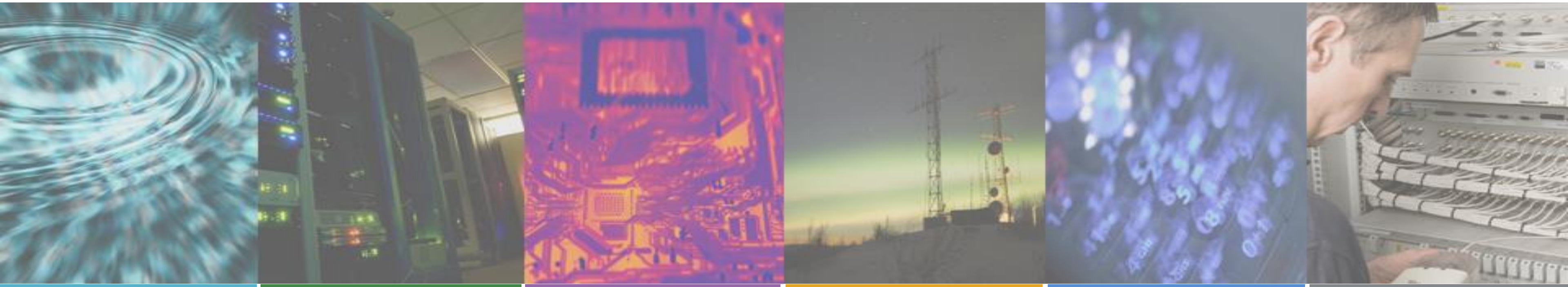
Tutorial: Network-based Frequency, Time & Phase Distribution



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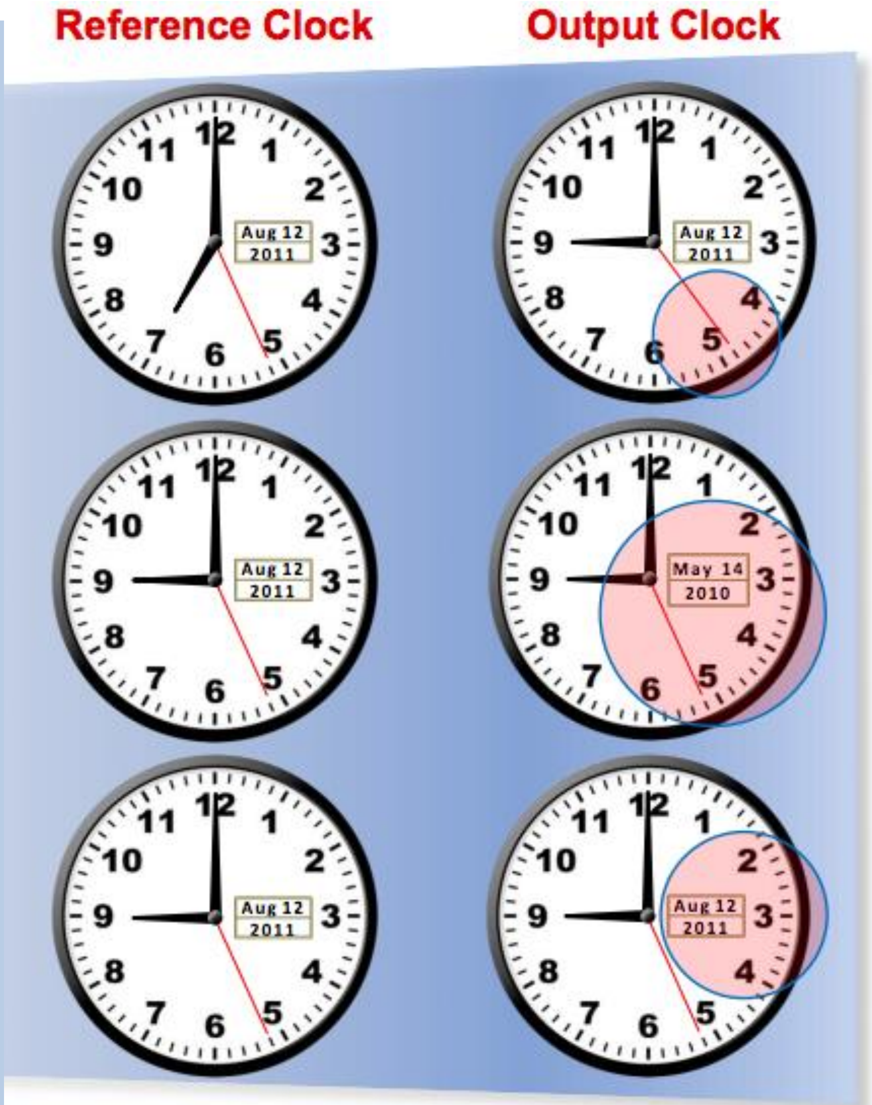
Presentation Contents

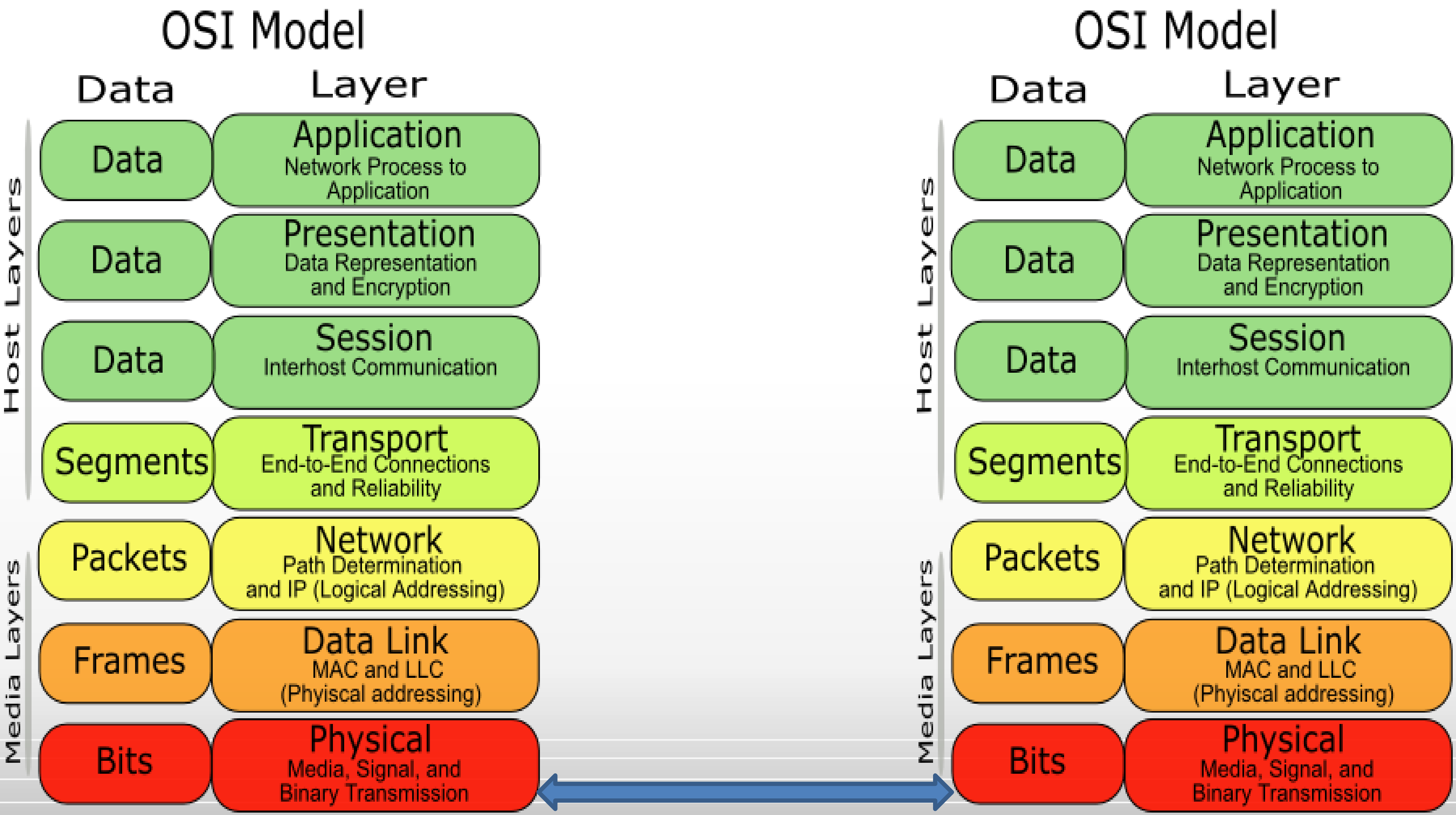
- Introduction
- Physical Layer Distribution
- Packet Layer Distribution
- Summary

Freq, Phase & Time

- **Frequency Synchronisation (Syntonisation):**
  - Clocks tick at the same rate
- **Phase Synchronisation:**
  - Clocks tick at the same moment
- **Time Synchronisation:**
  - Clocks tick at the same moment & are aware of the same time & date.

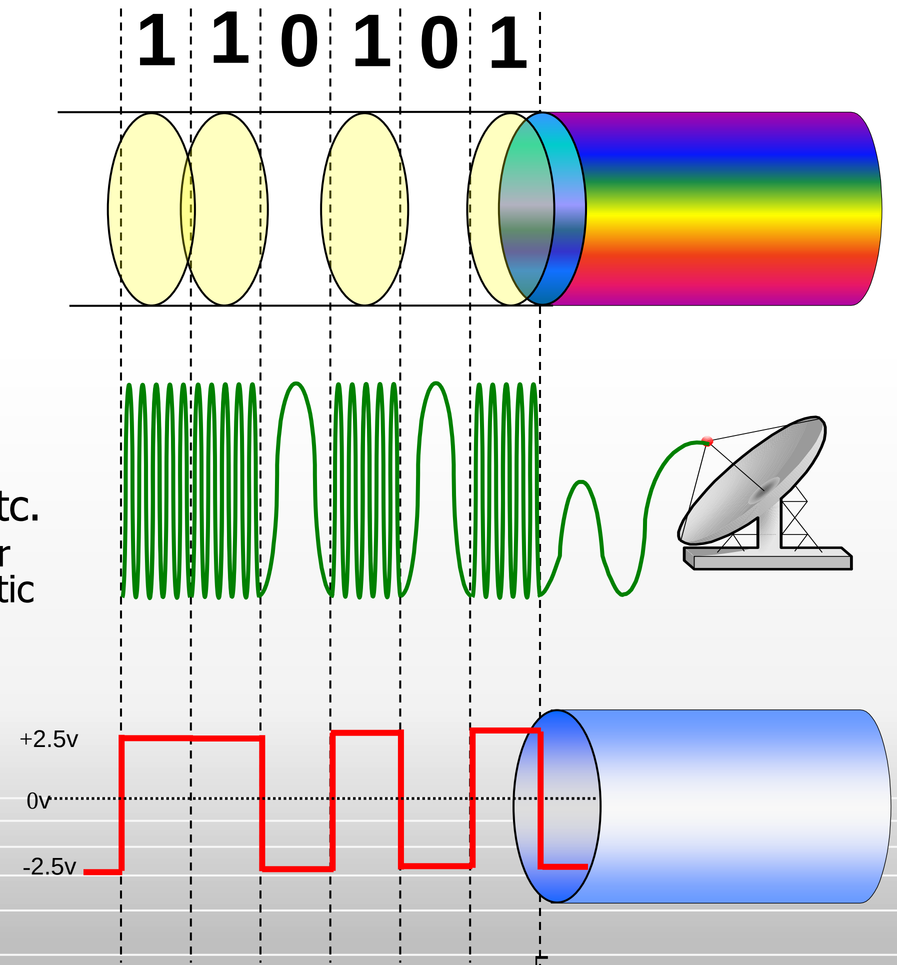


The (in)famous stack model



How Are “Bits” Represented..?

