Time Synchronization for Digital Substation

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Master of Engineering

in

Electronics Instrumentation and Control

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Declaration

I hereby declare that the work which is being presented in this dissertation entitles as, **'Time Synchronization for Digital Substation'** in partial fulfillment of the requirements for the award of degree Master of Engineering in Electronics Instrumentation & Control submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision and guidance of **Dr. Suraj Kumar Pardeshi** , Sr. Manager- Technology, Global R&D Crompton Greaves Ltd and **Dr. M.D. Singh**, Asst. Professor, EIED, Thapar University.

The matter embodied in this thesis has not been submitted to any other University for the award of any Degree or Discipline.

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ABSTRACT

In the present era of research and development, real time data synchronization is very important in digital substation. Time synchronization. In digital substation is required to ensure that devices have accurate time for system control and data acquisition. There are different types of time synchronization technologies like Global Positioning system (GPS), Inter range instrumentation-B Time code (IRIG-B), Simple Network Time Protocol (SNTP) and Precision Time Protocol (PTP) standardized by IEEE 1588. In the proposed thesis work all the above technologies has been studied and analyzed to get the best protocol on the basis of Time synchronization accuracy, High efficiency, adaptability and reliability for Digital substation. The second objective is to achieve redundancy in the best protocol. For this Network Redundancy protocol has been studied and implemented through two different protocols. Finally a case study has been done on SNTP protocol using SEL-2401 Satellite-synchronization clock.

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1 INTRODUCTION

Time synchronization is problem of network consists of computers, routers, switches and other devices, all of which rely on clocks. For a successful communication between these devices, clocks play a significant role in maintaining the same global time across network devices. Now the main question comes that how these clocks maintain global time with each other. The short answer is synchronizing the time. In essence, Time synchronization is setting the time on two or more clocks to be identical. Every node on the network must count time in the same way and every node has to agree when time “zero” occurs Clocks are typically made from inexpensive oscillator circuits, or battery backed quartz crystals. Each of these clocks tends to drift due to inherent instabilities in the source of oscillator, in addition to environmental factors such as temperature, aging, manufacturer imprecision, air pressure, mechanical pressure etc. If the network clocks are not synchronized, unexpected things may start to happen data could be lost, processes could fail, security could be compromised, legal implications could be faced and most importantly the organizations could lose credibility with customers so Synchronization requires communications between individual clocks to check whether their difference is tolerable and whether the clock needs to be corrected. It takes time to go through the process of correcting time and maintaining the precision of time relative to another clock. The correction mechanism to synchronize individual clock is a challenging task and is a limiting factor in how accurately two clocks maintain a common time. So for this maintenance of time there are many technologies are used for providing time synchronization. These technologies are differing by their providing accuracy.

1.1 Time synchronization

We use clocks to synchronize ourselves with persons or processes. The required accuracy of the clock depends on the application. Anyone wanting to catch a train has to have his eye on the clock to within a minute. In competitive sport, a hundredth of a second can be decisive and drives in a packing machine need synchronization in the microsecond range. We get the microsecond time synchronization accuracy by using the Ethernet Technology, especially in the office world, has been the interoperability between equipment from different vendors and the widespread availability of Ethernet [1].

Many technical systems have a sense of time. An understood system time exists when there is no actual clock and the timing behavior is resolute by processes in the hardware and software. This is often sufficient in a lot of systems. An implicit time system is implemented, for example, by regular trigger events to every user which indicate the beginning of a unit of time and then trigger the appropriate actions.

The system time is clearly available when it is represented by a clock. This is often necessary in complex systems especially. This decouples the communication from the execution. But not every clock is exact. Now and again it has to be checked whether the deviation is tolerable and whether the clock needs to be corrected. Communication between the individual clocks is necessary for this.

Two effects are in confirmation when setting or synchronizing clocks: independent clocks initially run at an offset for one thing. To synchronize them, the more imprecise clock is set to the more accurate one. One more thing is that real clocks do not run at accurately the same speed. Therefore, the speed of the more imprecise cock has to be regulated constantly. Precise time synchronization is necessary to ensure that devices have accurate clocks for system control and data acquisition. In substation automation, time synchronization is especially important for time stamping of sampled values (IEC61850-9-2) of current, and voltage values need accurate clocks within the merging units [7].

Precision timing is always in insisting in automation technology when procedures require precise synchronization. The field of Motion Control is a main area of application. Here, Precision Time Protocol (PTP) helps to synchronize drives inside a robot [14], for example, or a printing press, a packaging or paper processing machine.

Time synchronization is used to precisely synchronize internal (time) clocks in IEDs, MUs, protection/control units, and Ethernet switches and wherever processes required to be synchronized. Time synchronization helps to achieve accurate control and precise global analysis of network reaction and when, where and why any faults has occurred [7].

