TDM Techniques

Time Division Multiplexing (synchronous, statistical)
Digital Voice Transmission, PDH, SDH

Agenda

- <u>**Introduction**</u>
- **Synchronous (Deterministic) TDM**
- **Asynchronous (Statistical) TDM**
- **Digital Voice Transmission**
- **PDH**
- **SDH**

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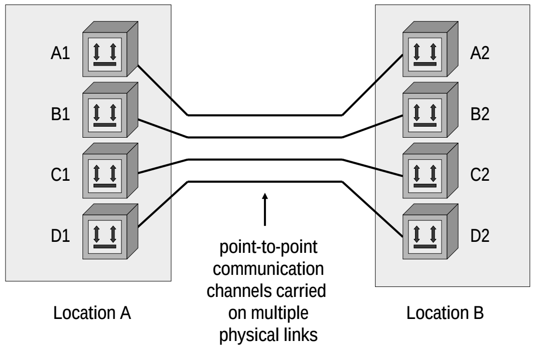
Introduction

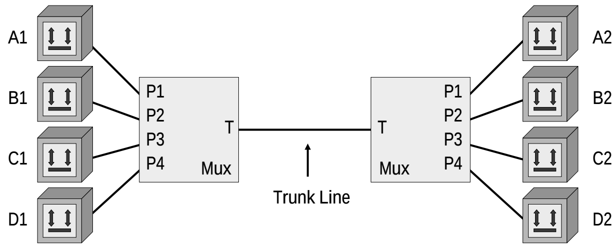
- **line protocol techniques (data link procedures)**
  - were developed for communication between two devices on one physical point-to-point link
  - bandwidth of physical link is used exclusively by the two stations
- **in case multiple communication channels are necessary between two locations**
  - multiple physical point-to-point are needed
  - expensive solution
- **in order to use one physical link for multiple channels**
  - multiplexing techniques were developed

Point-To-Point Channels



Multiplexing / Demultiplexing

- **multiplexer is a device**
  - which can take a number of input channels and, by interleaving them, output them as one data stream on one physical trunk line



Time Division Multiplexing (TDM)

- **time division multiplexer**
  - allocates each input channel a period of time or timeslot
  - controls bandwidth of trunk line among input channels
- **individual time slots**
  - are assembled into frames to form a single high-speed digital data stream
- **available transmission capacity of the trunk**
  - is time shared between various channels
- **at the destination demultiplexer reconstructs**
  - individual channel data streams

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Types of TDM

- **depending on timing behavior two methods**
  - synchronous TDM
    - timeslots have constant length (capacity) and can be used in a synchronous, periodical manner
  - asynchronous (statistical) TDM
    - timeslots have variable length and are used on demand (depending on the statistics of channel communication)

Synchronous TDM Standards

- **TDM framing on the trunk line**
  - can be vendor dependent
    - proprietary TDM products
  - can be standard based
- **two main architectures for standardizing synchronous TDM for trunk lines**
  - **PDH – Plesiochronous Digital Hierarchy**
    - e.g. E1 (2Mbit/s), E3 (34Mbit/s), E4, T1 (1,544Mbit/s), T3
  - **SDH - Synchronous Digital Hierarchy**
    - e.g. STM-1 (155Mbit/s), STM-4 (622Mbit/s), STM-16

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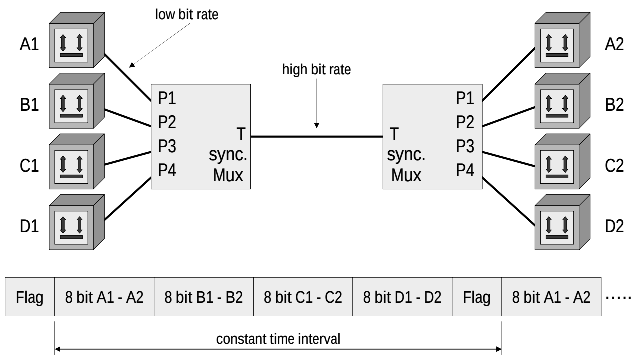
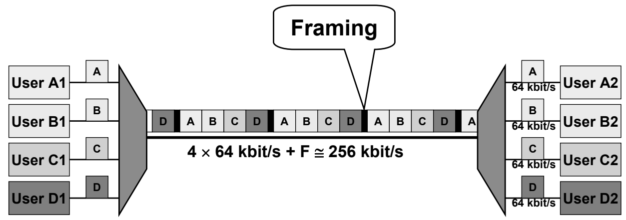
Synchronous Time Division Multiplexing

