PHYSICAL LAYER TIMING

Physical Layer Timing

- Timing in TDM Networks
- Synchronous Multiplexing (TDM)
- Transferring Timing (Timing Distribution)
- Stratum Levels
- Slips
- Asynchronous Multiplexing (TDM)

Timing in TDM Networks

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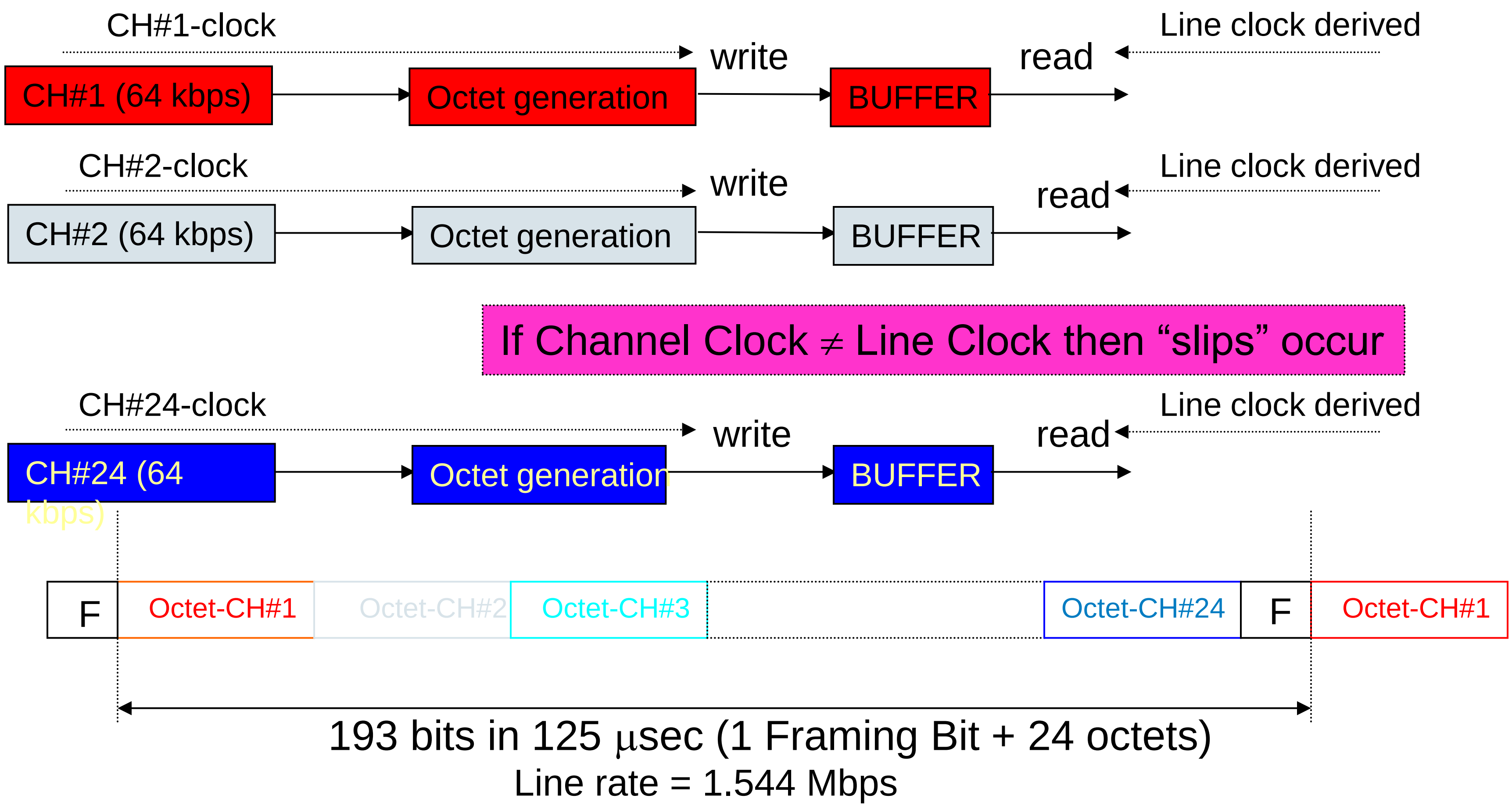
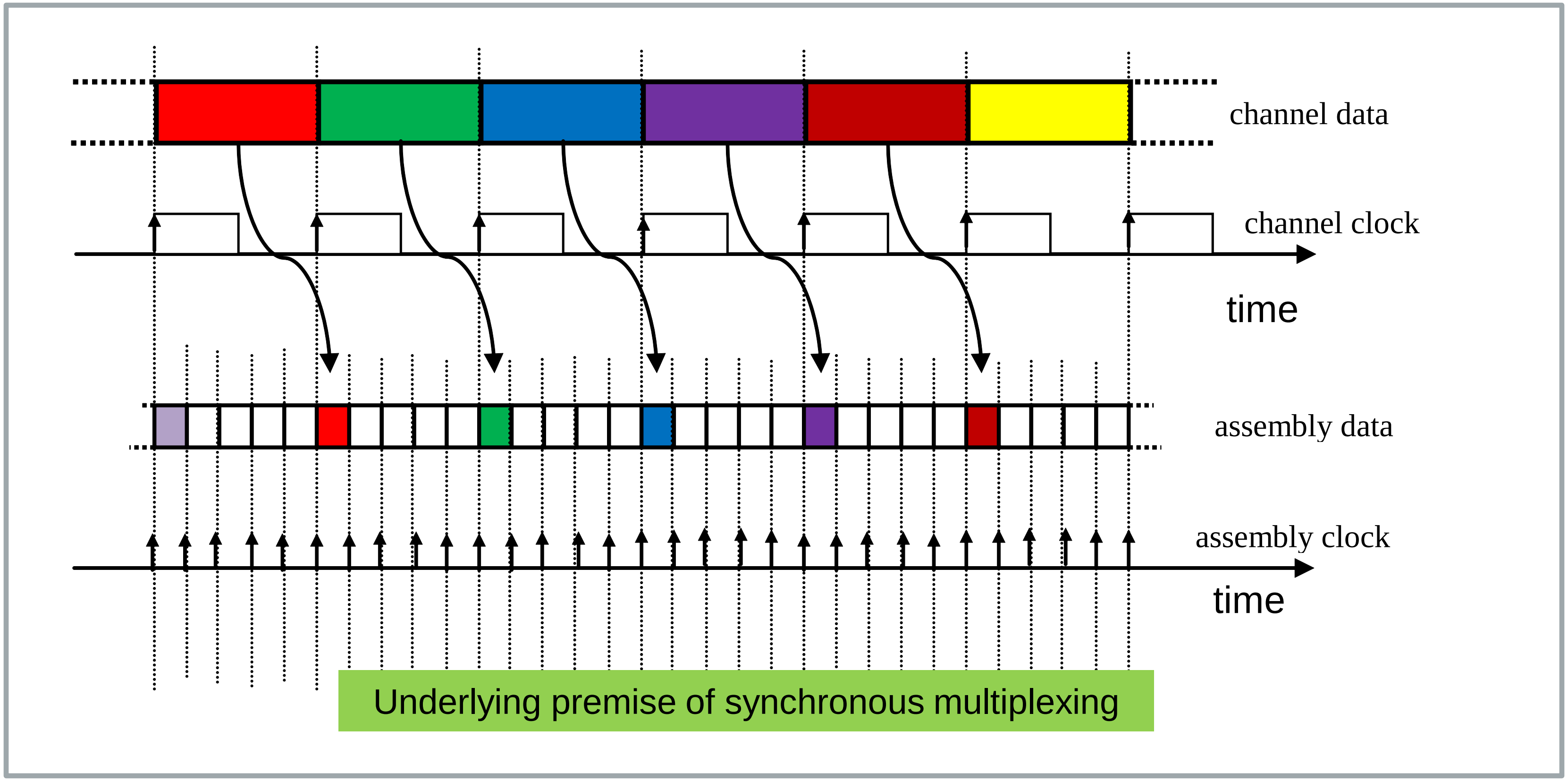
- Synchronization is essential for synchronous multiplexing
  - To avoid information loss
- Synchronous multiplexing assemblies are used as carriers of timing information (DS1/E1, SONET/SDH)
  - The recovered clock is used as a reference for the BITS
  - The transmit signals must meet the “sync” mask for timing information
- Asynchronous multiplexing can preserve timing (up to a point) *if done correctly*
- Bearer signals (DS1/E1) in asynchronously multiplexed assemblies (e.g. DS1 in DS3) can be used as carriers of timing
  - Asynchronous multiplexing is done correctly
- DS1/E1 bearer signals in SONET/SDH are <u>not</u> suitable as carriers of (good) timing
  - SONET/SDH encapsulation of DS1/E1 was done in a way that protects data but not (good) timing information