1.2 Background

There have earlier been different ways to synchronize distributed clocks through a network. The most common of these are the Network Time Protocol (NTP)[4] and the simpler Simple Network Time Protocol (SNTP) derived from it. These methods are generally distributed in LANs (Local Area Networks) or in the Internet and permit accuracies into the millisecond range. Another option is the use of radio signals from GPS satellites [14]. However, this necessitates comparatively costly GPS receivers in every clock as well as the suitable antennae. This theoretically gives you high-precision clocks but the high costs and effort often avoid it.

Another solution is to send a high-precision time pulse (e.g. pulse per second signal) to every user on split lines. However, this entails an enormous additional wiring effort.

This is where the Precision Time Protocol (PTP) described in IEEE 1588 comes in. It has been developed with the following aims [7]:

- Synchronization accuracy in the sub-microsecond range
- Minimum requirements of the processor performance and network bandwidth which enables it to be implemented on simple and low-cost devices
- Low administration effort
- Use via Ethernet networks but also via other networks
- Specification as an international standard

1.3 Literature review

F. Peter *et.al* [1] has proposed a method of achieving redundancy with Audio and Video Bridging (AVB) with the help of Ethernet teachnology. It has been verified through simulation and has been proposed to the AVB Task Group for use in future revisions of the standard.

Jingyi Yu *et.al* [6] has proposed the compression between two time synchronization protocol SNTP and IEEE 1588 PTP at the bay level of digital substation. Also they Implementation and analysis IEEE 1588 time synchronization which had higher time synchronization accuracy was applied of bay level.

Orner Gurewitz *et.al* [7] has proposed the time synchronization protocol which is based on clock offset optimization. They develop a distributed protocol that can be implemented over a communication network and they prove its convergence to the optimal clock offset and also shows its properties. They also present methodology and numerical result for evaluating and comparing the accuracy of the time synchronization scheme. They shows that the classless time protocol out performs hierarchical scheme such as NTP in the sense of clock accuracy with respect to a reference clock.

Massimo Ussoli *et.al* [8] proposed about the SNTP protocol for small network to achieve the accuracy at the millisecond level. They analyzed the SNTP and how it is implement in the network infrastructure and the end node contribute to the measured accuracy. They discussed about SNTP time synchronization accuracy and achieve accuracy using SNTP protocol in millisecond level.

P. Ferrari *et.al* [9] has proposed the performance of redundant network for substation automation. Mainly they are focused on synchronization system which is applied to redundant network infrastructure for substation automation .The SNTP synchronization has been analyze by using two network named are Parallel redundancy protocol (PRP) AND Rapid spanning Tree Protocol (RSTP) . Also discuss about the comparison between them.

Te-Kwei Wang *et.al* [10] has proposed the NTP concept which is based on time varying encryption system for smart grid meter. The main purpose of the concept is provided millisecond time synchronization accuracy among the clients clocks and the server clock if follow the NTP. They also provide the time tags and the parameters are updated every second.

J. Viejo *et.al* [12] has presented the design and implementation of SNTP client module foe IEC 61850 environmentally fully done in hardware. This hardware module is able to generate synchronization and accurate time reference with in microsecond with respect to a SNTP server ,in a extremely compact ,effective and low power device completely implementing low grade FPGA and SNTP protocol for implementing remote terminal unit under IEC 61850.

Hu jv *et.al* [13] has introduced a real time synchronization system of digital substation .Testing the accuracy of time synchronization system. mainly result depend upon the that time synchronization system based on SNTP it can reach the require of accuracy of device in digital substation. The testing system based on the sequence of event resolution of controlling device is composed with some element. Through analyze or testing they conclude the result. They proposed the SNTP is a good choice of digital substation time synchronization system.

Lopez-Victor Pallares *et.al* [15] has proposed a experimental PTP based system for synchronized IEDs. They used NI PCI 1588 card as a experimental feasible master managed by the virtual instruments implementation in the lab view environment and IED with a PTP slave LM358902 microcontroller. Main objective to the reach a compression between the quality and cost for the future development to industrial EDS. Synchronization accuracy with some 100 nanosecond can be achieved

D. M. E. Ingram *et.al* [16] has presented demonstrate that PTPV2 is reliable method for provided time synchronization for sampled value process bus using IEC 61850-9.2 .ALSO they discovered that the use of transparent clocks does impact that PTPv2 timing system with sampling errors increasing on transparent clock are added to system . They investigated the transient response of slave clocks to correction transmitted by grandmaster when recovering from a time errors.

Qin Lijun *et.al* [17] has presented the research on IEEE 1588 standard. By using this standard achieved microsecond time synchronization accuracy. This sub - microsecond precision clock synchronization protocol used in a distributed network. IEEE 1588 has a important significance on the digital substation. They present a design of the industrial Ethernet system that supports the IEEE 1588 Standard.

1.4 Role of Time Synchronization in Digital Substation

Before touching the basic function and advantage of these all protocol for time synchronization in this section we are providing short overview of the time synchronization role in the digital substation.. ALL processor and event in a facility in the digital substation are controlled from the central point. The absolute accuracy of the station system time is rarely important but Time synchronization switching event involving more than one substation have to perform the absolute accuracy of each stations .The main important role for time synchronization is time reference.

