Synchronisation Overview

ALBEDO Telecom

the Path to Excellence

About ALBEDO Telecom

ALBEDO Telecom offers a full range of telecommunication products and services to the international market.

- **Hand-held Filtering Taps**: battery operated, 1kg. double port
- **Stream-to-disk appliance**: SSD disk, wirespeed capture, wirespeed storage, 2Gb/s
- **Impairment Generator**: Carrier Ethernet and IP
- **Hand-held testers**: E1, SDH, GbE, SyncE, IP, IPTV, VoIP, Datacom, Jitter, Wander
- **Acceptance Labs**: IPTV, VoIP, ISDN, POTS
- **Consultancy / Integration**: IPTV, VoIP

Many systems need to be synchronized

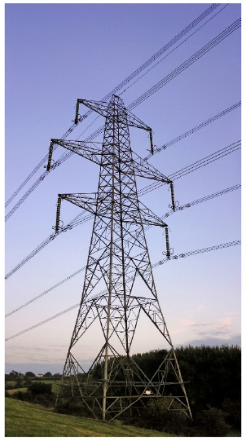
The accuracy of a watch depends on the application. Anyone who wants to catch a train has to have an eye on the minutes. In competitive sport, a hundredth of a second can be decisive and a packaging machine of Coca-Cola may need microsecond synchronization.

Two effects are apparent to synchronize clocks:

- actual clocks do not operate at exactly the same speed
- therefore clocks have to be constantly regulated to keep them at the same time.

Synchronization Market

Telecoms



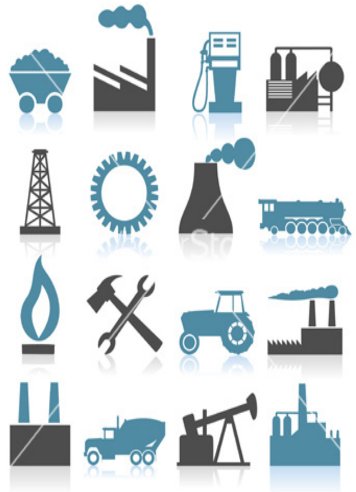
Power Utilities

Lawful / Army

R&D Labs

Airports

Police



Industry

- Mobile Backhaul and Carrier Ethernet
- Circuit emulation (PDH / SDH)
- Contents Synchronization (Caption synchronization, Video encoding/decoding)
- Fiber optic transmission Networks and PON
- Military / Police
- Manufacturing Industry
- Power Industry
- Airports, Railways, Motorway.

Financial Institutions

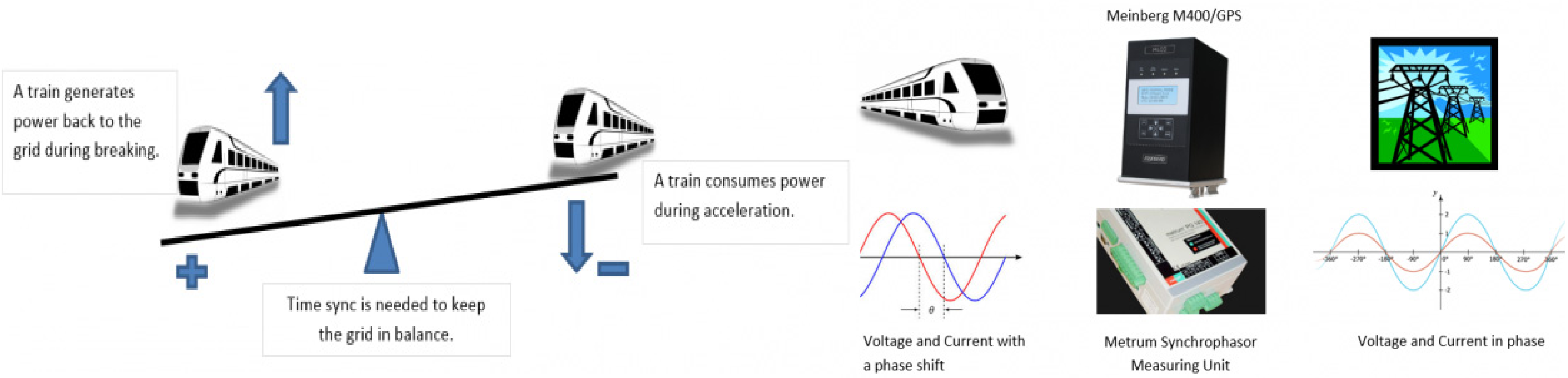
Financial institutions, hedge funds and market-makers need to address a variety of challenges with accurate, traceable time for their critical networks and network elements. High frequency trading requires real-time decisions based on microsecond time accuracy in order to remain competitive. This level of accuracy is available today through a combination of a GPS timing, new network synchronization protocol (PTP), PTP masters and slaves.

- Traffic in capital markets requiring accurate time pace of over one million per second.
- Trading decisions in real time environment use algorithms requires precision timing.
- Increasingly stringent regulatory oversight requiring high precision timed log files.

Energy production & distribution

- IEC 61850 is a standard for the design of electrical substation automation that defines a number of protocols that run over TCP/IP networks or substation LANs using high speed switched Ethernet to obtain the necessary response times below four milliseconds for protective relaying.
- In energy distribution systems, parameters such as currents and voltages are measured in distributed sensors, linked centrally and evaluated.
- Turbine controls use the PTP protocol to set up even more efficient plants.
- Monitoring processes, decentralise detected events are marked with precise time stamps and transferred to the control station for logging and analysis.

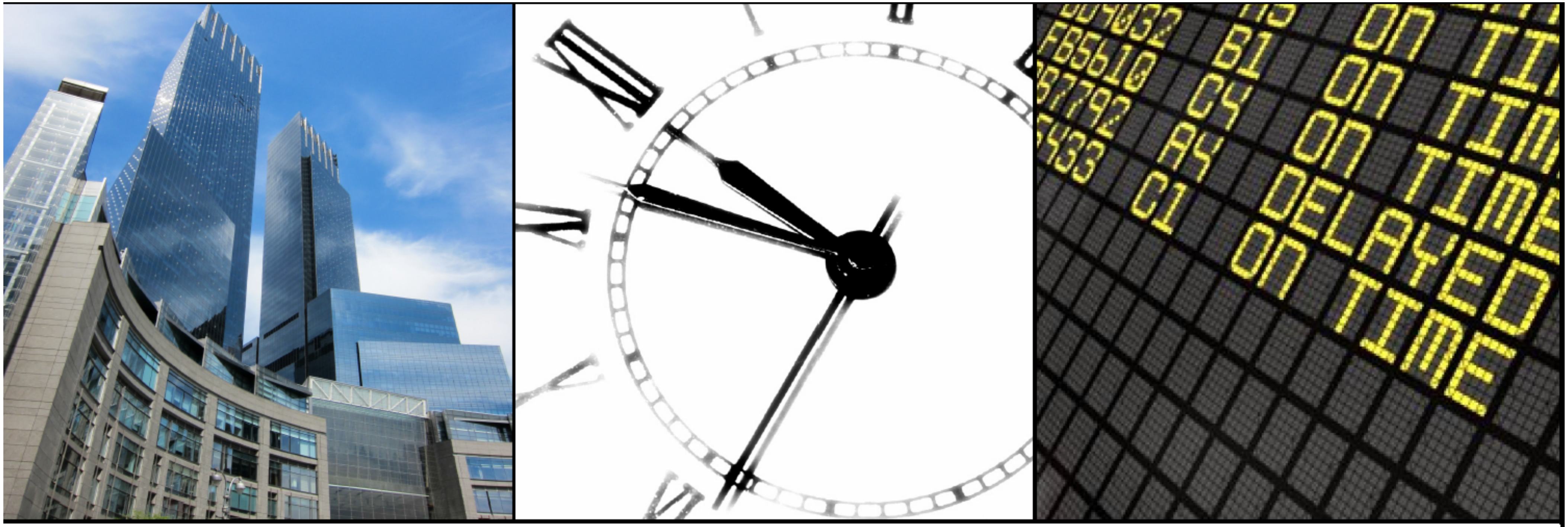
Railways



Modern railway engines consume energy when they start, but when they slow down or break the engine rotates backwards and therefore produces power back to the grid. Trains are moving around all the time so this is happening anywhere in the power grid network.

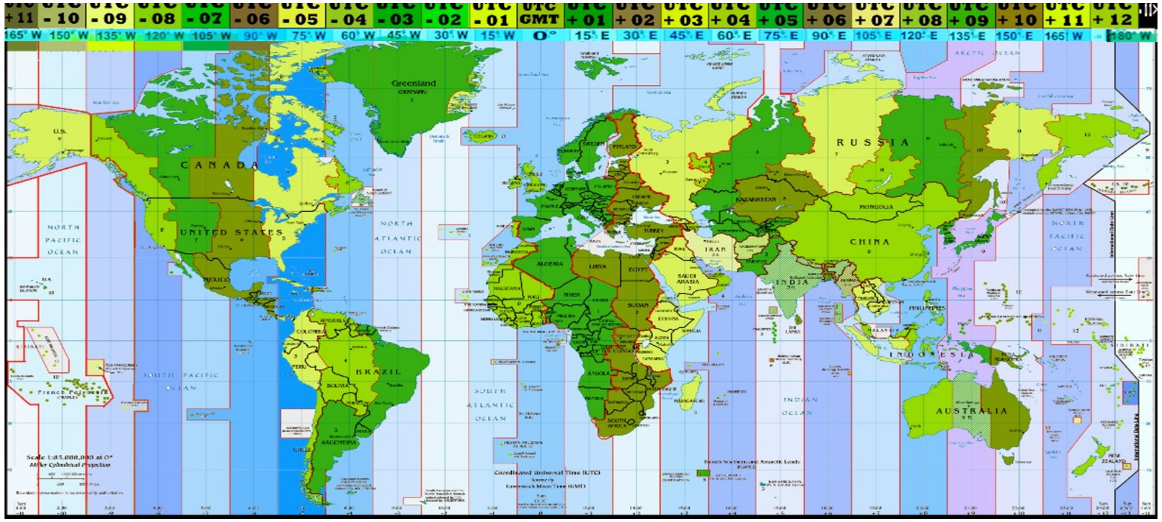
Accurate monitoring and time stamped measurements are essential to ensure optimal operation of converter stations at all times. This way power flows can be precisely analyzed and the converters can be fine-tuned to correct their static phase shifting properties and the dynamic behavior.

However, What the time is?



- Time is a fundamental physical dimension
  - It allows the chronological ordering
  - It allows the distribution of resources
- Time is measured by counting an event that is repeated regularly
  - It is measured by counting an event -physical or astronomical- that is repeated regularly
  - Astronomical events such as day, night, years
  - Physical events such as a pendulum, resonance quartz or atomic transitions

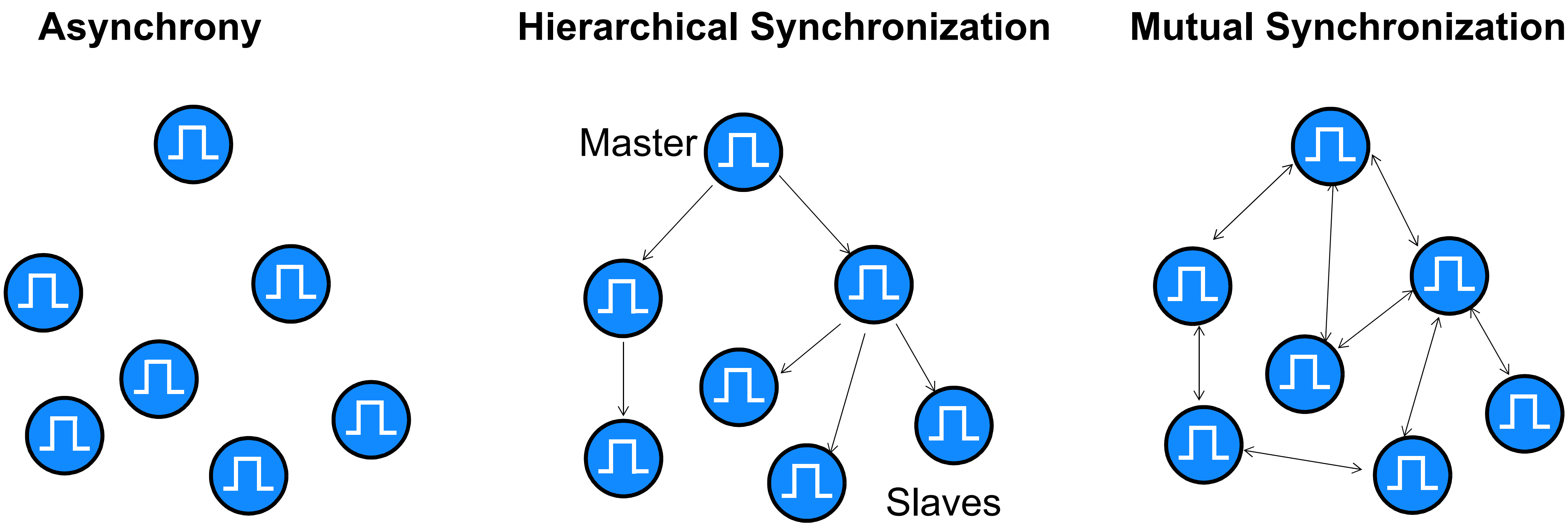
How to unify the time



GMT:	2015-07-17 02:33:00
UTC:	2015-07-17 02:33:00
GPS:	2015-07-17 02:33:17
LORAN:	2015-07-17 02:33:26
TAI:	2015-07-17 02:33:36

- The time requires a **reference** to start counting at one common point
  - Example: Gregorian calendar counts years from the birth of Christ
  - A reference gives a constant from a known epoch
- **Time stamps** on the messages... (how much it takes?)
  - A letter - it is useful to know the date when it was written
  - A phone call - can be used to adjust the hour / minute / second
  - A telecom package - assures millisecond accuracy level
- **Time Scales** UTC (Coordinated Universal Time), GMT (Greenwich Mean Time), TAI, LORAN, GPS...
  - GMT based on the rotation of the Earth
  - UTC atomic accuracy must compensate the 'unpredictable' earth rotation (1m. Of 59s / 61s.)
  - UAT (Universal Atomic Time) based on 200 atomic clocks and makes corrections.