- **synchronous TDM**
  - periodically generates a frame consisting of a constant number of timeslots each timeslot of constant length
  - timeslots can be identified by position in the frame
    - timeslot 0, timeslot 1, ...
  - frame synchronization achieved by extra flag field
- **every input channel is assigned**
  - a reserved timeslot
  - e.g. timeslot numbers refer to port numbers of a multiplexer
    - traffic of port P1 in timeslot 1 for A1- A2 channel
    - traffic of port P2 in timeslot 2 for B1- B2 channel
    - ......

Synchronous Time Division Multiplexing

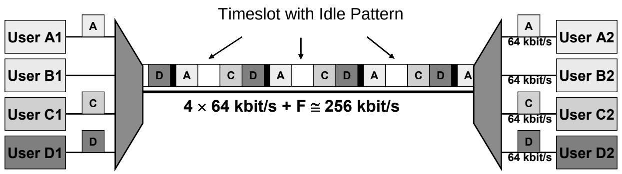


Trunk Speed with Synchronous TDM



- **Trunk speed = Number of slots × User access rate**
- **Each user gets a constant timeslot of the trunk**

Idle Timeslots with Synchronous TDM



- **If a communication channel has nothing to transmit**
- **-> Idle timeslots -> Waste of bandwidth**

Advantages

- **compared to pure point-to-point physical links**
  - synchronous multiplexing adds only minimal delays
    - time necessary to packetize and depacketize a byte
    - transmission/propagation delay on trunk
- **the delay for transporting a byte is <u>constant</u>**
- **the time between two bytes to be transported is constant**
  - hence optimal for synchronous transmission requirements like traditional digital voice
- **any line protocol could be used between devices**
  - method is <u>protocol-transparent</u>
- **to endsystems**
  - channel looks like a single physical point-to-point line

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Disadvantages

- **bitrate on trunk line T**
  - sum of all port bitrates (P1-P4) plus frame synchronization (flag)
  - high bitrate is required
  - hence expensive
- **if no data is to be sent on a channel**
  - special idle pattern will be inserted by the multiplexer in that particular timeslot
  - waste of bandwidth of trunk line
- **asynchronous (statistic) time division multiplex avoids both disadvantages**
  - making use of communication statistics between devices

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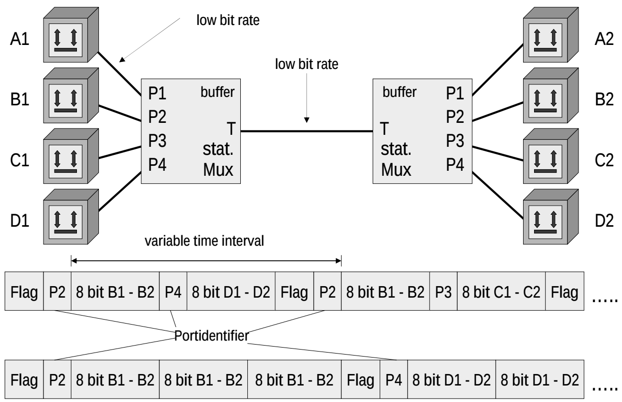
Asynchronous Time Division Multiplexing

- **usually devices communicate in a statistical manner**
  - not all devices have data to transmit at the same time
- **therefore it is sufficient**
  - to calculate necessary bitrate of the multiplexer trunk line according to the average bitrates caused by device communication
- **if devices transmit simultaneously**
  - only one channel can occupy trunk line
  - data must be buffered inside multiplexer until trunk is available again
  - statistics must guarantee that trunk will not be monopolized by a single channel

