**Kyland Technology Co., Ltd.**

# White Paper

## High Precision Time Synchronization

# High Precision Time Synchronization Solution over Industrial Ethernet Network

**Keywords: IEEE1588, PTP**

**Acronyms:**

| Acronym | Full Spelling |
|---|---|
| PTP | Precise Time Protocol |
| GPS | Global Positioning Satellite |
| NTP | Network Time Protocol |
| SNTP | Simple Network Time Protocol |
| IRIG-B | Inter-range instrumentation group-B |

# Contents

# High Precision Time Synchronization Solution over Industrial Ethernet Network

# 1 Introduction

## 1.1Background

Smart Grid or IntelliGrid has had many discussions over the last several years as a state strategy as well as a leading technology highly emphasized by government for we are now facing energy shortage and environmental pressures.

Technologies are developing rapidly and contribute to changes in the power industry, like the successful implementation and research of IEC61850 in substation automation system. The standard is now widely deployed all over the world and well accepted by the industrial market.

It is well known that the power grid is a widespread, complex, interconnected system that one part of the system may affect another part of the system. Time and frequency system plays an important role in the power Industry to better interpret power system operation, predict and prevent system faults, test and verify operations of protective device using synchronized measurements or time-tagged records, for real-time applications such as protection schemes or post analysis of cascading blackout reason, etc.

## 1.2Why High Precision

Synchronized timing system is crucial for power utilities to distribute power reliably among all power stations. The widespread synchronized time distribution requires RTU. IEDs in the power grid run on the same correct clock so that synchronous operations for sampling and protection can be guaranteed and link faults can be detected more timely because of a consistent timeline for event timestamps.

While in Energy Automation Application, the time accuracy requirement is different:

| System | Sync Accuracy |
|---|---|
| SCADA | 1s |
| Distribution Automation | 100ms |

| | |
|---|---|
| Substation Automation (Sequence of Event) | 1ms |
| Process Bus | 10us |
| Synchrophasors | 1us |

In IEC61850, functional requirements of time synchronization for substations fall into 5 categories.

For standard IED synchronizing for control and protection events

| Time Perf. Class | Accuracy [ms] | Purpose |
|---|---|---|
| T1 | 1 | Time tagging of events |
| T2 | 0.1 | Time tagging of zero crossing and of data for the distributed synchrocheck. Time tags to support point on wave switching |

For standard IED synchronizing for instrument transformers

| Time Perf. Class | Accuracy [us] | Reference | | Phase Angle 50Hz | Phase Angle 60Hz | Fault Location [m] |
|---|---|---|---|---|---|---|
| T3 | 25 | P1 | | 27 | 32 | 7500 |
| T4 | 4 | P2 | M1 | 4 | 5 | 1200 |
| T5 | 1 | P3 | M2/M3 | 1 | 1 | 300 |

The process level network in IEC61850-9-2 demands time synchronization accuracy of 1 us. The highest 1 us accuracy is calling for solutions and products which will in turn promote the industry's development.

# 1.3Solutions

## 1.3.1 Previous Solutions

For direct synchronization (dedicated wiring systems such as GPS, IRIG-B, and PPS), wiring results in limited transmission distance and poor scalability.

For synchronization over LAN such as NTP, SNTP, software-based synchronization with low costs but only 1ms accuracy cannot fulfill the 1us requirement for certain applications. SNTP is known as a less complex implementation of NTP, using the same protocol without requiring the storage of state over extended periods of time.

GPS is perfectly acceptable for high-precision application but it costs too much to equip each end-node with a GPS receiver. A less costly solution is needed.

There is a great challenge for the existing time synchronization method.

With the advent of IEEE1588, also called PTP, 1 ms accuracy and scalability for a widespread power grid system becomes possible with hardware-assisted timestamps and less costs than GPS.

