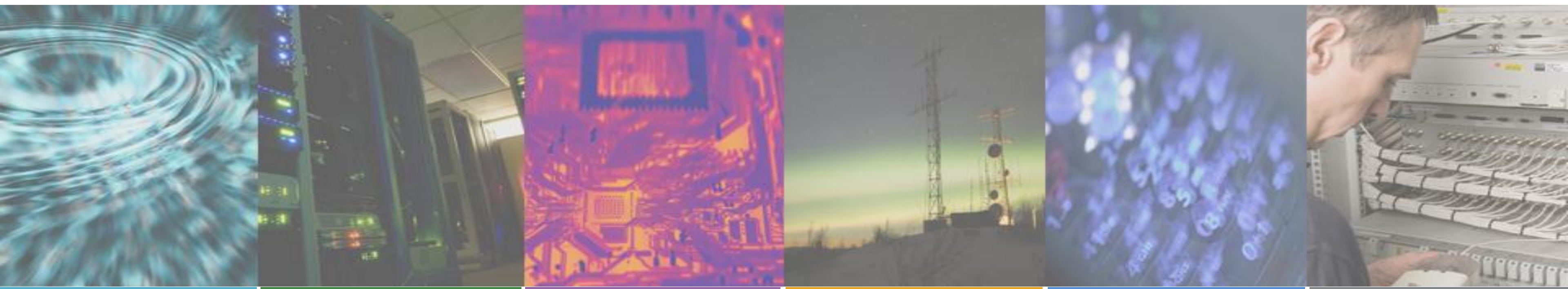
Tutorial: Network-based Frequency, Time & Phase Distribution



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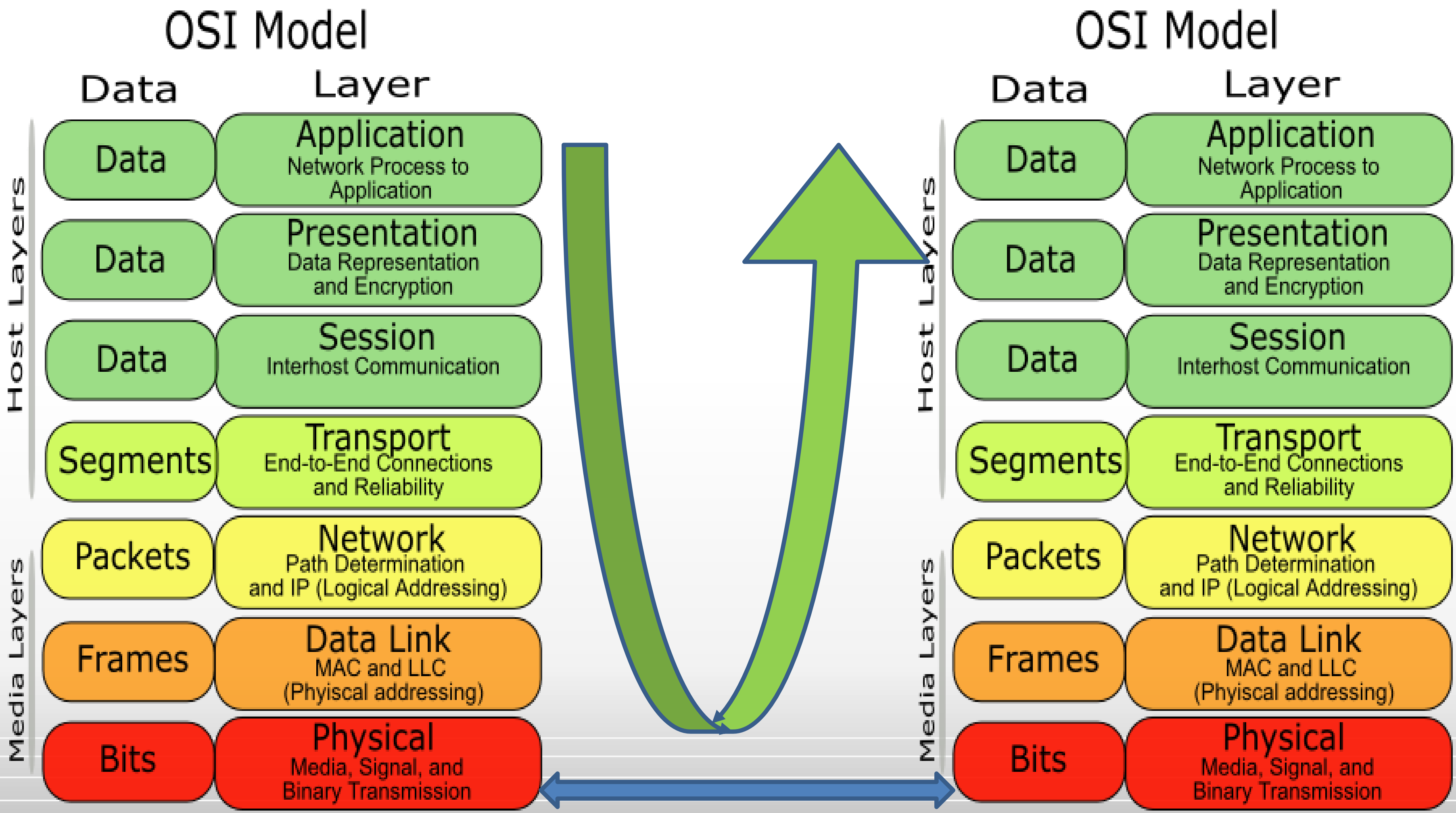
WSTS – San Jose

Presentation Contents

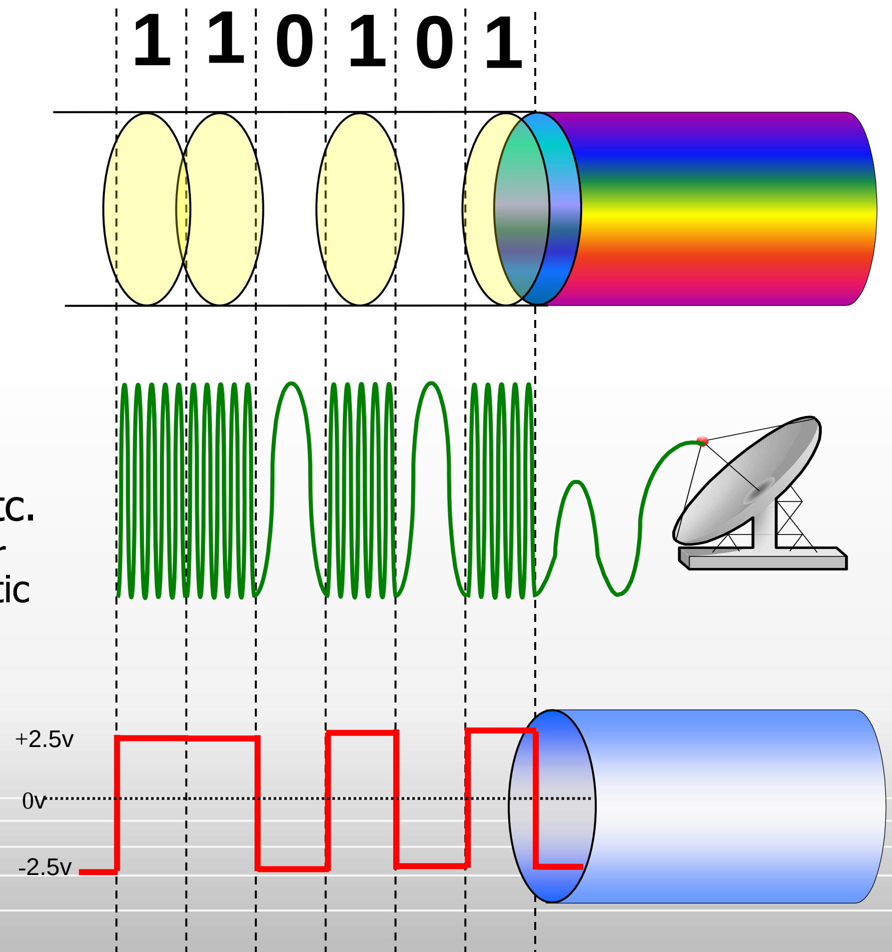
- Introduction
- Physical Layer Distribution
- Packet Layer Distribution
- Summary

The (in)famous stack model



How Are “Bits” Represented..?

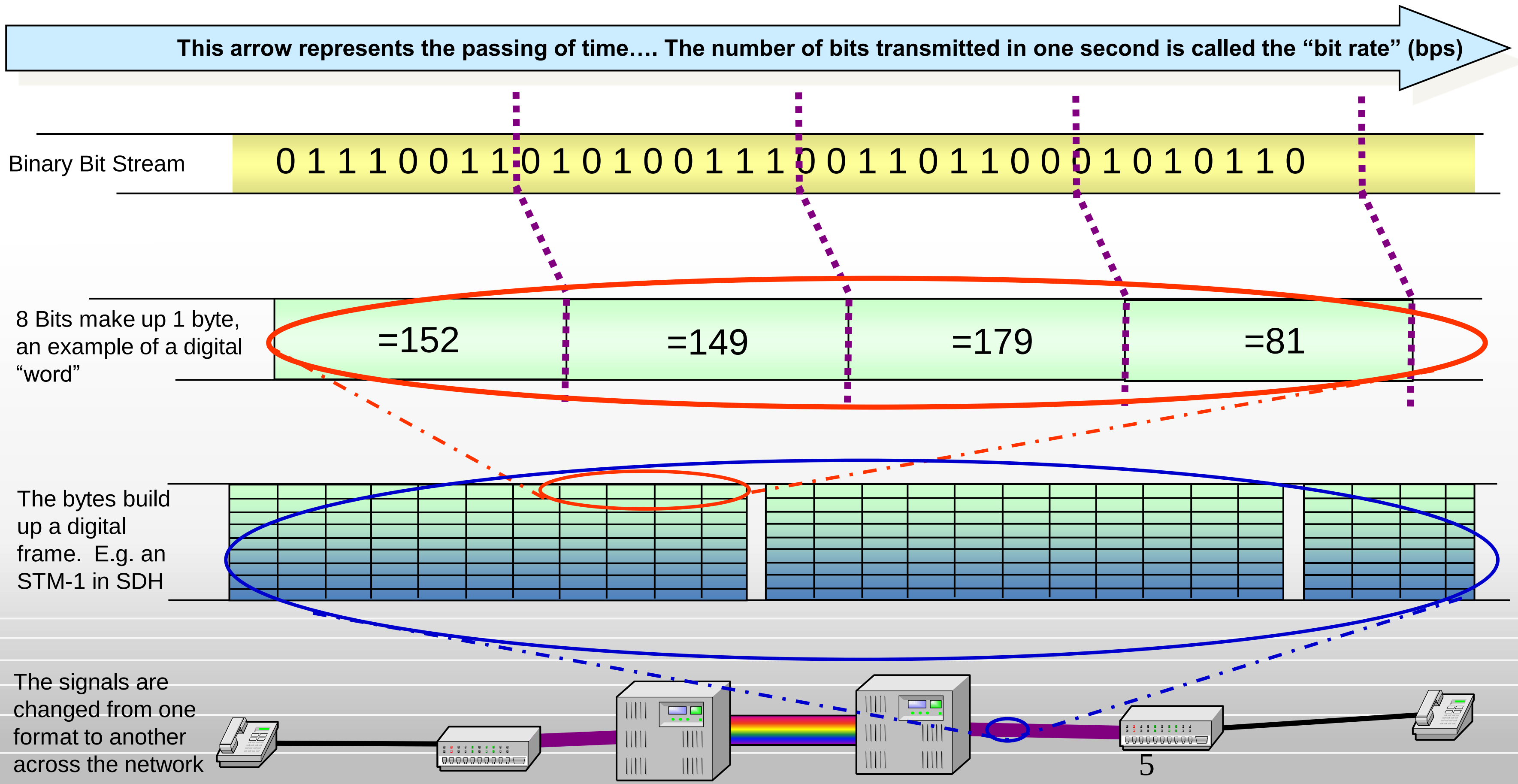
- The value of a Bit (0 or 1) can be represented by different modulations of a carrier signal examples are:
  - Fibre Optics
    - The presence or absence of a light pulse
    - Different frequencies of light
  - Radio/Microwaves - Mobile phone, satellite comms, WiFi, etc.
    - Changes in phase, frequency or amplitude of the electromagnetic waves
  - Electrical Cabling - Coaxial, twisted pair, etc
    - Voltage levels on the wire