Asynchronous Time Division Multiplexing



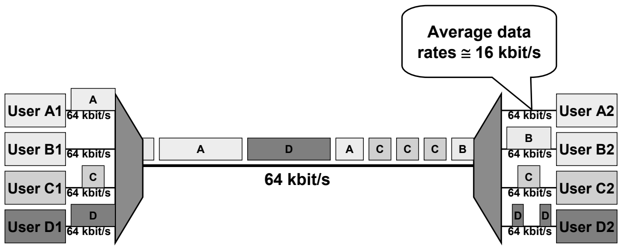
ATDM Operation

- **multiplexer only generates a transmission frame**
  - if data octets are present at input ports
- **source of data**
  - must be explicitly identified in transmission frames
  - addressing
- **reason for addressing**
  - there exists no constant relationship between timeslot and portnumber as with synchronous TDM
    - Note: addressing in synchronous TDM is implicit by recognizing the flag of the frame and hence the position of a certain timeslot
- **port identifier**
  - is used as address of source and sent across the trunk

ATDM Operation / Facts

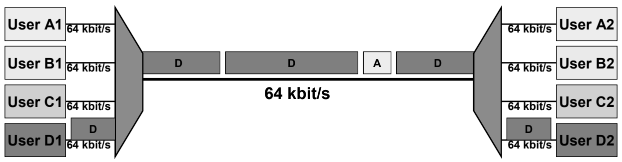
- **transmission frame can be assembled using**
  - either a single channel octet by frame
    - suitable for character oriented terminal sessions
  - or multiple channel octets per frame
    - suitable for block oriented computer sessions
- **in case of congestion**
  - buffering causes additional delays compared to synchronous TDM
- **delays are variable because of statistical behavior**
  - hence not optimal for synchronous transmission requirements like traditional digital voice
  - sufficient for transmission requirements of bursty data transfers

Asynchronous / Statistical TDM



- **Trunk speed dimensioned for average usage**
- **Each user can send packets whenever he wants**
- **Buffering necessary if trunk already occupied**

Asynchronous / Statistical TDM



- **If other users are silent, one user can fully utilize his access rate**

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ATDM Facts

- **ATDM can be used protocol transparent**
  - however in case of buffer overflow transmission errors will be seen by devices
    - FCS errors
- **to avoid FCS errors a kind of <u>flow control between multiplexer and device (end system)</u> should be used**
  - which is a new element in data communication methods
  - this is different from flow control between end systems learned so far in module about line protocols
  - examples for flow control
    - HW flow control based on handshake signals (e.g. RTS, CTS)
    - SW flow control (e.g. XON/XOFF)
    - Protocol based flow control such as known in connection oriented line protocols like HDLC (e.g. RR and RNR)
  - end system and ADTM have to speak the same protocol language

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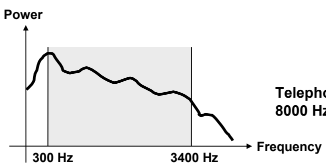
Voice Transmission

- **digital voice transmission**
  - based on Nyquist´s Theorem
  - analogous voice can be digitized using pulse-code-modulation (PCM) technique requiring a 64kbit/s digital channel
    - voice is sampled every 125usec (8000 times per second)
    - every sample is encoded in 8 bits
  - used nowadays in the backbone of our telephone network
  - today analogous transmission only between home and local office -> so called local loop
- **synchronous TDM**
  - originated from digital voice transmission

Sampling of Voice

- **Nyquist´s Theorem**
  - any analogue signal with limited bandwidth f_B can be sampled and reconstructed properly when the sampling frequency is $2 \cdot f_B$
  - transmission of sampling pulses allows reconstruction of original analogous signal
  - sampling pulses are quantized resulting in binary code word which is actually transmitted



$R = 2 * B * \log_2 V$

Telephone channel: 300-3400 Hz
8000 Hz x 8 bit resolution = 64 kbit/s

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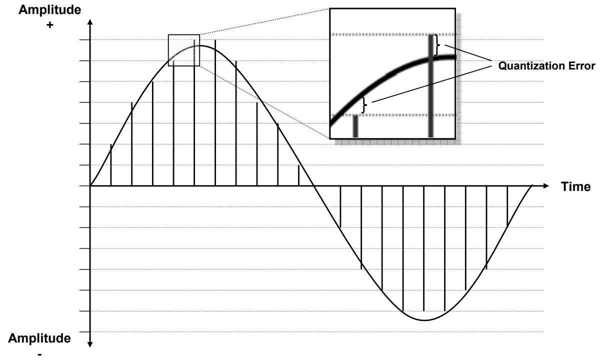
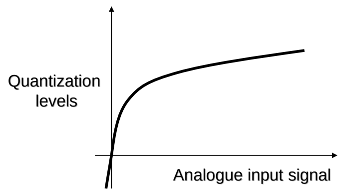
Linear Quantization