### 1.3.2 IEEE1588

IEEE1588 is a standard that defines a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing and distributed objects. Different from NTP and SNTP, IEEE1588 is based on hardware-assisted timestamps for high precision.

The TC (transparent clock) and peer delay mechanism introduced in IEEE1588V2-2008 make PTP more scalable as a result of less protocol traffic for master than in end-to-end delay mechanism and more accurate by PTP timing messages traversing the network with calculating residence time and peer-to-peer propagation delays.

The most advantageous parts of IEEE1588 are the sub-microsecond accuracy, a well-defined time distribution solution for IEC61850-9-2 process bus where synchronization between MUs (Merging Unit), MU and IEDs is the key for proper function, as well as synchrophasors application in C37.118. With a network based communication, the conventional cabling of IRIG is reduced with hardware-assisted timestamps in IEDs and makes it easier to install.

C37.238 is an IEEE Standard Profile for the application of IEEE1588 Precision Time Protocol in power systems.

A profile is a set of required options, prohibited options, and the ranges and defaults of configurable attribute features applicable to a device. It is used to allow organizations to specify selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-work and achieve a performance that meets the requirements of a particular application.

- ✓ A PTP profile should include:
  - ■ Best master clock algorithm (BMCA) options

  - Configuration management options
  - Path delay measurement option (delay request-response or peer delay)
  - Range and default values of all configurable attributes and data set members
  - Transport mechanisms required, permitted, or prohibited
  - Node types required, permitted, or prohibited
  - Options required, permitted, or prohibited
- ✓ A PTP profile shall extend the standard only by:
  - TLV mechanism
  - Optional BMCA
  - Optional management mechanism

It is permitted to create an implementation based on a unicast model providing that the behavior of the protocol is preserved (PTP is written based on the multicast model) in a profile.

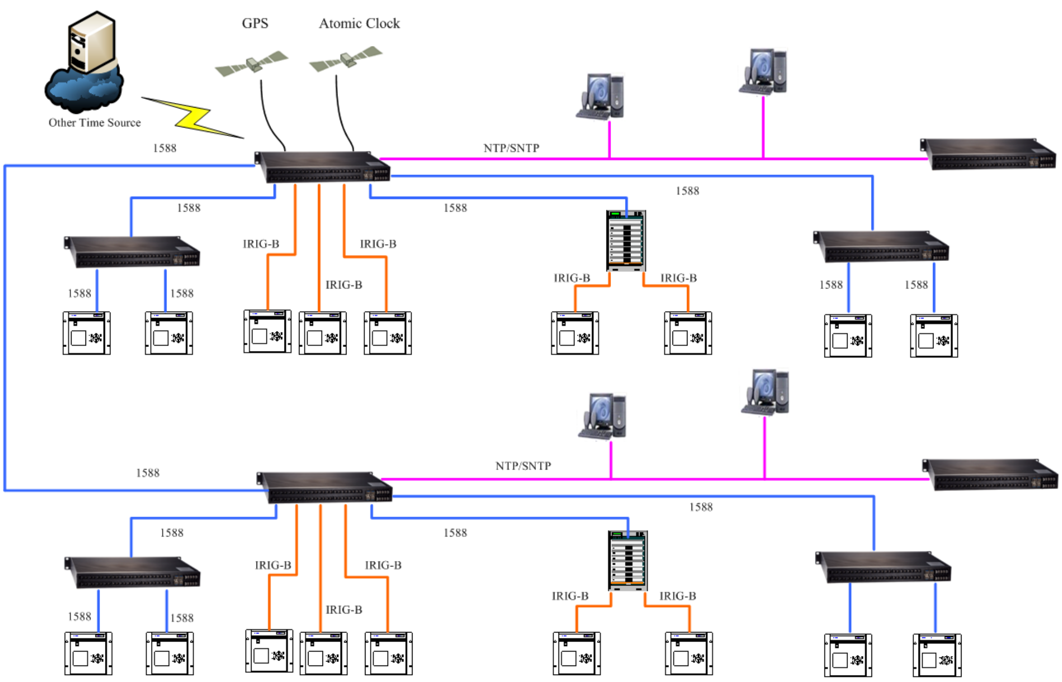
C37.238 is a guideline for both communication devices and IED manufacturers. Utilities will deploy IEEE1588 compliant IED's at different speeds, but the clock installed today should be future proof and have a natural path to C37.238.