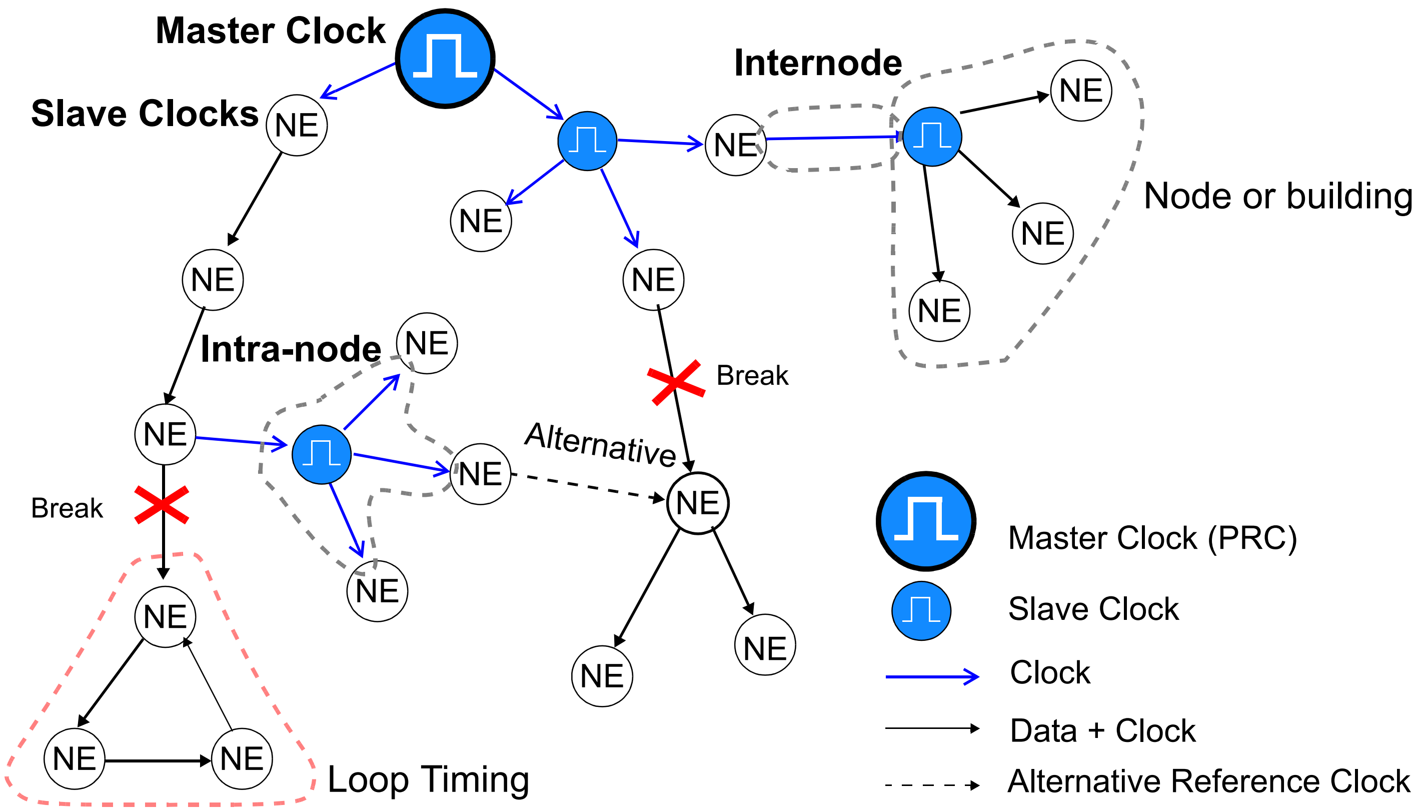
About Synchronization



Synchronization is the set of techniques that enable the frequency and phase of the equipment clocks in a network to remain constrained within the specified limits.

The first digital networks were asynchronous, and therefore did not call for properly working external synchronization. It was the arrival of SONET networks that started to make synchronization essential to maintain transmission quality and efficiency.

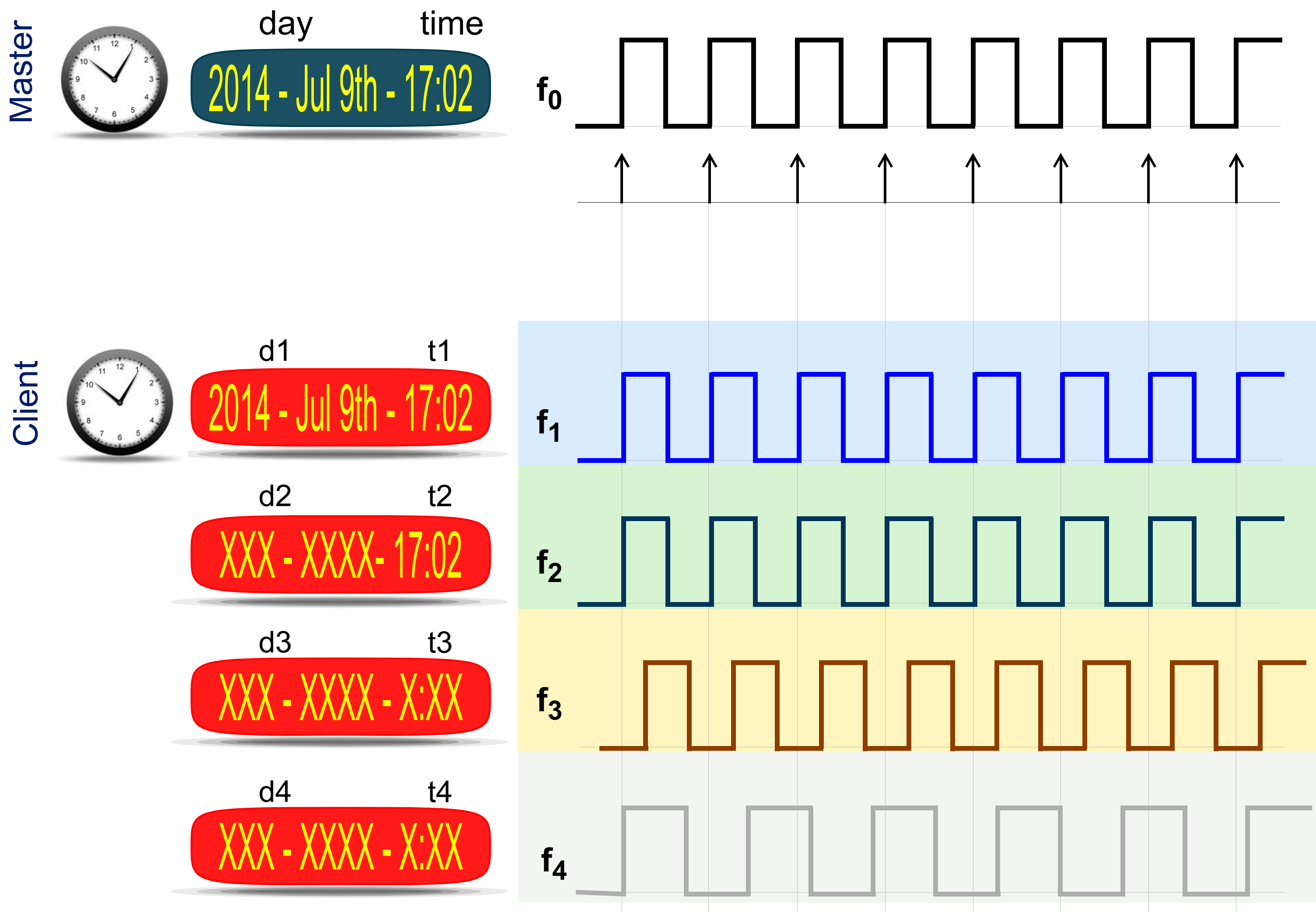
Time distribution



There are two basic ways to distribute synchronization across the whole network:

- **Intranode**, which is a high-quality slave clock known as either synchronization supply unit (SSU) or building integrated timing supply (BITS). These are responsible for distributing synchronization to NEs situated inside the node.
- **Internode**, where the synchronization signal is sent to another node by a link specifically dedicated to this purpose, or by an TDM signal or an Ethernet packet.

Sinchronization, Sintonization..



Reference Clock (frequency)

Clock significant instants (phase)

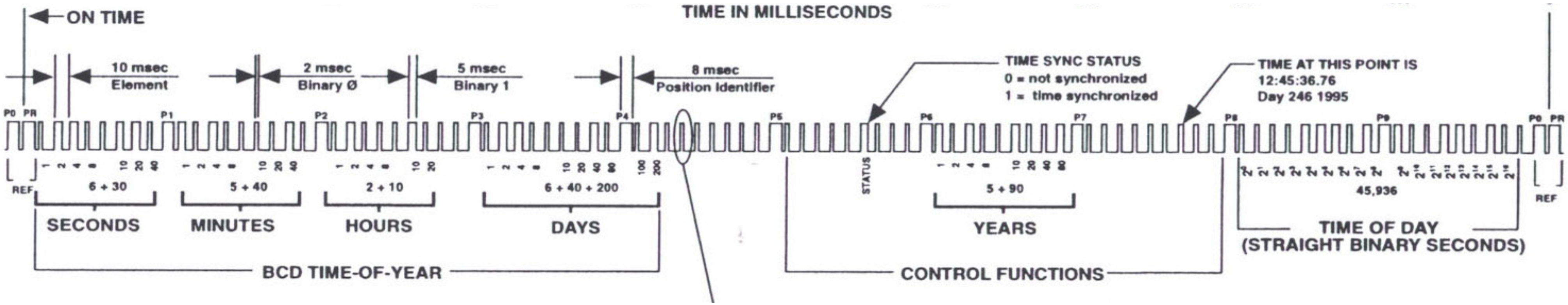
1 - **Time/Day Synchronization** ($f_1=f_0$; $ph_1=ph_0$; $t_1=t_0$; $d_1=d_0$)

2 - **Phase Synchronization** ($f_2=f_0$; $ph_2=ph_0$; $t_2=t_0$)

3 - **Syntonization** ($f_3=f_0$)

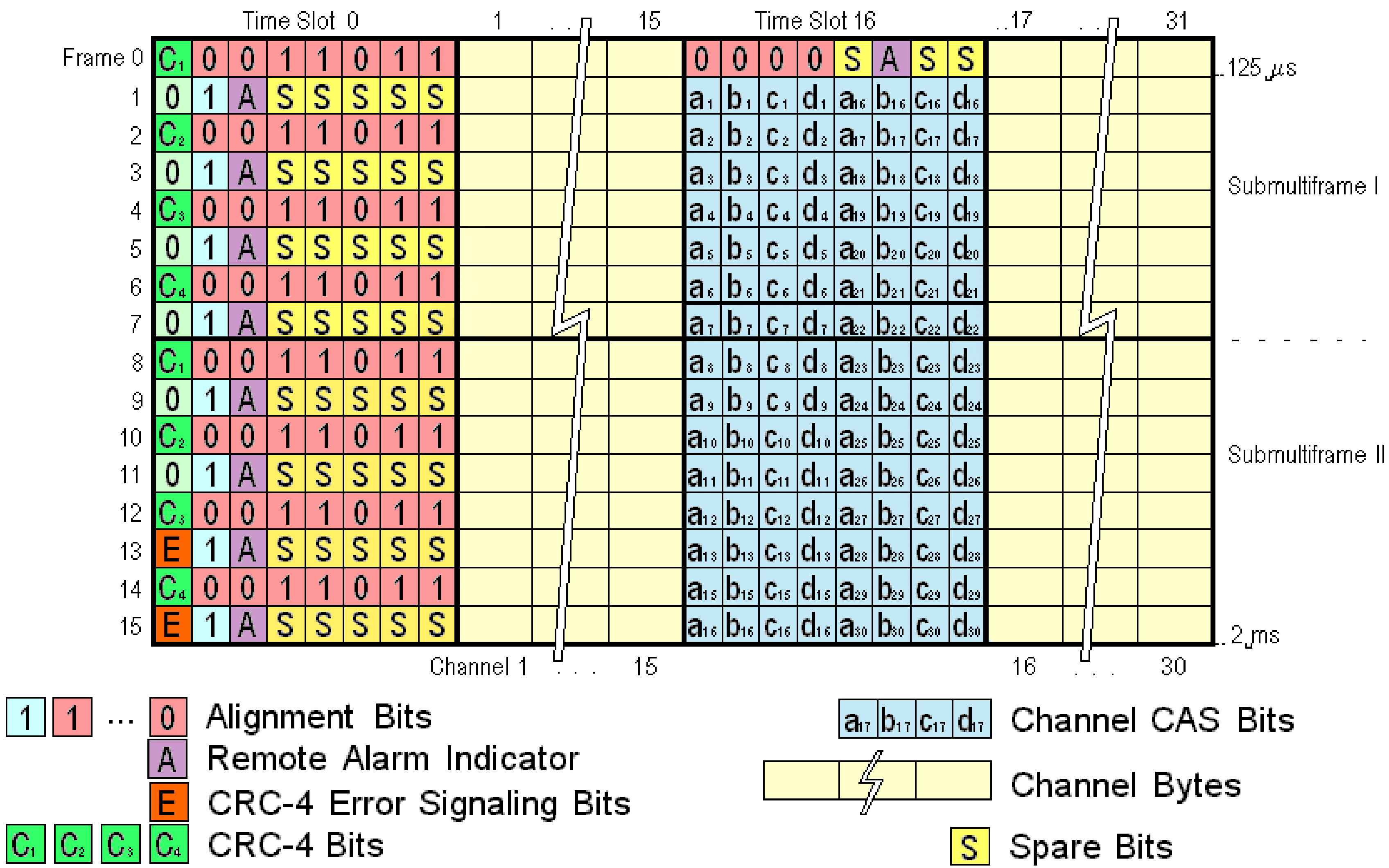
4 - **Asinchrony** ($f_4 \neq f_0$)

IRIG-B



- Developed for the US Army (1960) and it is widely used in **Power Utilities**.
- **IRIG Frame Format**
  - Consists of 100 bits produced every second, 74 bits of which contain time information
  - Various time, date, time changes and time quality information of the time signal
  - IEEE-1344 extension included year data information
- Unmodulated **IRIG-B transmission**
  - TTL-level signal over coaxial cable or shielded twisted-pair cable
  - Multi-point distribution using 24 Vdc for signal and control power
  - RS-485 differential signal over shielded twisted-pair cable
  - RS-232 signal over shielded cable (short distances only)
  - Optical fiber