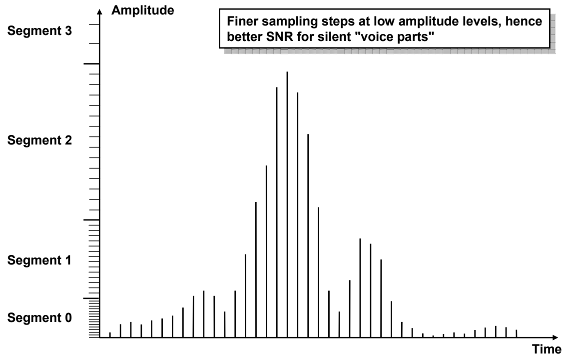


Improving SNR (Signal Noise Ratio)

- **to improve the SNR of speech signals**
  - lower amplitudes receive a finer resolution than greater amplitudes
- **a nonlinear function (logarithmic) is used for quantization**
  - USA: µ-law (Bell)
  - Europe: A-law (ITU)

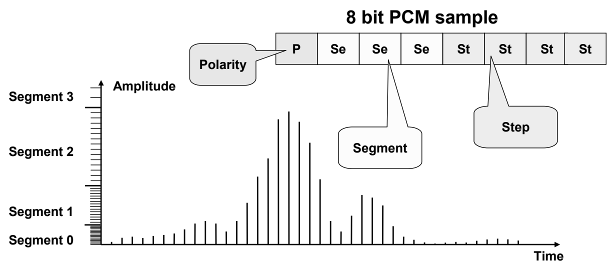


Log. Quantization



Encoding (PCM)

- **Putting digital values in a defined form for transmission**



Voice Compression

- **Waveform Coders**
  - Non-linear approximation of analog waveform
  - PCM (no compression), ADPCM
- **Vocoders**
  - speech is analyzed and compared to a codebook
  - only codebook values are transmitted and speed synthesizer at the receiver
- **Hybrid coders**
  - Combination of waveform coders and vocoders
  - 4.8 kbps to 16 kbps
  - Used for mobile phones
  - CELP, GSM

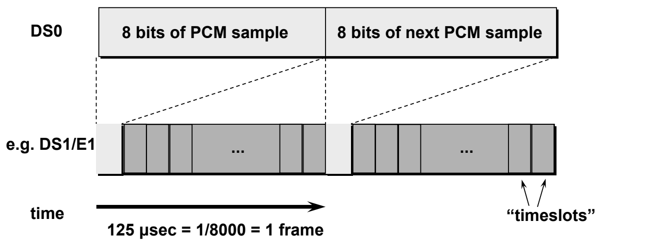
Standardized Codec's

- PCM
  - G.711 (64 kbps)
- Adaptive Differential Pulse Code Modulation (ADPCM)
  - only the difference from one sample pulse to the next will be transmitted
  - fewer bits used for encoding the difference value
  - G.726 (16, 24, 32, 40 kbps)
- Low Delay Code Excited Linear Predictor (LD-CELP)
  - G.728 (16 kbps)
- Conjugate Structure Algebraic Code Excited Linear Predictor (CS-ACELP)
  - G.729 (8 kbps)
- Dual Rate Speech Coding Standard G.723
  - is the basic standard for voice transmission in IP networks
  - basis is the CELP-Technique of GSM
  - uses minimal data rate of 5,3K at fair quality or 6,3K with good quality

Digital voice channel

- **DS0 = Digital Signal, Level 0**
  - 1 timeslot in multiplexing frames
- **Base for hierarchical digital communication systems**
- **Equals one PCM coded voice channel**
  - 64 kbit/s
- **Each samples (byte) must arrive within 125 μs**
  - To receive 8000 samples (bytes) per second
  - Higher order frames must ensure the same byte-rate per user(!)