The bits arrive at regular intervals, represented here

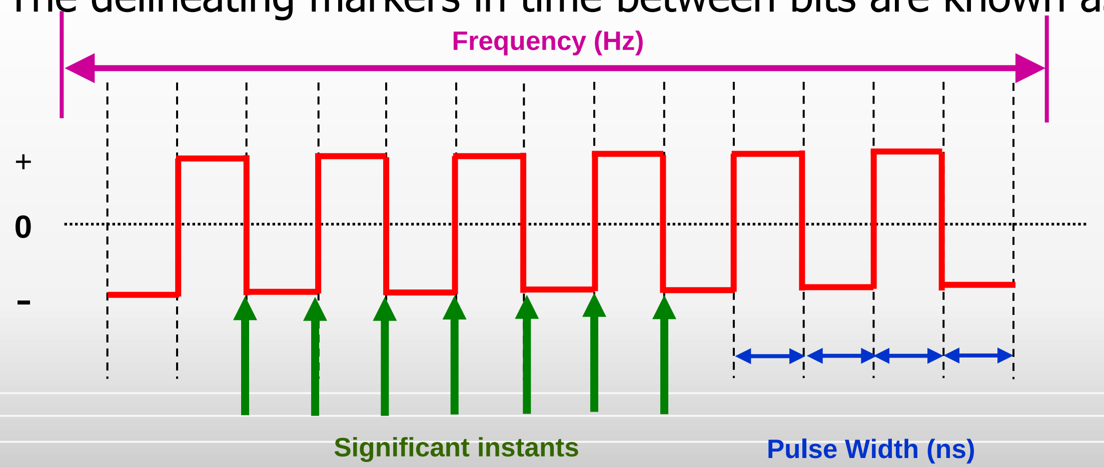
Bits and Bytes

- Digital signals are transmitted as a stream of single “Bits”. A Digital Bit is the underlying base of all digital communications, its value can either be a binary “0” or a “1”, the “0”s and “1”s are used to build digital “words” and ultimately make up all digital services.



Timing (Frequency) Signal Characteristics

- **Frequency** - *noun*. - the number of periods or regularly occurring events of any given kind in unit of time. **dictionary.com**
- The intervals between the bits is known as the "pulse width" and is directly related to the bitrate of the signal. These are usually measured in nanoseconds (ns).
- The faster the bitrate, the shorter the pulse width.
- The frequency of a signal refers to the number of "cycles" per second and is measured in Hertz for an analogue signal with no digital data mapped onto it or bits per second (bps) for a digital data signal.
- The delineating markers in time between bits are known as "<u>significant instants</u>"



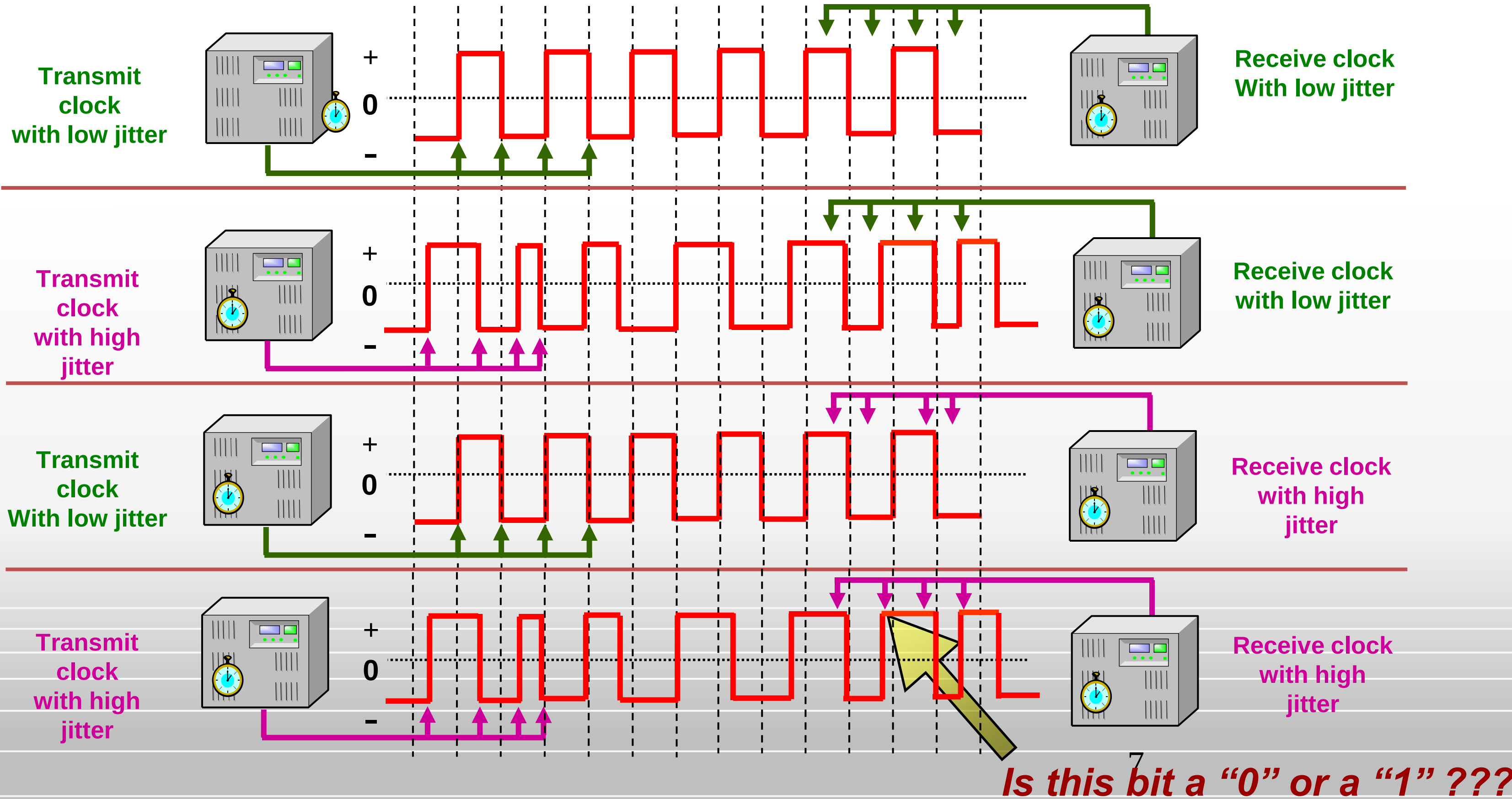
<u>Pulse Width = 1/Frequency</u>

For an E1 signal:

1 / 2.048 Mbp/s
= 1 / 2048000 bps
= 0.00000048828125 s
= 488.28 ns

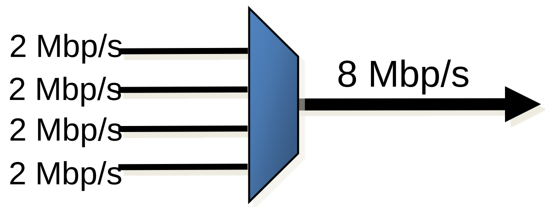
Bit Synchronisation

- The precise frequency and pulse width of a transmitted signal are determined by a clock on the network equipment, the "Write Clock"
- Receiving equipment has a "Read Clock" that determines the precise time that the received signal is sampled.
- The clocks of the two elements must be within set tolerances or the signal may be misread.

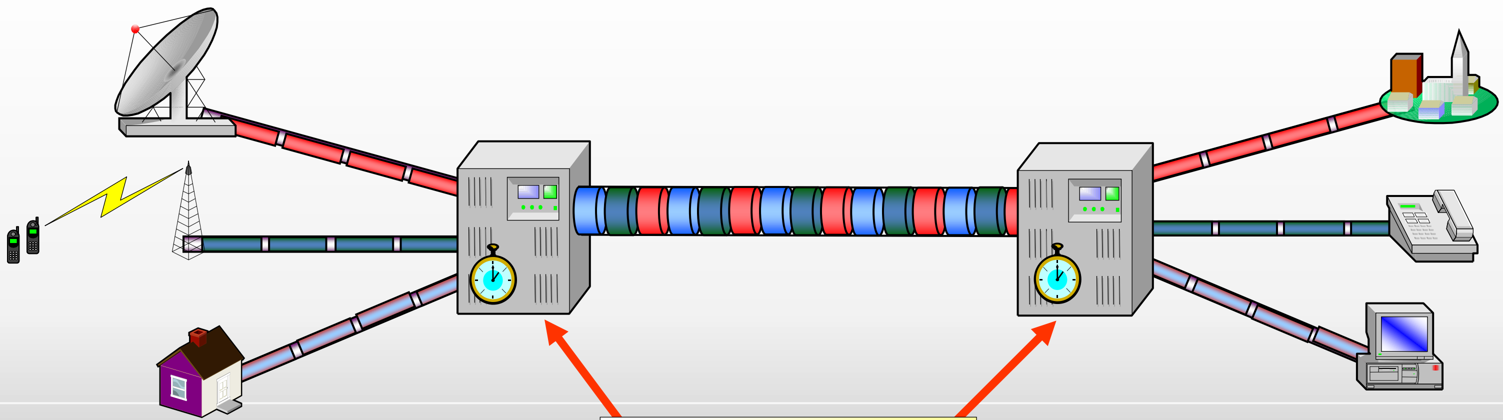


Time Division Multiplexing (TDM)

- Multiplexing is the method of combining two or more lower rate signals into a single higher rate signal for transport over a single transmission medium.



