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Precision Time Protocol (PTP) explained

1. Ethernet Synchronization with IEEE 1588

Precision Time Protocol (PTP), included in IEEE standard 1588 was originally designed to provide timing for critical industrial automation. With the 2008 version of this standard (IEEE 1588v2), PTP overcomes effects of latency and jitter though chains of Ethernet switches, providing accuracy in the nanosecond range which was required for the high speed, high quality telecom networks.

Legacy: IP Synchronization with NTP

The Network Time Protocol (NTP), is one of the oldest protocols still in use and enjoys great popularity in many installations. Two flavours are available:

- Simple NTP or the complete version
- Simple NTP (SNTP) which is a subset

The latest version of NTP (NTPv4) can usually maintain time to within 1-20 ms using traditional software-interrupt based solutions over the public Internet. It can achieve accuracies of microseconds, or better, in LANs under ideal conditions. Arguably NTP has been the most popular synchronization solution because it performs well over LANs and WANs and at the same time it is inexpensive, requiring very little hardware.

Figure 1 *ALBEDO Ether.Sync is a field tester for Synchronous Ethernet equipped with all the features to install and maintain Precision Time Protocol (PTP / IEEE 1588v2), Synchronous Ethernet infrastructures, and Gigabit Ethernet supporting legacy features such as BER and RFC2544 while new test such as eSAM Y.1564.*

NTP should be able to deliver accuracy of 1-2 ms on a LAN and 1-20 ms on a WAN, it is far from guaranteed network-wide largely because of variable delays added by switches and routers.

PTP Protocol Details

PTP requires a central Master clock and low-cost PTP slave clocks at remote sites. Master and slave network devices are kept synchronized by the transmission of timestamps sent within the PTP messages.

Depending on how many ports has a network clock, it is referred by the IEEE 1588 standard as a Ordinary Clock (single port device) or a Boundary Clock (multi port device). The version IEEE 1588v2 standard also defines the concept of Transparent Clocks that improve timing accuracy when the protocol runs in network paths containing intermediate switches (see Table 1).

Table 1
IEEE 1588v2 Device Description

Device	***Description***
Ordinary Clock	Single-port device that can be a master or slave clock
Boundary Clock	Multi-port device that can be a master or slave clock
End-to-end Transparent Clock	Multi-port device that is not a master or slave clock but a bridge between both forwarding / correcting PTP messages
Peer-to-peer Transparent Clock	Multi-port device that is not a master or slave clock but a bridge between both forwarding / correcting Sync and Follow-up messages
Management Node	A device that configures and monitors clocks

The execution of PTP has two phases:

1. *Master-Slave Hierarchy Establishment*. Ordinary and boundary clocks decide which port has the master or slave role in each link with the help of the Best Master Clock (BMC) algorithm. Data from the remote-end of a path are provided by *Announce* message.
2. *Clock Synchronization*. Slave clocks may have a positive or negative offsets when compared with their masters and latency from masters to slaves is also unknown. PTP devices start a procedure to compute latencies and offsets. These parameters will be used to adjust timing in slave devices.

Once the master and slave hierarchies have been established, by observing the clock property information contained in *Announce* messages sent by PTP devices, the synchronization process starts (see Figure 2).

Before synchronization between the master and the slave clock has been achieved, it may exist an offset between both clocks. This offset is computed with the help of the *Sync* message that are sent periodically (usually once every a few seconds) by the master to upgrade offset information in the slave. *Sync* messages may carry an accurate timestamp indicating the departure time of the own message but this requires expensive time-stamping hardware which may not be available. In order to improve the protocol *Follow_Up* messages carry timestamps for a previous *Sync* message allowing a more relaxed timestamping procedure and cheaper hardware. *Sync* procedure is based on multicast to enable a more efficient message transmission and processing.

The *Sync* mechanism, however, does not take into account propagation time of *Sync* messages through the network. For this reason, the slave requests a latency measurement with a *Delay_Req* message. Masters reply to a *Delay_Req* with *Delay_Resp* message. The timestamps the slave gets from the Delay Request-Response mechanism are used to correct *Sync* with a more accurate time estimation.