# 2 Kyland Solution

## 2.1Overview

Kyland is a leading company devoted in industrial Ethernet communication. In the last few years in this industry we have noticed that more demands are called on high precision time synchronization for measurement and control systems, especially in smart grid.

This solution is designed for power industry to set up time synchronization between end devices in the system, including the reference time source, PTP, NTP, devices for extensive time signal, etc. The solution can be used for the clock synchronization throughout the power system from generation in power plant, transmission in substation automation to distribution for end users in family and enterprises.




Precise timing signal is received from satellite systems like GPS, atomic standard clock, or other sources like IRIG-B time code, 2 MHz, E1, 1 PPS, 10 MHz benchmark signal, and is converted to various time or frequency output signal, to meet synchronization requirements for different applications, for example: remote data acquisition, equipment control, or measure and parameters adjustment.

Other output interfaces can also be supported by extensive time devices, such as: IRIG-B time code, DCLS, RS232, and RS422.

For end nodes such as electric power RTU, SCADA, office equipment, switches or routers that support Ethernet communication networking, time synchronization can be achieved by using NTP, PTP, or simply SNTP through a TCP/IP network.

### 2.1.1 Reference Time Source

Reference time source is a standard reference clock traceable with high availability and stability so that all other clocks in the network can be synchronized to this clock.

There are multiple reference resources:

1. Satellite timing signal. Devices equipped with built-in high accuracy oscillator like TCXO, OCXO, or rubidium and high accuracy of GPS receiver, adopting elegant algorithm, will output time signal synchronized by GPS.
2. IRIG-B time code. Devices can interpret PPS and time information as source benchmark in IRIG-B time code, and utilize built-in high accuracy oscillator for

time-keeping and hold-over.

3. Other time source from upper layer network, for example, NTP server with higher stratum, atomic clock, or SONET.

GPS signal is easily attainable and its high accuracy within 1 us makes it preferable for the time reference source. An oscillator upgrade is possible to enhance performance for accuracy and holdover performance calibrated by GPS signal from time to time.

| | TCXO | OCXOI | OCXOII | Rubidum |
|---|---|---|---|---|
| Short term stability (t=1s) | $2\times10^{-9}$ | $1\times10^{-9}$ | $5\times10^{-12}$ | $2\times10^{-11}$ |
| Accuracy of PPS | $\pm100ns$ | $\pm100ns$ | $\pm30ns$ | $\pm30ns$ |
| Accuracy free run,1 day | $\pm1\times10^{-7}$ | $\pm2\times10^{-8}$ | $\pm5\times10^{-10}$ | $\pm2\times10^{-11}$ |
| Accuracy free run, 1 year | $\pm1\times10^{-6}$ | $\pm4\times10^{-7}$ | $\pm5\times10^{-8}$ | $\pm5\times10^{-10}$ |
| Accuracy GPS-synchronous | $\pm1\times10^{-11}$ | $\pm1\times10^{-11}$ | $\pm1\times10^{-12}$ | $\pm1\times10^{-12}$ |
| Accuracy of time free run,1 hour | $\pm90\mu s$ | $\pm6\mu s$ | $\pm1\mu s$ | $\pm1\mu s$ |
| Accuracy of time free run,1 day | $\pm4.3ms$ | $\pm865\mu s$ | $\pm22\mu s$ | $\pm1.1\mu s$ |
| Accuracy of time free run,1 year | $\pm16s$ | $\pm6.3s$ | $\pm788ms$ | $\pm8ms$ |
| Temperature dependant drift free run | $\pm2\times10^{-7}$ (0-50℃) | $\pm2\times10^{-7}$ (0-50℃) | $\pm1\times10^{-8}$ (0-50℃) | $\pm6\times10^{-10}$ (-25-70℃) |
| Lock Time | Cold start <20 min(typical) | Cold start <20 min(typical) | Cold start <20 min(typical) | Cold start <20 min(typical) |

Two different time sources can be used for redundancy backup with election algorithm to maintain the high availability of reference clock in the system.