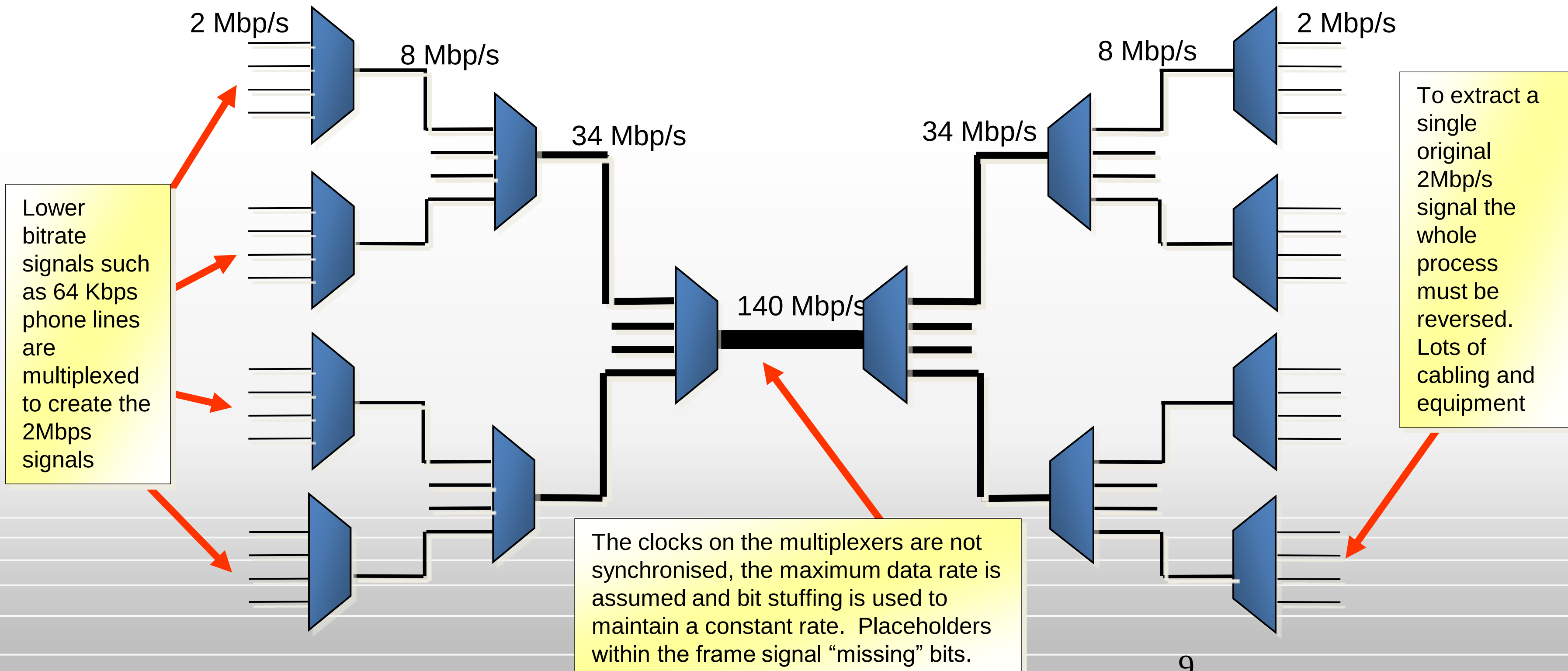
- Data is transmitted in chunks usually referred to as bytes, cells or frames.
- The frames each have a “timeslot” reserved in the higher rate signal.



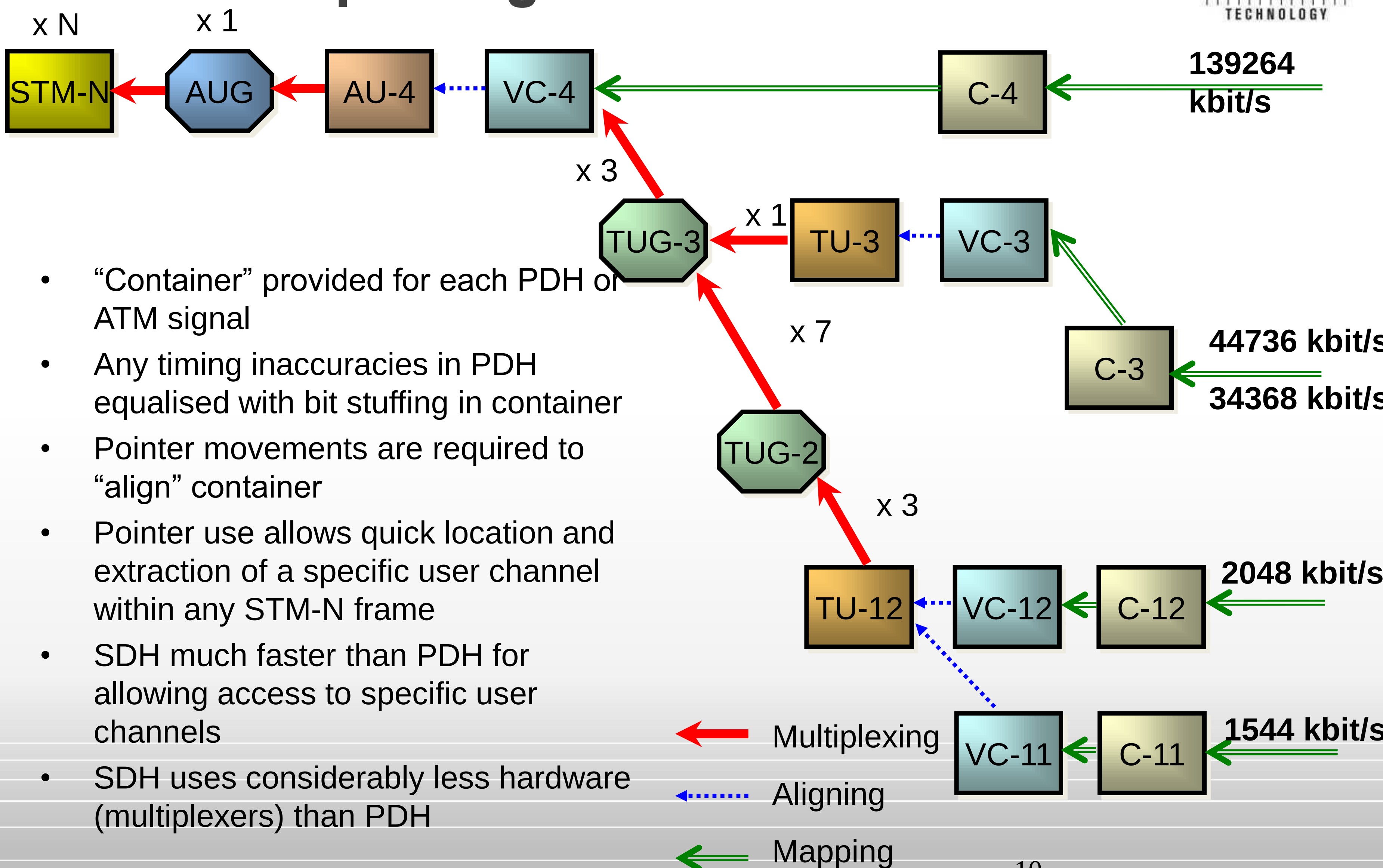
The clocks on the multiplexers / de-multiplexers must be synchronised to allow correct differentiation between frames and a smooth flow of data

PDH Multiplexing

- Plesiochronos Digital Hierarchy is a method of multiplexing signals into higher rates then de-multiplexing when required.
- Plesiochronos - "plesi" – near and "chronos" – time. The clocks on the equipment run at a nominal frequency within a set tolerance**, any frequency offsets are taken up by "bit stuffing",** the addition of extra bits to fill the transmission.



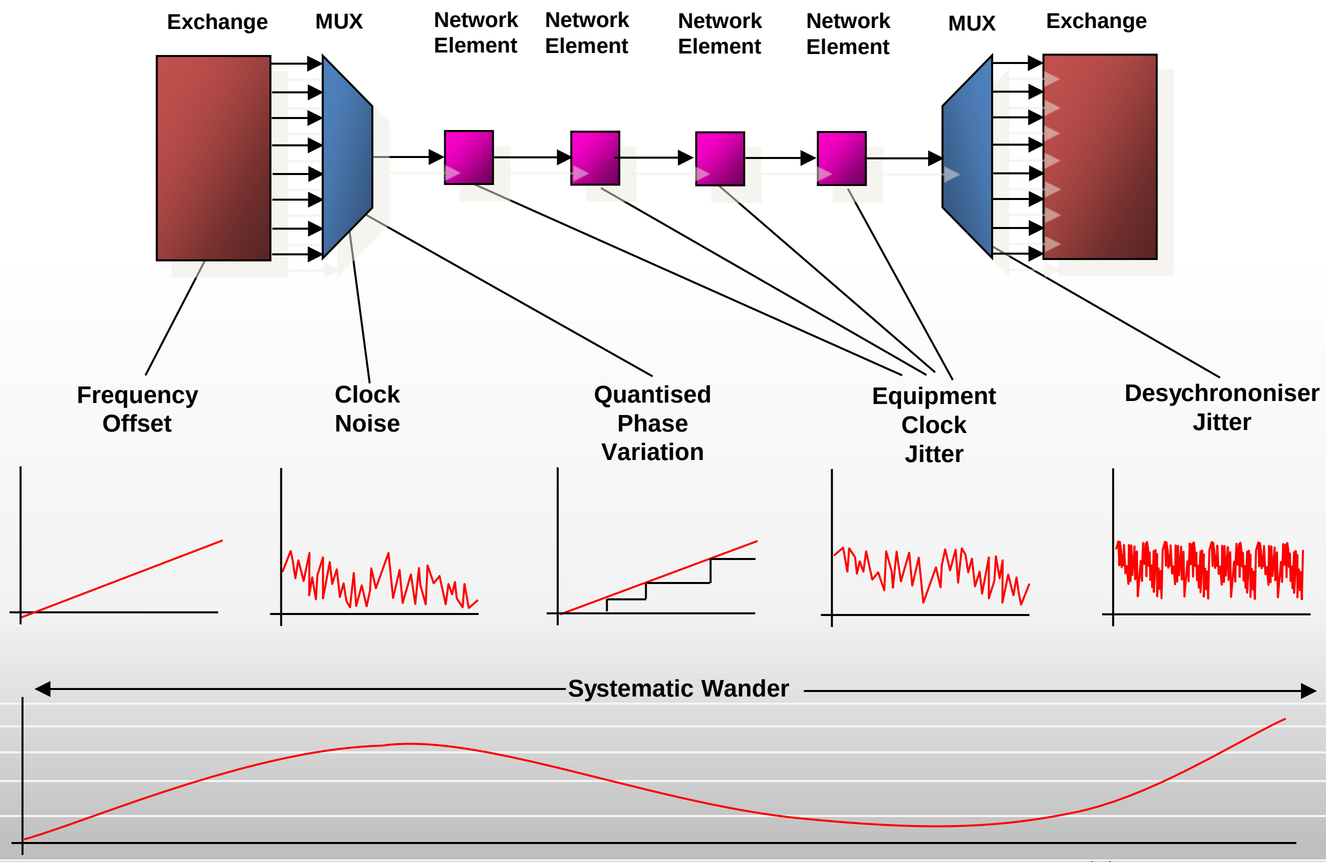
SDH Multiplexing



- “Container” provided for each PDH or ATM signal
- Any timing inaccuracies in PDH equalised with bit stuffing in container
- Pointer movements are required to “align” container
- Pointer use allows quick location and extraction of a specific user channel within any STM-N frame
- SDH much faster than PDH for allowing access to specific user channels
- SDH uses considerably less hardware (multiplexers) than PDH

Noise Accumulation

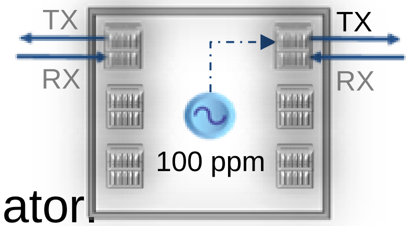
- As a synchronisation is passed through network elements, additional noise is accumulated along the sync trail.