Synchronization TDM: E1 / T1

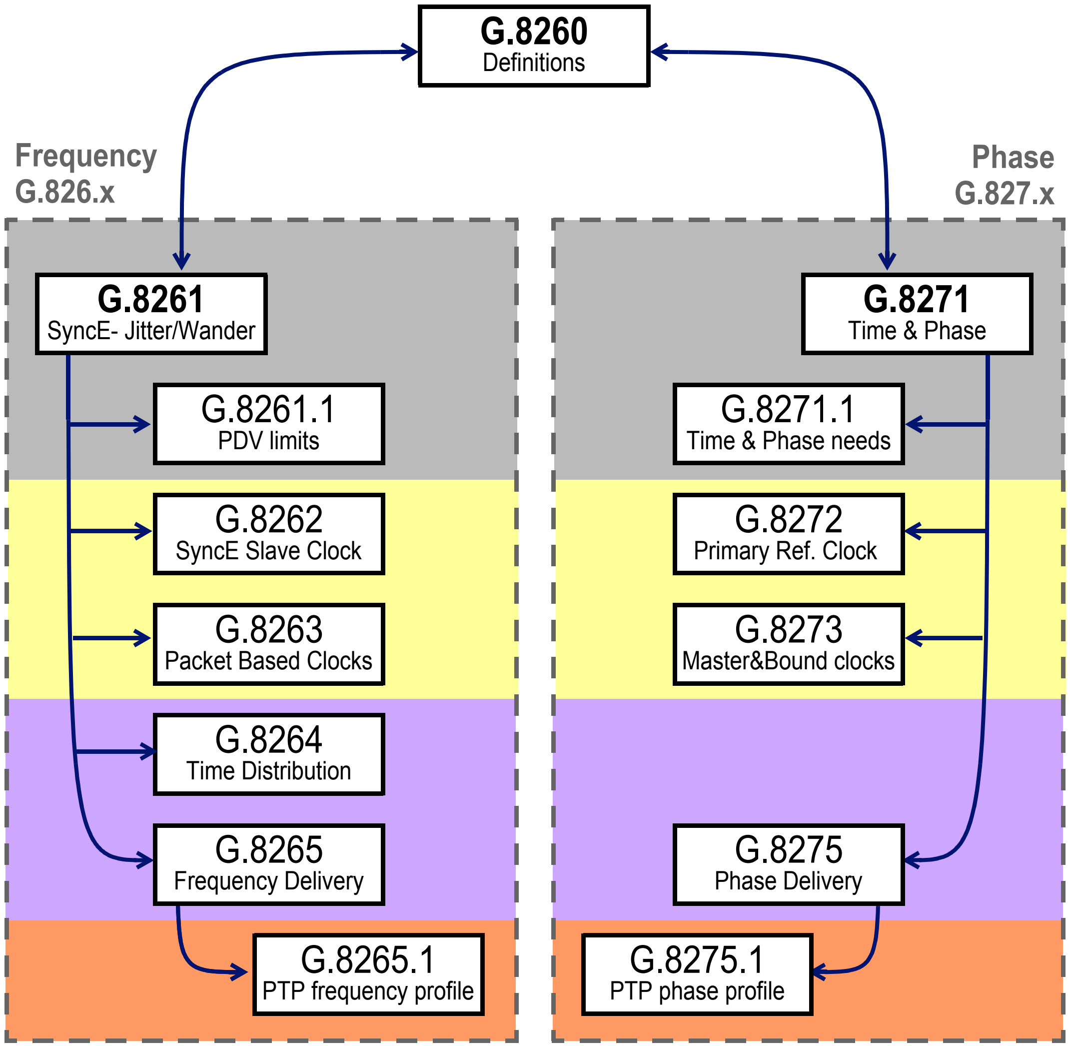


Objective of SyncE: internetworking

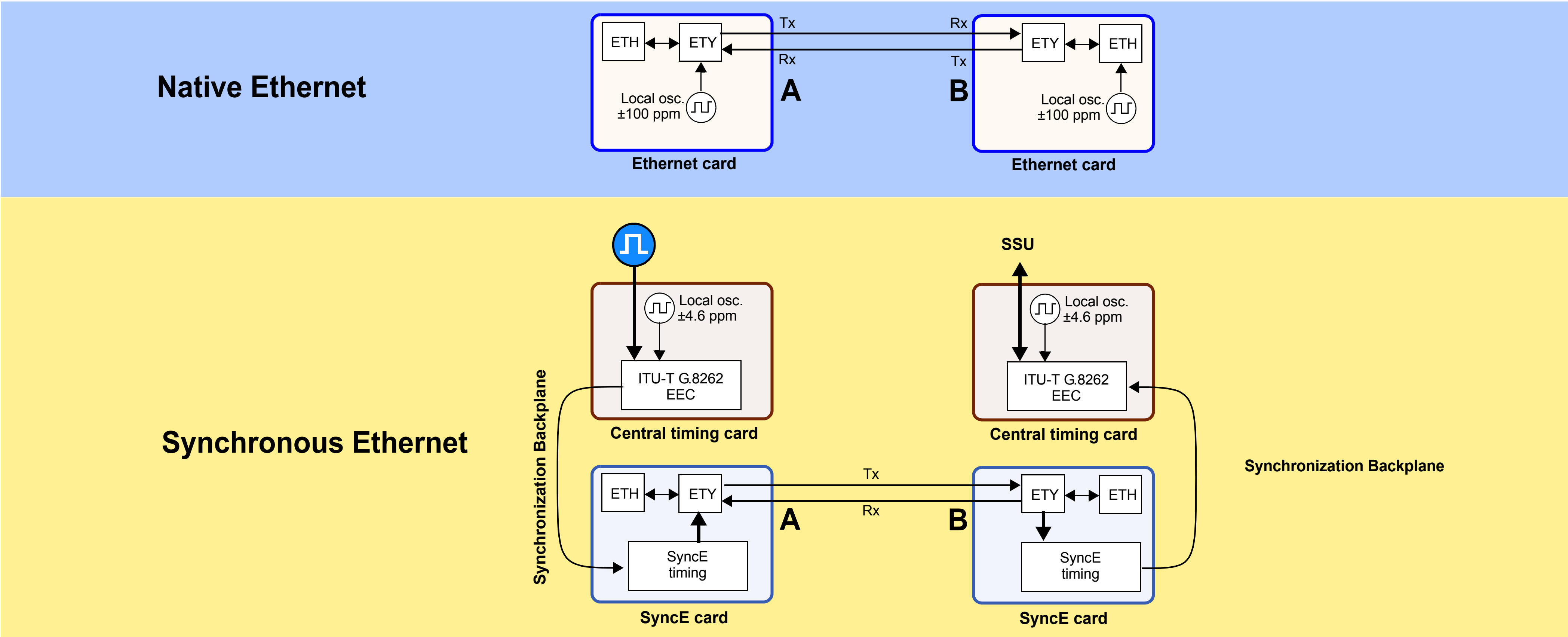
Defined in ITU-T G.8261, G.8262, G.8264
Objectives:

- Inclusion of Ethernet (SyncE) as part of SONET/SDH synchronization network **(G.8261)**
- SyncE become slave clocks thanks to higher accuracy, less noise and stability **(G.8262)**
- Extension of the Synchronization Status Message of SDH to SyncE by means of Ethernet Status Message Channel ESMC **(G.8264)**

The difference between conventional Ethernet is that SyncE is prepared to accept external timing



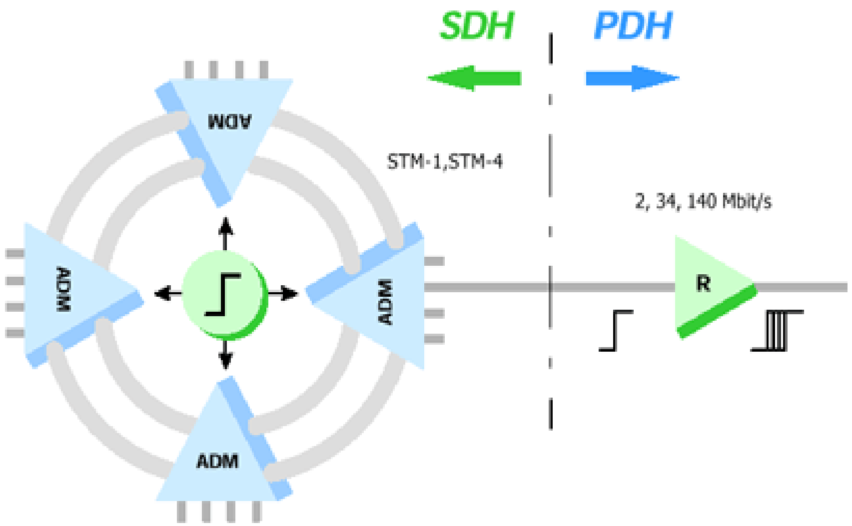
Synchronous Ethernet



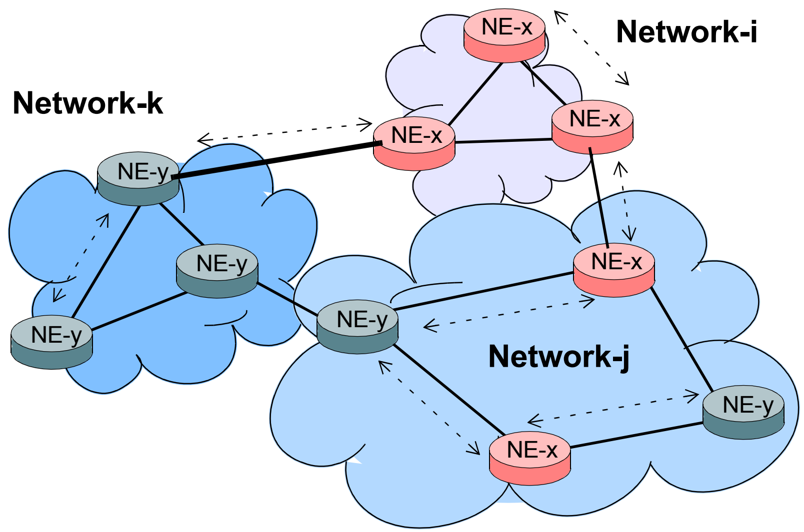
- **PHY Ethernet**
  - Rx gets synchronized using the input line [Tx (port B) >>> Rx (port A)]
  - BUT there is no time relation between the Rx and Tx of the same Port
- **SyncE PHY** (physical layer)
  - Rx gets synchronized using the recovered clock
  - Tx uses a traceable reference clock

Synchronization moves from TDM to Packets

Circuit Networks

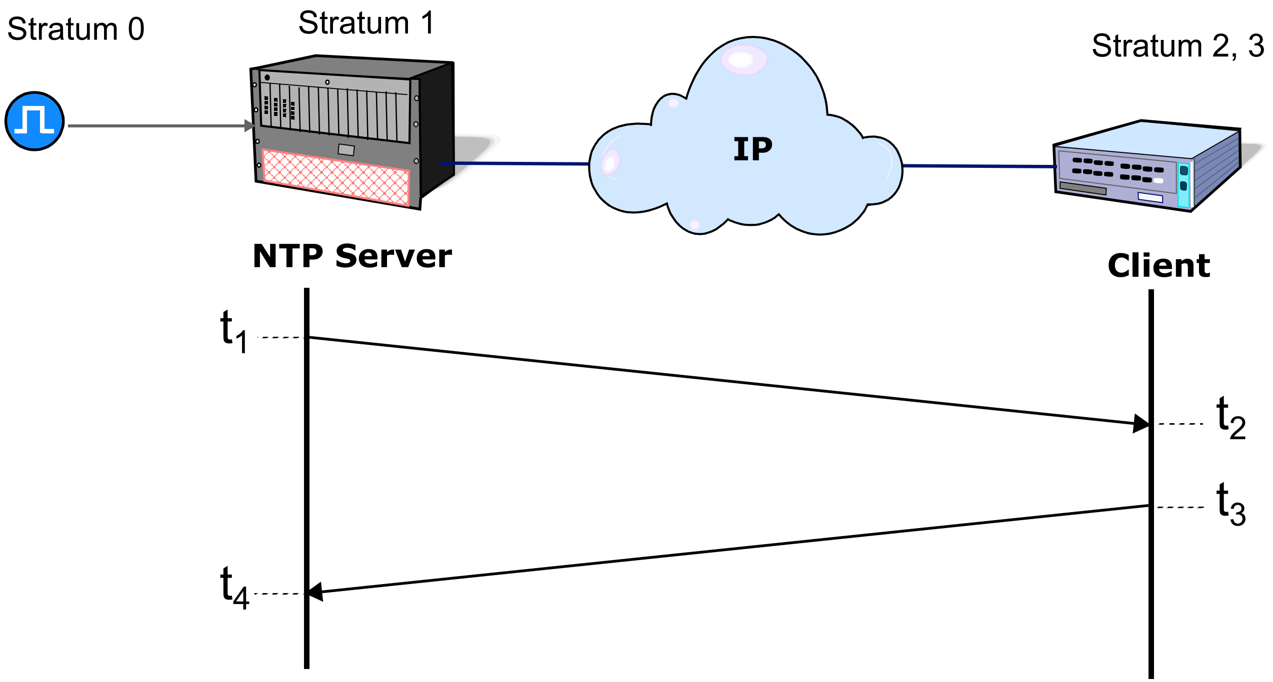


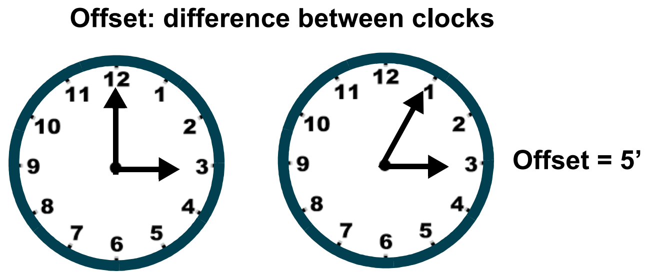
Packet Networks



- Is it possible to synchronize using a Packet Network?
- With TDM frames it easier as have a regular pattern i.e. E1/T1 = 125us
- However, packets do not arrive regularly. Then how to synchronize?
  - There are Ethernet PHY layer that allow it (i.e. 8B10B and SyncE too)
  - Alternatively Ethernet may carry timestamps!
- Therefore time and frequency can be distributed from point A to point B