2 Digital Substation

2.1 Overview

Substation is main information source and execution terminal of power grid, therefore, to understand digital substation is the necessary condition for digital power grid. Digital substation is Data acquisition and control of substation device through the automation and control Time synchronization is problem of network consists of computers, routers, switches and other Substation is main information source and execution terminal of power grid, therefore, to understand digital substation is the necessary condition for digital power grid. It is useful for the scientific management and decision of power grid and can improve the security and constancy of system.

The main characteristic of digital substation is “intelligentize the primary equipment and network the secondary equipment”. In digital substation, signal output and control input of primary equipment is both digitalized. Transmitting with network communication technology, the regular relay and its logic circuit for secondary circuit design can be replaced by programmable software. The regular analog signal will be replaced by digital signal; the regular control cable can be replaced by fiber optic or Ethernet. This can save a lot of resources. The simple secondary circuit design improves the dependability of substation automation system. In digital substation, the unified modeling of information enables information sharing. This can optimize the control function of substation. The digital substation which is currently the latest technology both at aboard and home. Network communication technology is the key technology to realize digital substation. IEC61850 provides complete network communication explanation for digital substation [4]. At present, digital substations at home or abroad are all designed following IEC61850 standard [10]. IEC61850 standard can divide the substation into three levels from network communication point of view: substation level, bay level, process level.

2.2 Digital Substation Architecture

The Digital substation is divided into three level these three level is defined top to bottom are given below.

- The station control area
- The Protection and control level
- The primary equipment process level

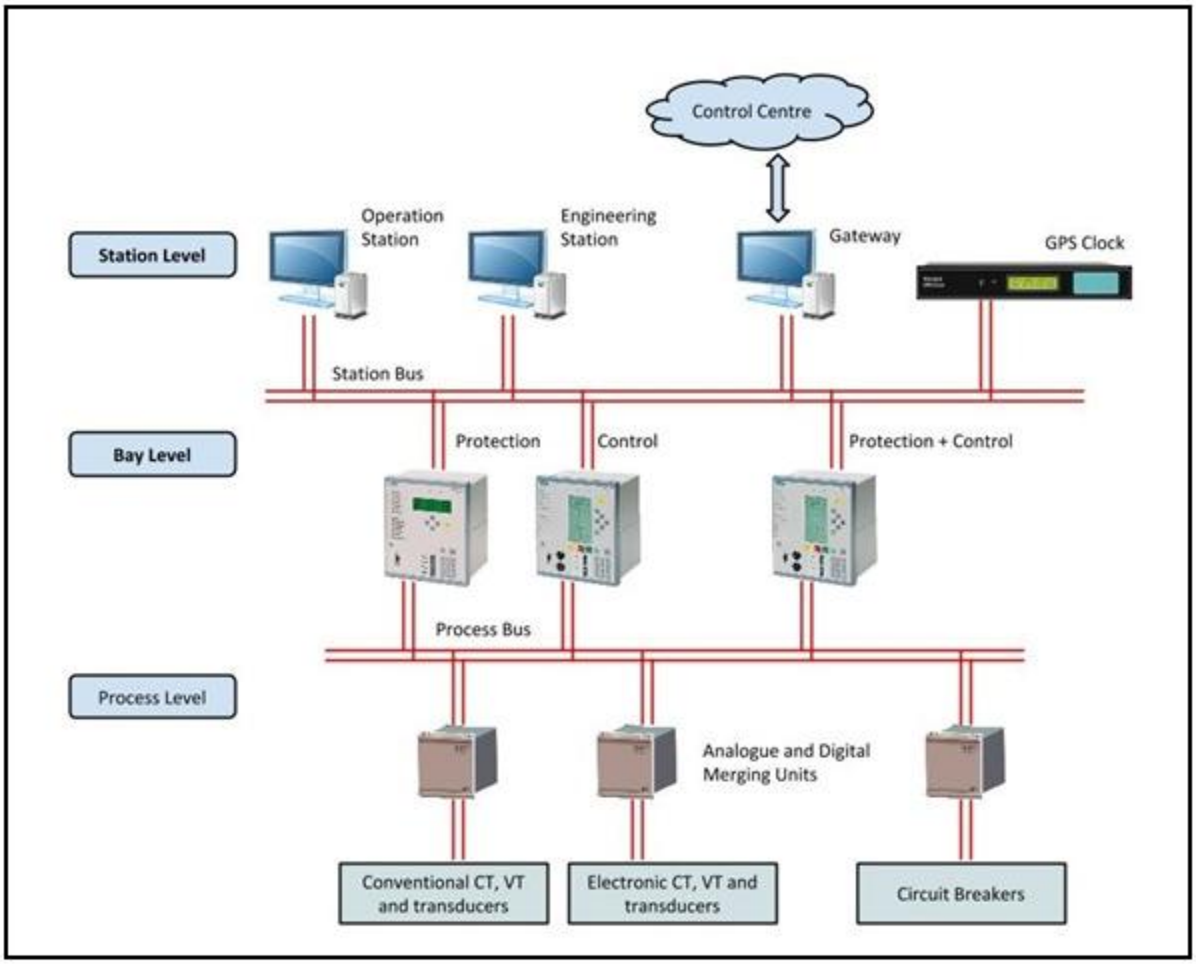

Figure 1: Digital Substation Architecture [2]

2.2.1 The station control area

Communication within substation and control system coordination with in substation operational function and the station level support function. The device available in the station level is (remote terminal unit, SCADA and gateway device)[2].