Synchronous Multiplexing (DS1)



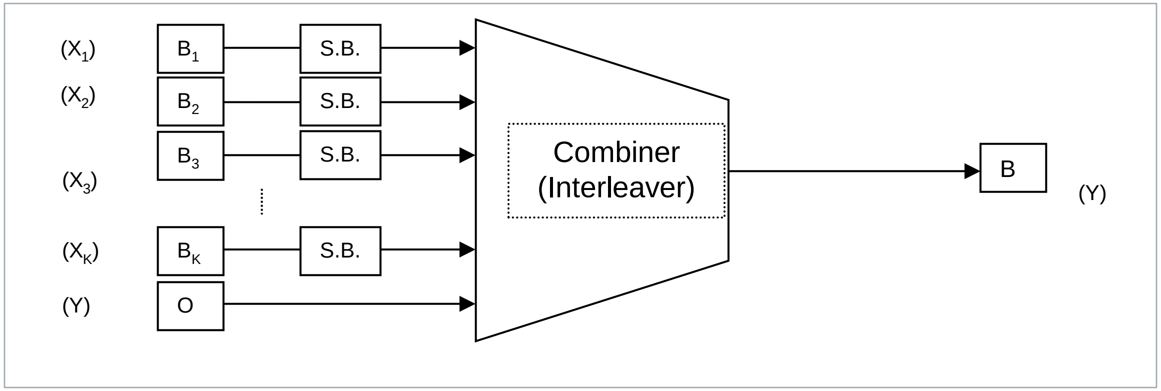
Switching machines such as DACS have multiple DS1s (input). Office clock (BITS) used to generate outputs.

Synchronous Multiplexing



- Predetermined (rigid) ratio between channel clock and assembly clock
- 1-to-1 correspondence between channel bits and allowed bit positions
- *Fractional frequency difference between channel and assembly clocks = 0*

Synchronous Multiplexing – Rate Adaptation



- Composite (assembly) (Y) comprised of individual channels (X_i) plus framing overhead
- Nominal bit rates: $B = B_1 + B_2 + \ldots + B_K + O$
- *Frequency alignment achieved with a "slip buffer" (SB)*
- Fractional frequency difference between channel and assembly results in data errors (slips)
  - DS1: B_i = 64 kbit/s; O = 8 kbit/s; B = 1544 kbit/sec; K = 24
  - E1: B_i = 64 kbit/s; O = 64 kbit/s; B = 2048 kbit/sec; K = 31
  - Offset of Δf ppm results in (125/ Δf) slips per second
  - 64 kbit/s channels can be combined to get Nx64 kbit/s channels

Transferring Timing (Physical Layer)