SyncE Overview

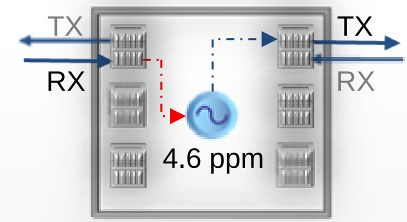
How is SyncE different from normal Ethernet?

Existing Ethernet PHY (Physical Layer)

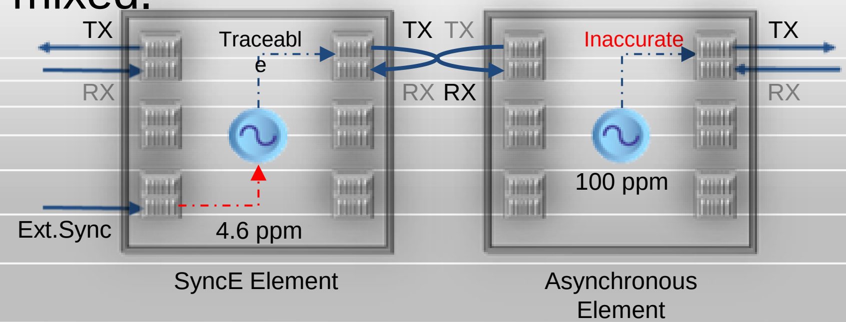


- IEEE 802.3 defines Ethernet PHY
- Rx uses incoming line timing. Tx uses free-running 100ppm oscillator.
- No relationship between the Rx & Tx.

SyncE PHY (Physical Layer)



- Rx disciplines the internal oscillator
- Tx uses the traceable clock reference, creating end-to-end scheme.
- PRC can provide the reference. SSUs filter jitter/wander.
- SyncE and asynchronous switches **cannot** be mixed.

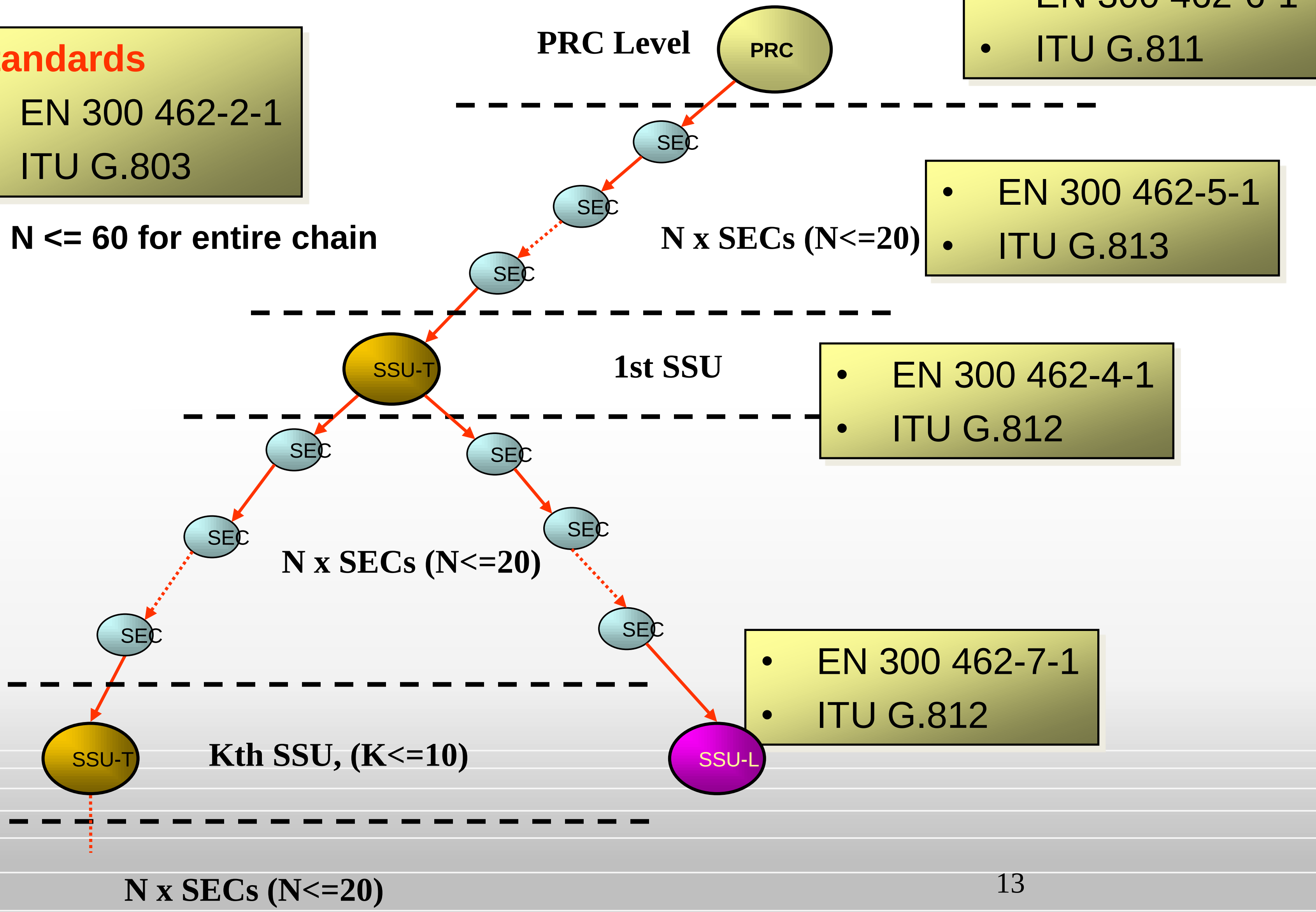


Sync Trail Architecture Rules

Standards

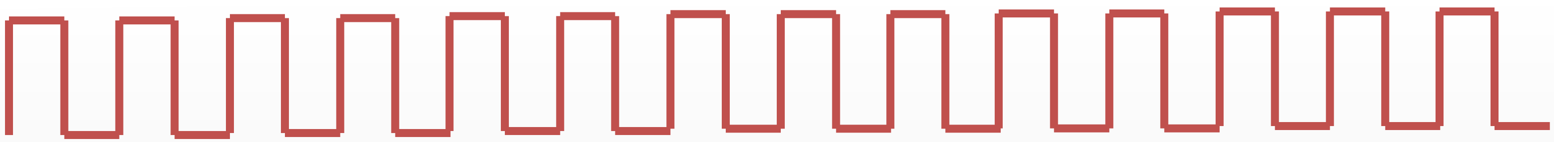
- EN 300 462-2-1
- ITU G.803

N <= 60 for entire chain



From clocks to packets

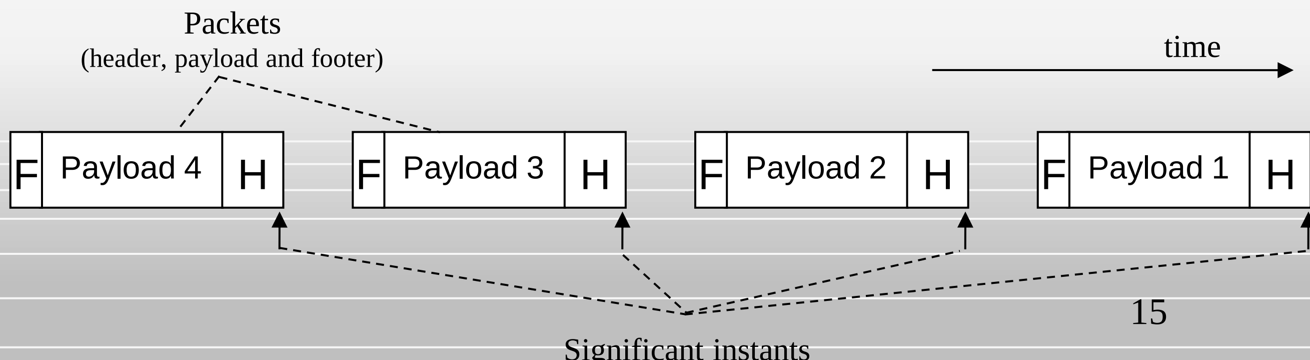
- It’s just transfer of information…
  - A detectable event signifies the passage of a certain amount of time:
    Clock Chimes… Ticks… Clock Edges…



- Analogue clock signals – known transmission media – known delays etc.
- By their very nature packet transmission systems have indeterminate & varying delays – not good for transfer of time information!