## 2.1.2 Time Distribution

A well-defined time distribution network is used to synchronize all clocks scattered in distributed system. Usually network time protocol, NTP, SNTP, or PTP is taken into design for different synchronization accuracy for its dependence on protocol mechanism. Although different hierarchical networks involve different protocol packets, the synchronization theory is similar, using round-trip delay time and offset between slave clock and master clock for local clock calibration. So the symmetrical path depends on synchronization accuracy.

In the deployment of time distribution system, to make a reliable and cost-effective system, questions below should be evaluated and answered:

- Reliability

Specific occasions that lead to uncertainty in the time system should be identified and carefully dealt with to accomplish reliability in the system. For example, the master clock redundancy to switchover when there is a disturbance.

- Accuracy issues

The selection of techniques as well as working modes is based on practical projects' performance requirements and limitations. NTP and SNTP are cheaper and easily deployed using software with milliseconds accuracy while PTP demands hardware assistance for sub-microsecond accuracy for both master clock and slave clock which means that end nodes shall be compliant with PTP as well.

Different working modes are defined in NTP and IEEE1588 for different application scenarios, such as BC, P2P TC, and E2E TC with different delay mechanisms for PTP, while multicast, unicast, and broadcast for NTP.

- Absolute time

Different timescale, the timing system is absolute rather than relative. This means that the time standard is related to a Universal Coordinated Time (UTC). For absolute time display, the time zone and leap second should be considered for this information is outside its scope and must be obtained separately.

- Flexibility

Modular designs make it flexible to integrate in one platform and future network extension.

- Manageability

Additional debugging tools and MIB information contribute to management of the system. Less attendance with automatic status and alarm reports make it easy for use and maintenance.

C37.238 is a good reference for answers on the above question. Future revision of C37.238 is expected for more detailed information as well as implementation instructions.

### 2.1.3 Time Signal

For end users, multiple time output interfaces are required for different devices and manufacturers, like PPS, serial time string, time code for IRIG-B, etc.