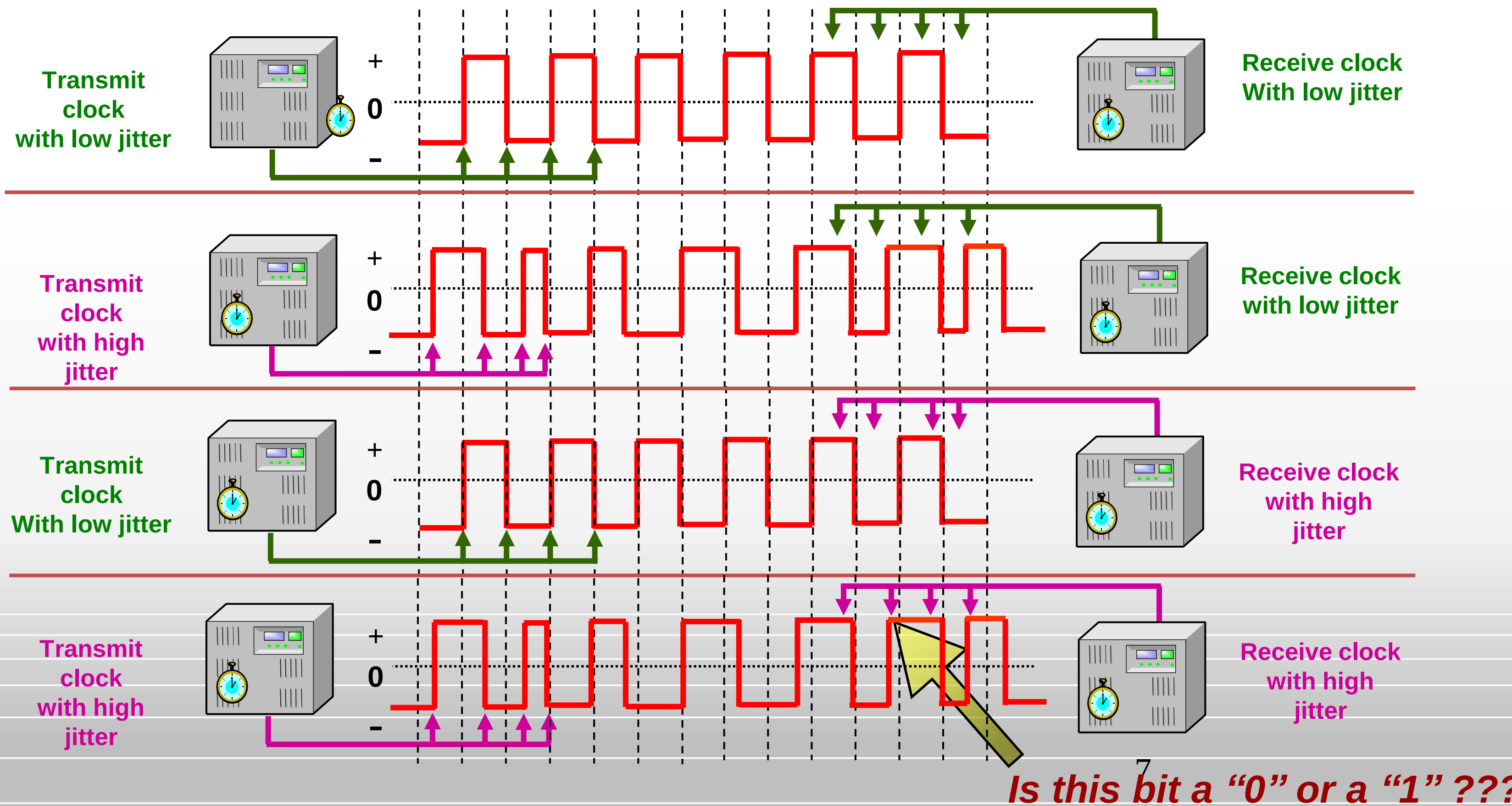
- The value of a Bit (0 or 1) can be represented by different modulations of a carrier signal examples are:
  - Fibre Optics
    - The presence or absence of a light pulse
    - Different frequencies of light
  - Radio/Microwaves - Mobile phone, satellite comms, WiFi, etc.
    - Changes in phase, frequency 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

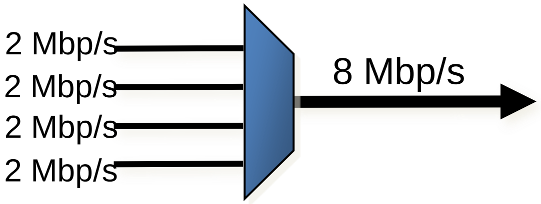
Bit Synchronisation

- 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.

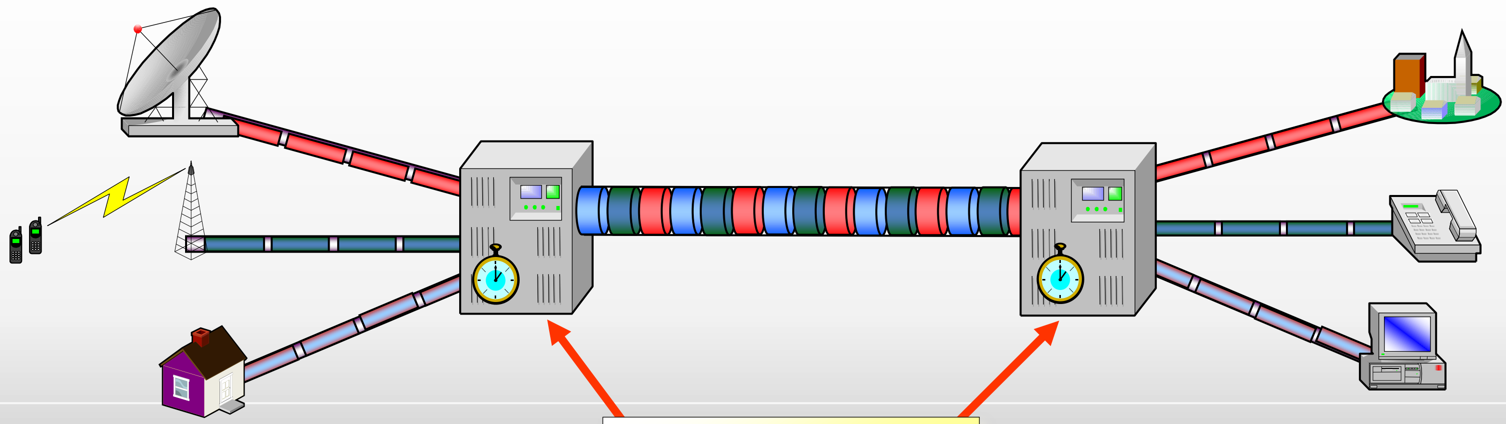


Time Division Multiplexing (TDM)

- 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

Classical Sync "Levels"