From clocks to packets

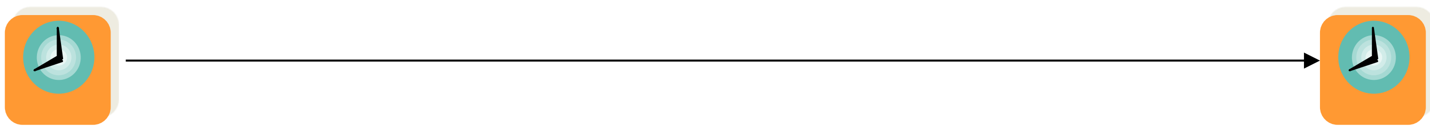
- Packet "clocks" are just the same…
- CES Packets do have a regular rhythm – E1 = 1mS
- NTP/PTP Packets may not arrive regularly, but timestamps within the packets themselves mean time information can be extracted
- Time and timing can be distributed from point A to point B



Clock and Time Transfer

- Physical layer, direct connection

nS



- Physical layer, Cascaded PLLs

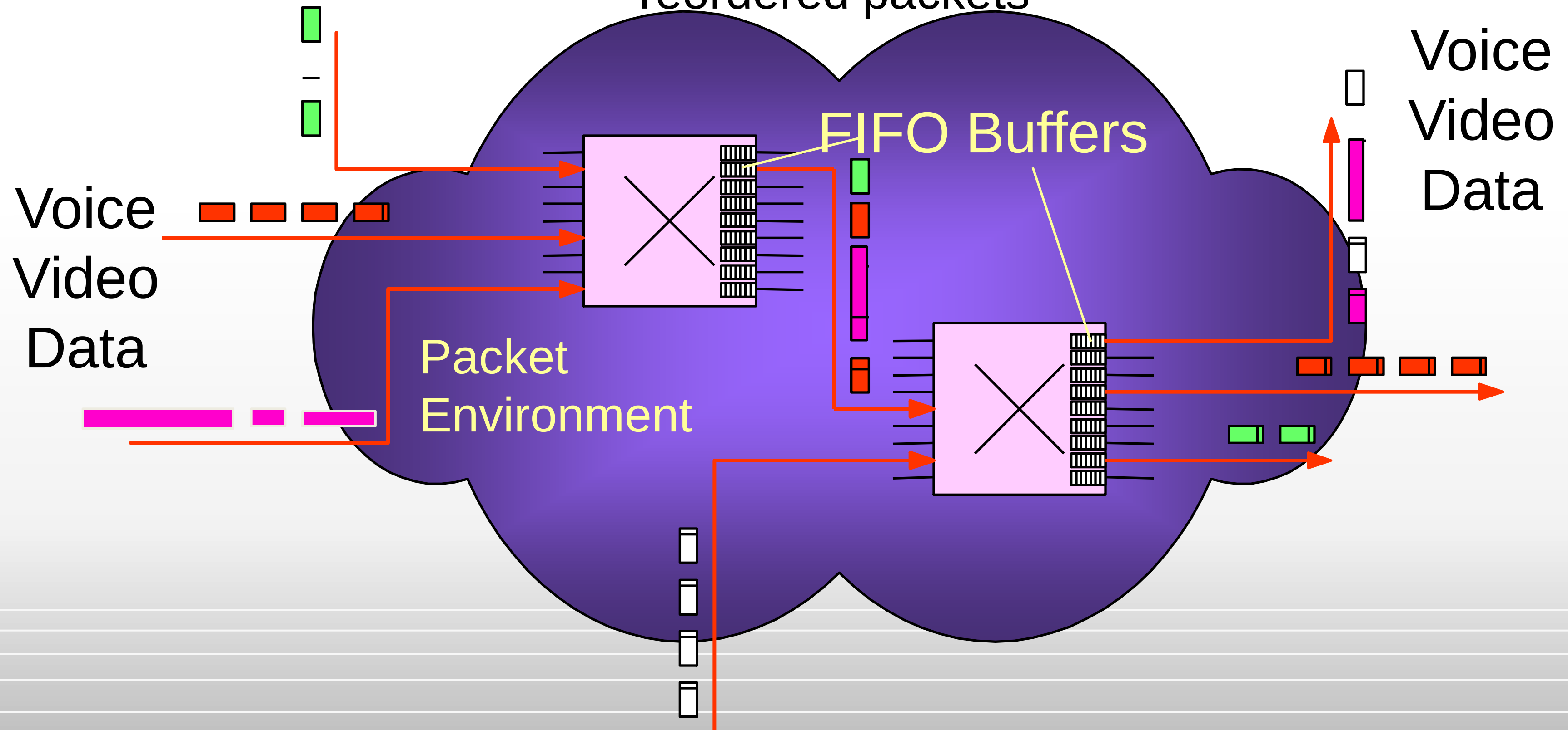
µS

- Packet layer, Cascaded “PLL”s

100µS

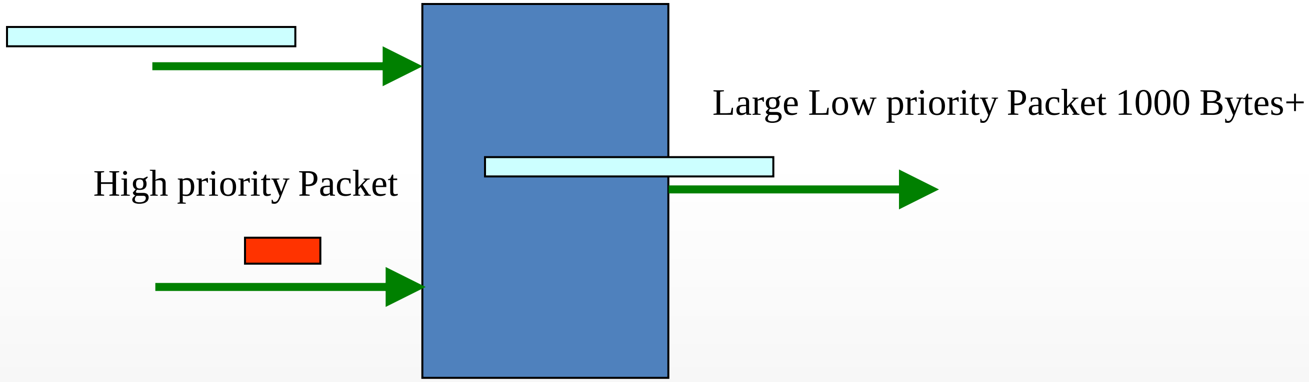
Packet Transport & Switching

Main reason for problems with sync transport across an packet environment is “Packet Delay Variation” and possible lost packets/ reordered packets



Packet Delay Variation

- Even with priority schemes packet delay variation can be significant

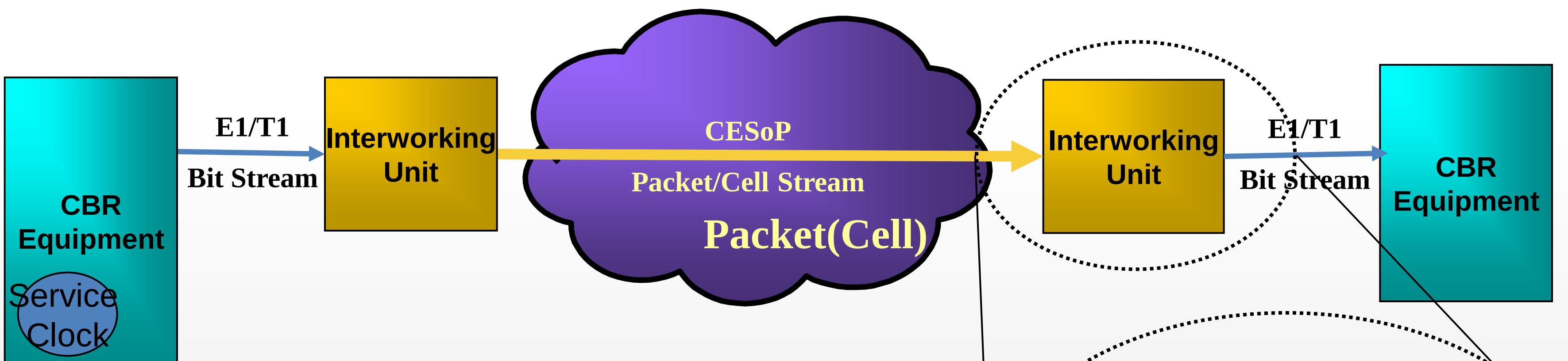


At 100 Mbit/s 1000 byte packet = $8 \times 1000 / 100 \times 10^6 = 80\mu s$

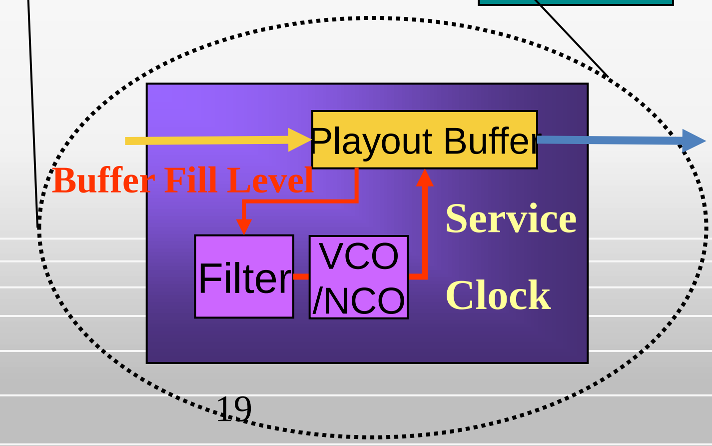
At 10 Mbit/s 1000 byte packet = $8 \times 1000 / 10 \times 10^6 = 0.8ms$

Adaptive Clock Operation

- A common network clock may not be available at Packet/(Cell) network boundary
- May not need clock purity provided by network-synchronous and Differential/SRTS methods



- Service clock adjusts based on buffer fill level/ packet arrival rate
- PDV influeneces wander at the network output