The most difficult challenge of PTP is operation though chains of Ethernet switches. Most switches store packets in local memory while the MAC address table is searched and the cyclic redundancy field (CRC) of the packet is calculated before it is sent out to the appropriate port(s). This process introduces variations in the time latency of packet forwarding and damages accuracy of the PTP protocol. Version 1 of the PTP protocol deals with this problem by implementing *Boundary Clocks* within the switches. Version 2 uses the more advanced concept of Peer-to-Peer *Transparent Clock* to deal with the same problem.

Transparent clocks do not participate in the master-slave hierarchy but they process PTP messages by adding special correction fields within the message with their own estimations of packet residence times in the device and propagation delays from remote peers (which can be also a Peer-to-Peer Transparent Clocks). Network paths where Peer-to-Peer Transparent Clocks are employed do not need the Delay Request-Response mechanism. This mechanism is replaced by a peer-to-peer path correction mechanism based on the *Pdelay_Req* and *Pdelay_Resp* and *Pdelay_Resp_Follow_Up* messages.

Protocol Encapsulation

PTP messages can be carried over a large family of protocols including IPv4, IPv6, IEEE 802.3 Ethernet, DeviceNET, ControlNET and IEC 61158 Type 10. The most important encapsulations are the IP and Ethernet variations (see Figure 3).

PTP Synchronization Tests

The PTP protocol was developed to enable the high accuracy time synchronization for Ethernet quality services and protocols, in particular for video, the new mobile networks such LTE, and critical enterprise data. Then it is healthy to check the synchronization periodically to assure low error level, in order to maintain a good QoS.

ALBEDO Ether.Sync and Ether.Genius testers are devices that facilitate users to verify the connectivity, quality, and synchronization of networks controlled by means of 1588v2 PTP. With the PTP functionality experts can now