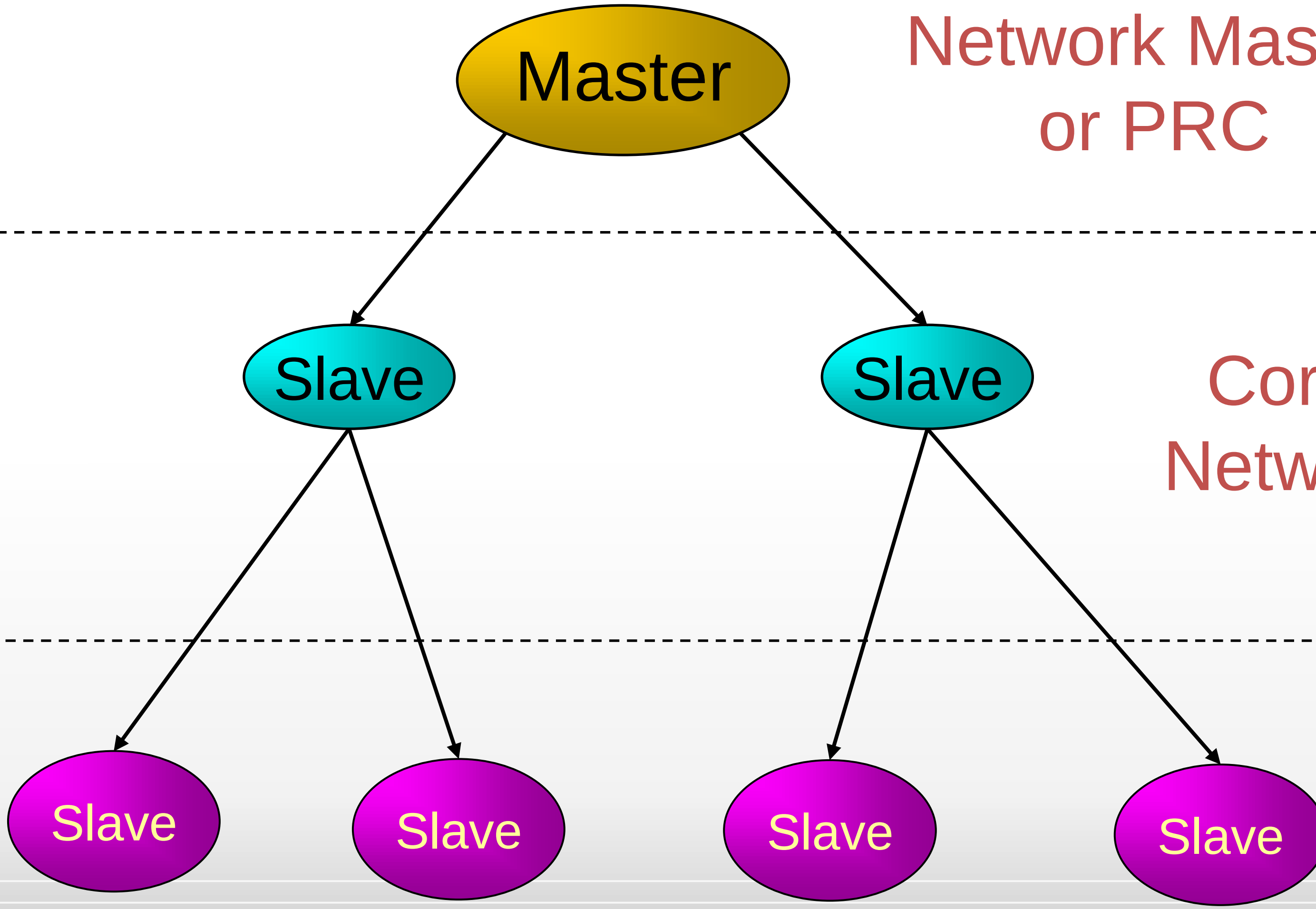
Level I

Network Master or PRC

Level II

Core Network

Level III



Access Layer - Customer Facing

Different Types of Clock

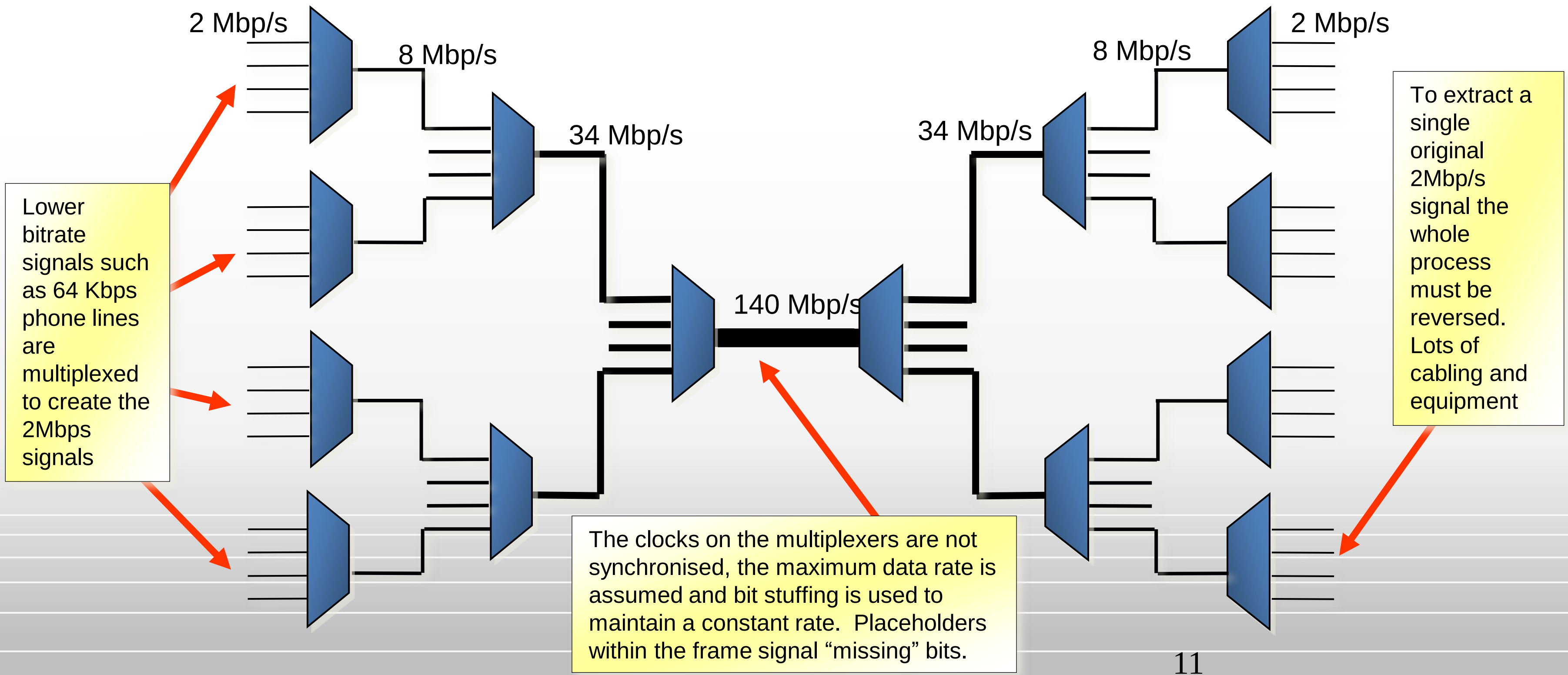
- There are 3 basic types of clock, what they are called depends on technology & standards

Stability	***Master***	***Core***	***Access***
PDH - Old	PRC	Transit	Local
PDH - Old	Level I	Level II	Level III
PDH - ANSI	Stratum 1	Stratum 2	Stratum 3
SDH - New	PRC/PRS	SSU/SASE	Local SSU
ANSI - Terms	PRC	BITS	SMC

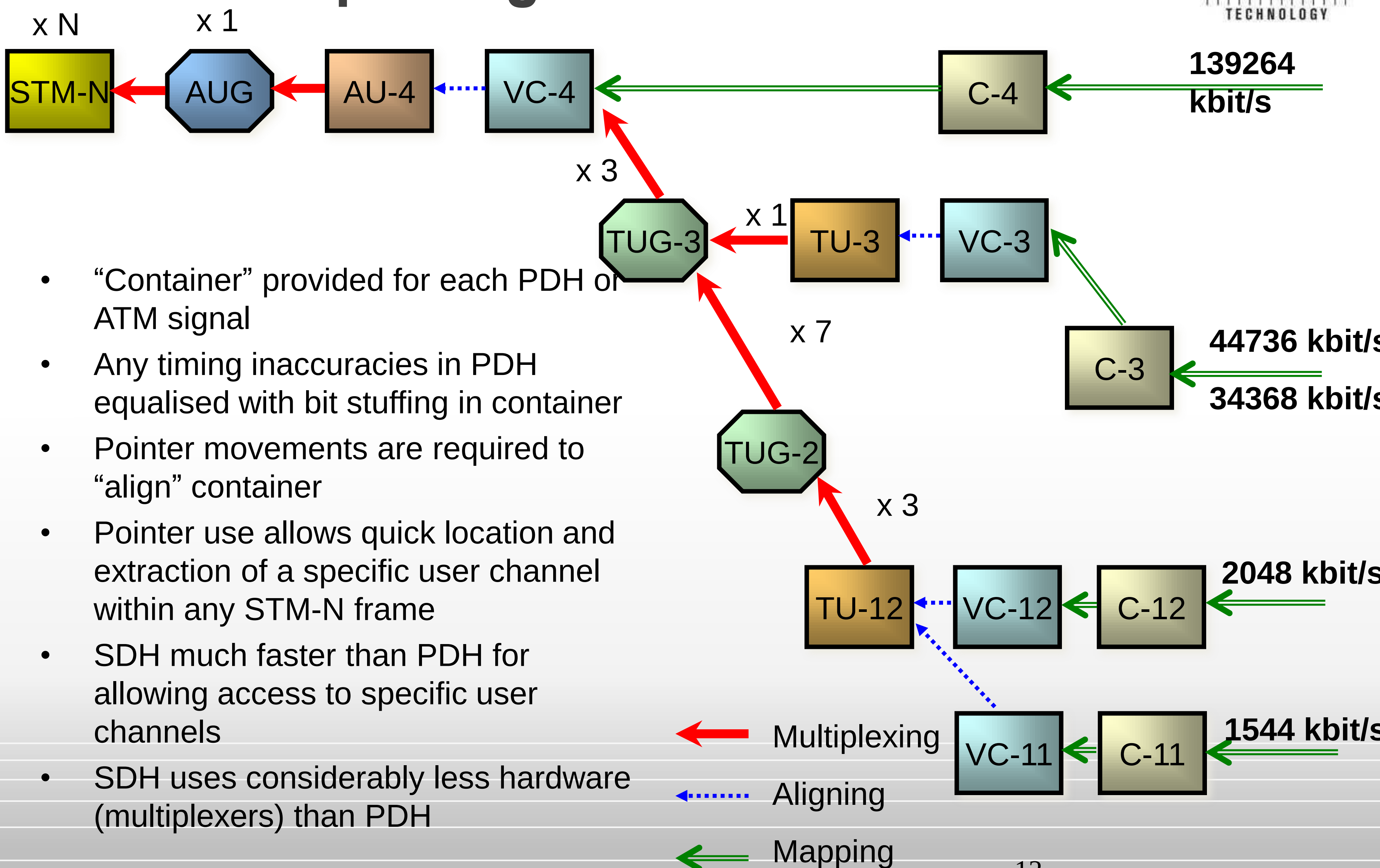
- Sync distribution starts at PRC - Level I - Stratum I
- A slave clock must never be connected to a lower level clock in holdover
- A slave clock must never be connected to itself - “Sync Loop”

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.