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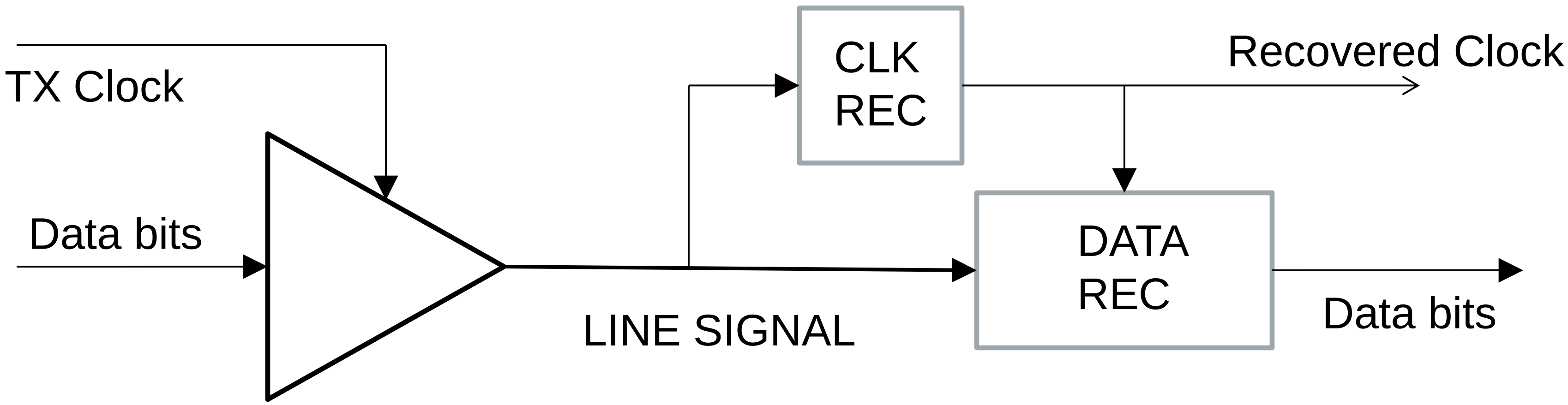
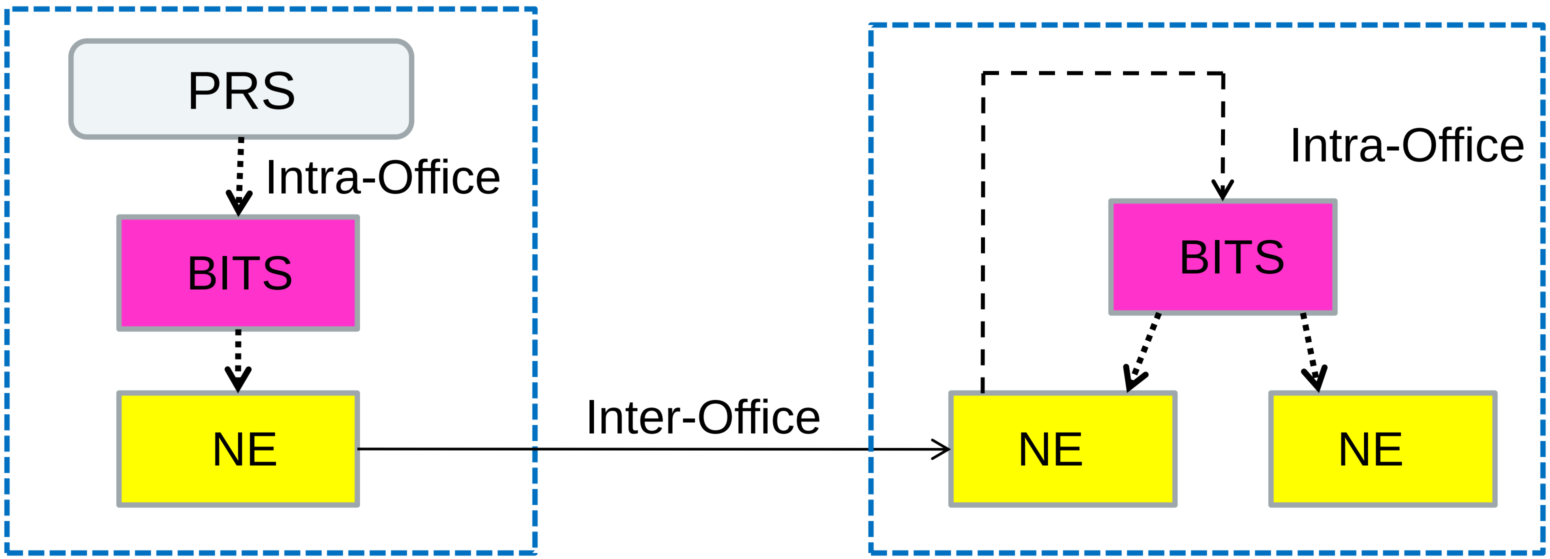