NTP (Network Time Protocol)



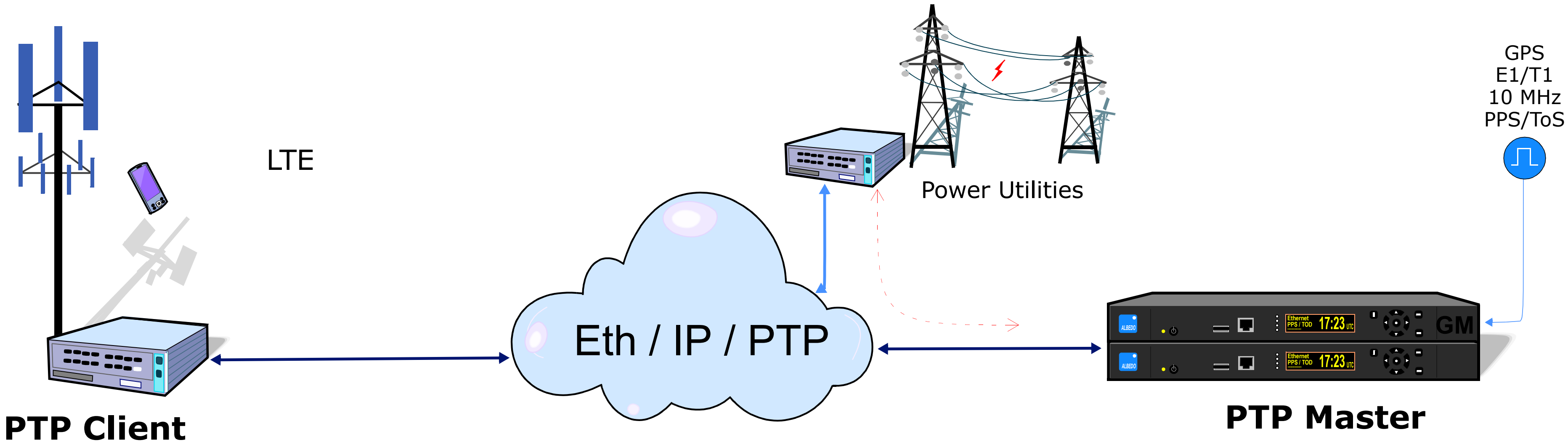


$$\text{Offset} = \frac{(t_2 - t_1) + (t_3 - t_4)}{2}$$

$$\text{Round Trip Delay} = (t_2 - t_1) + (t_4 - t_3)$$

- Network Time Protocol (NTP) is an Internet protocol for synchronizing the clocks of computer systems over packet network with variable latency.
- The clock frequency is then adjusted to reduce the offset gradually, creating
- Precision 1 - 10 ms. in Internet, (0,5 - 1 ms for LAN ideal conditions)

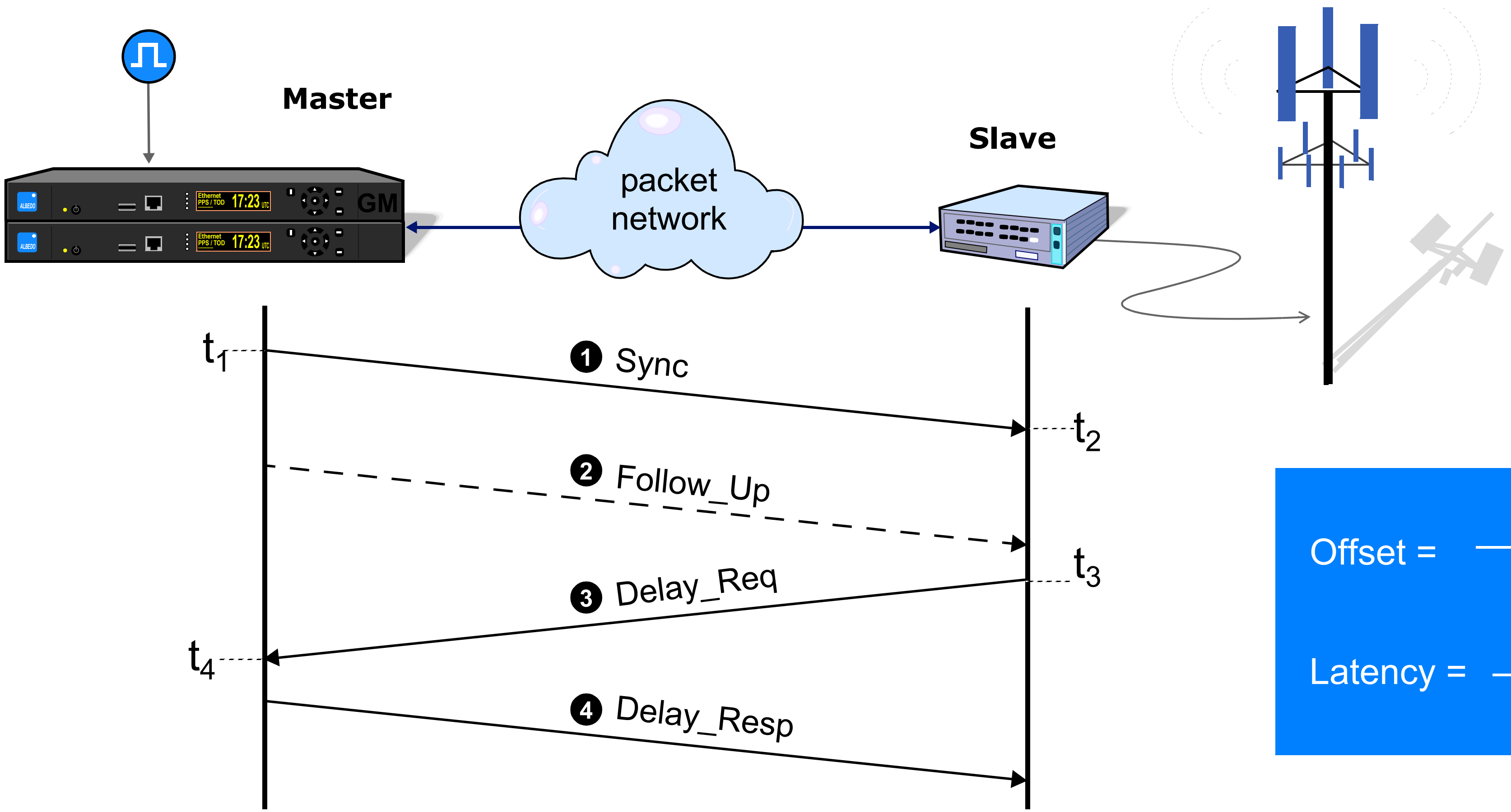
IEEE 1588 **PTP**v2



The idea for PTP was born at the end of the 90s in the USA at Agilent Technologies in the field of measuring technology. The process principle developed there was submitted to the IEEE as a suggestion and created the basis for the IEEE 1588 standard. At the end of 2002 PTP was passed as a standard under the name of *"1588TM - IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems"*. In addition, PTP was also adopted as an IEC standard in May 2004 and was published under the name of IEC 61588.

- Grandmaster sends a series of messages with date and time to client-clocks
- Client-clocks compensate the delays and get synchronized with the Master
- Frequency is then recovered with a precise time-of-day

PTP - Precision Time Protocol (IEEE 1588)

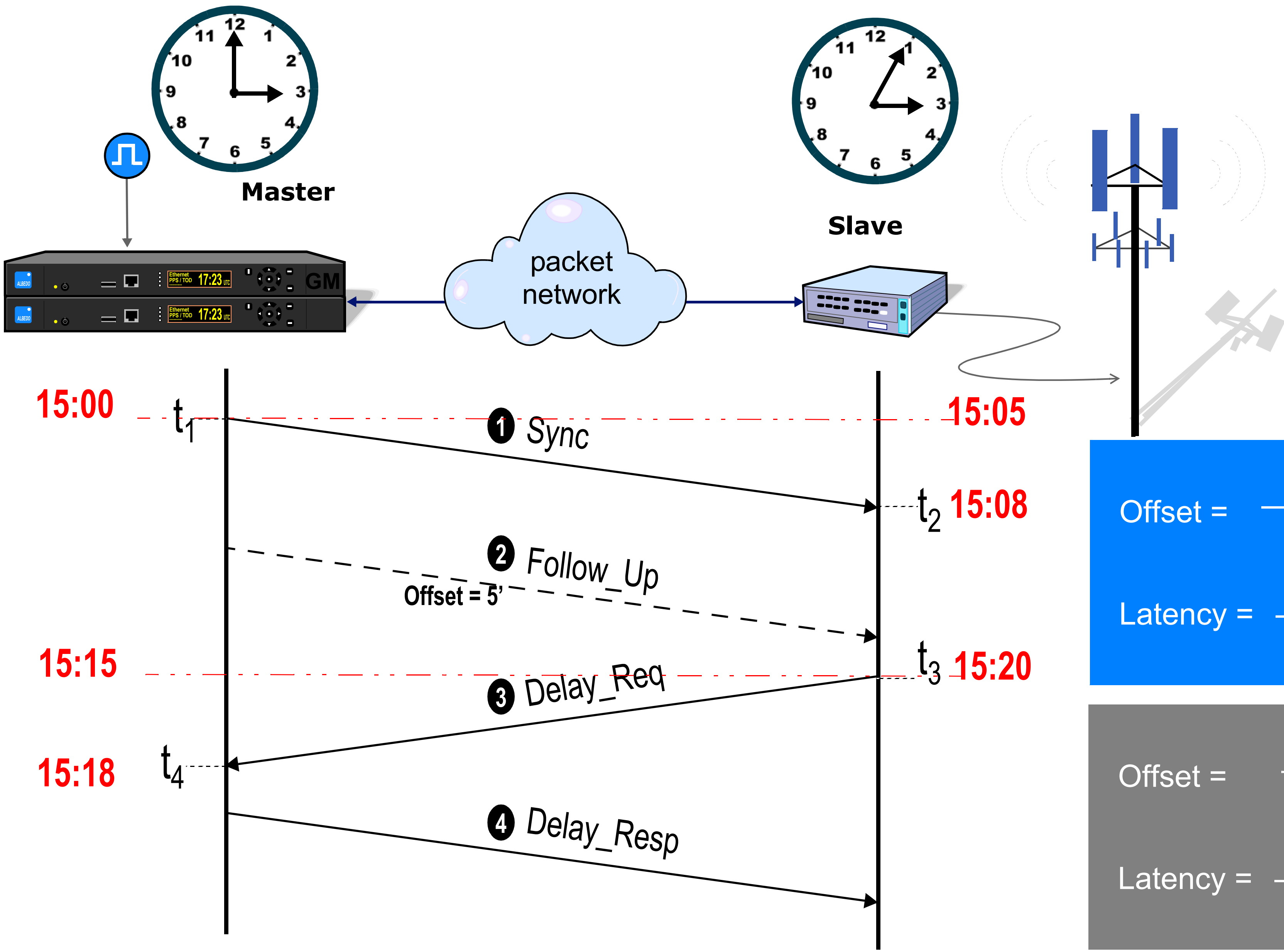


$$\text{Offset} = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}$$

$$\text{Latency} = \frac{(t_2 - t_1) + (t_4 - t_3)}{2}$$

- The basic parameters of Latency / Offset are computed from the $t_{1...4}$ timestamps
- The precision is achieved
  - Frequent Packets (up to 128 per second)
  - Hardware Timestamp (NTP is software)
- Best Master Clock algorithm

PTP - Sample



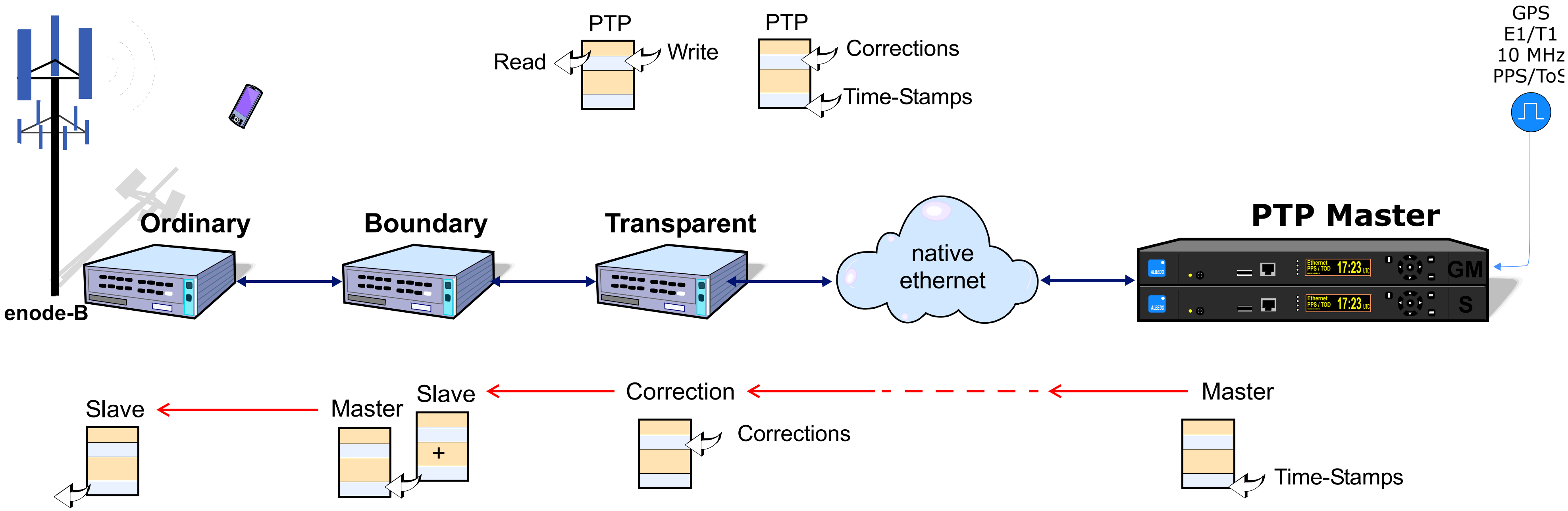
$$\text{Offset} = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}$$