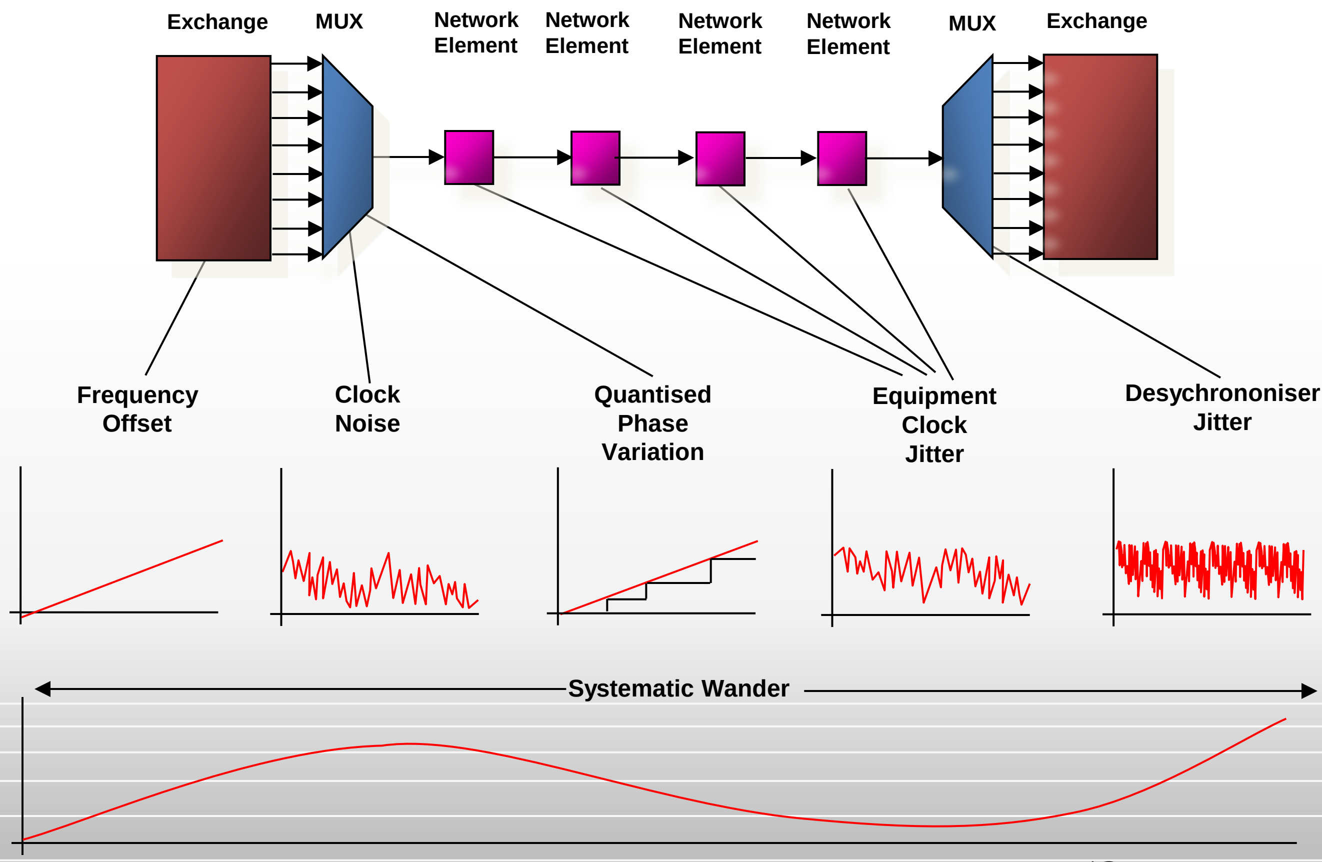
SDH Multiplexing



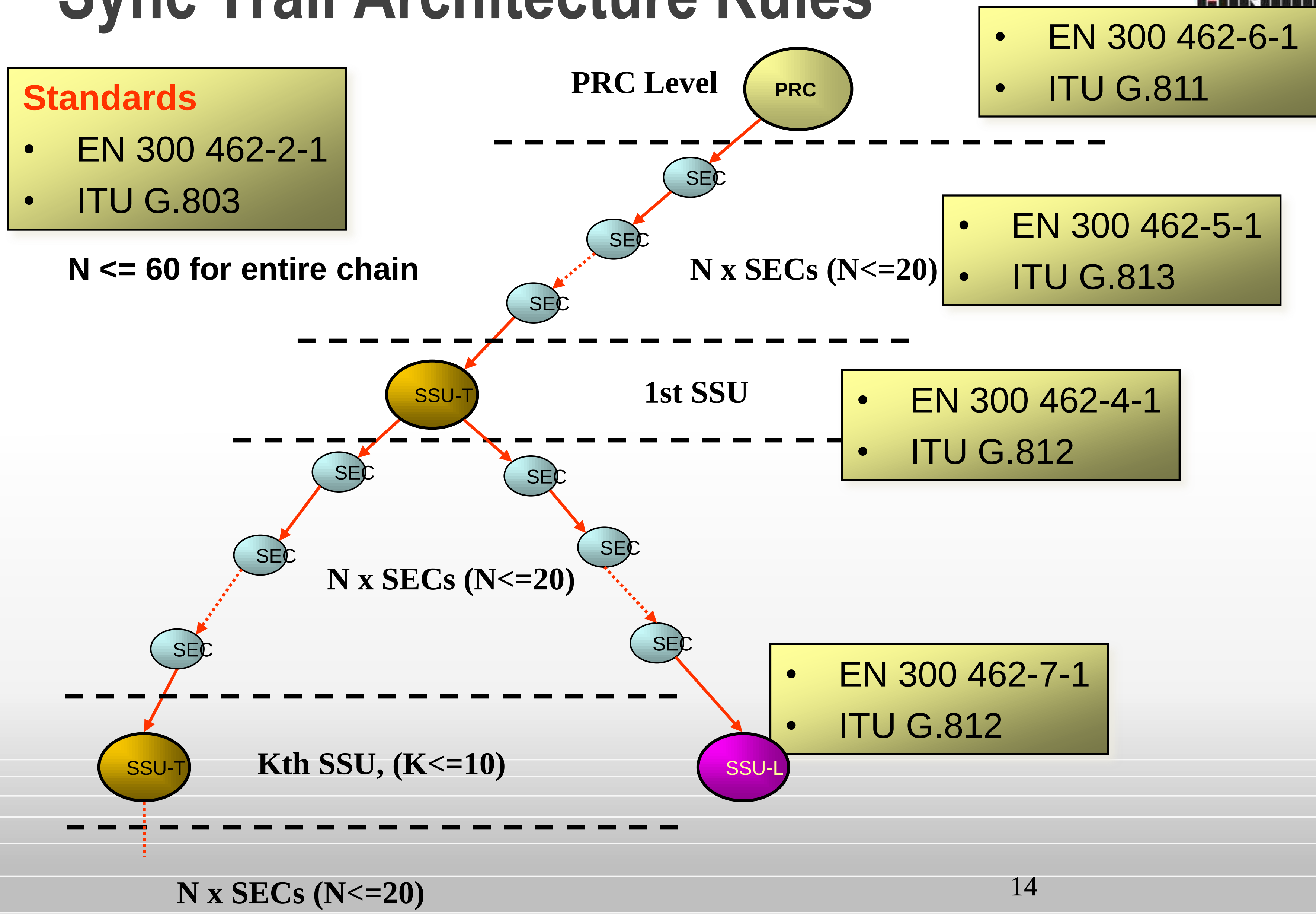
- “Container” provided for each PDH or ATM signal
- Any timing inaccuracies in PDH equalised with bit stuffing in container
- Pointer movements are required to “align” container
- Pointer use allows quick location and extraction of a specific user channel within any STM-N frame
- SDH much faster than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

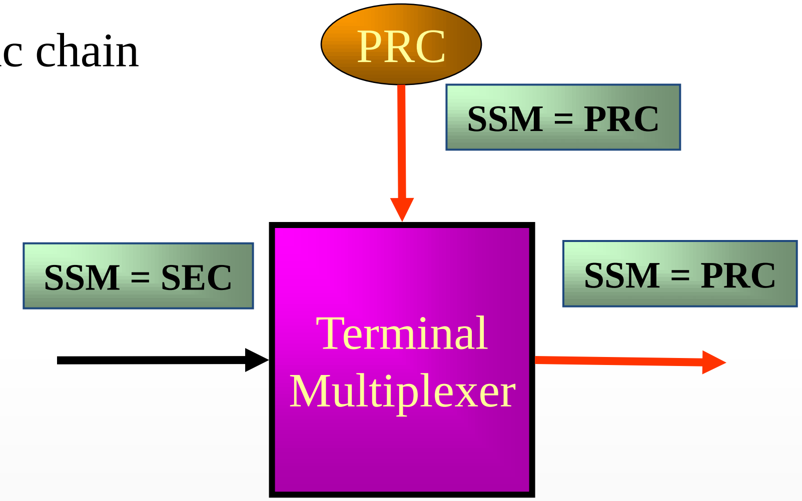


Sync Trail Architecture Rules



Synchronisation Status Message in SDH

- SSM in Bits 5-8 of S1 byte of STM-N G.707
- SSM is a quality indicator for the source of the sync chain
  - Defined in EN 300 417-6-1
- Always select best clock input in selection list
  - $SSM_{out} = SSM_{in}$ of selected source
- SSM overrides operator priority selection
- Assumed quality assigned to non SSM supporting interfaces



Standards

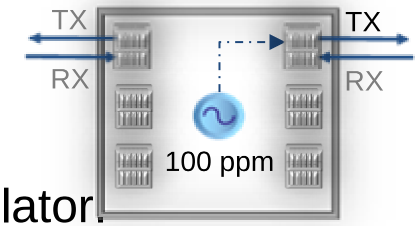
- G.707
- EN 300 147
- EN 300 417-6-1

S1 Byte (bits 5-8)	Source of Sync Trail
0000	Synchronisation quality unknown
0010	PRC - EN 300 462-6-1
0100	SSU-T - EN 300 462-4-1
1000	SSU-L - EN 300 462-7-1
1011	SEC (SETS) - EN 300 462-5-1
1111	Do Not Use (DNU) for synchronisation

SyncE Overview

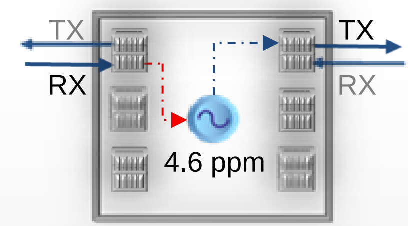
How is SyncE different from normal Ethernet?

Existing Ethernet PHY (Physical Layer)

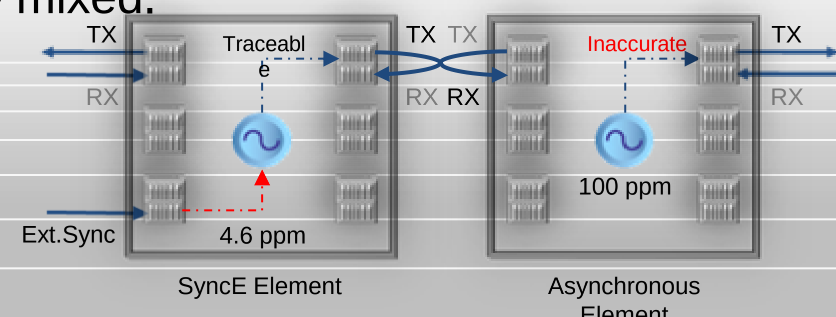


- IEEE 802.3 defines Ethernet PHY
- Rx uses incoming line timing. Tx uses free-running 100ppm oscillator.
- No relationship between the Rx & Tx.