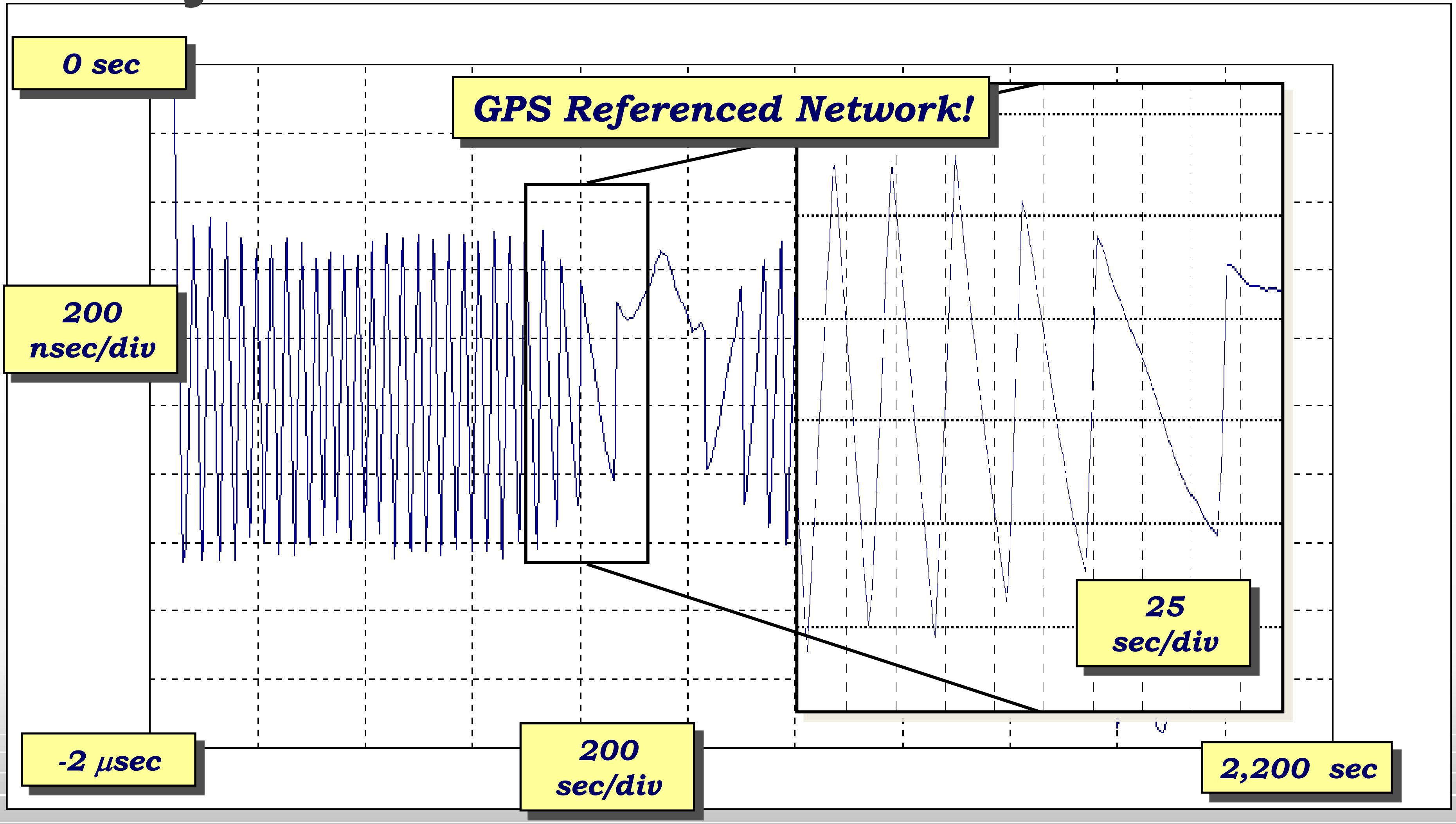
Adaptive Clock Methods

- Should track the transmit service clock whilst at the same time not tracking changes implied erroneously by the Delay Variation of the network
- Have a reasonable convergence time
- Respond quickly to phase or frequency transients in the transmit service clock
- Generate a clock signal which is stable in phase, follows the transmit service clock and meets the service specific jitter-wander limits
- Control the playout buffer fill so it doesn't deviate too much from its defined nominal fill level
- Different manufacturers have different interpretations and algorithms
  - Evaluate carefully before using for a particular application!

ACR – TDM over IP standards

TDM PW	IETF	ITU-T	MFA Forum	MEF
TDMoIP	RFC5087	Y.1413, Y.1453	IA 4.0, 4.1	MEF 8
CESoPSN	RFC5086	Y.1413, Y.1453	IA 8.0.0	MEF 8
SAToP	RFC4533	Y.1413, Y.1453	IA 8.0.0	MEF 8

Playout Buffer Wander



NTP Versions

Features and mechanisms of NTP described in RFCs

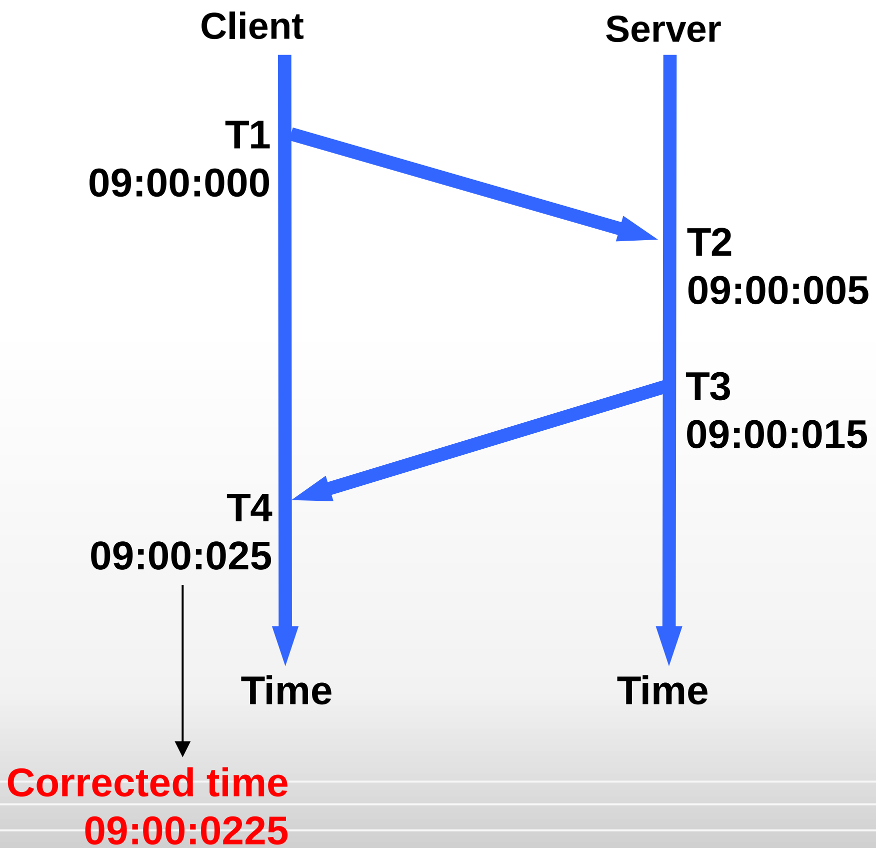
“Request For Comments”

the blueprints for the internet

1985	NTPv0	RFC 958
1988	NTPv1	RFC 1059
1989	NTPv2	RFC 1119
1992	NTPv3	RFC 1305
2010	NTPv4	RFC 5905/6/7/8 Security, IPV6, DHCP, MIB
1996	SNTPv4	RFC 2030

How NTP Works

- T1 Originate Timestamp
  - Time request sent by client
- T2 Receive Timestamp
  - Time request received by server
- T3 Transmit Timestamp
  - Time reply sent by server
- T4 Destination Timestamp
  - Time reply received by client
- Round Trip Delay=(T4-T1)-(T3-T2)
  - Round Trip Delay =25-10=15
- Clock Offset= [(T2-T1)-(T4-T3)]/2
  - Clock Offset =[5-10]/2= **-2.5**
    (Clients actual time when reply received was therefore **09:00:0225**)



- **Key Assumptions:**
  - One way delay is half Round Trip (symmetry!)
  - Drift of client and server clocks are small and close to same value
  - Time is traceable (worth distributing!)

NTP protocol header and timestamp formats

NTP Protocol Header Format (32 bits)

LI	VN	Mode	Strat	Poll	Prec
Root Delay					
Root Dispersion					
Reference Identifier					
Reference Timestamp (64)					
Originate Timestamp (64)					
Receive Timestamp (64)					
Transmit Timestamp (64)					
Extension Field 1 (optional)					
Extension Field 2… (optional)					
Key/Algorithm Identifier					
Message Hash (64 or 128)					

Cryptosum

Authenticator (Optional)

LI	leap warning indicator
VN	version number (4)
Strat	stratum (0-15)
Poll	poll interval (log2)
Prec	precision (log2)

NTP Timestamp Format (64 bits)

Seconds (32)	Fraction (32)

Value is in seconds and fraction since 0^h 1 January 1900

NTPv4 Extension Field

Field Length	Field Type
Extension Field (padded to 32-bit boundary)	

Last field padded to 64-bit boundary

NTP v3 and v4
NTP v4 only
authentication only

Authenticator uses DES-CBC or MD5 cryptosum of NTP header plus extension fields (NTPv4)