2.2.2 The protection and control level

Protection and control of the substation equipment includes IEDs traditionally called ‘secondary equipment’ like (protections, measurement devices, bay controllers, recorders etc)[2].

2.2.3 The primary equipment process level

Capture of voltage and current signal, consolidation, processing and transmission of data via optical fibers. Intelligent primary device (electronic power, and instrument transformer, circuit breakers, disconnections, and optic fiber have replaced traditional CT/VT system and conventional cable wiring).

2.3 How Digital Substation Work

Traditionally substations have used circuit breakers, current transformers (CT), voltage transformers (VT) and protection relays all wired mutually using copper cables. But day by day development in digital technology, communications and standards, this is now shifting to what is known as the digital substation. The digital substation starts with IEC 61850 "Communication networks and systems in substations"[4]. This is the international standard governing communications, SCADA and automation systems within substations. It is the backbone and framework around which a digital substation is built

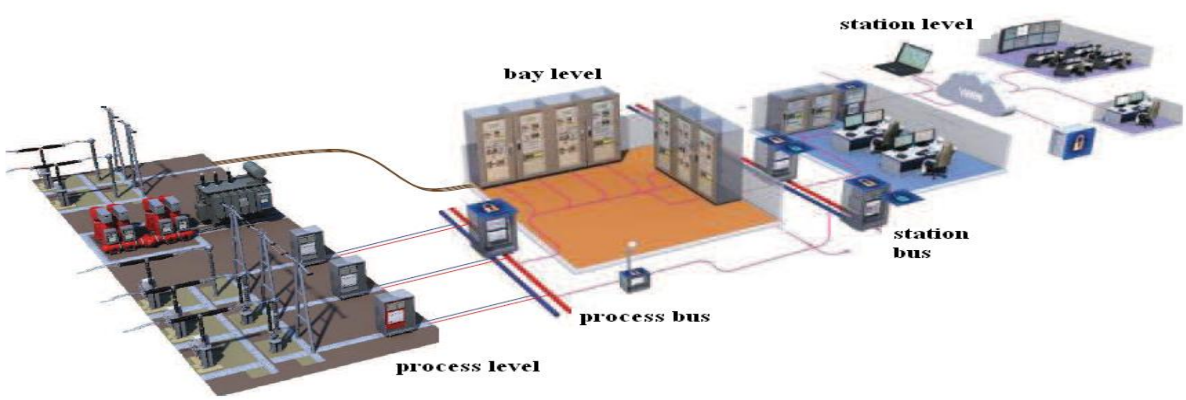

Figure 2: Digital Substation [2]

In the arrangement, the workstations, protection devices and low level transducers are connected together on an optical fiber communications backbone. The substation system architecture is dividing into three levels, 1) the station level where operations, engineering functions and reporting take place, 2) the bay level where system protection and control functions are implements and 3) the process level where signals from CTs and other transducers are transmitted.

2.4 System architecture

The digital substation is implemented using the elements and components shown in the given below figures. While the arrangement shown in not the only way to implement a digital substation, it does represent one of the more commonly adopted approaches.

By taking the various elements required of a substation (circuit breakers, protection relays, CTs and VTs, etc.) and interconnecting these using optical fiber[16], the physical realization of a substation becomes easier while at the same time, it's reliability and understandability increases.
Compared to the traditional substation where everything is connected together with hundreds of individual copper cables, the advantages become obvious.

The digital substations consist of several key components and elements.

2.4.1 Station and process bus

These two communication bus allow signals to be exchanged between the bay level IED and station control (station bus) and the bay level IED and system equipment, devices and transducers (process bus).

Figure 3: Compact Industrial Ethernet Switch [3]

The above diagram shows dual redundant station and process bus. This provides a greater reliability for important substations as compared to a single bus. The station and process bus systems are typically implemented using Ethernet switches [1] (external or built into the IED), connected together in a ring configuration.

2.4.2 Intelligent electronic device

The substation primary devices (protection relays, tap-changers, CTs, etc) are implemented as intelligent electronic devices (IED). These devices can communication with each other (and higher level substation control) via the 61850 optical networks [11].

2.4.3 GOOSE (Generic Object Oriented Substation Event)

The 61850 optical networks operate using the Ethernet protocol [4]. Within this framework established digital signals are transmitted using a generic object-oriented substation event (GOOSE). GOOSE is a specific format of data which enable protection status signals to be transmitted in a time period under 4 ms. The is necessary to ensure the reliable and timely operation of interconnected IED.