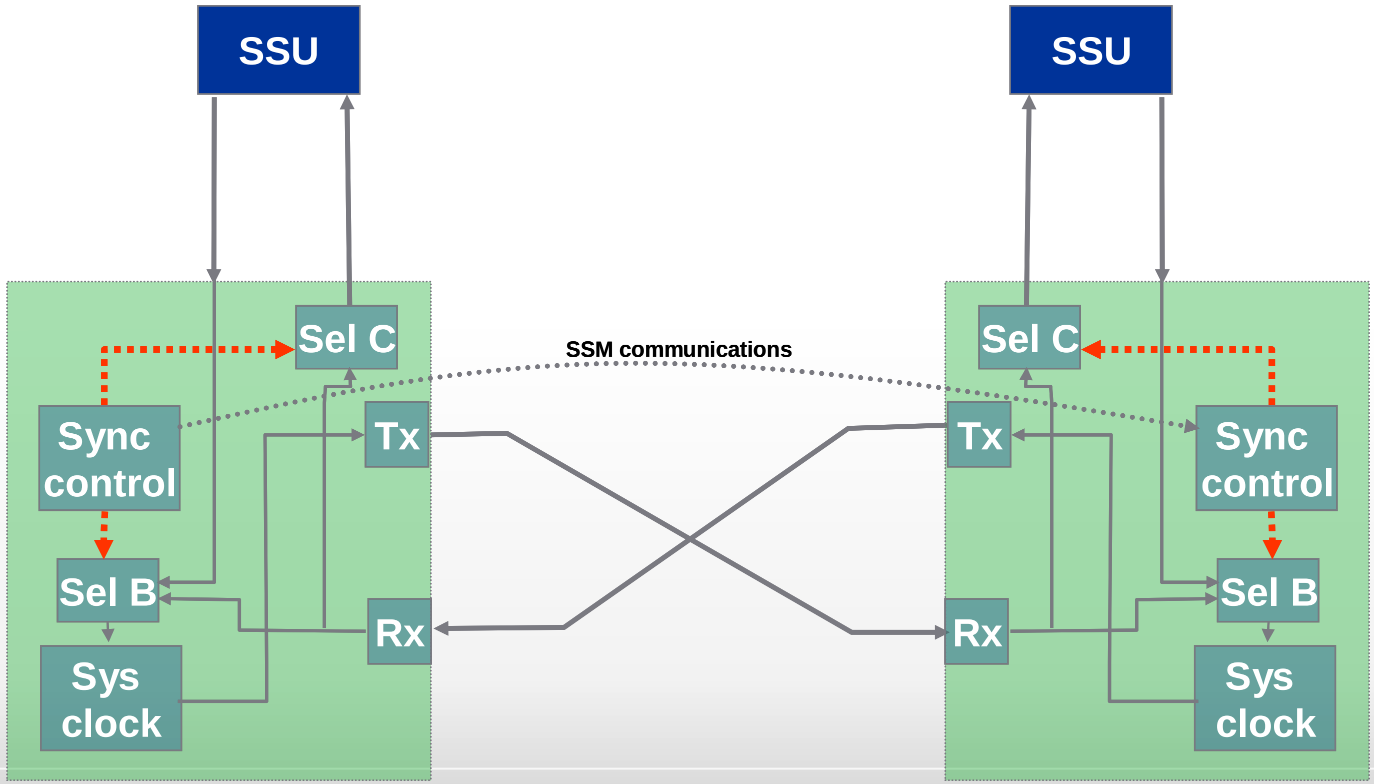
SyncE PHY (Physical Layer)



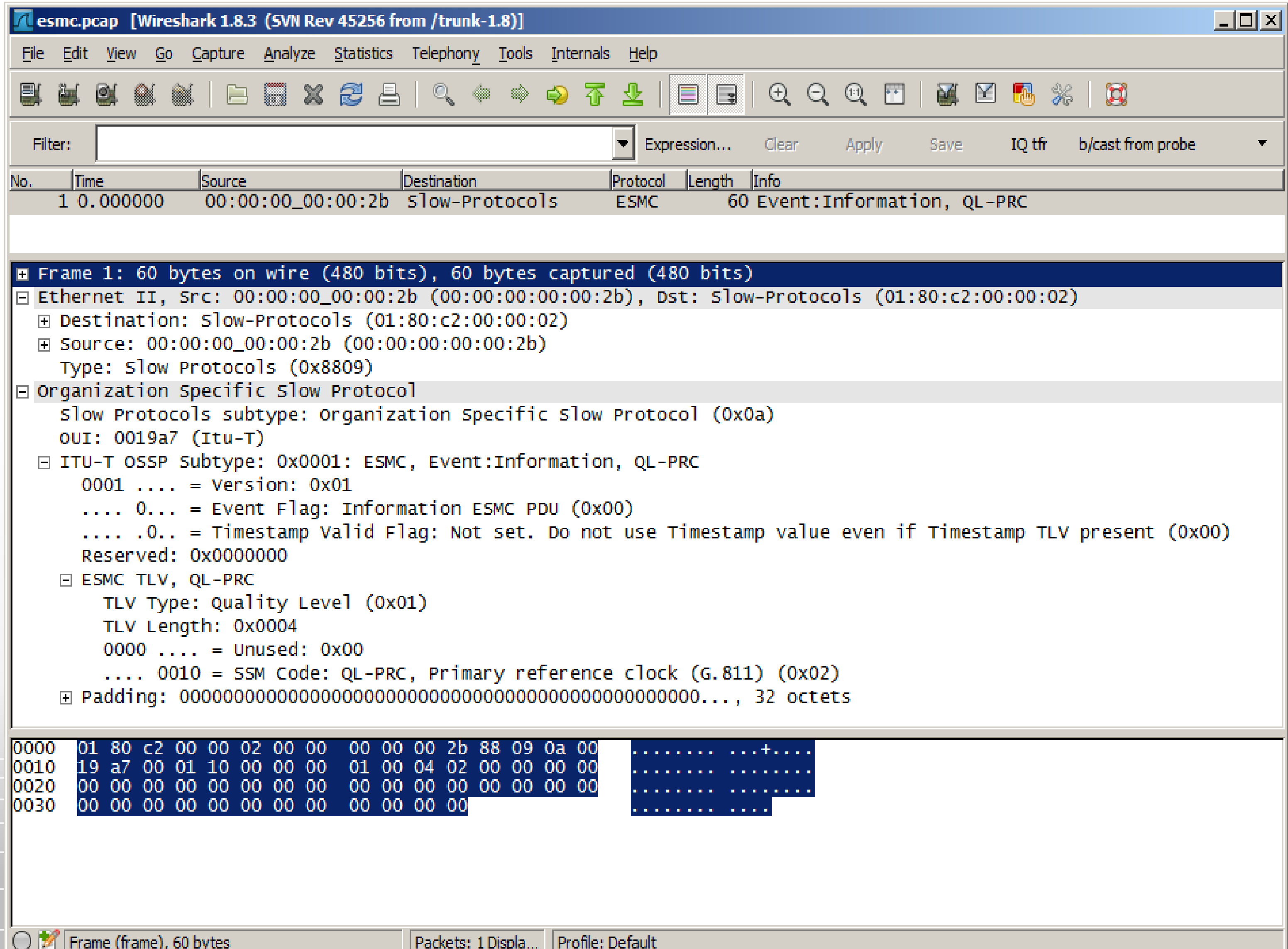
- Rx disciplines the internal oscillator
- Tx uses the traceable clock reference, creating end-to-end scheme.
- PRC can provide the reference. SSUs filter jitter/wander.
- SyncE and asynchronous switches **cannot** be mixed.



QL in SyncE - ESMC

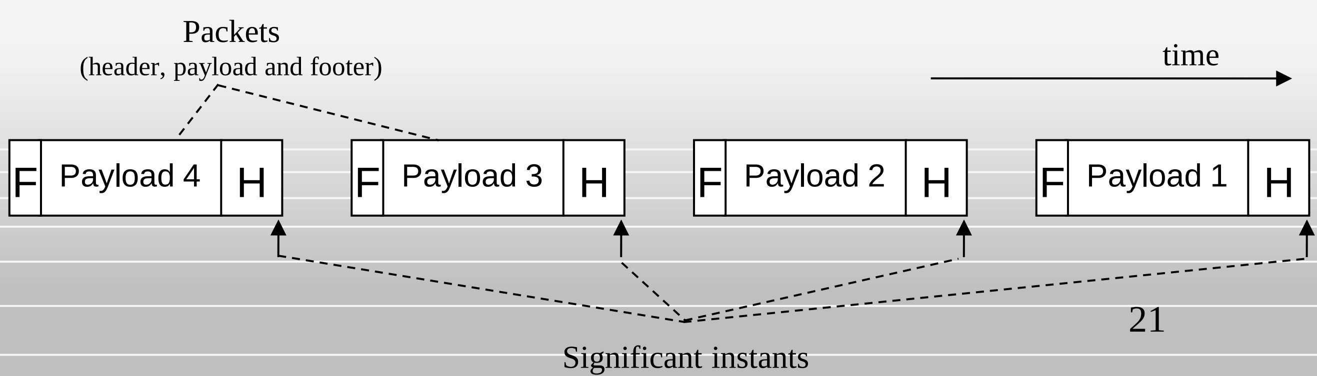


ESMC & IEEE 802.3ay OSSP



From clocks to packets

- Packet "clocks" can be thought of in the same way as physical layer clocks…
- 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



“The Telecom Profiles” (G.8265.n/G.8275.n)

- 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.

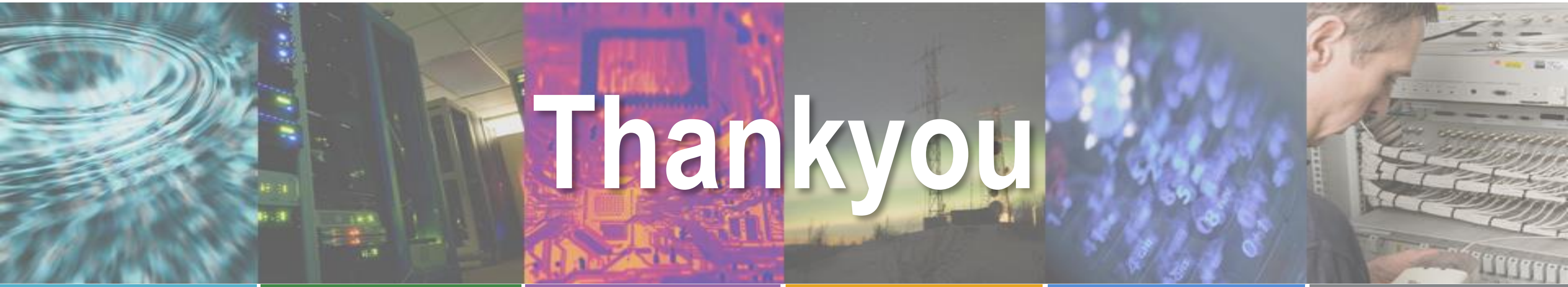
- PTP profiles are created to allow organizations to specify selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-works and achieve a performance that meets the requirements of a particular application

- *Other (non-Telecom) profiles:*
  - IEEE C37 238 Power Distribution Industry
  - 802.11AS AV bridging (AV over domestic LAN)

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.