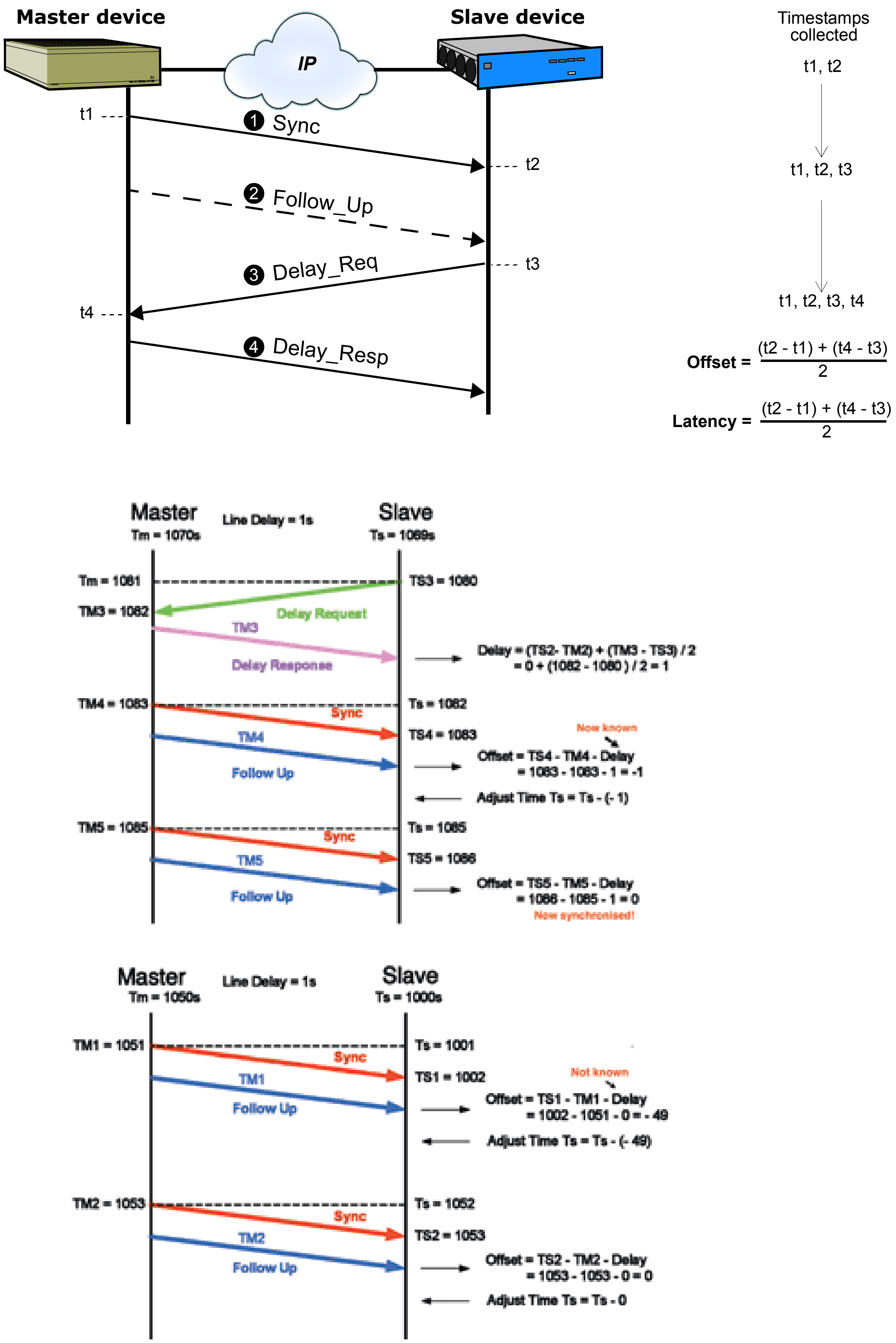

Figure 2 *Delay Request-Response mechanism used by the PTP. The basic parameters of Latency and Offset are computed from the t1, t2, t3 and t4 timestamps.*

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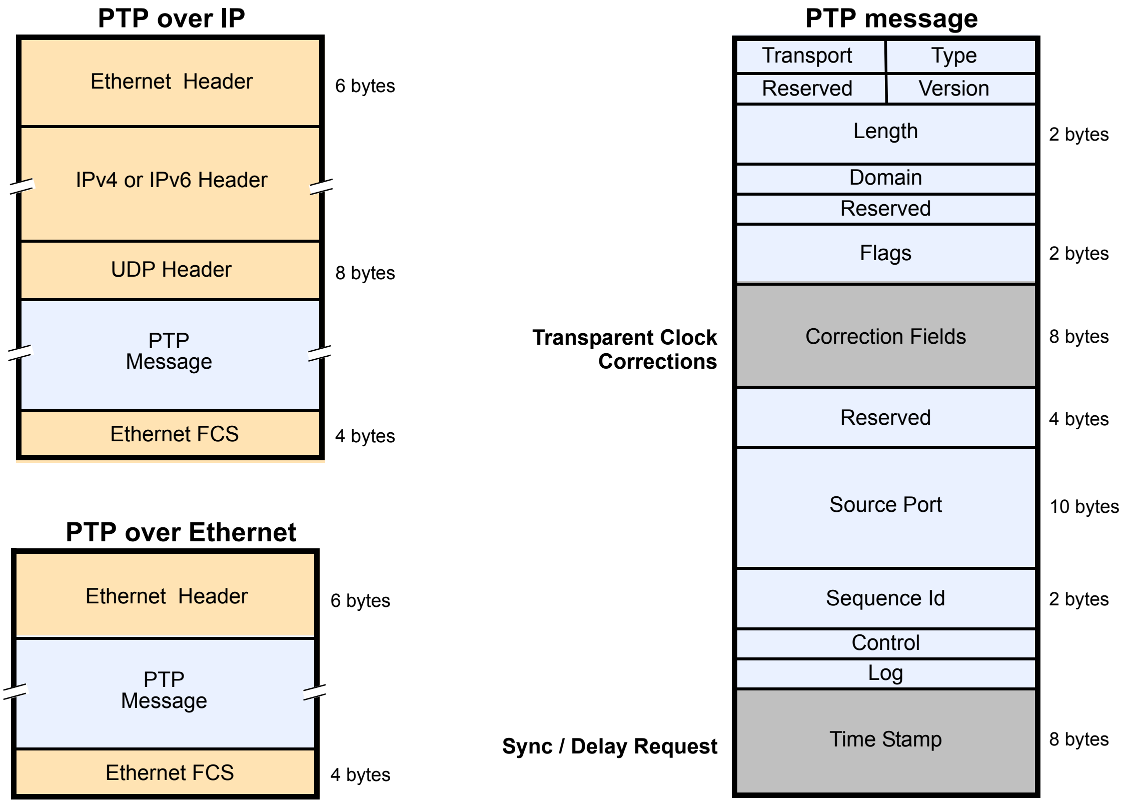

Figure 3 *IP and Ethernet encapsulations for PTP messages.*

emulate 1588v2 slave/master clocks, and ensure network QoS by generating PTP messages and measure packet delay variation (PDV) stability over time which is a key parameter to maintain the quality.