2.4.4 GPS Time clock

Figure 4: Sel-2401 GPS Clock [5]

An important requirement of the digital substation is the accurate keeping of time. This not only ensures the protection functions work within the mandatory times, but synchronizes substations in different locations so that event and operation logs can be compare and trip events analyzed.

The preferred approach to achieving this is by the use of a GPS clock to transmit time synchronization signals to the IED, using Simple Network Time Protocol (SNTP).

2.4.5 Merging Unit

Merging units collect signals for a variety of objects of equipment and transducers. These signals are then transmitted via the process bus to other devices. The merging unit is the interface between the traditional analogue signals and the bay controllers and protection relays [11].

2.4.6 Different type of time synchronization technology used in bay level of digital substation [6]

2.4.6.1 Time synchronization technology

There are two type of technology used which is based on:-

- Time synchronization based on the network

- Time synchronization based on the hardwire communication

GPS is time synchronization technology and used this technology in wide range of application. GPS is mainly used for acquire not only position information but also time information. A satellite transmit the wireless time signal to the GPS clock getting device on the ground this time signal is transformed and send to the terminal to be synchronized .GPS can provide 100ns time synchronization accuracy but it need a dedicated media to issue the time to the end user, every device in the network need IRIG-B or serial interface to receive the GPS timing information from a separate network , when we transmit GPS timing information one network to other network we need a packet based protocol ,IEE1588 PTP protocol and SNTP protocol etc.

conventional substation used a GPS time synchronization technology [6] .GPS clock receive device placed at the process level of substation convert the wireless standard time signal to pulse signal or IRIG-B code signal, then it transmit the signal to the device located at the bay level of the substation .IRIG-B is serial time code using pulse width coding and is also kind of signal which is generated signal per second by using through hardwire [6]. But this signal mainly contain number of second, minutes , date , hours and daylight saving time information ,another kind of signal is pulse signal .it has two kinds .one is pulse per minute, another is pulse per second. Both IRIG-B and pulse signal need a hardwire communication connection to all device to be synchronize. As shown in Figure 5

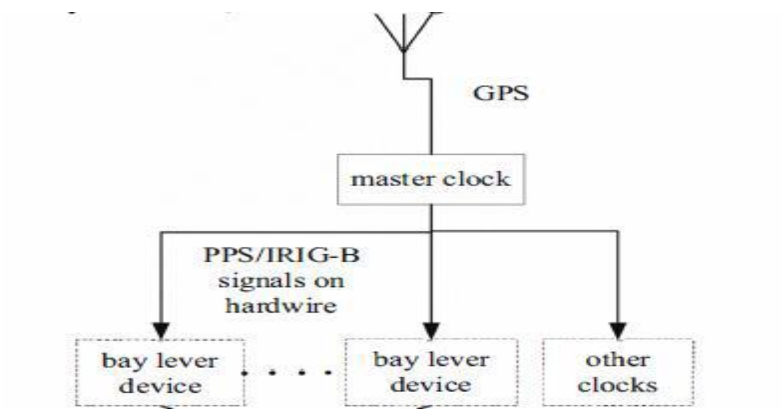

Figure 5 : Time Synchronization based on Hardwire Communication connection [6]

In digital substation, network time synchronization is introduced. This substation used a direct Ethernet network for time synchronization.GPS clock receiving device and Ethernet network can be directly used to transmit synchronizing signal in its place of hardwire connection, using Ethernet network its time synchronization accuracy can be achieved in microsecond, as shown in the 5.

There are two types of protocol used in the digital substation, SNTP and IEEE 1588 Protocol. Mainly IEEE1588 protocol is used in the process level because the device placed to this level its need time synchronization accuracy in microsecond, but at bay level device can be synchronized in millisecond 2.

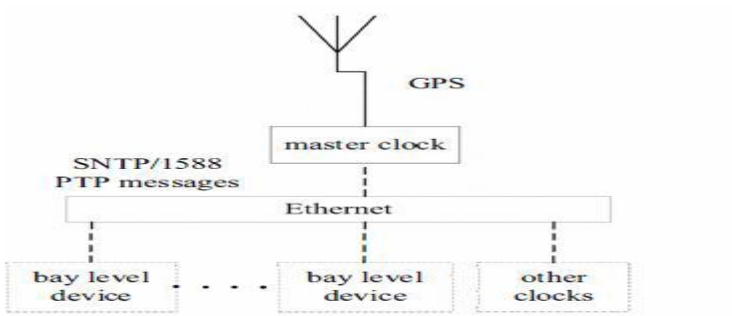

Figure 6: Time Synchronization based on the Ethernet Network [6]

2.4.6.2 Time synchronization technology based on the network

SNTP is simple network time protocol this technology based on the network that allows you to synchronize over the network SNTP use Server/Client mode. SNTP can operate point to multipoint (broadcast) mode or point (unicast) mode. SNTP server get time from GPS clock receiving device and send time information to the client, broadcast server periodically send a message to a IP multicast group address or IP broadcast address. A SNTP unicast client sends a request to a SNTP server and expects a replay from the server. SNTP are client of THE UDP (user datagram protocol). The UDP port number assigned to SNTP 567, which should be used in both source port and destination port in the user datagram protocol header [6].