Thank you for listening



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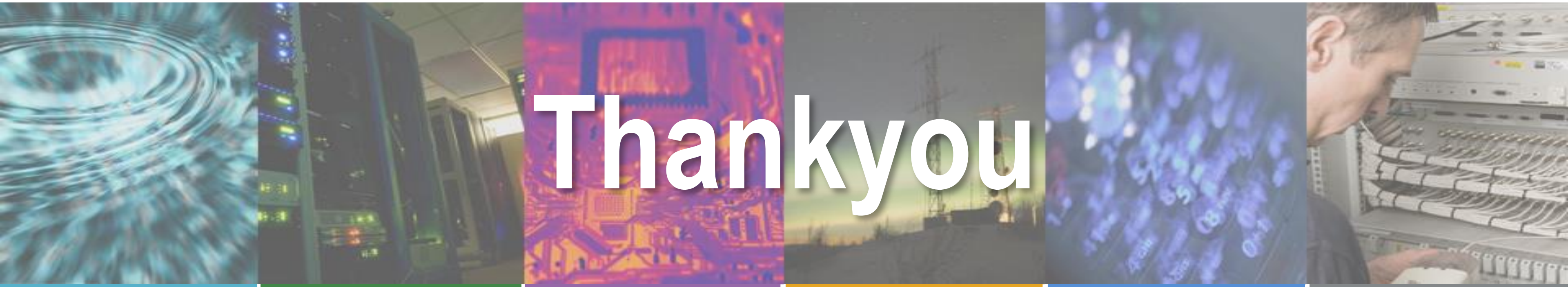
Reference Slides



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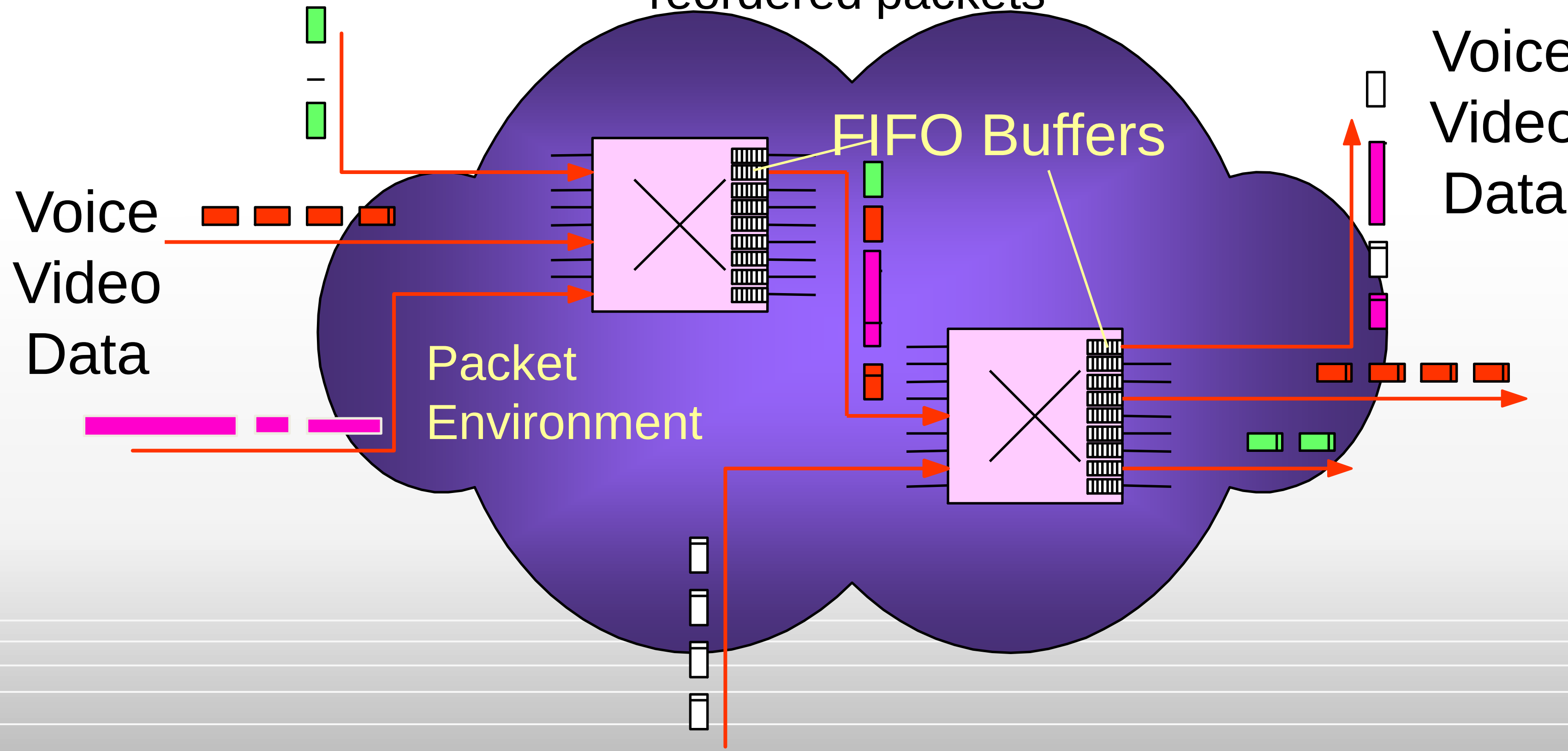
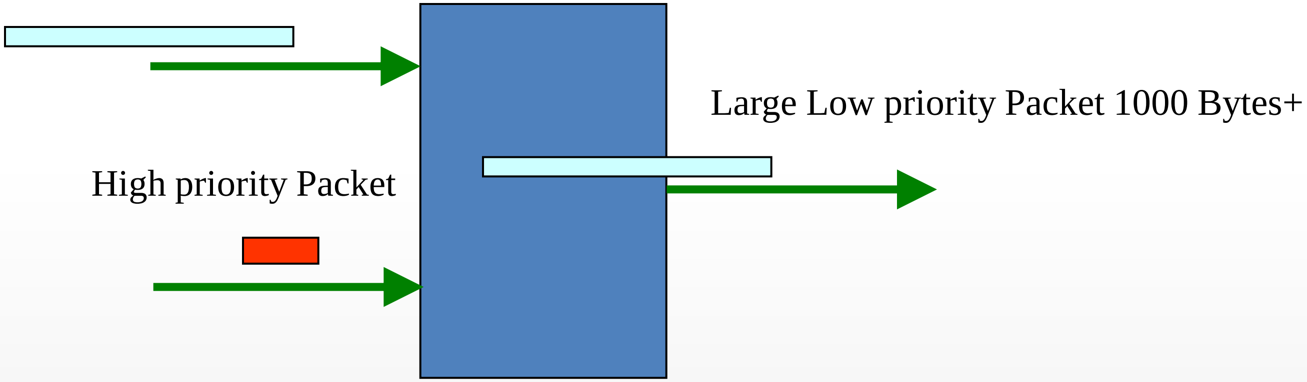
Packet Transport & Switching

