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

- 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, 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.
• 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.
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

• 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.
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.
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.
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
\((f_4\neq f_0)\)
• 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

Frame 0

Time Slot 0

C1 0 0 1 1 0 1 1
C2 0 0 1 1 0 1 1
C3 0 0 1 1 0 1 1
C4 0 0 1 1 0 1 1
C5 0 0 1 1 0 1 1
C6 0 0 1 1 0 1 1
C7 0 0 1 1 0 1 1
C8 0 0 1 1 0 1 1
C9 0 0 1 1 0 1 1
C10 0 0 1 1 0 1 1
C11 0 0 1 1 0 1 1
C12 0 0 1 1 0 1 1
C13 1 1 0 1 1 0 1
C14 1 1 0 1 1 0 1
C15 1 1 0 1 1 0 1

Submultiframe I

125 µs

Submultiframe II

2 ms

Alignment Bits
Remote Alarm Indicator
CRC-4 Error Signaling Bits
CRC-4 Bits

Channel CAS Bits
Channel Bytes
Spare Bits
Objective of SyncE: internetworking

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

Objectives:

• Inclusion of Ethernet (SyncE) as part of SON-ET/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

Native Ethernet

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

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)

- 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)

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

Round Trip Delay = \( (t_2 - t_1) + (t_4 - t_3) \)
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
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

Master

Slave

packet network

15:00

\[ t_1 \]

15:05

\[ t_2 \]

15:15

\[ t_3 \]

15:18

\[ t_4 \]

\[ 1 \] Sync

\[ 2 \] Follow_Up

\[ offset = 5' \]

\[ 3 \] Delay_Req

\[ 4 \] Delay_Resp

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

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

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

Latency = \( \frac{(8) + (-2)}{2} \) = 3
Clocks and Nodes in PTP

**Clocks & Nodes**

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary Clock</td>
</tr>
<tr>
<td>A single port device that can be a master or slave clock.</td>
</tr>
<tr>
<td>Boundary Clock</td>
</tr>
<tr>
<td>A multi port device that can be a master or slave clock.</td>
</tr>
<tr>
<td>End-to-end Transparent</td>
</tr>
<tr>
<td>A multi port device that is a bridge between master/slave. Forwards and corrects all PTP msgs</td>
</tr>
<tr>
<td>Peer-to-peer Transparent</td>
</tr>
<tr>
<td>A multi port device that is a bridge between master/slave. Forwards /corrects Sync &amp; Follow-up</td>
</tr>
<tr>
<td>Management Node</td>
</tr>
<tr>
<td>A device that configures and monitors clocks.</td>
</tr>
</tbody>
</table>
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)
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)

Amplitud

Wander  Jitter

10 Hz

frec
Bad synchronization in TDM: Slips

Write clock = $f_1$

Buffer

Read clock = $f_2$

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

<table>
<thead>
<tr>
<th>$\Delta$freq</th>
<th>Slip rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$32 \times 10^{-6}$ (32 ppm)</td>
<td>1 in 4 sec.</td>
</tr>
<tr>
<td>$4.6 \times 10^{-6}$ (4.6 ppm)</td>
<td>1 in 27 sec.</td>
</tr>
<tr>
<td>$1.6 \times 10^{-8}$ (16 ppb)</td>
<td>1 in 8000 sec.</td>
</tr>
<tr>
<td>$1 \times 10^{-11}$ (&quot;0&quot;)</td>
<td>1 in $12.5 \times 10^6$ sec.</td>
</tr>
</tbody>
</table>

wander $\rightarrow$ pointer moves $\rightarrow$ jitter $\rightarrow$ slips in buffers $\rightarrow$ errors $\rightarrow$ $\$
• 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

\[ x(t) = T(t) - T_{\text{ref}}(t) \]

- \( x(t) \): error
- \( T(t) \): time in the clock
- \( T_{\text{ref}}(t) \): reference time
Time Interval Error (TIE)

- 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.

Begining: $TIE(t_0) = 0$
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
Packets arrive to destination with a variable delay (or Packet Delay Variation) then Floor metrics are indicators that at least a portion of the packets arrive on time (for instance more than 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

![Diagram showing floor packet measurements](image)
Portfolio ALBEDO: clocks y testers

Net.Sync Master/Slave
- MTIE, TDEV, FCP (1, 2, 3, 5)
- Y.1564, RFC2544, ICMP (4, 5)
- BER, Loop-Back (4)
- Ethernet/IP Statistics (2, 3, 4)
- One-way Delay (1, 2, 3)
- Frequency measures (1...5)

1 - Network + PTP Characterization
2 - PTP Synchronization
3 - Network Characterization
4 - Transport Qualification
5 - PTP Sync Ethernet SLA
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
Benchmarking: acceptance / approval PTP test suites

ALBEDO Synchronization Lab

1 - PTP client Characterization
2 - PTP Synchronization
3 - Network Characterization
4 - Transport Qualification
5 - PTP Synchronization SLA
6 - NTP Synchronization
7 - NTP Synchronization SLA
8 - Protocol Analysis