$$\text{Latency} = \frac{(t_2 - t_1) + (t_4 - t_3)}{2}$$

$$\text{Offset} = \frac{(8) - (-2)}{2} = 5$$

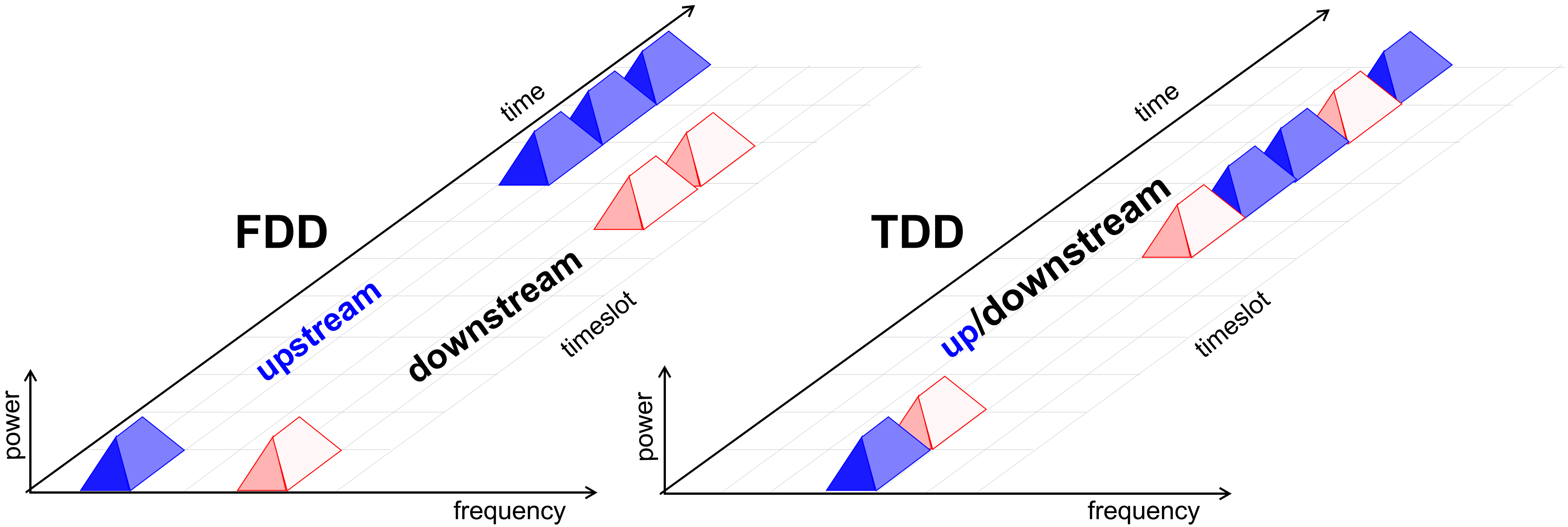
$$\text{Latency} = \frac{(8) + (-2)}{2} = 3$$

Clocks and Nodes in PTP



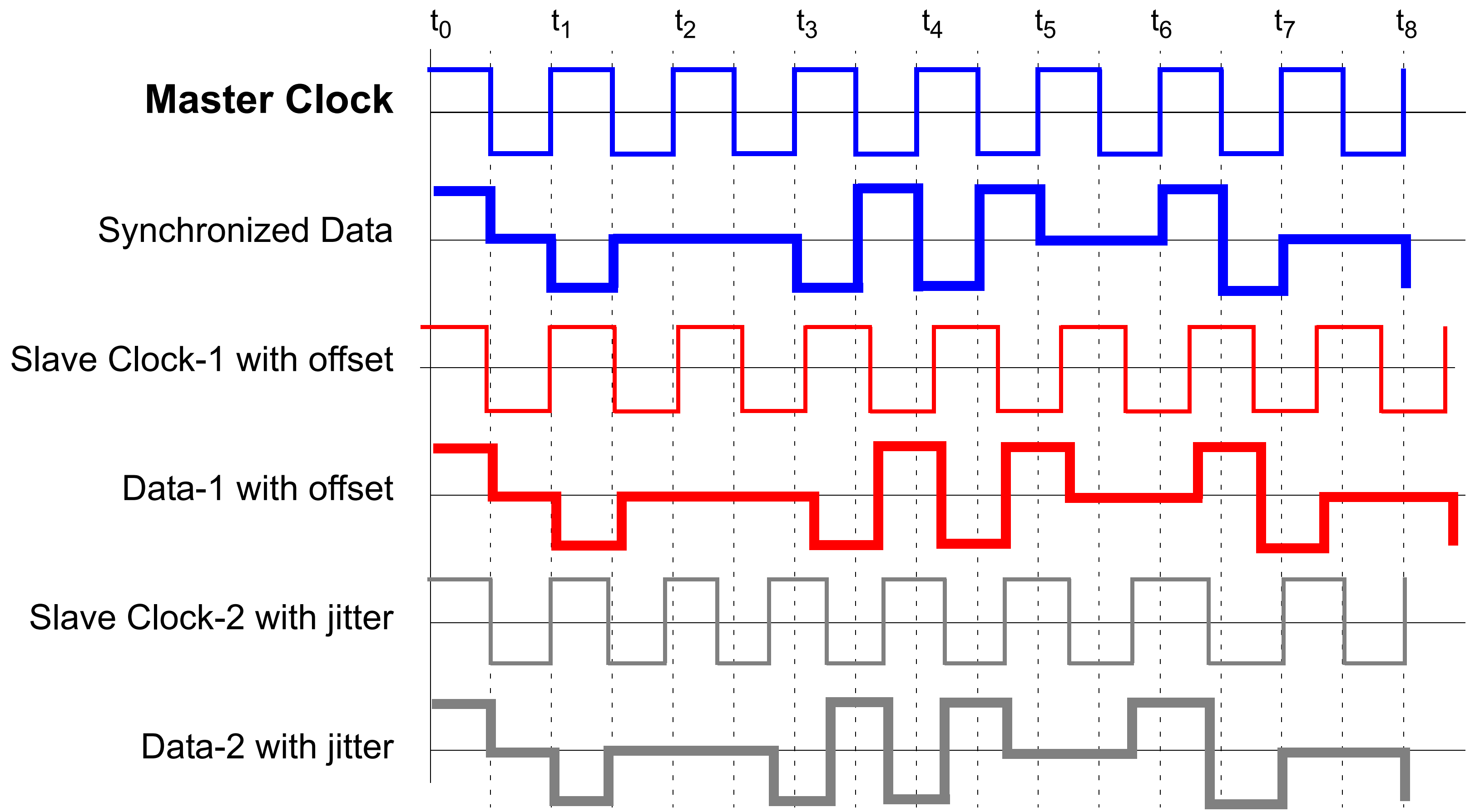
Clocks & Nodes	Description
Ordinary Clock	A single port device that can be a master or slave clock.
Boundary Clock	A multi port device that can be a master or slave clock.
End-to-end Transparent	A multi port device that is is a bridge between master/slave. Forwards and corrects all PTP msgs
Peer-to-peer Transparent	A multi port device that is a bridge between master/slave. Forwards /corrects Sync & Follow-up
Management Node	A device that configures and monitors clocks.

New Opportunities in Telecom: LTE



- In FDD duplexing upstream and downstream use separate frequencies
- In TDD upstream and downstream share the frequency (more efficient use bandwidth)
- Then FDD requires only Syntonization (frequency)
- TDD requires Phase Synchronization (phase and frequency)

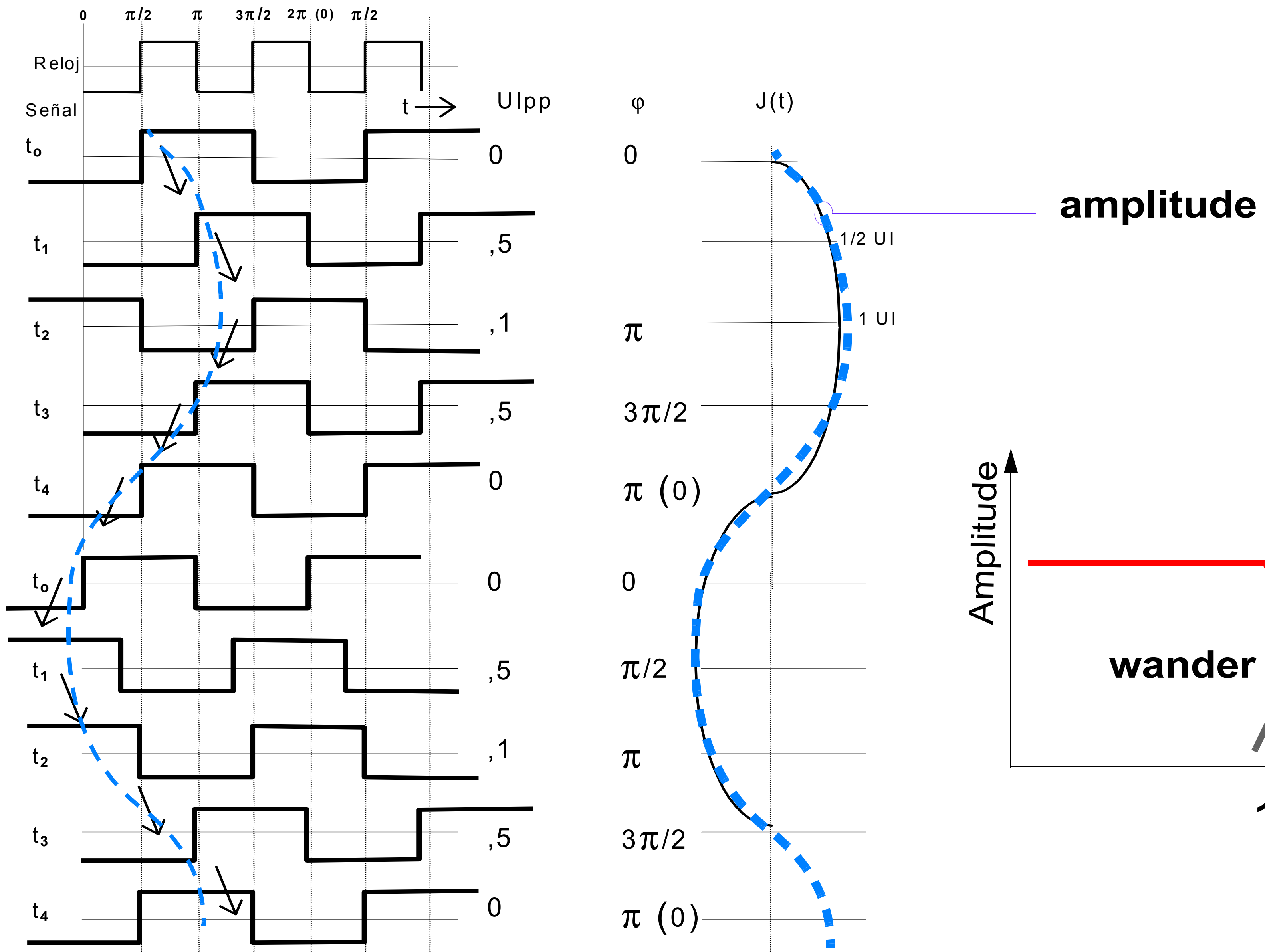
Jitter y Wander (i)

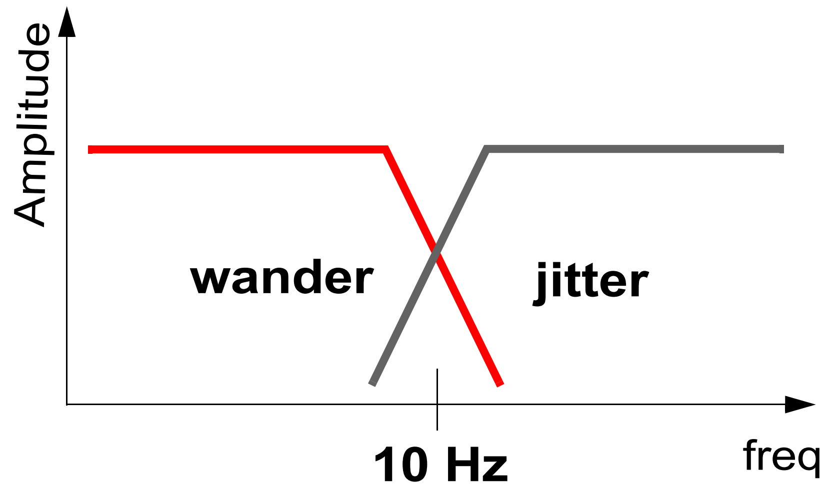


A master clock that marks the significant instances for data transmission.

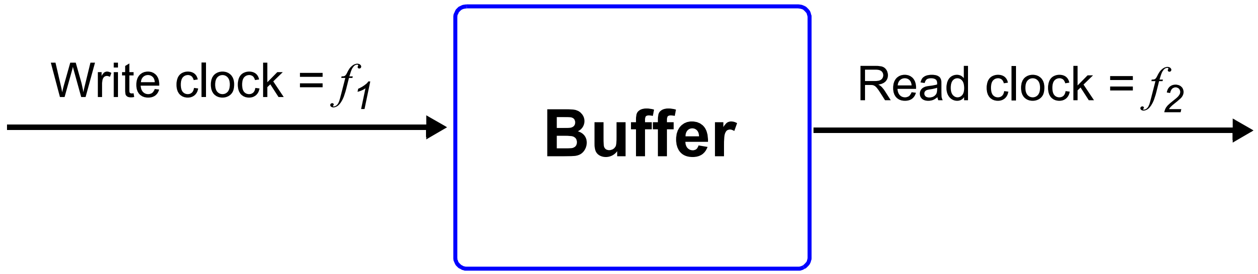
- Clocks 1 and 2 are badly synchronized,
- Data transmitted with these references is also affected by the same phase error.