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

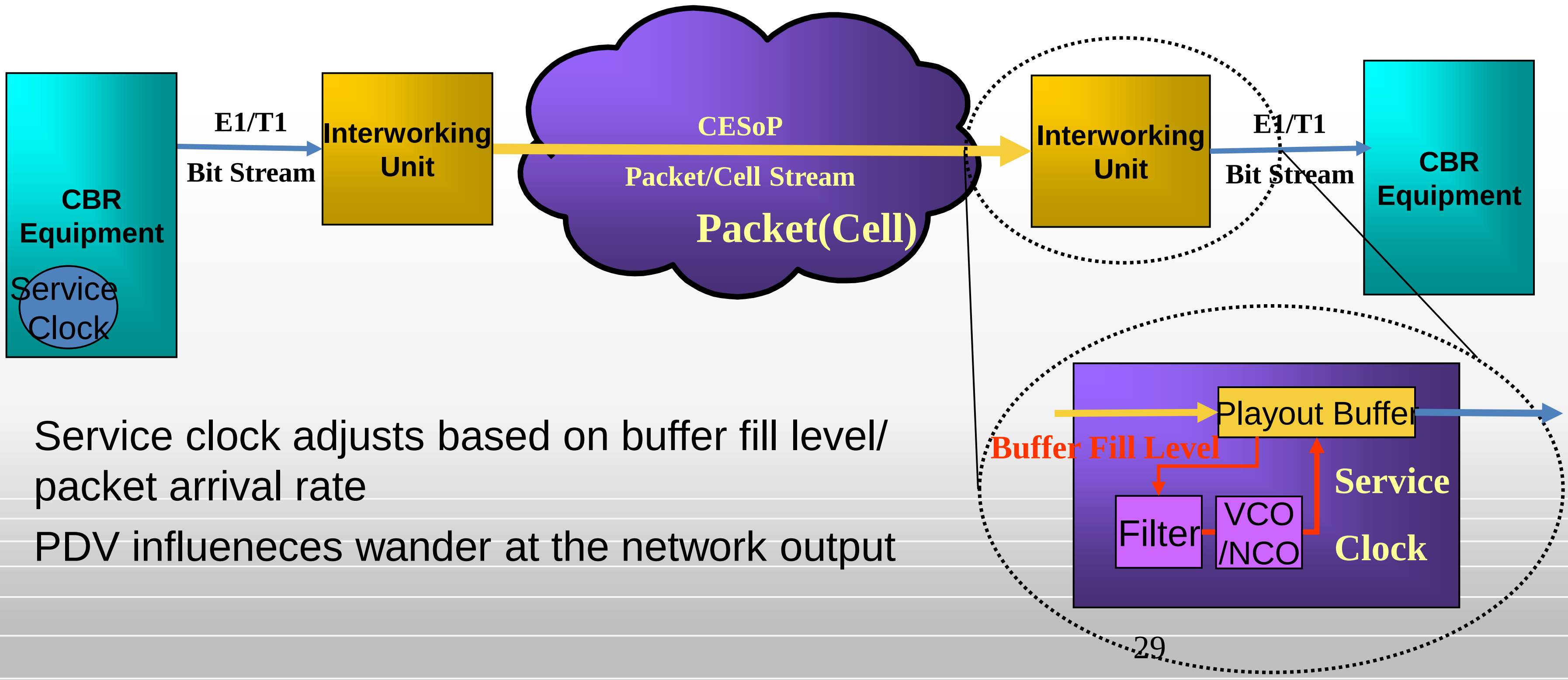


At 100 Mbit/s 1000 byte packet = $8 \times 1000 / 100 \times 10^6 = 80\mu s$

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

NTP Versions

Features and mechanisms of NTP described in RFCs

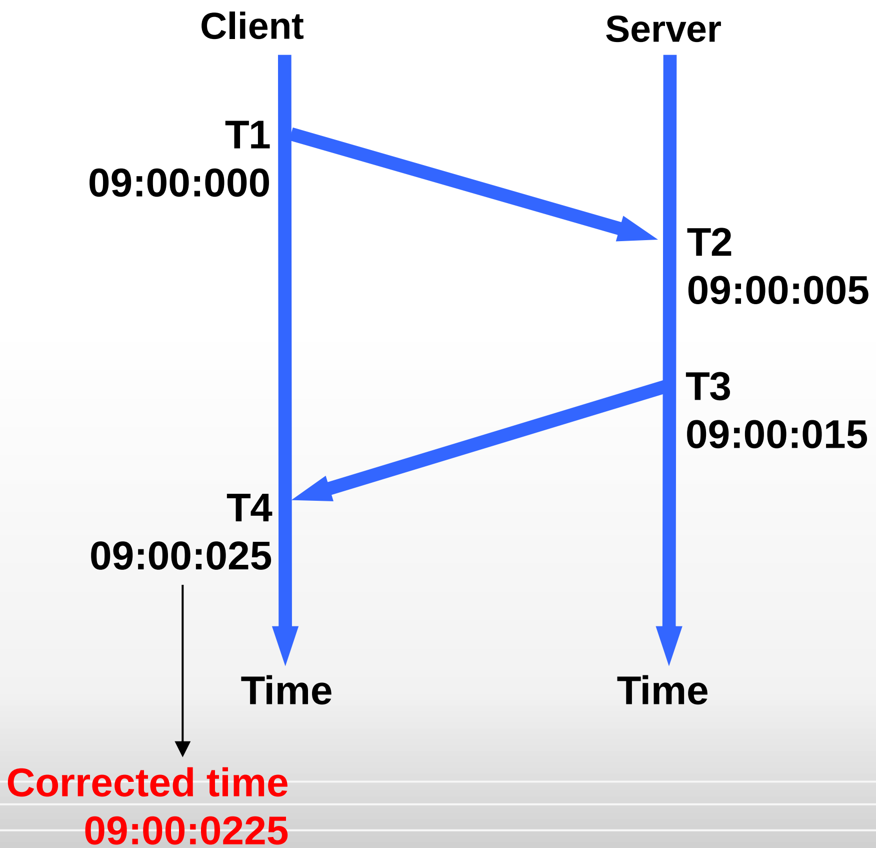
“Request For Comments”

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

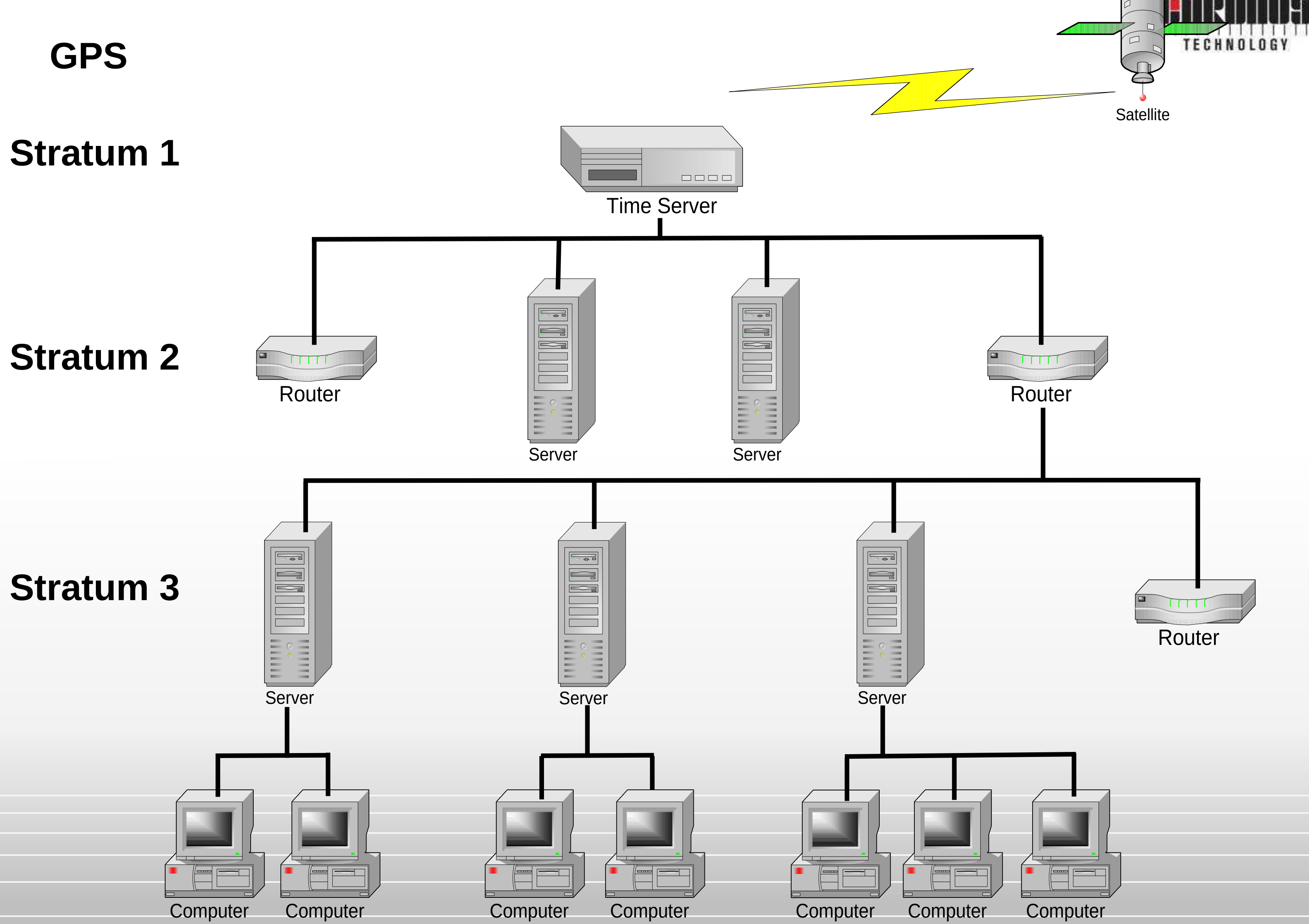
How NTP Works

- 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**)



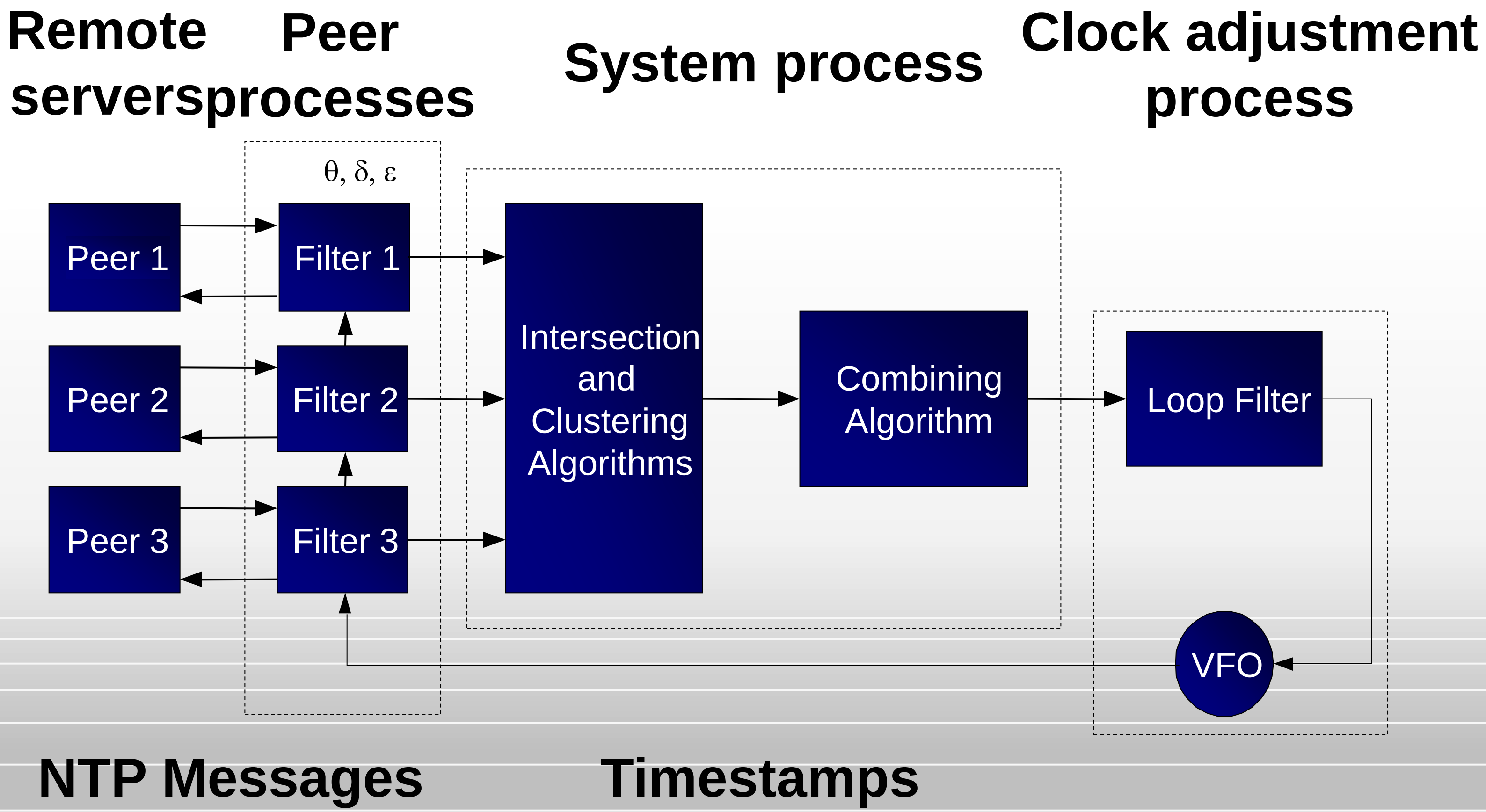
- **Key Assumptions:**
  - One way delay is half Round Trip (symmetry!)
  - Drift of client and server clocks are small and close to same value
  - Time is traceable (worth distributing!)