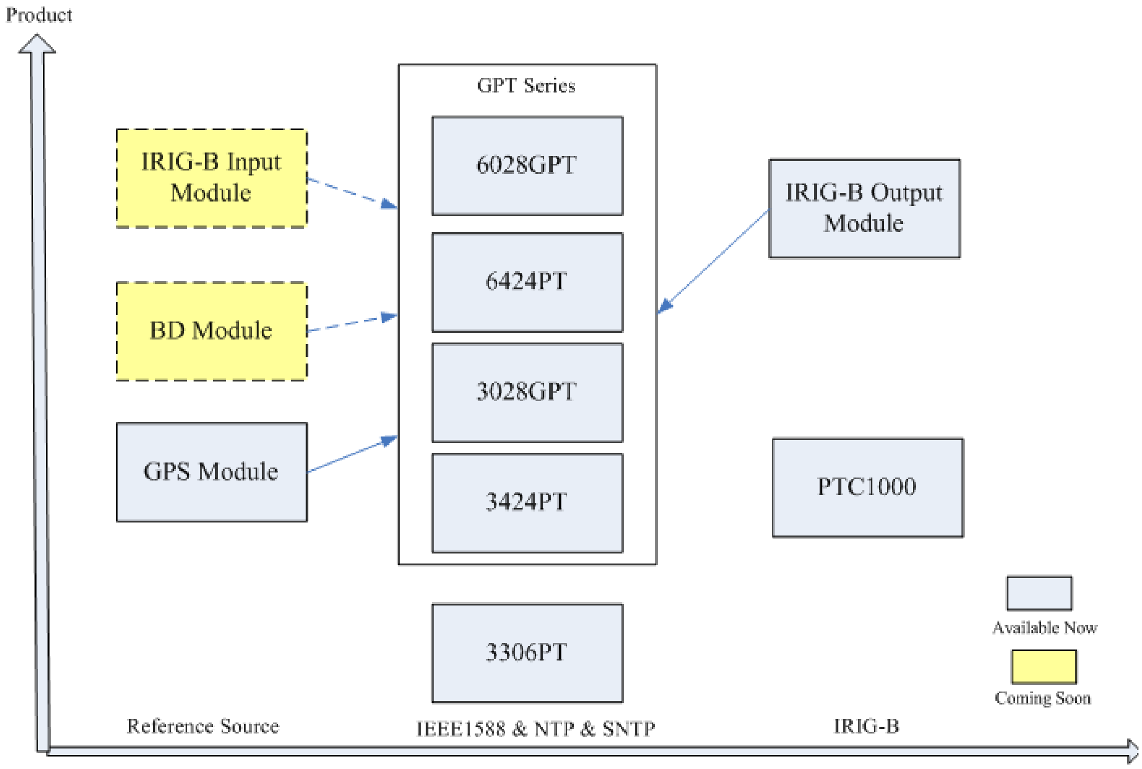
For backward compatibility, IEEE 1588 can be converted to IRIG-B on "last meter" for non-IEEE1588 capable IEDs.

| | | |
|---|---|---|
| IRIG-B | TTL | IRIG-B000: 100pps, DCLS signal, BCD, CF, SBS |
| | | IRIG-B002: 100pps, DCLS signal, no carrier, BCD time of year |
| | | IRIG-B003: 100pps, DCLS signal, DCLS signal, no carrier, BCD time of year, SBS time-of-day |
| | AM | IRIG-B123: 100pps, AM sine wave signal, 1kHz carrier frequency, BCD time of year, SBS time-of-day |
| PPS | TTL | 50Ω, Rising pulse with rise time≤60ns, Pulse width adjustable in 1ms~255ms |

## 2.2Product Family

Kyland time synchronization product family has a portfolio of 7 products and modules accommodated:

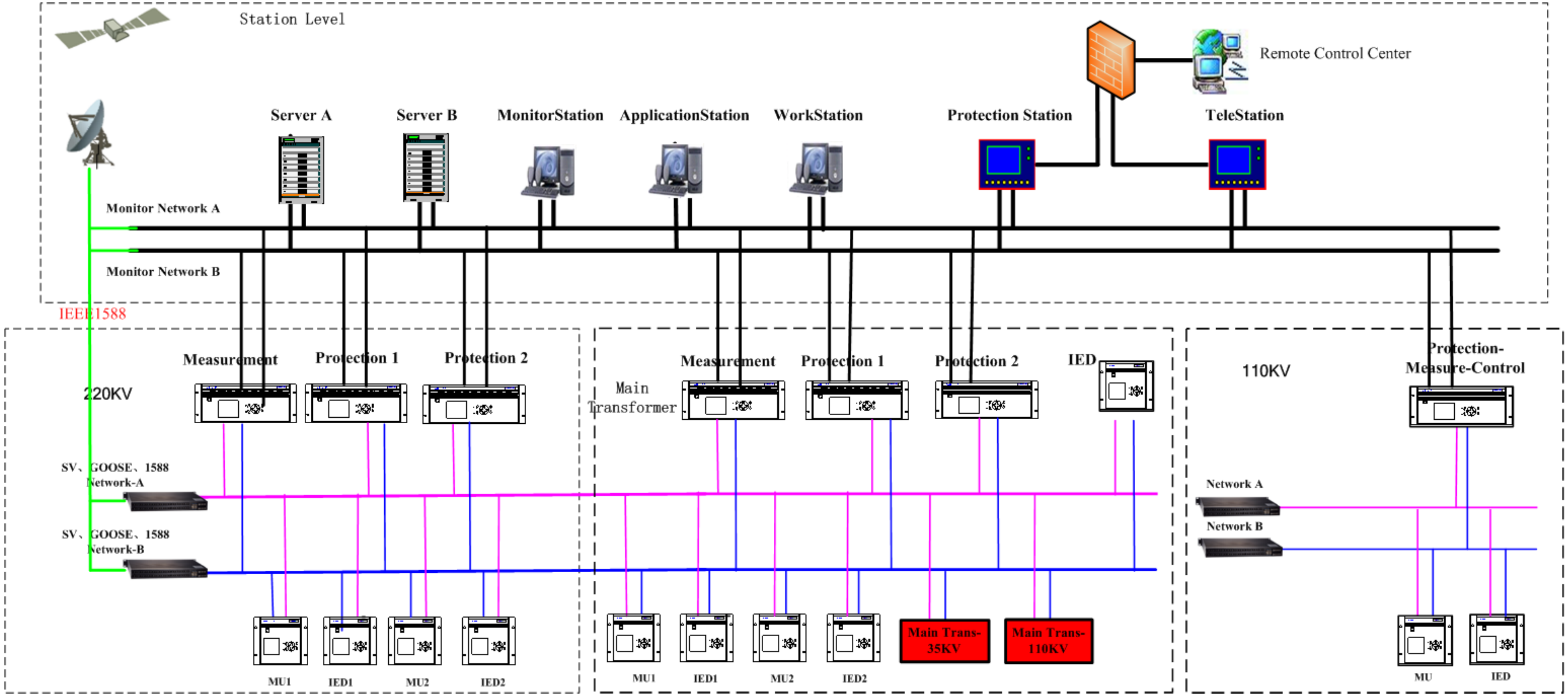
| | | |
|---|---|---|
| Industrial Ethernet Switch | SICOM6028GPT | 19 inch rack-mounting modular Layer 3 switches with up to 28G IEEE1588 ports |
| | SICOM6424PT | 19 inch rack-mounting modular Layer 3 switches with up to 4G+24T IEEE1588 ports |
| | SICOM3028GPT | 19 inch rack-mounting modular Layer 2 switches with up to 28G IEEE1588 ports |
| | SICOM3424PT | 19 inch rack-mounting modular Layer 2 switches with up to 4G+24T IEEE1588 ports |
| | SICOM3306PT | DIN-Rail IEEE1588 switches with 3G+6T IEEE1588 ports |
| Time Converter | PTC1000 | DIN-Rail IEEE1588 time converter |
| Time Interface Module | GPS Module | Modules with GPS receiver and Oscillator that can be accommodated in GPT series |
| | IRIG-B Input Module | Modules with IRIG-B input conversion that can be accommodated in GPT series |
| | IRIB-B Output Module | Modules with IRIG-B output conversion that can be accommodated in GPT series |




## 2.3Features & Advantages

- ✓ A complete product series cover all needs for high precision time synchronization solution from time source to end node
- ✓ Compatible with legacy devices using PPS or IRIG-B output with DCLS or AM.
- ✓ 19 inch 1U rack-mounting modular IEEE1588 industrial switch with multiple time sources.
- ✓ Universal GPS and IRIG-B modules for the modular platform.
- ✓ Full implementation of IEEE1588 with Delay-Request and Peer delay request mechanism working for BC, P2P, and E2E modes compliant with C37.238 profile.
- ✓ Oscillator upgrades for GPS and BD module to meet different performance requirements.
- ✓ Modular design integrated in GPT series platform with high flexibility and cost effectiveness for investment protection and future extension.