Jitter y Wander (ii)



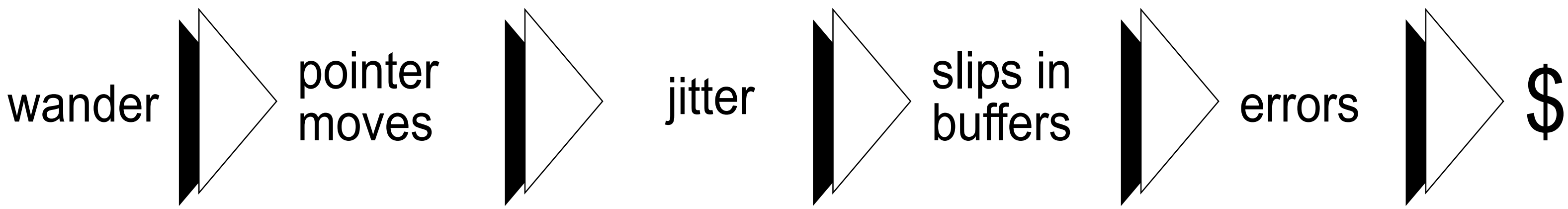


Bad synchronization in TDM: Slips

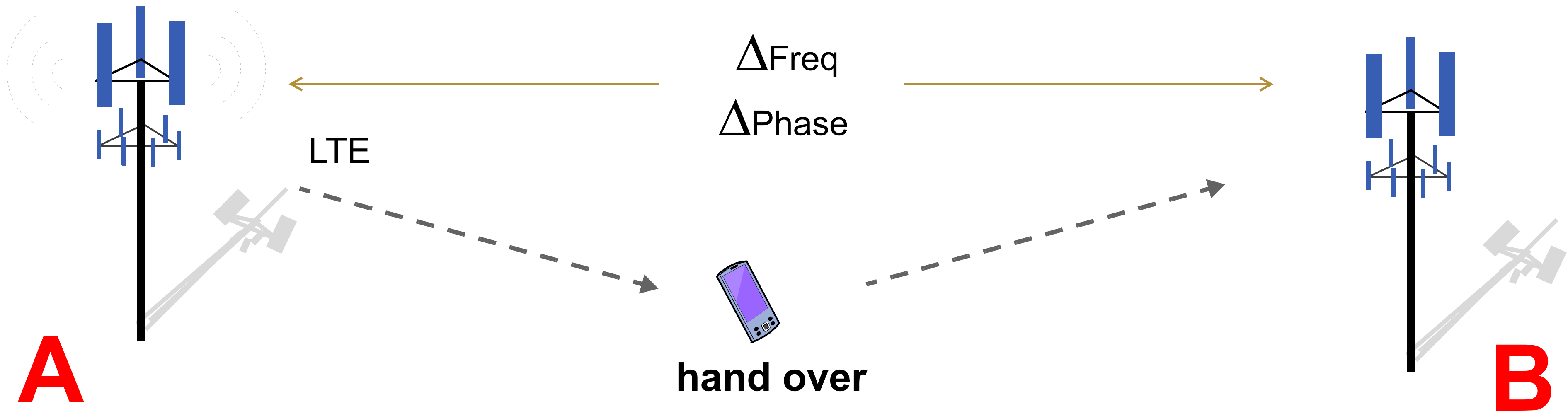


if $f_1 > f_2$ then overflows; if $f_1 < f_2$ then underflows

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



Timing Alignment in Wireless

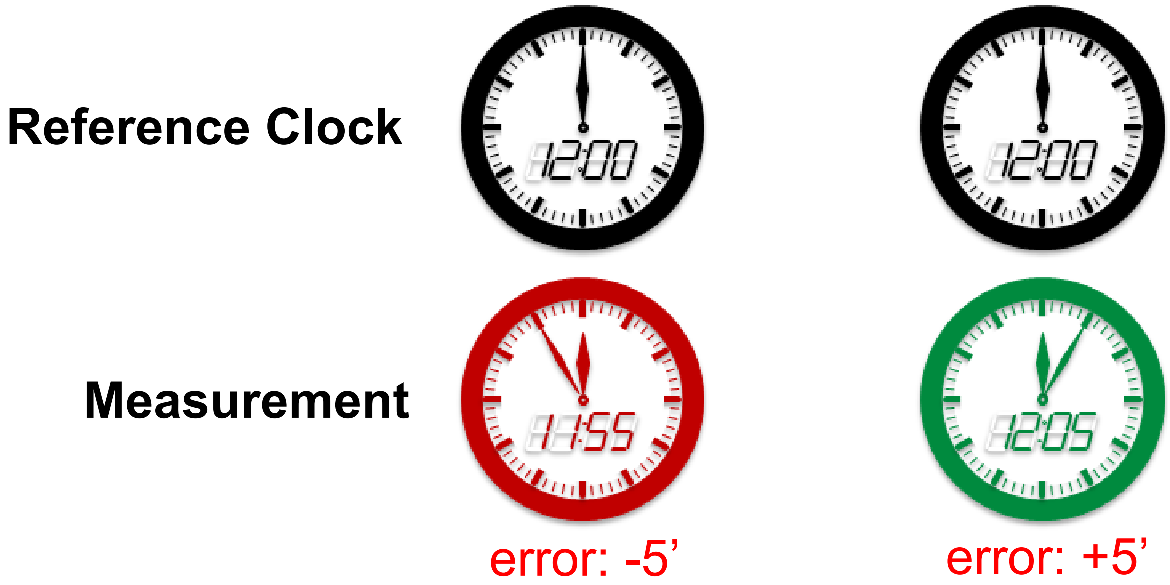


- When hand-over occurs, the mobile must reacquire carrier frequency
  - Large Df compromises the reliability of hand-over; 50 ppb typical requirement

- TDD networks require time/phase alignment between A & B
  - To control interference between uplink and downlink
  - Requirement in the microsecond range
  - To avoid time overlapping requires phase synchronization 1.5 us

- TDD networks require time/phase alignment between A & B
  - To control interference between uplink and downlink
  - Requirement in the microsecond range

Time error (TE)



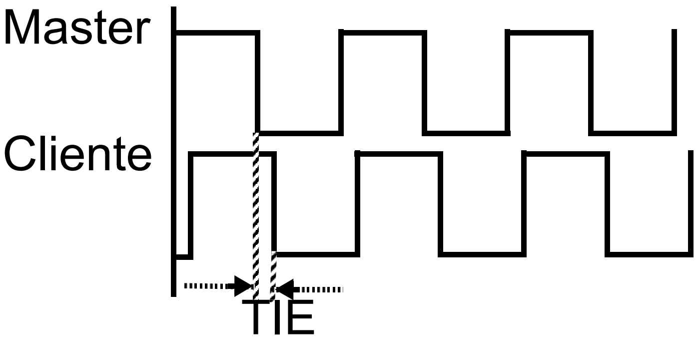
- Time Error (TE) is the difference between the announced time and its time reference
- It is a relative measurement because it does not make sense without reference
- Defined by the ITU-T Recommendation G.810

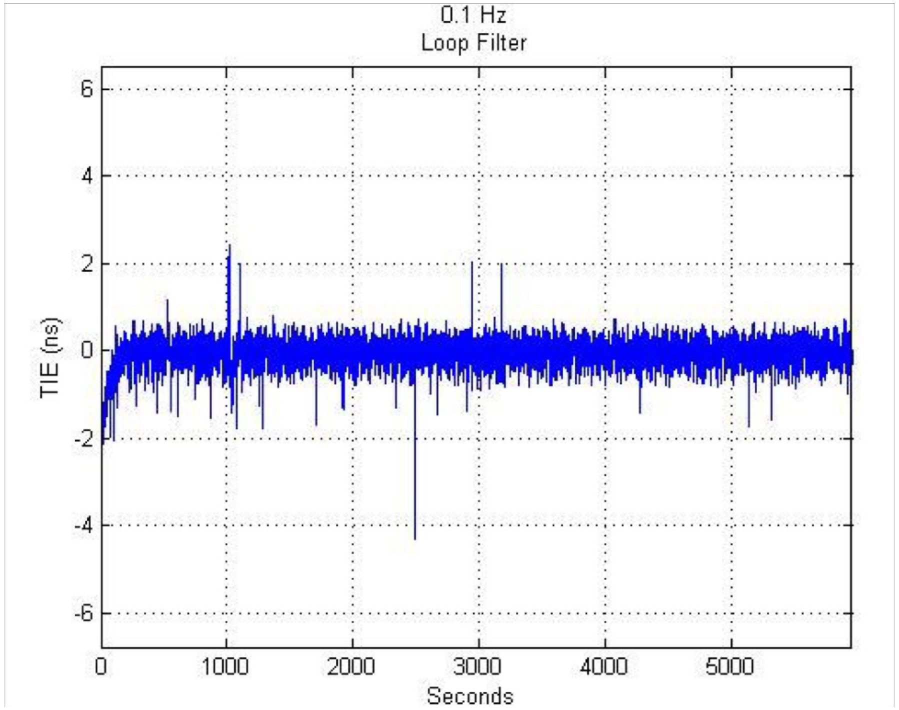
$x(t) = T(t) - T_{ref}(t)$

$x(t)$: *error*
$T(t)$: *time in the clock*
$T_{ref}(t)$: *reference time*

Time Interval Error (TIE)

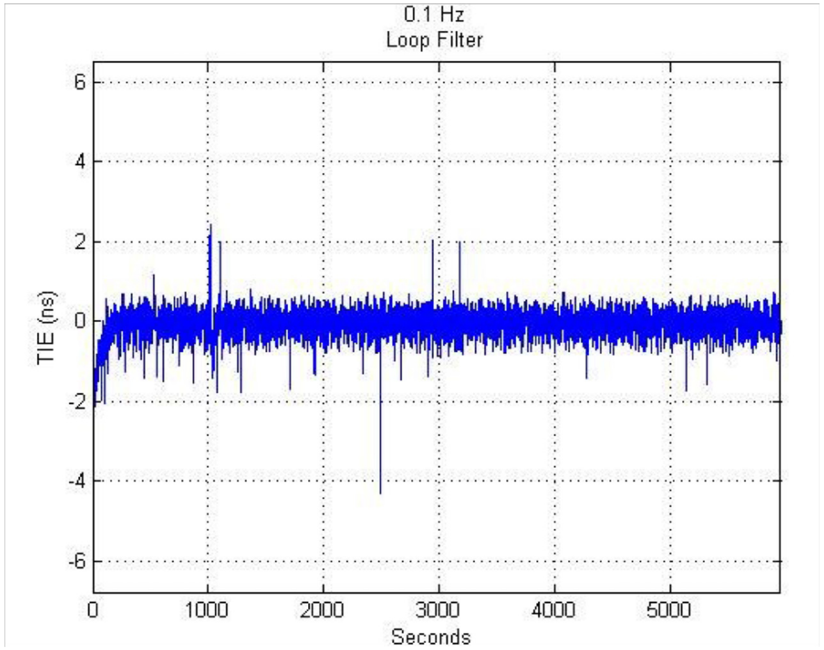
Begining: TIE(t_0) = 0

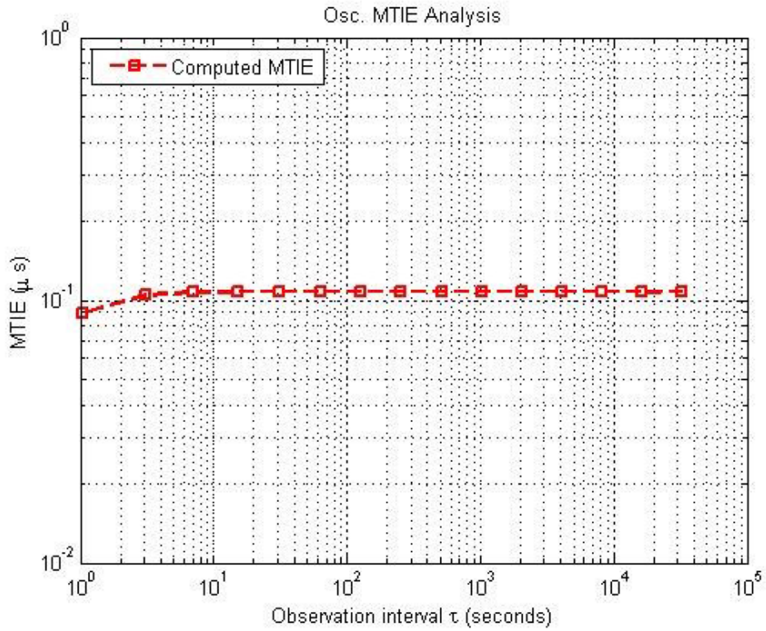




- TIE is the basic measure of wander used in TDM. The unit is the nanosecond
- TIE gives the instantaneous phase error in f(t) from the start of the measurement TIE (t_0) = 0
- It is not relevant in itself but its calculation is prior to the remaining measures
- Appropriate for measuring quality because the reference frequency is the beginning of the measure while TE is requires an absolute scale such as TAI or GPS