NTP Network Architecture



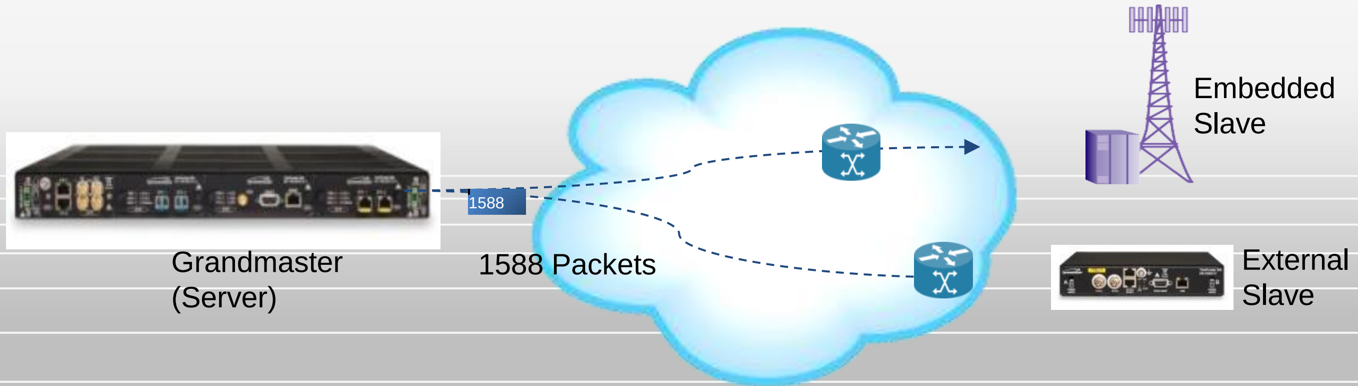
NTP Inputs and Outputs

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



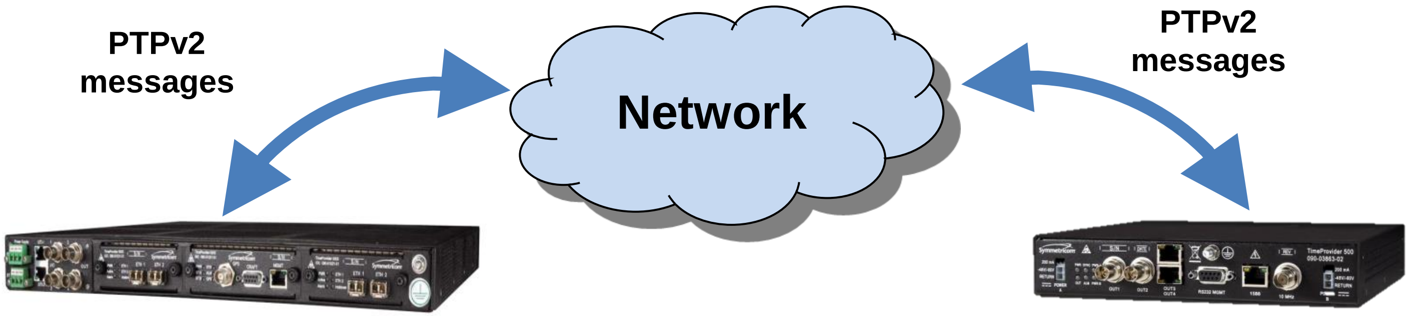
IEEE 1588-2008 PTPv2 Overview

- 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

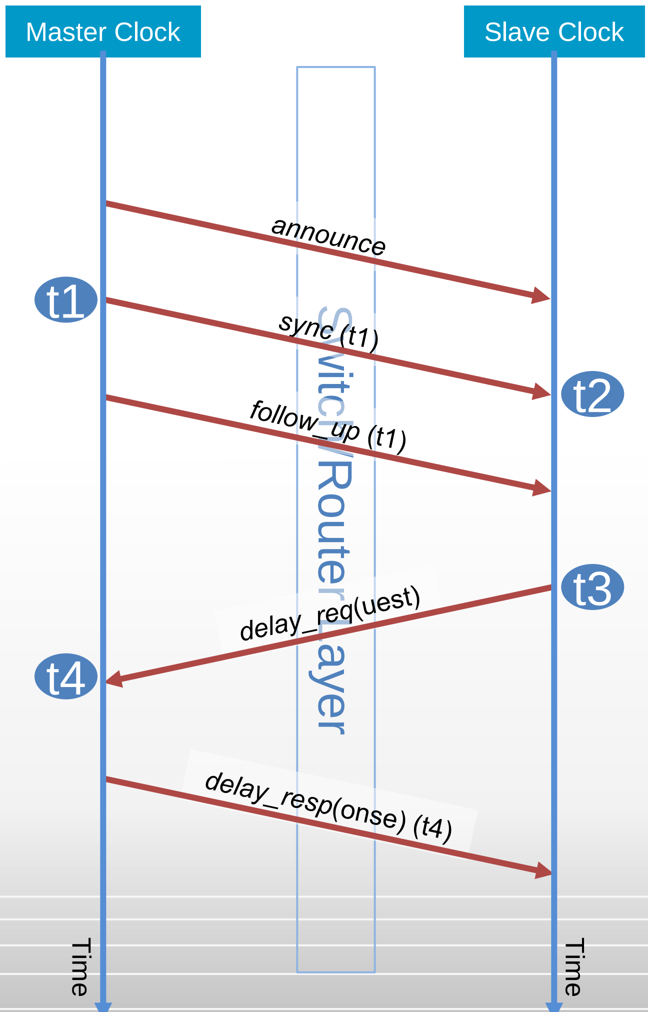
PTPv2 Timing Message Types



- 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)

Time Transfer Technique



Data At Slave Clock

- Leap second offset
- t2 (& t1 for 1-step)
- t1,t2
- t1, t2, t3
- t1, t2, t3, t4

Round Trip Delay

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

Offset:

(slave clock error and one-way path delay)

$\text{Offset}_{SYNC} = t2 – t1$

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

We assume path symmetry, therefore

One-Way Path Delay = RTD ÷ 2

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

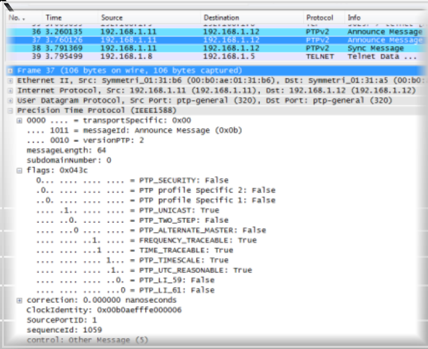
Notes:

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

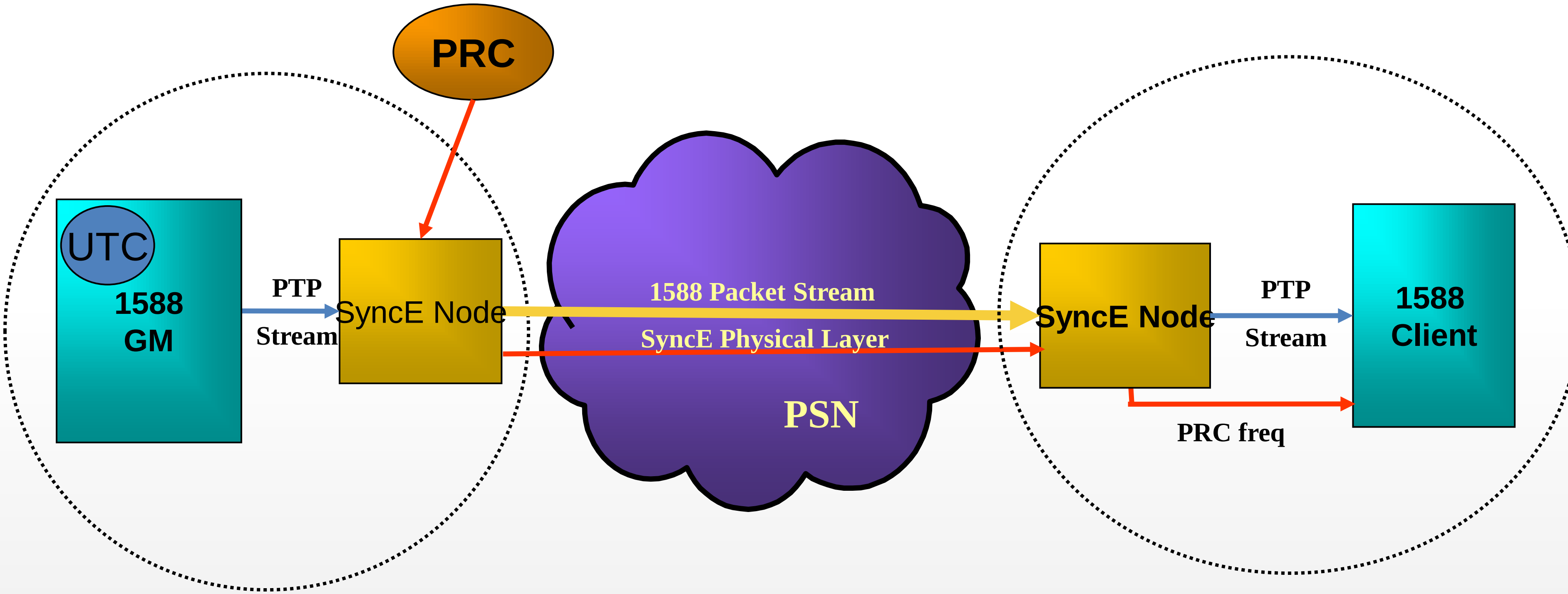
- Announce messages hold information about the status, precision and accuracy of the Grandmaster
  - Changes in values within Announce packets reflect changes in conditions at the GM
- Transmitted to all Slave clocks at regular intervals (1 per second is normal)
  - Slave clocks use information in the 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.

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