# 3 Typical Application



# 4 Product Introduction

## 4.1SICOM6028GPT

- ✓ Supports layer 3 routing protocols, such as RIP and OSPF
- ✓ Flexible modular design for easy expansion, 1U rack-mounting
- ✓ Supports up to 28 Gigabit ports
- ✓ Precise time synchronization supporting IEEE1588v2 and ITU-T.G.8261/G.8262 (Sync-E)
- ✓ Supports redundancy protocols: IEC62439-6(DRP), DT-Ring family, MSTP, and VRRP
- ✓ Extensive GPS and IRIG-B modules available
- ✓ Mini USB for Console port, VCT, etc.
- ✓ Exceeds IEC61850-3 and IEEE 1613

## 4.2SICOM3028GPT

- ✓ Flexible modular design for easy extension, 1U rack-mounting
- ✓ Supports up to 28 Gigabit ports
- ✓ Precise time synchronization supporting IEEE1588v2 and ITU-T.G.8261/G.8262 (Sync-E)
- ✓ Supports redundancy protocol: IEC62439-6 (DRP), DT-Ring family, MSTP
- ✓ Extensive GPS and IRIG-B modules available
- ✓ Mini USB for Console port, VCT, etc.
- ✓ Exceeds IEC61850-3 and IEEE 1613
- ✓ KEMA (pending), CE, and FCC certificates

# 4.3Time Interface Module

## 4.3.1 GPS Module


- ✓ High precision time source from GPS with ±100ns accuracy of PPS
- ✓ High-stability oscillators for holdover performance and various options for upgrade
- ✓ One BNC connector for GPS input, One BNC connector for PPS output
- ✓ 14 channels GPS C/A coding receiver in 1575.42MHz
- ✓ FIX and Lock LEDs for working status indication

## 4.3.2 IRIG-B Module


- ✓ Synchronized time conversion from IEEE1588 to time code output for legacy devices
- ✓ One channel for PPS output, two channels for IRIG-B (DC) output , two channels for IRIG-B (AC) output
- ✓ Supports time code: IRIG-B 000, 002, 003, 123
- ✓ Module Running LED

## 4.4SICOM3306PT


- ✓ 3 SFP ports supporting Gigabit or fast Ethernet, 6 10/100Base-TX ports
- ✓ Precise time synchronization supporting IEEE1588v2, ITU-T.G.8261/G.8262 (Sync-E)
- ✓ Supports redundancy protocol: IEC62439-6 (DRP), DT-Ring family, MSTP
- ✓ Extensive GPS and IRIG-B modules available
- ✓ Mini USB for Console port, VCT, and one-touch recovery, etc.
- ✓ Exceeds IEC61850-3 and IEEE 1613
- ✓ Exceeds IEC61850-3 and IEEE 1613
- ✓ CE and FCC Certificate (pending)

## 4.5PTC1000

- ✓ DIN-Rail IEEE1588 time converter
- ✓ One PTP input port for 100Base-FX (SC/ST/FC) or 10/100Base-TX
- ✓ One channel for PPS output, two channels for IRIG-B (DC) output, two channels for IRIG-B (AC) output, one channel for IRIG-B (RS422) output
- ✓ Precise time synchronization supporting IEEE1588v2, ITU-T.G.8261/G.8262 (Sync-E)
- ✓ Exceeds IEC61850-3 and IEEE 1613

# 5 Future Developments

As IEEE1588 is well designed and accepted on the automation and measurement market, a lot of interest has been aroused in telecommunication, synchronization over WAN, etc. It is fairly new and young, more potential can be explored and more feedback will be received from application:

- Synchronization over MAN or WAN, so that it can be deployed in other markets
- Testing Method for both performance and protocol conformity
- Management: MIB or Alarms definition, method for time quality management
- Switchover performance in ring topology to guarantee reliability
- Security issues, such as protection from access and malicious attacks