Multiplexing Basics



- **frame rate is always 8000 frame per second at all levels of the hierarchy**
- **byte interleaved multiplexing**

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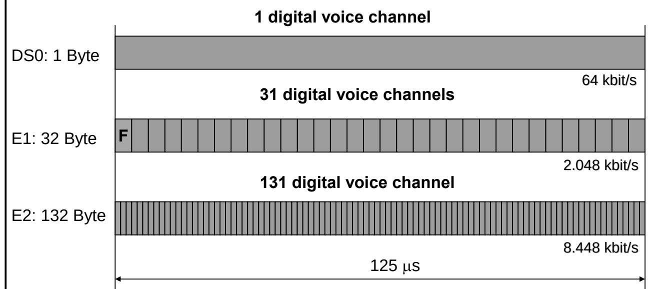
Multiplexing Basics



- note: DS0 and higher rates can be used for any transport digital information -> data transmission

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Multiplexing Hierarchies

- **why hierarchy and standardization?**
  - only a hierarchical digital multiplexing infrastructure which is standardized
    - can connect millions of (low speed) customers across the city/country/world
- **two main architectures**
  - PDH - plesiochronous digital hierarchy
    - plesio means nearly synchronous, clock differences are compensated by bit stuffing techniques / overhead bits
    - PDH is still used for low-speed lines
  - SDH - synchronous digital hierarchy
    - overcomes deficits of PDH
    - in North America SONET is used
    - telecommunication backbones move very quickly to SONET/SDH

PDH Hierarchy

North America / ANSI

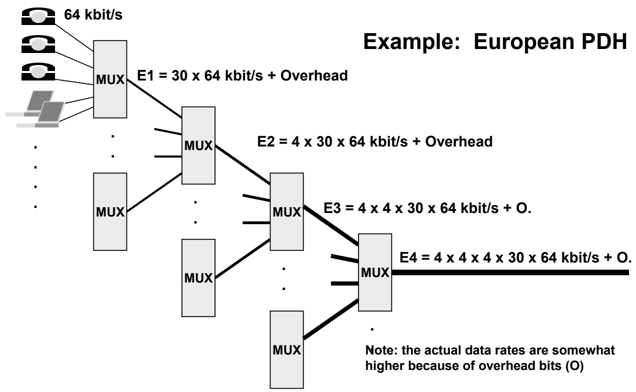
Signal	Carrier	Channels	Mbit/s
DS0		1	0.064
DS1	T1	24	1.544
DS1C	T1C	48	3.152
DS2	T2	96	6.312
DS3	T3	672	44.736
DS4	T4	4032	274.176

Europe / ITU

Signal	Carrier	Channels	Mbit/s
DS0	"E0"	1	0.064
CEPT-1	E1	32	2.048
CEPT-2	E2	128	8.448
CEPT-3	E3	512	34.368
CEPT-4	E4	2048	139.264
CEPT-5	E5	8192	565.148

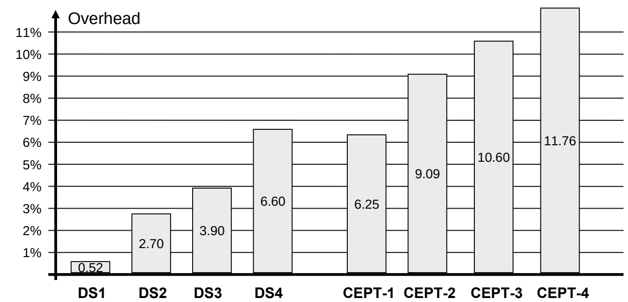
- **Incompatible MUX rates**
- **Different signalling schemes**
- **Different overhead**
- **μ-law versus A-law**