Case Study I: Set up a PTP Synchronization Network

The PTP protocol requires the establishment of time synchronization between master and slave nodes during the handshaking. This process occurs constantly to maintain the accuracy of the synchronization. Failure to establish PTP message connectivity, makes achieving synchronization impossible

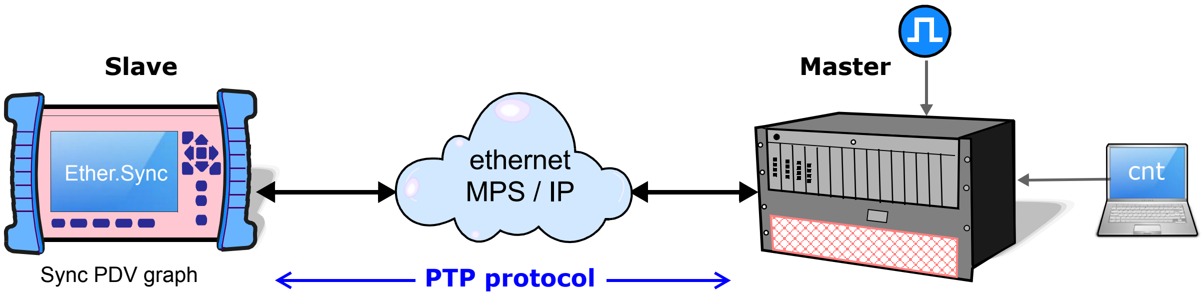

Figure 4 *ALBEDO Ether.Sync and ALBEDO Ether.Genius are testers that can emulate up to eight streams at data plane traffic, and PTP messages simultaneously.*

and disables support for synchronized services. With ALBEDO Ether.Sync or Ether.Genius, users can emulate PTP messages to verify how works the far-end protocol management (see Figure 4).

Case Study II: Verify Accurate Time Synchronization

The accuracy of the synchronization requires a permanent exchange of messages between master and slave clocks. However network perturbations may affect the latency of PTP messages because they have to pass-thru the same queues than data packets. Therefore, a network with high utilization can affect the delay of end-to-end PTP messages and consequently synchronization could be degraded.

To control this effects is required to measure packet delay jitter of the PTP messages exchanged between master and slave clocks. With the ALBEDO Ether.Sync or Ether.Genius, users can verify easily the proper delivery of PTP messages by measuring PDV stability over time (see Figure 5).

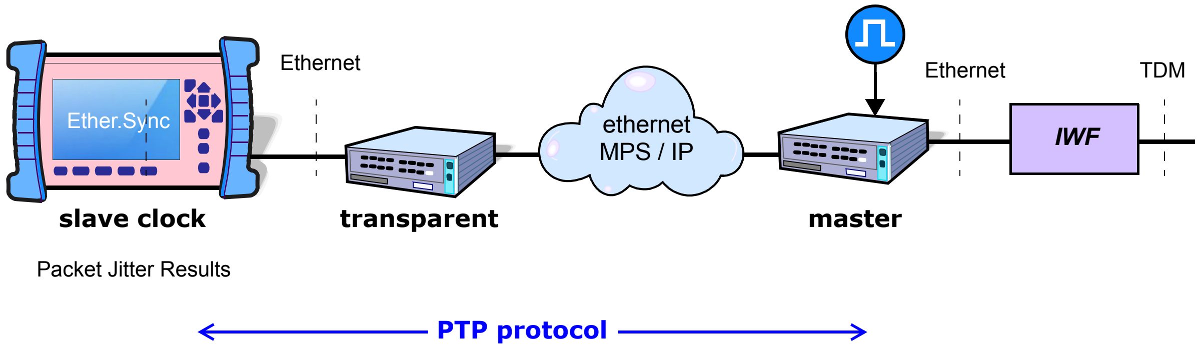

Figure 5 *With the ALBEDO Ether.Sync or ALBEDO Ether.Genius, users can verify the proper delivery of PTP messages by measuring PDV stability over time.*

Case Study III: Generation of impairments to PTP messages

ALBEDO Net.Storm generates those protuberances typical of IP and Carrier Ethernet to test PTP message, devices and protocols that should be tolerant with packet delay, jitter, loss, duplication, reordering, error and bandwidth variations.

