taken from <http://www.webproforum.com/sdh/>



SDH - Clocking

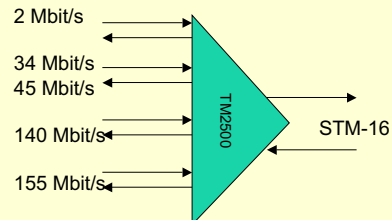
- All network elements are totally synchronous
- Expensive clocks needed
- Still, there are delays in the network
- Delay variance of 5×10^{-10} means that two tributaries differ in one frame length every 3 days
- Justification still needed
 - Put the tributaries into containers
 - Let the container start anywhere in the payload frame
 - Keep and manage the movement of pointers to these containers

SDH - Justification

- Problem: Streams of slightly different speed arrive at the multiplexer
 - Arriving data of stream A slower than output rate:
 - Positive stuffing
 - Increment AU pointer H1A and H2A by 1
 - Leave AU pointer H3A empty
 - Leave 1 byte (for STS-1) or 3 byte (for STM-1) after H3C empty
 - Arriving data of stream A faster than output rate:
 - Negative stuffing
 - Decrement AU pointer H1A and H2A by 1
 - 1 byte (for STS-1) or 3 byte (for STM-1) of user data is put into AU pointer H3A
- Differences in the data rates can be adjusted this way without the use of overhead bits

Elements of the SONET/SDH Infrastructure

- Terminal Multiplexer
 - Tributaries may be electrical or optical



- Works as termination of the Path layer
 - Write POH (Path Overhead)

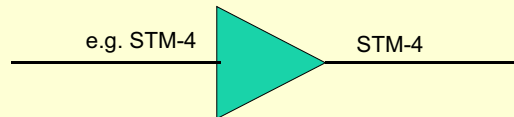
Elements of the SONET/SDH Infrastructure (cont.)

- Add-Drop Multiplexer
- Terminate connections in the Line layer (Write LOH – Line Overhead)
 - Direct access to the SONET/SDH-frames in the bitstream
 - Example: drop and add a STM-1 from/to a STM-4
 - Every STM-1 frame can be mapped in and out separately without changing the remaining STM-N structure



Elements of the SONET/SDH Infrastructure (cont.)

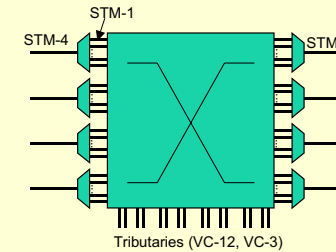
- Regenerator:
 - Perform 3-R regeneration of the signals (amplify, re-shape, re-clock)
- Terminates connections in the Section Layer
 - write SOH (Section Overhead)
- Regenerators perform opto/electro/optical conversion



- ADMs and DXCs have the functionality of regenerators, too

Elements of the SONET/SDH Infrastructure (cont.)

- Digital Crossconnect System (DXC or DCS)
 - Higher order DXC
 - HDXC only switch STM-1 frames
 - DXC 4|4 means „receive AU-4 and switch AU-4 granularity“
 - Lower order DXC
 - LDXC mostly receive AU-4, but switch Tributary Units (TU)
 - DXC 4|3|1 receives STM-1, but may switch VC-12, VC-3 and VC-4
- DXC switches connections according of day-time-changes
 - Can be used to change the network topology



SONET – Physical Layer

Bit Rate	Loss	Wavelength	Fiber Type	Transmitter
OC-3	SR (Short Range)	1310 nm	MMF	LED
			SMF	LED/MLM
	IR (Intermediate R.)	1310 nm	SMF	MLM
	LR (Long Range)	1550 nm	SMF	MLM/SLM
		1310/1550 nm	SMF	MLM/SLM
OC-12	SR	1310 nm	SMF	LED/MLM
	IR	1310 nm	SMF	SLM
		1550 nm	SMF	SLM
	LR	1310 nm	SMF	MLM/SLM
1550 nm		SMF	SLM	
OC-48	SR	1310 nm	SMF	MLM
	IR/LR	1310/1550 nm	SMF	SLM

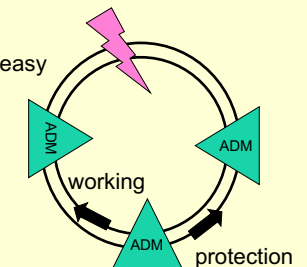
Loss is defined as measure of distance

SR<7dB, IR<12dB, 10<LR<28 dB for OC-3, 10<LR<24dB for OC-12

MLM=Multi Longitudinal Mode Laser, SLM=Single LM Laser

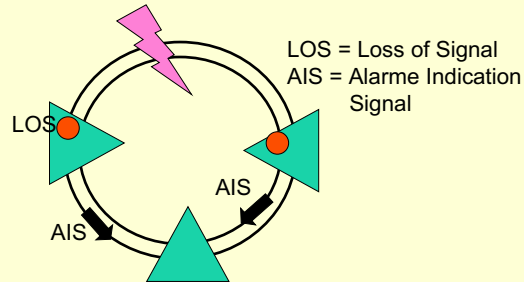
SONET/SDH – Topologies

- Basically, SONET/SDH define point-to-point links
 - Different topologies can be configured using either ADMs or DXCs
- Ring topologies are often used in North America
- Europe mainly relies on meshed networks
 - Protection switching is to be done in OXCs
- Unidirectional Path-Switched Ring (UPSR)
 - Two counter-rotating fibers, one is *working*, the other *protection*
 - Send simultaneously on both fibers
 - Receiver picks the stronger signal of both
 - No excessive signalling needed, fast and easy
 - No spatial reuse of the ring



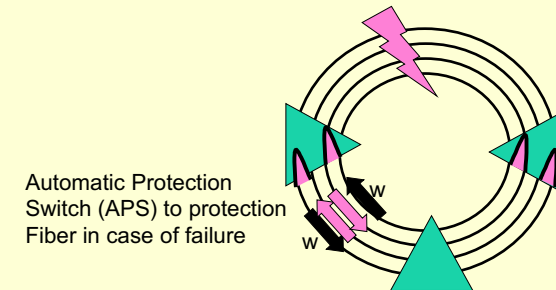
SONET/SDH – Topologies

- Bidirectional Line-Switched Ring (BLSR)
 - BLSR/2 and BLSR/4 exist (number of fibers)
 - BLSR/2 means two counter-rotating fibers, as in UPSR
 - Send on either of the fibers, depending on the hop distance
 - Spatial reuse increases ring capacity
 - BLSR supports up to 16 nodes (4-bit node ID)
 - Maximum ring length is 1200km (6ms propagation delay)
 - Payload redundancy (use less than 50% of total capacity)



SONET/SDH – Topologies

- BLSR/4
 - 2 pairs of fiber
 - Two working fibers, two (normally unused) protection fibers
 - Span and Line protection
 - Span protection: Switch to a protection fiber if transmitter or receiver on the working fiber fails
 - If laid out separately, span switching can be used to handle fiber cut



SONET/SDH – Summary

- SDH and SONET are the leading optical transmission standards for the next 10 years or so
 - Almost every newly installed equipment is SONET/SDH
- Transmit data of 1.5, 2, 6, 34, 45, 140 Mbit/s in multiples of 155 Mbit/s (51 Mbit/s for SONET only)
- Overall data rates grow with a factor of 4, i.e. 622 Mbit/s for STM-4, STM-16, STM-64,...
- Mappings of other payload into SDH/SONET frames defined
 - ATM cells (we will see later)
 - FDDI packets
 - IP packets (we will see later)
- Physical layer definitions for copper and radio as well, but mainly single mode fiber
- Extensive Management and protection features