Digital Hierarchy of Multiplexers

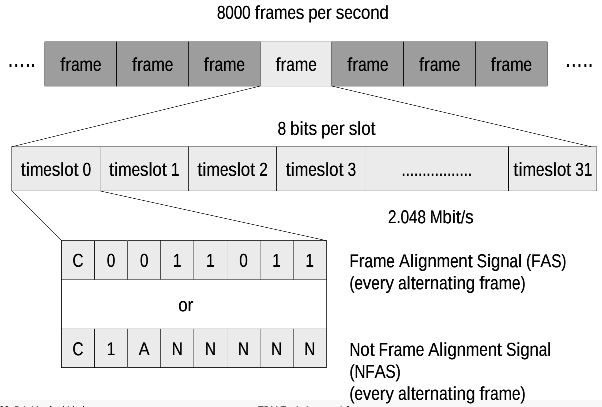


PDH Limitations

- **PDH overhead increases dramatically with high bit rates**



E1 Frame Structure



E1 Frame Structure

- **every second frame**
  - timeslot 0 contains FAS used for frame synchronization
- **C (CRC) bit**
  - is part of an optional 4-bit CRC sequence
  - provides frame checking and multiframe synchronization
- **A (Alarm Indication) bit**
  - so called Yellow (remote) alarm
  - used to signal loss of signal (LOS) or out of frame (OOF) condition to the far end
- **N (National) bits**
  - reserved for future use

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CRC Multiframe Structure Timeslot 0

	timeslot 0		timeslot 1 .... timeslot 31
frame 0	C1	FAS	semimultiframe 1
frame 1	0	NFAS	
frame 2	C2	FAS	
frame 3	0	NFAS	
frame 4	C3	FAS	
frame 5	1	NFAS	
frame 6	C4	FAS	
frame 7	0	NFAS	
frame 8	C1	FAS	semimultiframe 2
frame 9	1	NFAS	
frame 10	C2	FAS	
frame 11	1	NFAS	
frame 12	C3	FAS	
frame 13	Si	NFAS	
frame 14	C4	FAS	
frame 15	Si	NFAS	

CRC Multiframe Sync - bits: 0 0 1 0 1 1

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Reasons for SONET/SDH Development

- **Incompatible PDH standards !!!**
- **PDH does not scale to very high bit rates**
  - Increasing overhead
  - Various multiplexing procedures
  - Switching of channels requires demultiplexing first
- **Demand for a true synchronous network**
  - No pulse stuffing between higher MUX levels
  - Phase shifts are compensated by floating payload and pointer technique
- **Demand for add-drop MUXes and ring topologies**

SDH History

- After divestiture of AT&T
  - Many companies -> many proprietary solutions for PDH successor technology
- In 1984 ECSA (Exchange Carriers Standards Association) started on SONET
  - Goal: one common standard
  - Tuned to carry US PDH payloads
- In 1986 CCITT became interested in SONET
  - Created SDH as a superset
  - Tuned to carry European PDH payloads including E4 (140 Mbit/s)
- SDH is a world standard
  - SONET is subset of SDH
- Originally designed for fiber optics

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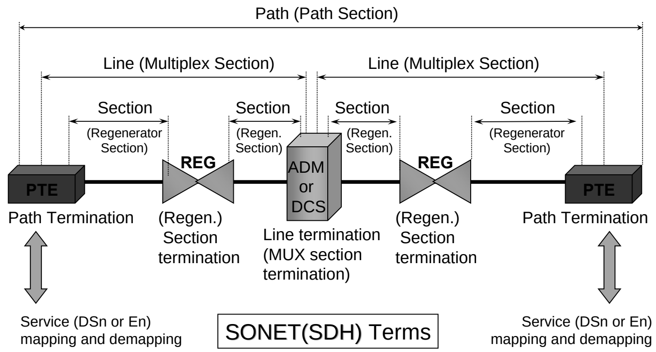
Network Structure



SONET/SDH Line Rates

SONET Optical Levels	SONET Electrical Level	Line Rates Mbit/s	SDH Levels
OC-1	**STS-1**	**51.84**	**STM-0**
OC-3	**STS-3**	**155.52**	**STM-1**
OC-9	**STS-9**	**466.56**	**STM-3**
OC-12	**STS-12**	**622.08**	**STM-4**
OC-18	**STS-18**	**933.12**	**STM-6**
OC-24	**STS-24**	**1244.16**	**STM-8**
OC-36	**STS-36**	**1866.24**	**STM-12**
OC-48	**STS-48**	**2488.32**	**STM-16**
OC-96	**STS-96**	**4976.64**	**STM-32**
OC-192	**STS-192**	**9953.28**	**STM-64**
OC-768	**STS-768**	**39813.12**	**STM-256**

Defined but later removed, and only the multiples by four were left!

(Coming soon)