Second one is IEEE 1588 (The Precision Time Protocol) technology used on the network and has been designed to improve the time synchronization of distributed network device .PTP allows for synchronization of distributed clock to microsecond accuracy and its implement over packet based protocol. Major focus is to implement PTP over UDP/IPV4.

Version 1 of the standard IEEE 1588 published in 2002 and version 2 of the standard IEEE 1588was published in May of 2008. IEEE 1588 PTP is a networked system consist a master clock and slave clock. The synchronization is achieved between master and slave clock by exchanging PTP timing message, the slave clock using the timing information to adjust their clock according to the time of their master clock. There are two phase. The first phase is the time difference between the master and slave clock is corrected this correction is the offset measurement and second phase is the calculate delay network between master and slave clock.
We discuss about on detail these two technologies on this chapter.

2.4.6.3 Time synchronization technology based on the hardwire communication

Traditional substation provide time synchronization which is based on the hardwire communication connection ,by using GPS clock receive device which convert wireless time signal to pulse signal or IRIG-B code signal[6].

IRIG-B is time codes were originally developed by inter-range instrumentation group. It a time code format, which provides date, day and time of day in a coded form. The accuracy of the IRIG-B runs into microseconds where accuracy of 1 μs can be achieved by 1 pulse per second (PPS) input. The location indentificate rate is 10 per second and frame rate of one per second symbol .B code is 0, 1 and p symbol and each symbol is occupied by the 10ms time. The symbol 0 and 1 correspond to pulse width of 2ms and 5ms and P symbol is the location code corresponding to the pulse width 8ms.

3 TIME SOURCE

3.1 Real time clock

A real-time clock (RTC) is a computer clock that keeps track of the current time mostly it is offered in integrated circuit form RTCs are present in almost any electronic device which requirements to keep accurate time. Mainly a real time clock allows a system to synchronize or time-stamps event to a time reference that can be easily understood by the user. Day by day RTC are used in all electronics device that require accurate time keeping. RTC also used for time synchronization in many application .like if there is no tome server or no network connection are to be had a solution when an external RTC must deployed. If there is time server is given then the application receive the time from this server and synchronized the RTC, if no time server is given then the application clock synchronize the system clock from the RTC [3]. So real time clock (RTC) sometime used as a time source.

3.2 Global positioning system

The **Global Positioning System** (**GPS**) is a space-based satellite direction-finding system that provides location and time information in all weather conditions, anyplace of the earth. The system provides critical capability to military, civil and commercial users approximately the world. It is maintained by the United States government and is freely available to anyone with a GPS receiver.

The GPS project was developed in 1973 to overcome the restrictions of previous navigation system. Integrating thoughts from several predecessors, as well as a number of classified engineering design studies from the 1960s. GPS was created and realized by the U.S department of defense and was initially run with 24 satellites.

GPS mainly used for acquire not only position information but also time information.. To provide time information to receivers on or near the earth's surface, about 24 satellites are positioned in earth orbit. GPS satellites are set with an atomic clock which is regularly synchronized with the clock of all other GPS satellites to within a few nanoseconds. GPS satellites constantly broadcast their time. Using the signals from four satellites, a GPS receiver can establish its position and its time. If GPS receivers were set with clocks precisely synchronized to the GPS 'satellites' clocks, only three signals would be required. Using four signals to establish the position information about time [3]. GPS receivers are capable to calculate UTC with an error of some hundred nanoseconds or even less

These GPS receivers can be used as a time synchronization source for radio base stations by generating precise 1 pulse per second signals. GPS provide time synchronization accuracy in nanosecond.

In Figure 7 show that the GPS receiver provides precise timing information to the Global Positioning System Synchronization Source (GPSS) and then GPSS will use this information to generate a 1 pulse per second (pps) signal and to create additional data including GPS time, position, etc. and sends this information to the MU [11]. The MU will use this information for synchronization. The GPS receiver provides precise timing information to the merging unit (MU).