With Net.Storm facilitates the verification of the IEEE 1588v2 synchronization by means of actual emulation of the real traffic conditions of IP networks that are being used to transport PTP messages. Therefore it enables engineers to model and modify arbitrary live PTP packets.

Net.Storm that can shape and manage up to 16 independent flows of traffic, then one of these flows can be programmed to filter PTP messages using for instance the PTP port being used. Then an specific packet delay or jitter can be applied to the PTP traffic to observe the consequences on the master/slave synchronization.

For the set up of any filter on PTP messages it is important to know the following information>

- *IP / UDP Encapsulation PTP messages Ports:* 319 (event) and 320 (general)
- *Multicast IP addresses*: 224.0.0.107 (peer delay messages), 224.0.1.129 (all other messages).
- *Ethernet Encapsulation Ethertype*: 0x88F7 Multicast MAC addresses: 01-80-C2-00-00-0E (peer delay messages), 01-1B-19-00-00-00 (all other messages)

Users of Net.Storm could the emulated test environment that resembles actual traffic profile as observed on the real network (see Figure 6).

Case Study IV: Packet Analysis of PTP Messages

During the installation of a IEEE 1588v2 network, PTP message connectivity problems may occur between the master and slave units. For instance failure to establish PTP message connectivity makes achieving synchronization impossible and disables support for services. When troubleshooting these links, the ALBEDO Ether.Sync can be used in Terminate mode to capture PTP messaging on both the transmit and receive test ports up to 1 Gbit/s. In this mode, the ALBEDO Ether.Sync simultaneously generates, receives, and captures PTP messages on the circuit under test. Users can quickly identify higher layer protocol issues that may be associated with PTP messages and/or provisioning.

Case Study V: Test the Link Quality / Accurate Synchronization

The protocol PTP is designed to work under network conditions including highly occupied networks. When there is a lot of contention the routing and switching of PTP messages could therefore be affected causing potential bad effects like packet delay variation in PTP messages will ultimately affect synchronization because it depends upon consistently timed message reception. Both ALBEDO Ether.Sync and ALBEDO Ether.Genius can emulate data plane traffic (up to eight streams) while PTP messages are transmitted simultaneously. Under these conditions, field engineers can verify if the new or the existing PTP network are capable to operate properly under many different load scenarios (see Figure 7).