- Synchronous digital transmission “embeds” the transmit clock (timing information)
- Recovered Clock is “noisy” version of TX Clock
  - Transfers frequency information from source to destination
- This method applies to SONET/SDH as well as Synchronous Ethernet

Distribution of timing (frequency)



- PRS: *Primary Reference Source* – provides stratum-1 quality output signal
  - Cesium Atomic Reference or GPS-receiver with high-quality oscillator (Rb or OCXO)
  - *aka* PRC or *Primary Reference Clock* (ITU-T terminology)
- BITS: Building Integrated Timing Supply (also TSG – Timing Sig. Gen.)
  - Provides clock reference to the different NEs in the CO
  - Accepts a reference input and performs clock-noise filtering (removes jitter/wander)
  - Provides HOLDOVER in case of reference failure
- NE: Network Element (e.g. SONET) – uses BITS timing for its outputs
  - Recovers clock from incoming signal and provides a reference for the BITS

Stratum Levels – Telecom

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- Represents the intrinsic accuracy of a clock
  - Stratum-1: $1x10^{-11}$ (one part in 10^{11})
  - Stratum-2: $1.6x10^{-8}$ (16 parts per billion, ppb)
  - Stratum-3: $4.6x10^{-6}$ (4.6 parts per million, ppm)
  - Stratum-4: $32x10^{-6}$ (32 parts per million, ppm)
- Implication:

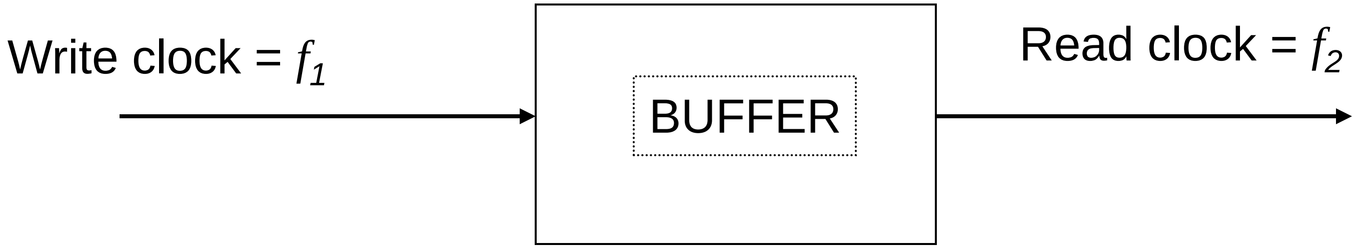
  output frequency is always accurate to *xxx* even if the reference fails and the clock goes into an autonomous mode of operation
- Normal operation:

  output frequency as accurate is as the reference frequency (locked condition) – maintain a hierarchy in any chain of clocks (why?)
- Time-constant achievable:

ST2	of the order of 10^5 sec	(bandwidth ~μHz)
ST3E	of the order of 10^3 sec	(bandwidth ~mHz)
ST3	of the order of 10 sec	(bandwidth ~Hz)
ST4	of the order of 1 sec	(bandwidth ~10Hz)

Order of magnitude!

Notion of a "slip" (clock domain boundary)



If $f_1 > f_2$ then we get overflows; if $f_1 < f_2$ then we get underflows

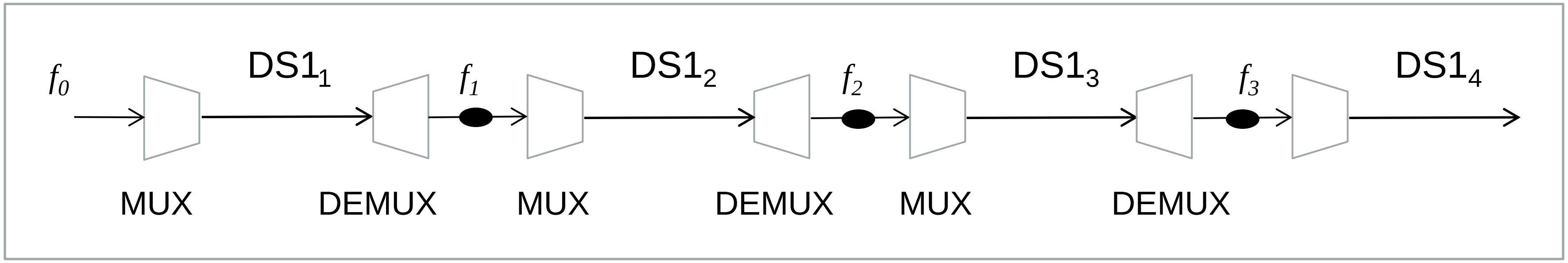
Slip rate determined by size of buffer and frequency difference