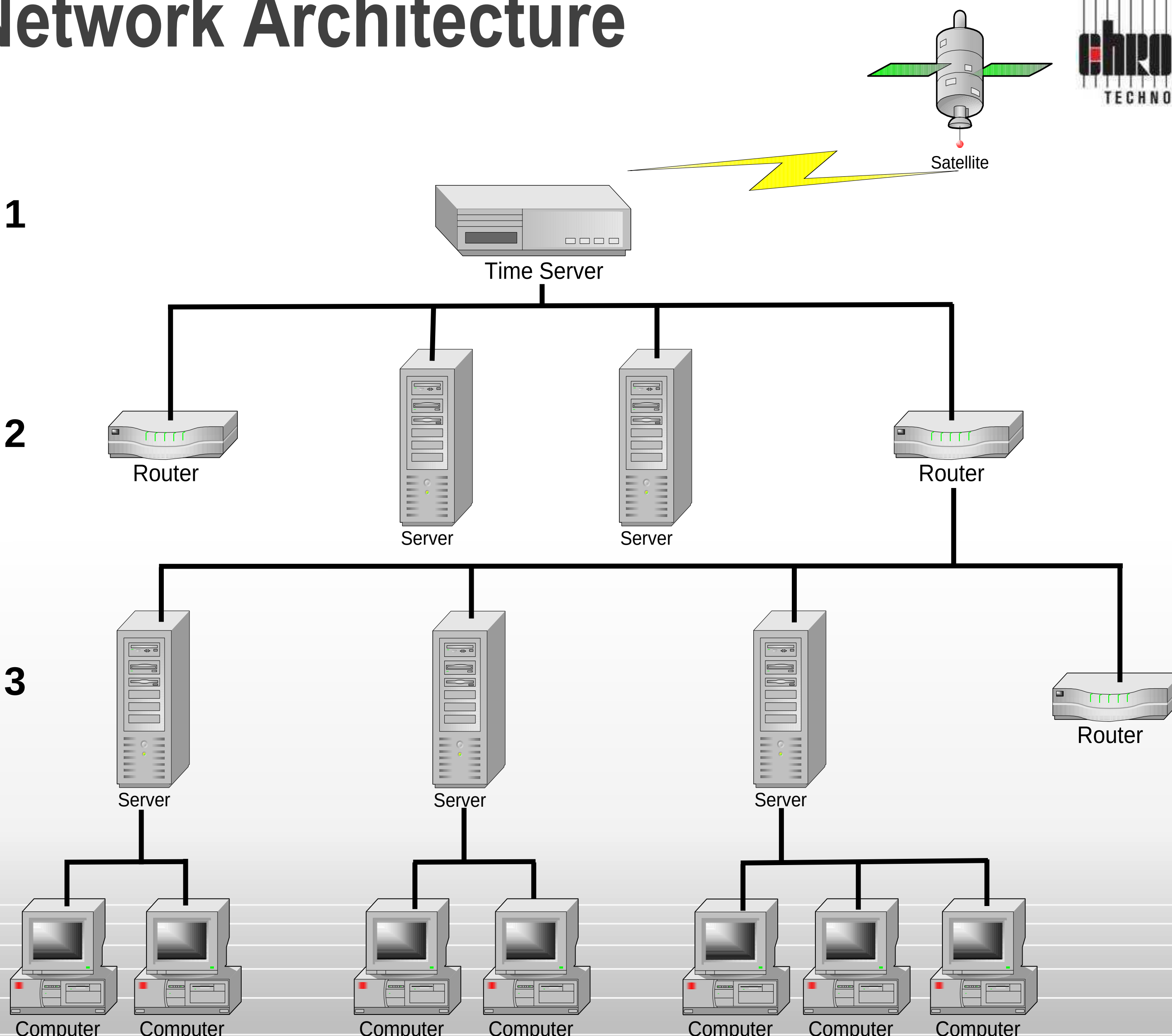
NTP Network Architecture

GPS

Stratum 1

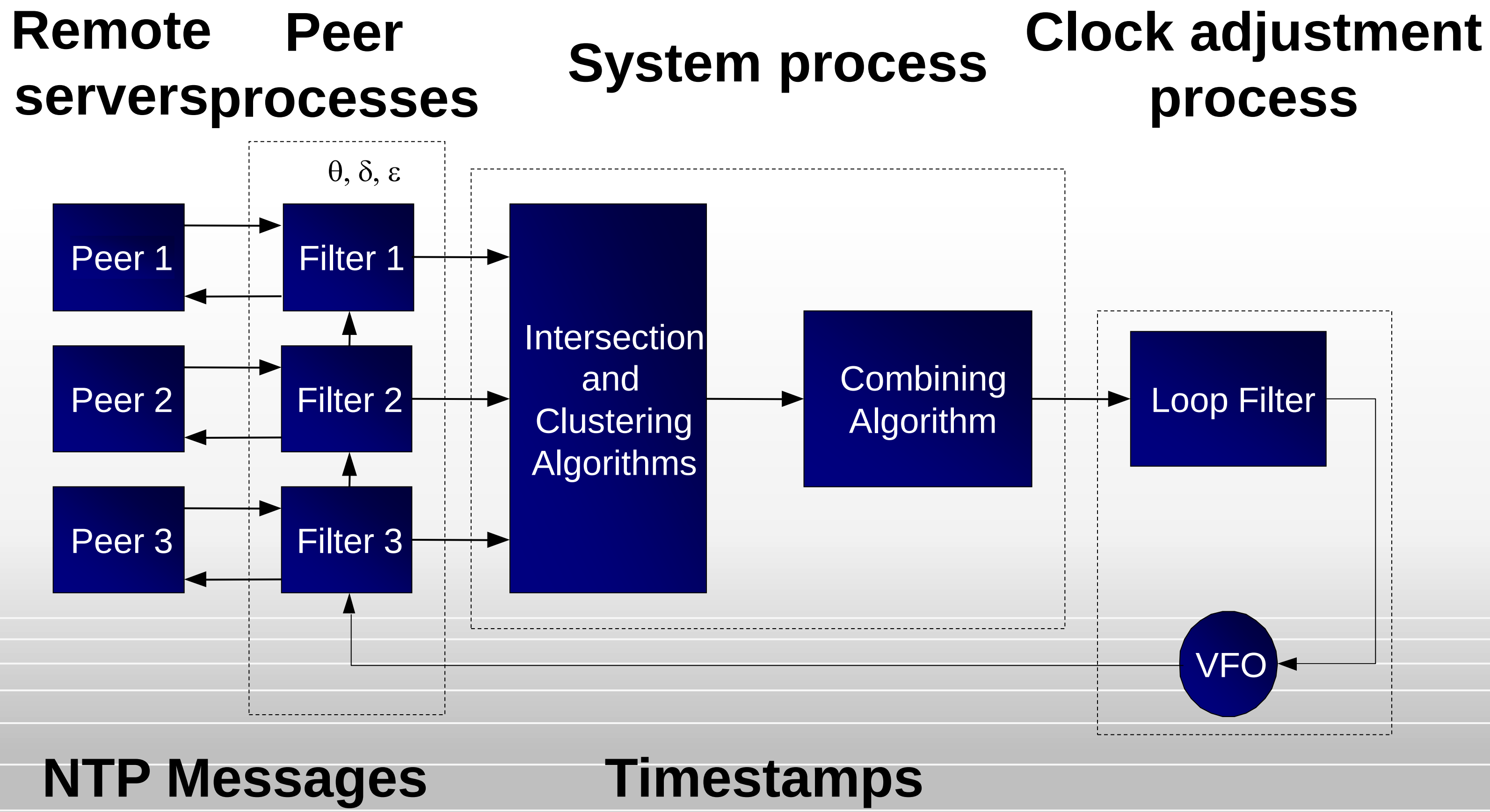
Stratum 2

Stratum 3



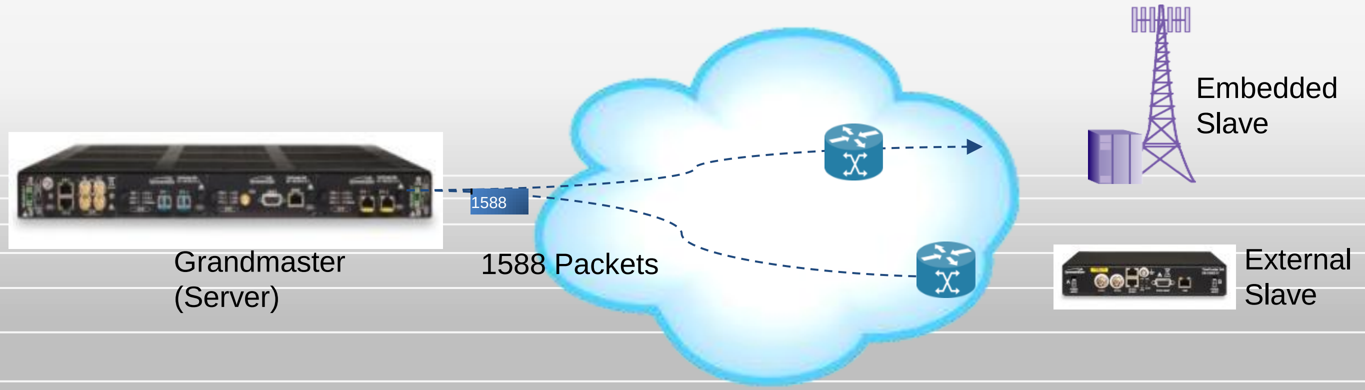
NTP Inputs and Outputs

Inputs - 3 x sources of equal or higher quality time from peers or servers
Output - Adjusted time available to peers and clients



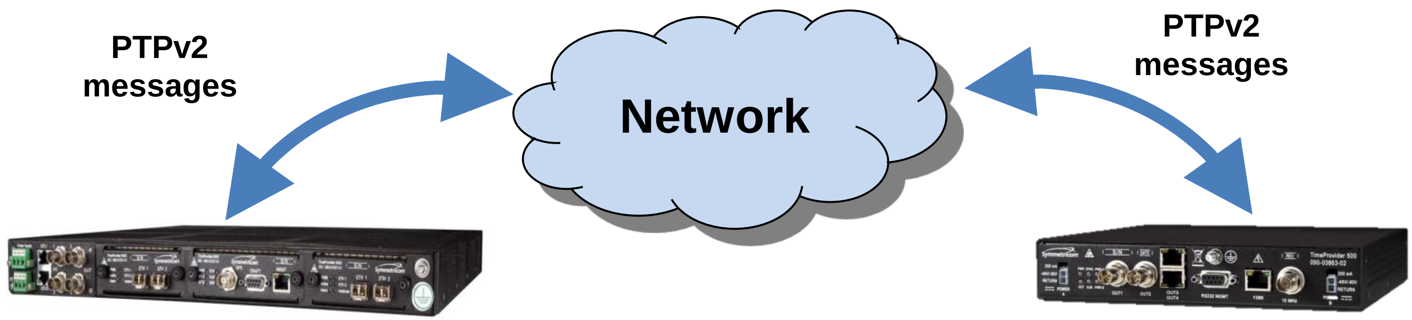
IEEE 1588-2008 PTPv2 Overview

- The Grandmaster "reference clock" sends a series of time-stamped messages to slaves.
- Slaves eliminate the round-trip delay & synchronize to the Grandmaster.
- Frequency is recovered from an accurate time of day reference.
- Accuracy is enhanced by:
  - Frequent packet send rate (up to 128 per second)
  - Hardware time-stamping (eliminate software processing delays)
  - Best Master Clock Algorithm (optional, "best" master voted by nodes)



PTPv2 Slave clocks can be either stand-alone or embedded in network equipment

PTPv2 Timing Message Types

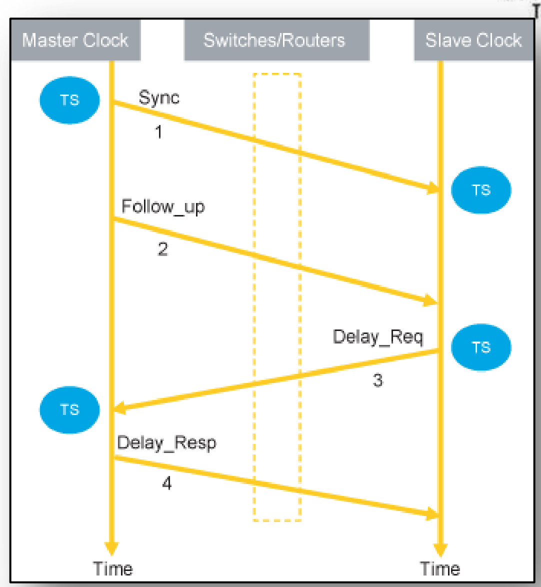


- The **Grandmaster** (Server) sends the following messages:
- Timing Messages (3 types):
  - **Sync** message
  - **Follow_Up** message (optional)
  - **Delay_Resp**(onse)
- **Announce** message (GM status)
- **Signaling** (2 types)
  - Acknowledge TLV (ACK)
  - Negative Acknowledge TLV (NACK)

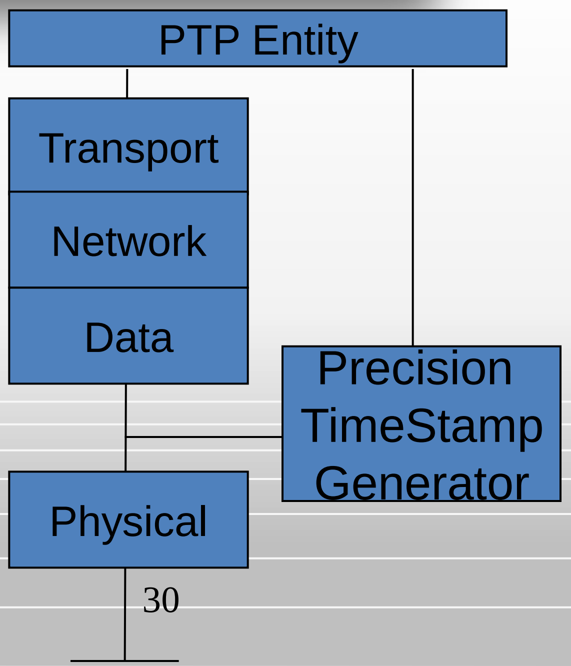
- The **Slave** (Client) sends the following messages:
- Timing Messages
  - **Delay_Req**(uest)
- **Signaling** (3 types)
  - Request announce
  - Request sync
  - Request delay_resp(onse)

How Is Precision Possible?