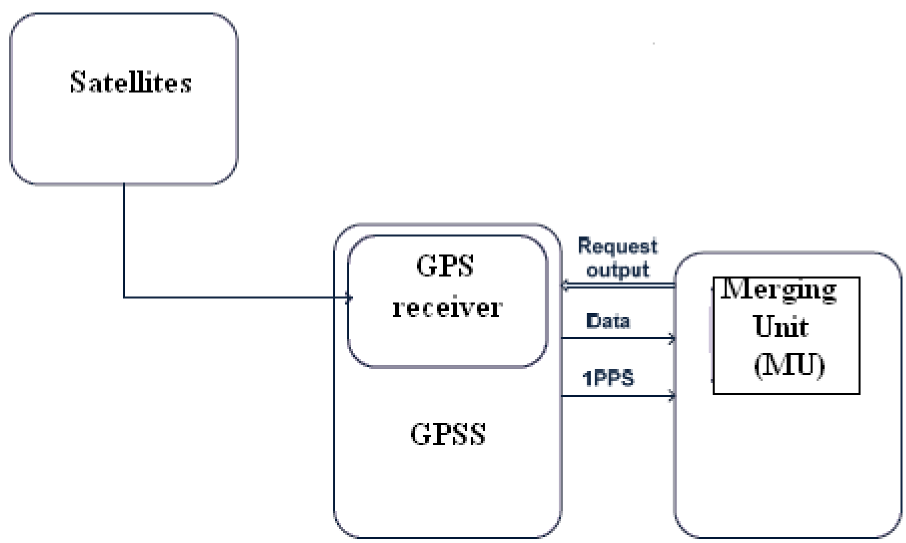

Figure 7: Time Synchronization to Merging Unit

3.2.1 GPS Parts

GPS divided into 3 segments

- Space segment
- Control segment

- User segment

The space segment includes the 27 satellites. The signal sent by the satellites contains 3 different parts: two sine waves, two digital codes, and a navigation message. The sine waves and digital code can be used to analyze the distance of the GPS receiver from the GPS satellites.

The control segment includes a network of tracking stations on the ground with one being elected as a master control station. The control segment is used to track the GPS satellites and guess their location, to check the precision of the satellites' atomic clocks [3].

The user segment is divided into two different applications is military and civilian, for which military and civilian users have unlike levels of access. The user segment includes the GPS receiver and antenna in arrange to receive the signals from the satellites, and a timing mechanism. The GPS receiver will use the digital code and sine wave to analyze its distance from the satellites and use the navigation information to analyze the satellites coordinates.

3.2.2 GPS receivers

GPS receivers are differentiated by their channel which are implemented, These Channels are allow the GPS receiver track different numbers of satellites simultaneously, like GPS receiver with four channels can track four satellite at a time.

There are different architectures for GPS receivers.

- Sequential receivers
- Continuous receivers
- Multiplexed receivers.

Sequential receiver has only one channel or two channel .mean it can observe one or two satellite at a time. This device is less costly but it is not a precise accuracy like a continuous receiver.

constant receiver has contain five or more channels .it can monitor four satellite at same time .but it is very costly and very high accuracy so it is suitable for very costly device which require very high accuracy, like aircraft.

Multiplexed receivers have a capacity to switch between the satellites it is tracking .this receiver also not much costly like continuous receiver .it has a lower resistance to congestion. GPS application used for varied the location and navigation but in this thesis focus on the GPS application used for timing purpose .In this thesis GPS clock used as a reference clock source which is used for time synchronization because it provide time accuracy in nanosecond.

For precise time we involve time transfer receiver. It can be used for application in required accurate timing. GPS receivers use 3 satellites for positioning and use one satellite to get the accurate time in order to synchronize the receiver’s clock with the satellites atomic clocks. GPS receivers have an substitute frequency source or a crystal oscillator .If the GPS receiver can see a enough number of satellites and can assemble the required positioning and timing information, then it will synchronize itself to UTC time and it will synchronize itself to UTC time or else it will simply use the internal oscillator or an external frequency source. This type of GPS receiver can provide timing synchronization with an accuracy of nanoseconds

4 IRIG-B

4.1 Introduction

Current day electronic systems such as communication systems, data management systems, missile and spacecraft tracking, and telemetry systems require time-of-day information for data correlation with time. Parallel and serial formatted time codes are used to efficiently interface the timing system (time-of-day source) to the user system [11]. Parallel time codes are defined in IRIG Standard 205-87. Standardization of time codes is necessary to ensure system compatibility among the various ranges, ground tracking networks, spacecraft and missile projects, data reduction and processing facilities, and international cooperative projects.

4.2 General Description of Standard

The IRIG time codes were initially developed by inter range instrumentation (IRIG) part of the range commander's council (RCC) of the US army. The standard was first published in 1969 and has been revise several times by Telecommunication and Time groups of the (RCC) [34].
The latest version is IRIG standard 200-04, IRIG serial time code updated in September 2004. The IRIG code available in six formats, these six code formats used different pulse rates or bit Rates, as shown in the table 2 given below.

4.2.1 IRIG Time Codes Formats:

4.2.1.1 Jitter

The modulated code is defined as < 1 percent at the carrier frequency. The dc level shift code is defined as the pulse-to-pulse variation at the 50 percent amplitude points on the most important edges of successive pulses or bits.

4.2.1.2 Bit Rate and Index counter

Each pulse in a time code word/sub-word is called a bit. The "on-time" reference point for all bits is the leading edge of the bit. The repetition rate at which the bits occur is called the bit rate Each bit has related numerical index count identification. The time interval between the leading edge of two consecutive bits is the index count interval. The index count begins at the frame reference point with index count 0 and increases one count each index count awaiting the time frame is complete [34].