"Typical" buffer size = 125 μsec (1 frame in DS1/E1 – one octet in each DS0 is affected)

Δf	Slip rate	Stratum level
32×10^{-6} (32 ppm)	1 in 4 sec.	4
4.6×10^{-6} (4.6 ppm)	1 in 27 sec.	3 (3E)
1.6×10^{-8} (16 ppb)	1 in 8000 sec.	2
1×10^{-11} ("0")	1 in 12.5×10^{6} sec.	1

Controlled slips are bad – uncontrolled slips are catastrophic

Slips can accumulate



- Each cross-connection/switching node introduces a demultiplex-multiplex operation with slip-buffer
- Each Central Office is a (potential) clock boundary
- Slips occur if $f_i \neq f_{(i+1)}$
  - end-points could be OK, but slips could occur in the middle!
- ITU-T Rec. G.822 : less than 5 slips in a 24hr period
  - in an end-to-end 64 kbit/s hypothetical reference connection
  - If only one slip buffer then Δf < ~5ppb
  - Basis for requiring G.811 (PRC) traceability [$\Delta f < \sim 2 \times 10^{-11}$]
- Impact of slips more severe for voice-band data (modems) than human-human speech

Impact of a slip

- Voice call
  - Snap crackle pop; maybe nothing (during silence interval)
- Facsimile/Modem
  - Bunch of bit errors; faulty lines (fax); could drop the call
- Encrypted data
  - Ouch!!!!
- Video
  - Noticeable error in audio and video
- Packet data transfer
  - Errored packets (discarded) — particularly nasty if the packets are large
- General rules:
  - *Human ears are tolerant, machines are not*
  - *More compression implies greater (more dire) consequences*

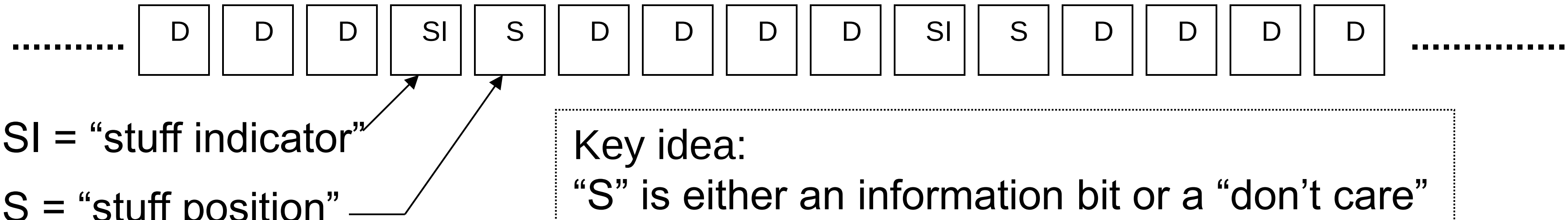
Multiplexing with Rate Adaption (bit-stuffing)

Intent: Multiplex *N* tributaries, each with nominal bit-rate f_L into a single stream with nominal bit-rate $f_H = N \cdot f_L + \Delta$.