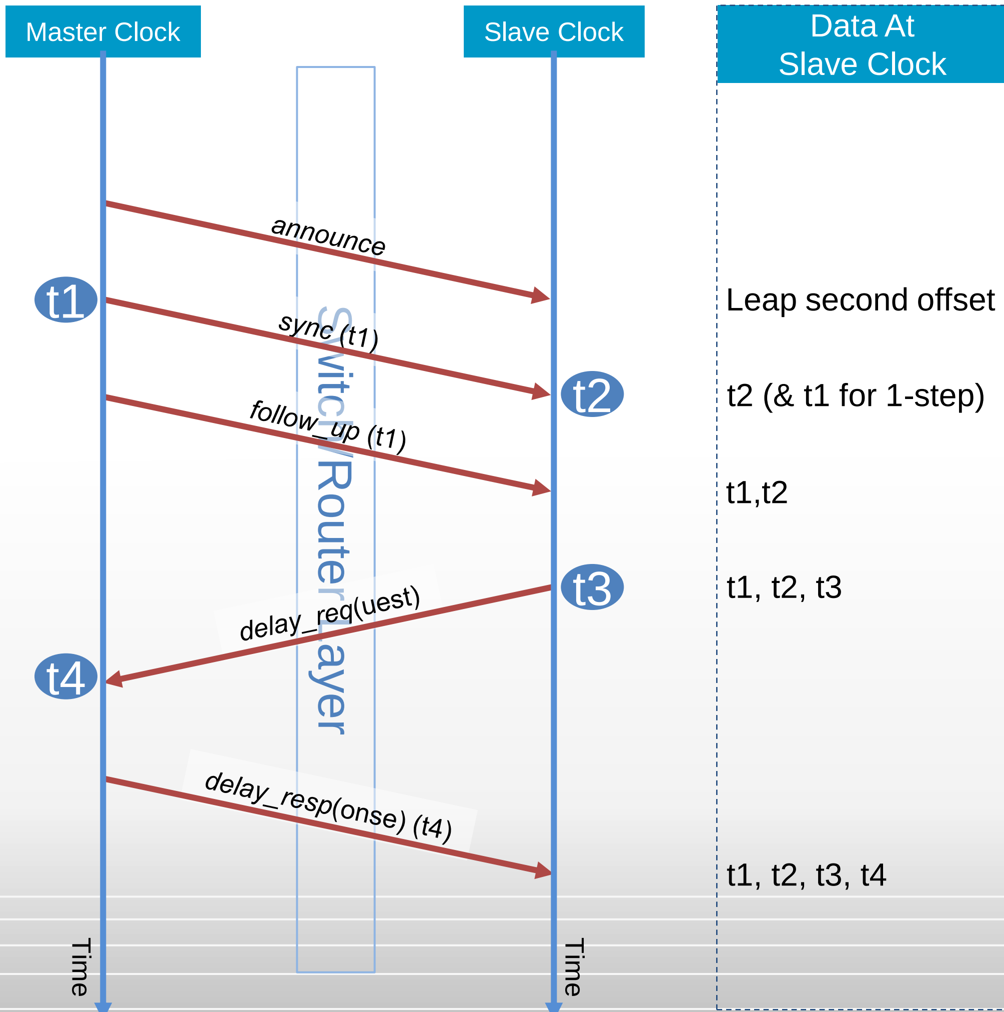
- **Message Exchange Technique**
  - Frequent “Sync” messages broadcast between master & slaves, and…
  - Delay measurement between slaves and master.



- **Hardware-Assisted Time Stamping**
  - Time stamp leading edge of IEEE 1588 message as it passes between the PHY and the MAC.
  - Removes O/S and stack processing delays.
  - Master & Slave use hardware assisted time stamping.



Time Transfer Technique



Round Trip Delay

RTD = (t2 - t1) + (t4 - t3)

Offset:

(slave clock error and one-way path delay)

Offset_{SYNC} = t2 – t1

$\text{Offset}_{DELAY\_REQ}$ = t4 – t3

We assume path symmetry, therefore

One-Way Path Delay = RTD ÷ 2

Slave Clock Error = (t2 - t1) - (RTD ÷ 2)

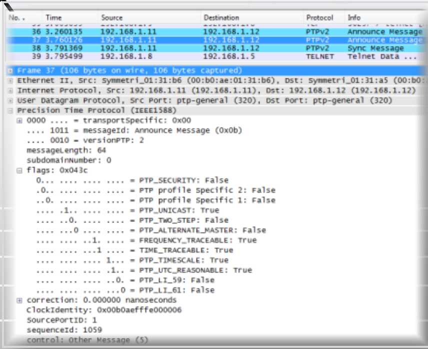
Notes:

1. One-way delay cannot be calculated exactly, but there is a bounded error.
2. The protocol transfers TAI (Atomic Time). UTC time is TAI + leap second offset from the *announce* message.

The process is repeated up to 128 times per second.
(Announce rate is lower than Sync rate)

PTPv2 Announce Messages

- Announce messages hold information about the status, precision and accuracy of the Grandmaster
  - Changes in values within Announce packets reflect changes in conditions at the GM
- Transmitted to all Slave clocks at regular intervals (1 per second is normal)
  - Slave clocks use information in the Announce message in the Best Master Clock algorithm or to switch GM if
- Holds the following information used by Slave clocks:
  - Leap second information
  - **GM clockClass** – lower values mean a higher class of clock
  - **GM Accuracy** – ranges from 100ns to Unknown
  - **GM TimeSource** – GPS, Arbitrary, Unknown
  - **Time Traceable Flag** – True/False
  - **Frequency Tracable Flag** – True/False
  - **PTP TimeScale Flag** – True/False



- Other information held also: Leap second indicator, Two-step clock mode, etc.

PTPv2 Profiles

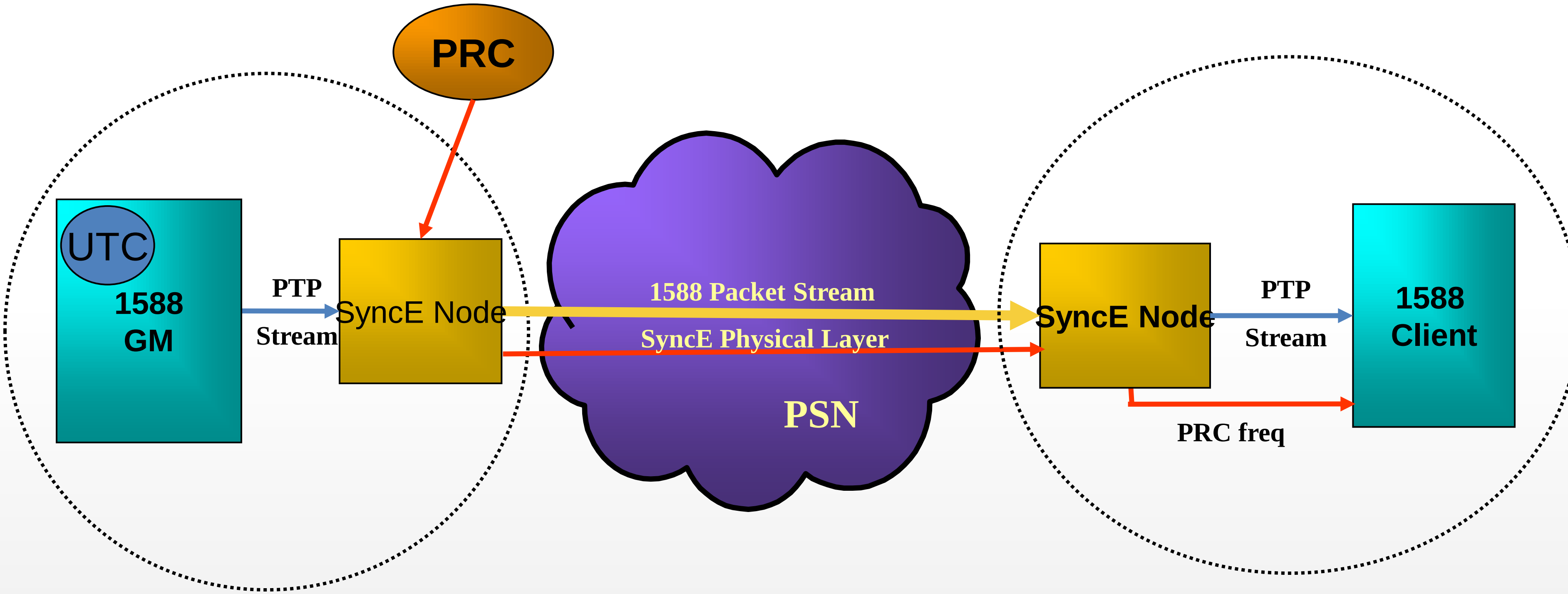
- A profile is a subset of required options, prohibited options, and the ranges and defaults of configurable attributes
  - e.g. for Telecom: Update rate, unicast/multicast, etc.
  - “The Telecom Profile” (G.8265.n/G.8275.n)

- PTP profiles are created to allow organizations to specify selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-works and achieve a performance that meets the requirements of a particular application

- *Other (non-Telecom) profiles:*
  - IEEE C37.238-2011 Power Distribution Industry “Smart grid”
  - 802.11AS AV bridging (e.g. AV over domestic LAN)

Combination Operation

- SyncE as “frequency assistance” to 1588

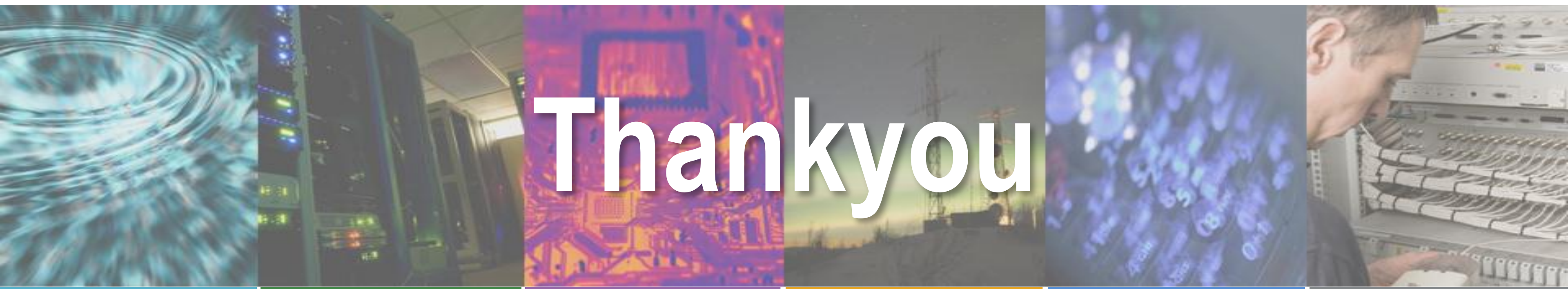


- Gives immediate “frequency lock” to 1588 client
- SyncE & 1588 functionality may be in the same node/element

Summary

- Physical Layer Sync Distribution
  - Historically frequency, phase
- Packet Layer Sync Distribution
  - Historically time (NTP)
  - PTP (& “carrier class” NTP) add frequency & phase
- Combination operation
  - Using both physical and packet layers to deliver frequency, phase & time with greater accuracy & reliability.

Questions?



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