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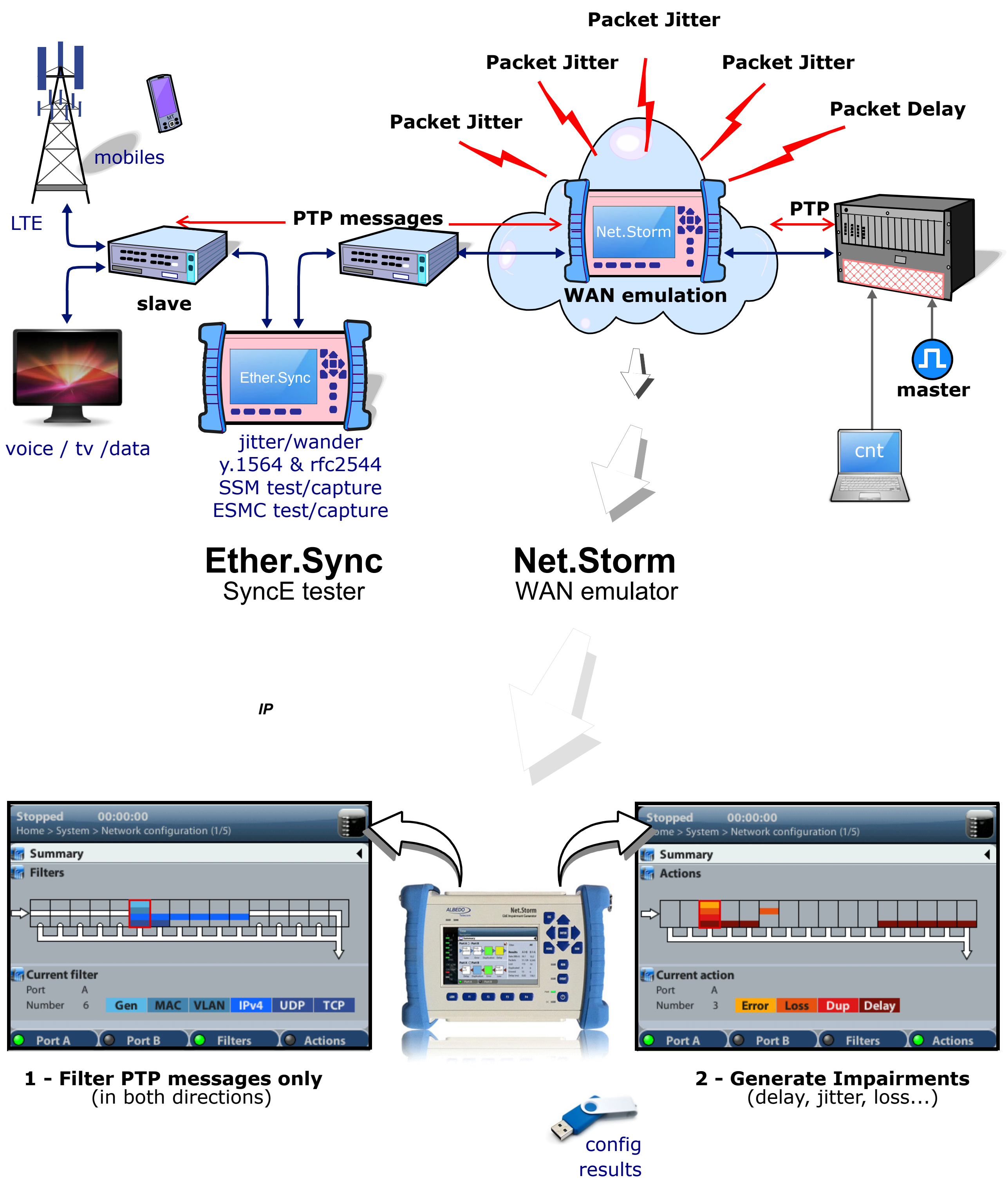

Figure 6 *Net.Storm and Ether.Sync are two ALBEDO instruments that combined are perfectly well prepared to test all the PTP protocol. Ether.Sync does the analysis of the PTP messages and the quality of the synchronization while the Net.Storm can generate -in a 100% controlled way- packets impairments to simulate accurately*

ALBEDO Net.Storm is a WAN emulator capable to generate packet impairments. First it is necessary to identify the PTP flow for instance using the 319 and 320 Ports. This allows to filter all the PTP messages and then the next step is to generate the delay or the jitter you want with an accuracy better than ns.

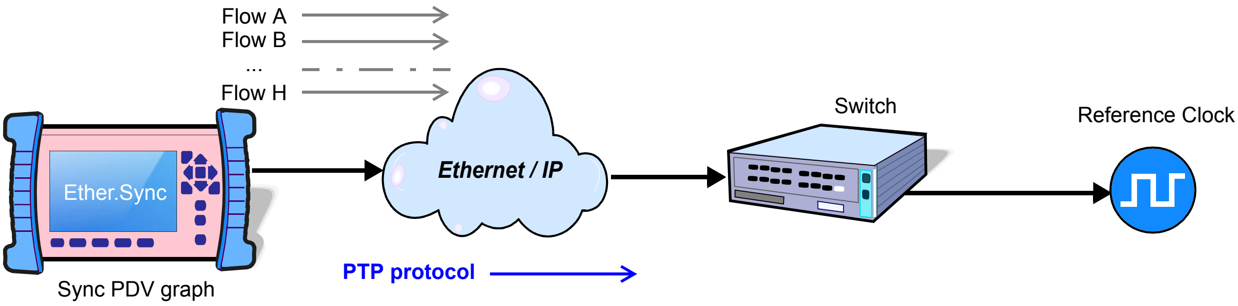

Figure 7 *There are tester that can emulate data plane traffic (up to eight streams) and PTP messages simultaneously..*

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test + measurement + WAN emulation + packet capture + synchronization + consultancy

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