Function of Δ (over-speed): provide over-head bits for the following -

- Framing bits : to identify which bit positions correspond to which tributary
- Other overhead for management purposes
- Stuffing positions and stuffing indicators for each tributary

Bit positions in high-speed stream for tributary #k (nominal rate = $f_{LH} > f_L$)



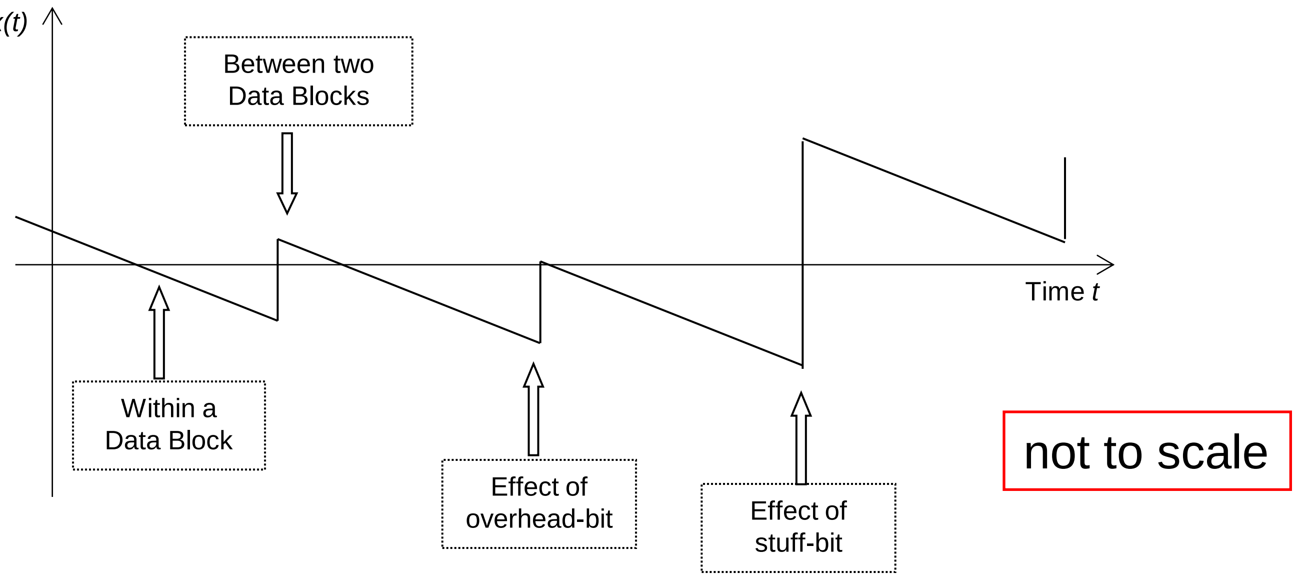
SI = “stuff indicator”

S = “stuff position”

Key idea:
“S” is either an information bit or a “don’t care”
“SI” indicates which choice was made

Effect of “robbing” 2 out of 6 bit-positions: $(5/6)f_{LH} \geq f_L \geq (4/6)f_{LH}$

Asynchronous Multiplexing



Time error signal associated with asynchronous multiplexing (bit-stuffing) at the desynchronizer

- "Gapped Clock" : non-uniform signal based on assembly clock associated with valid channel bits in the assembly. Non-uniform because of over-head bit positions and stuff bits.
- Equal to channel clock "<u>on the average</u>" (preserves long-term frequency)
- Goal: clock noise introduced by this non-uniformity is "high frequency" (i.e. <u>jitter</u>) and can be removed (filtered out) using a PLL (PDH bit-stuffing schemes are good)
- Channel clock noise = *assembly clock noise* + filtered version

SONET/SDH : SM & AM features

- STS-N created by interleaving N STS-1s; STM-N created by interleaving N STM-1s
  - STS-1s (STM-1s) must be synchronized (zero frequency offset between constituent channels and assembly)
  - Constituents channels of STS-1 are synchronous to STS1 (“containers”)
- Bearer channels encapsulated into “containers”.
  - e.g. VT1.5 is a container for a DS1 (1.544 Mbit/s signal)
  - The synchronizer function for DS1 → VT1.5 employs “positive-zero-negative stuffing”
- Synchronizer function differences
  - PDH uses “*positive stuffing*”. Clock noise introduced is high-frequency (jitter) and can be filtered out
  - SONET/SDH use “*positive-zero-negative*” stuffing that can introduce low-frequency (wander) components
  - DS1-bearer in PDH can be used as a synchronization reference; DS1-bearer in SONET is not used as a synchronization reference
- SONET/SDH synchronization reference carried in line clock