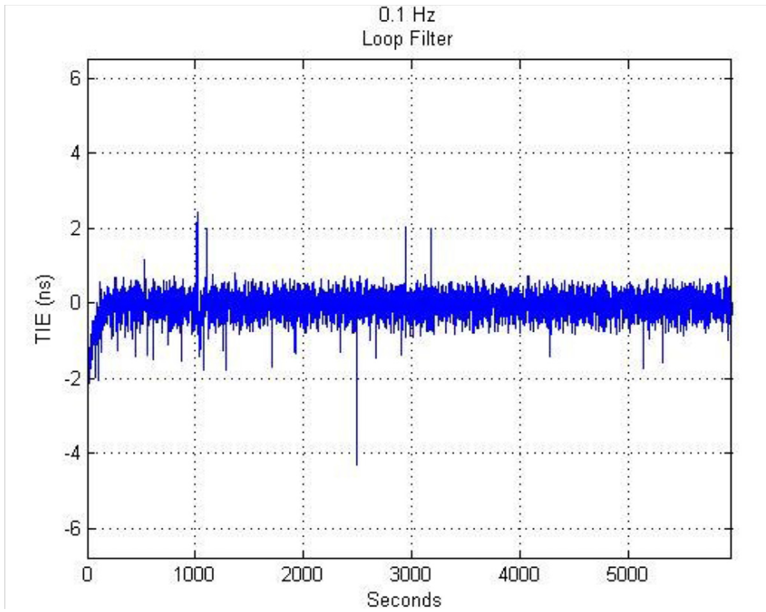
MTIE: Maximum TIE

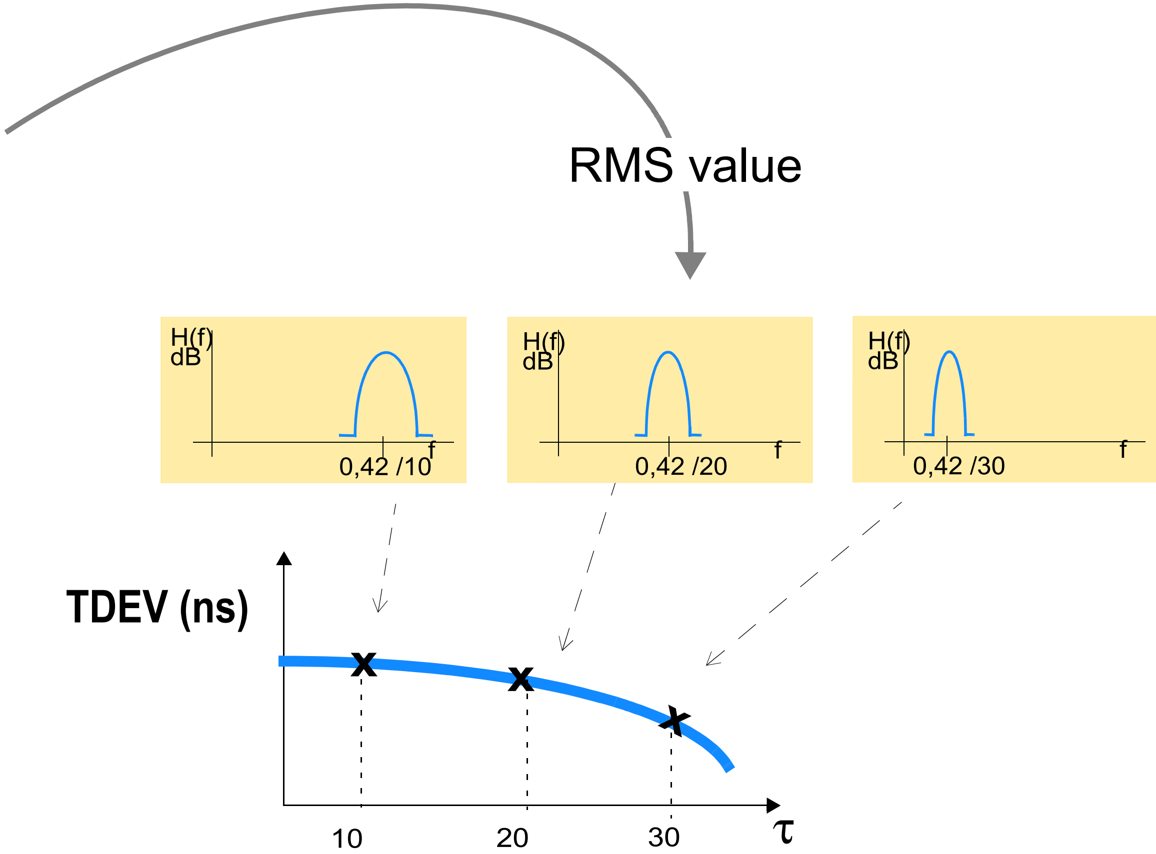




- MTIE measure the amplitude of the TIE variation
- It is useful to calculate the buffer size to filter the wander
- Packet Filtered MTIE (is an algorithm equivalent to MTIE at the packet interface)

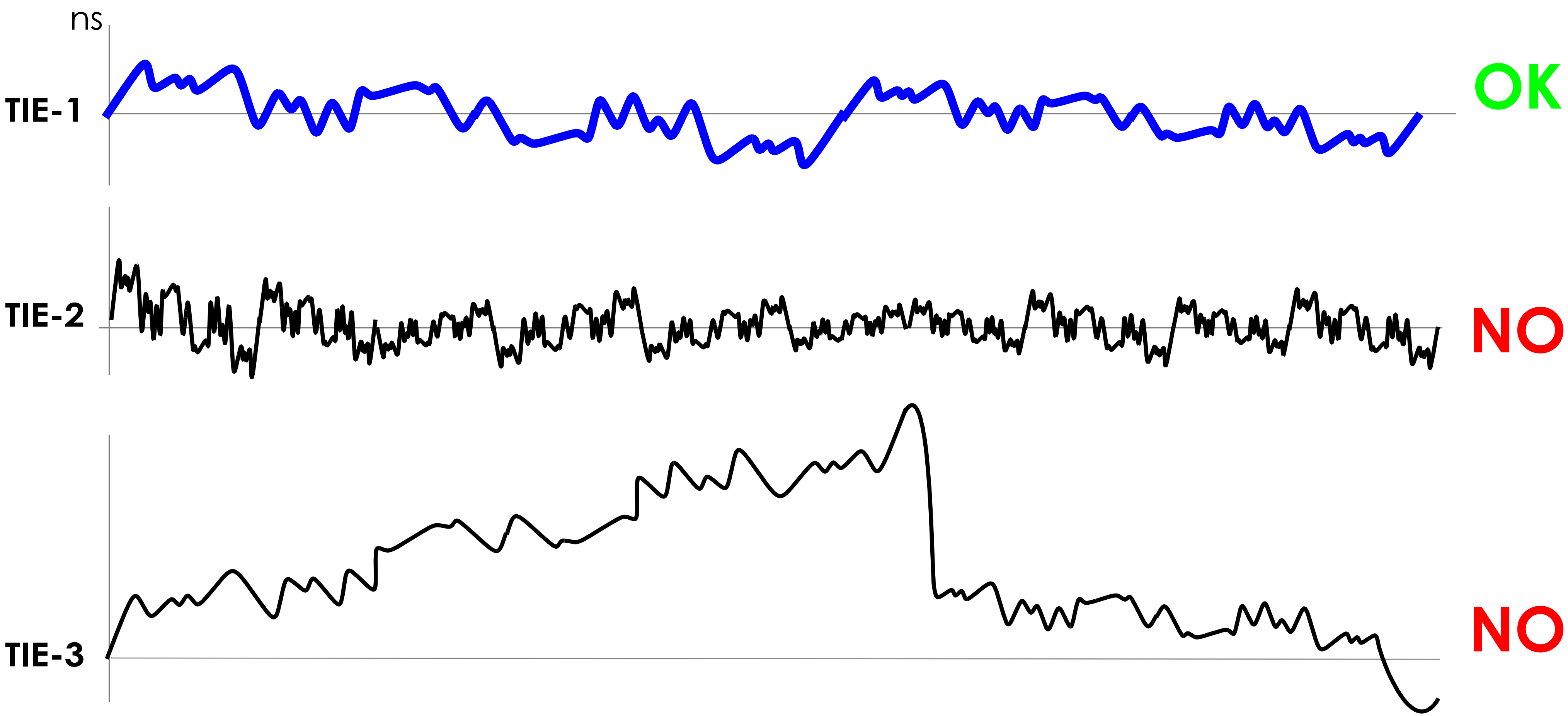
Time Deviation (TDEV)





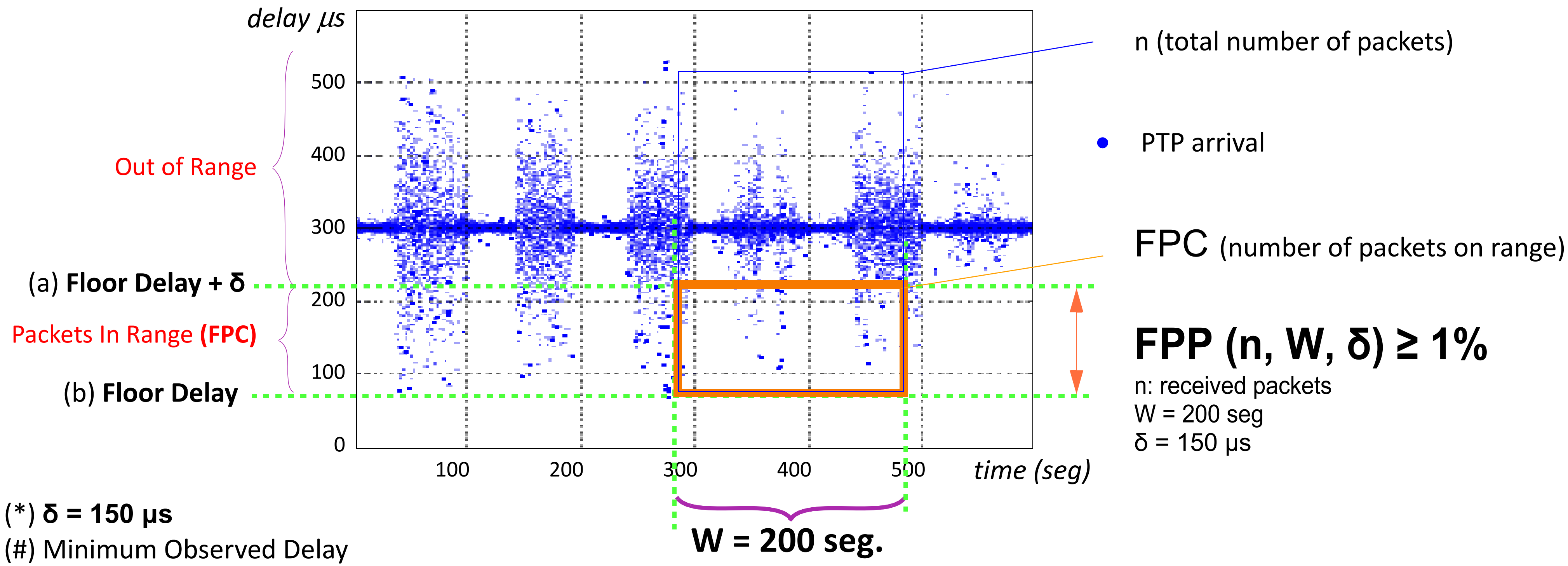
- Useful to characterize the spectral content of the wander
- It identifies the phase noise

Three Samples of TIE



- TIE-1 is ok
- TIE-2 is MTIE compliant, not with TDEV because there is too much spectral noise
- TIE-3 is TDEV compliant but fails in MTIE because the noise has too much amplitude

Floor Packet Measurements (ITU G.8271.1)

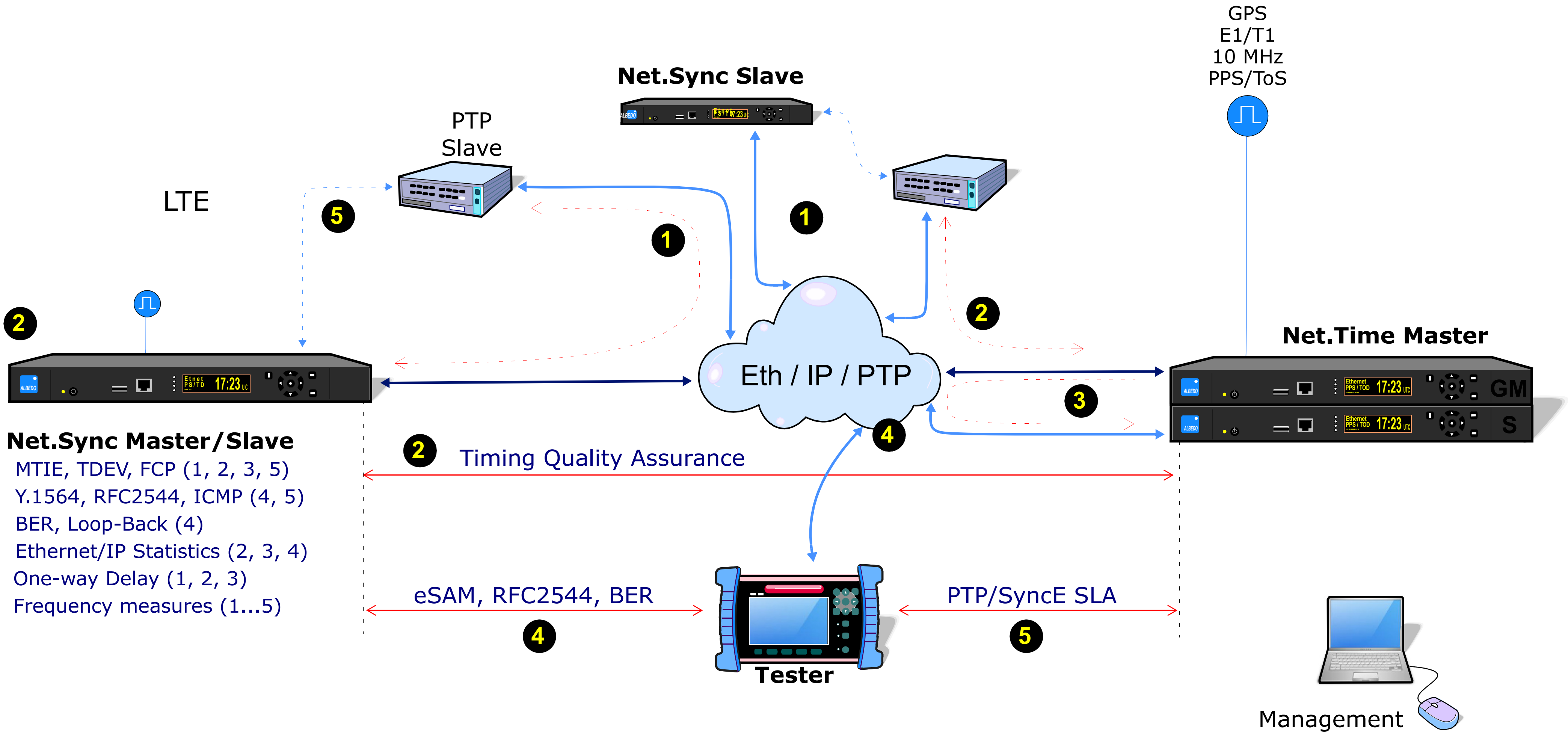


(*) **δ = 150 µs**
(#) Minimum Observed Delay

Packets arrive to destination with a variable delay (or Packet Delay Variation) then Floor metrics are indicators thar at least a portion of the packets arrive on time (for instance more that 1%)

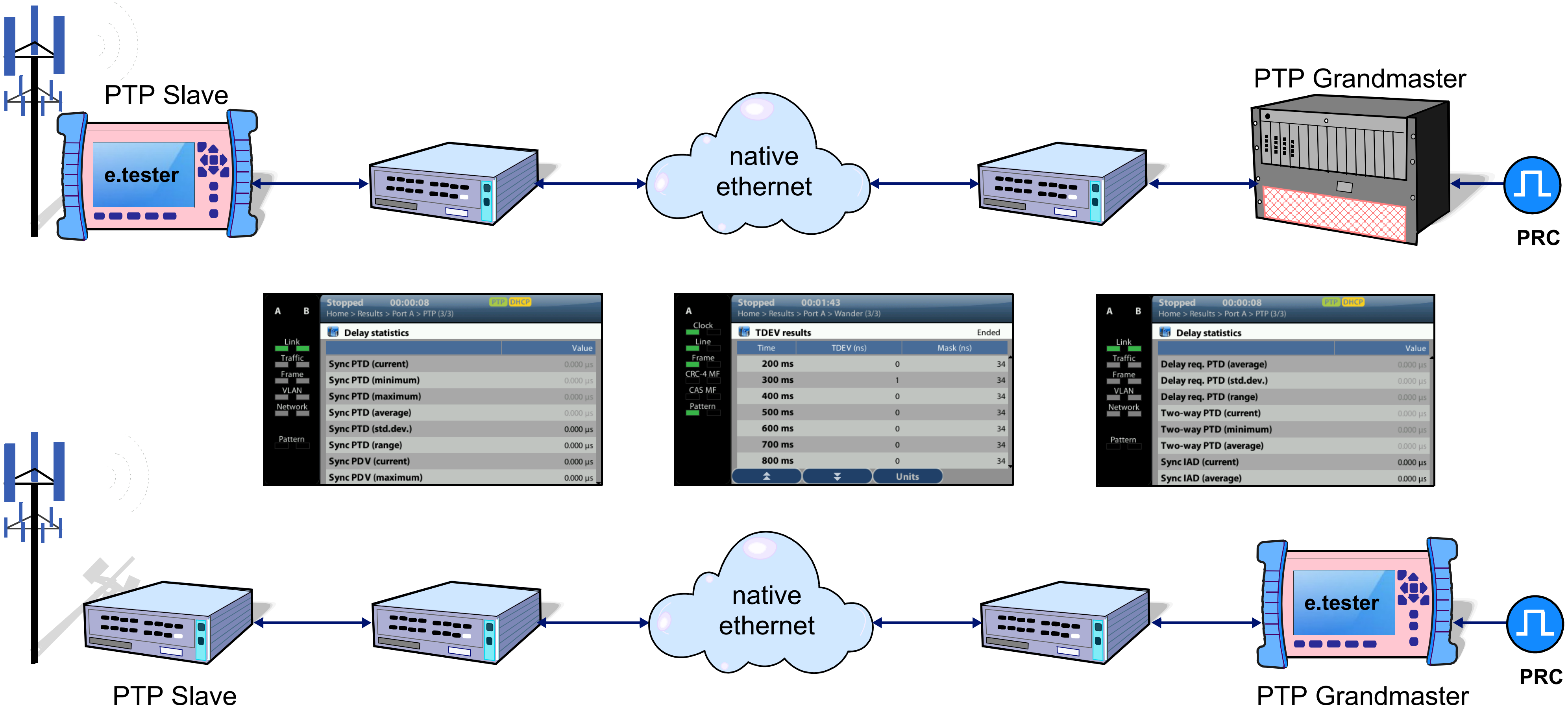
- **Floor Packet Count (FPC):** total number of PTP valid packet arrived
- **Floor Packet Percent (FPP)** percentage in a valid range (G.8261.1)
- **Floor Packet Rate (FPR):** PTP valid packets per second

Portfolio ALBEDO: clocks y testers



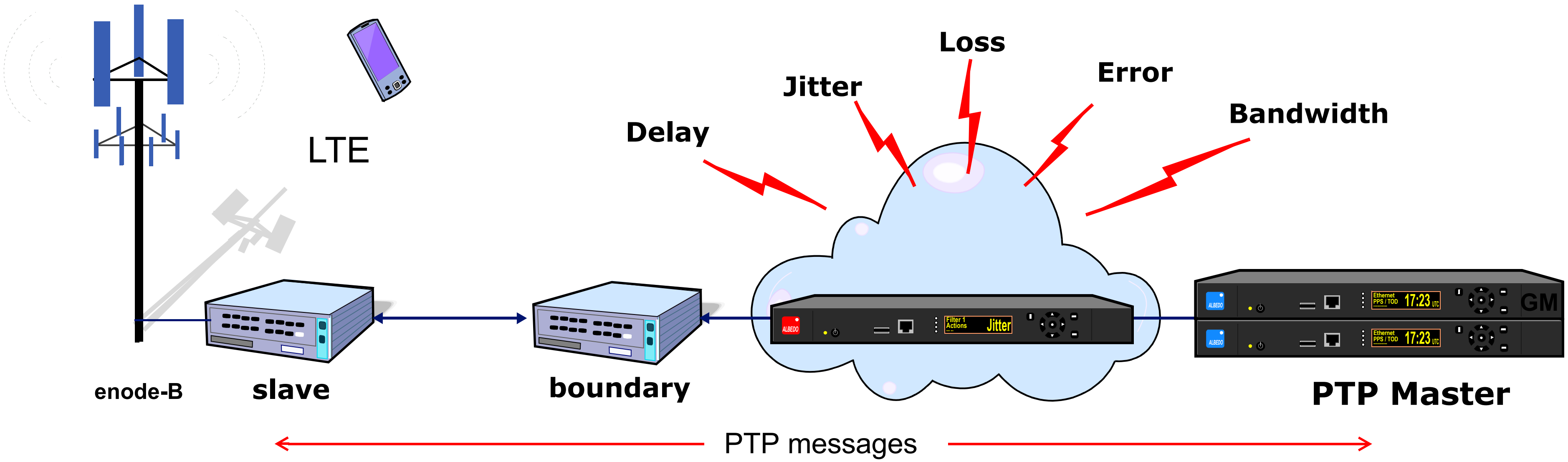
1 - Network + PTP Characterization
2 - PTP Synchronization
3 - Network Characterization
4 - Transport Qualification
5 - PTP Sync Ethernet SLA

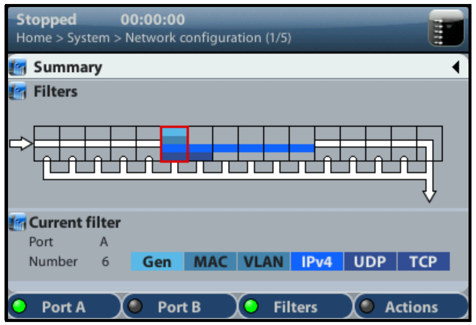
Portfolio ALBEDO: testers



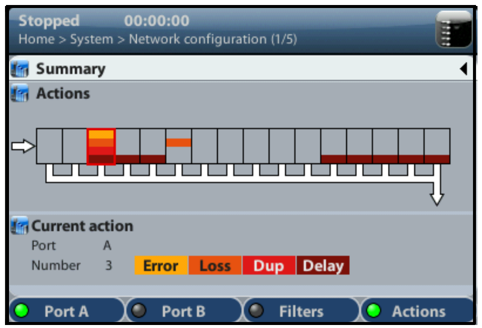
Ether.Sync, Ether.Genius and Ether10.Genius are testers that can emulate Master and Slaves nodes while measuring key parameters such as time offset, phase deviation, wander.

Net.Storm: emulates the PTP WAN



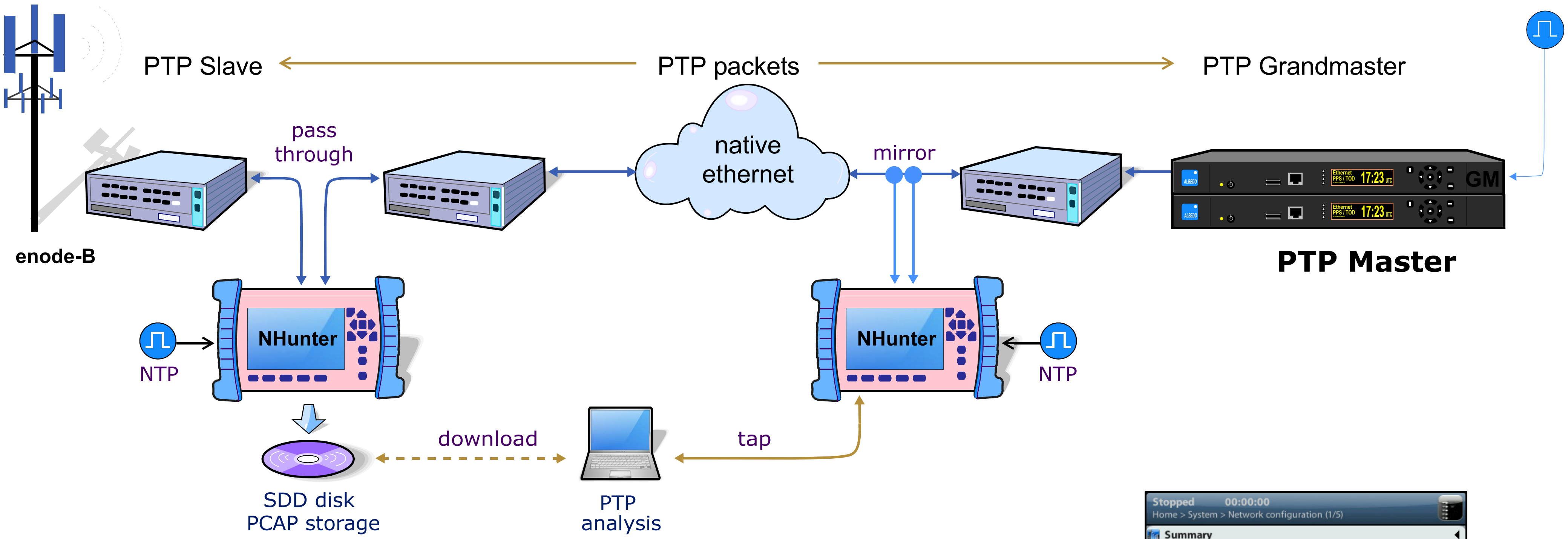


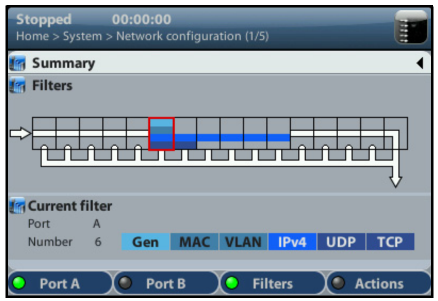
1 - Filter PTP messages only



2 - Generate Impairments

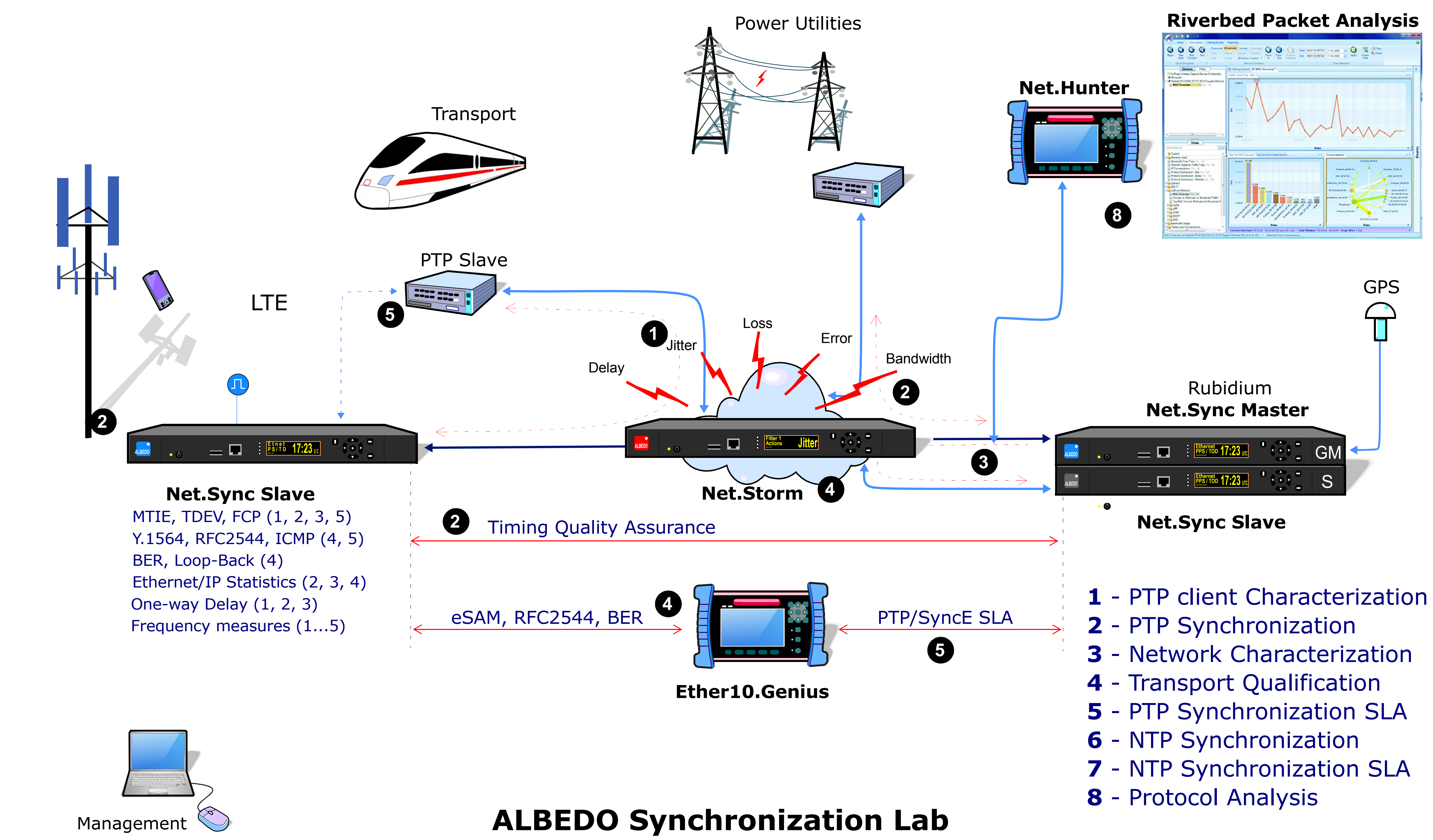
Net.Hunter for PTP packet captures and analysis





Net.Hunter Filters

Benchmarking: acceptance / approval PTP test suites



That's all

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