4.2.1.3 Pulse rate Time

The specified pulse (dc level shift bit) rise time shall be obtained between the 10 and 90 percent amplitude points.

Table 1: IRIG Time code formats [34]

FORMAT	PULSE RATE (BIT RATE)	INDEXCOUNTINTERVAL
A	1kpps	1ms
B	100pps	10ms
D	1ppm	1 minute
E	10pps	100ms
G	10kpps	0.1ms
H	1pps	1second

The IRIG Time code frame begin with a frame reference marker,P_0 (Position Identifier) followed by a reference bit P_r with each having a duration equal to 0.8 of the index count interval of the respective code .The on–time reference point of the time frame is the leading edge of the reference bit P_r . The recurrence rate at which the time frame occurs is called the time frame rate. The position identifier has duration equal to 0.8 the index count interval of the particular code. The leading edge of the position identifier occur one index count interval before the frame reference point and the following position identifier (P0 P0…P2) occur every tenth bit. The recurrence rate at which the position identifier occurs is always 0.1 of the time format bit rate .The Time frame rate and time frame interval of the format table 2 are given below.

4.2.1.4 Time frame, Time Frame Rate and Time Frame Reference

A time code frame begins with a frame reference marker P_0 (position identifier) followed by a reference bit P_r with each having a duration equal to 0.8 of the index count interval of the respective code. The on-time reference point of a time frame is the leading edge of the reference bit P_r. The repetition rate at which the time frames occur is called the time frame rate.

Table 2: The Time Frame rate and time Frame interval of the Format [34]

FORMAT	TIME FRAME RATE	INDEX FRAMEI NTERVAL
A	10fps	0.1 second
B	1fps	1 second
D	1fph	1 hours
E	6fpm	10 second
G	100fps	10 minute
H	1fpm	1minute

4.3 Time Codes Attributes

All IRIG time code format use Pulse width coding. A "binary 1" pulse has period of 50% of index count interval and "binary 0" pulse has period of 20% of index count interval. In addition "position identifier" has period of 80% and is used as reference markers.

IRIG time code signal may be [3]:

- **Unmodulated** (DC level shift, no carrier signal)
- **Modified Manchester (** Amplitude modulation, square wave modulation index)
- **Modulated** (Amplitude-modulated , sine wave carrier)

Three types of coded expression are used in IRIG standard:

- **Binary Coded Decimal** time-of-year ($BCD_{TOY)}$ and Year (BCD_{YEAR})
- **Control Functions** (Set of bits reserved for the user application)
- **Straight Binary Seconds** (SBS) Time-of-day (0 to 86400 seconds)

4.4 Time Code Designation

In addition to the letter used to assign one of the six IRIG code formats, signal identification numbers are used to further explain specific characteristics. Thus, the complete IRIG time code designation consists of a letter and three digits, as shown in Figure 8.

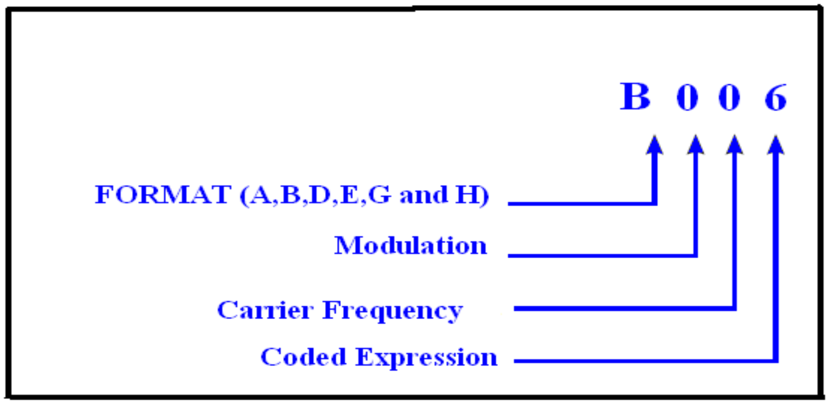

Figure 8: IRIG TIME CODE – Naming Convention

4.4.1 IRIG Signal Identification

Table 3: IRIG Signal identification [34]

1st Digit	**Modulation**
0	Unmodulated – DC Level Shift (DCLS), pulse-width coded
1	Amplitude modulated, sine wave carrier
2	Manchester modulated
2nd Digit	**Carrier Frequency / Resolution**
`0	No carrier (DCLS
1	100 Hz / 10 ms resolution
2	1 kHz / 1 ms resolution
3	10 kHz / 100 microsecond resolution
4	100 kHz / 10 microsecond resolution

3rd Digit	Coded Expressions
0	BCDTOY, CF, SBS (Binary coded division Time of year, control function, straight binary second)
1	BCDTOY, CF
2	BCDTOY
3	BCDTOY, SBS
4	BCDTOY, BCDYEAR, CF, SBS
5	BCDTOY, BCDYEAR, CF
6	BCDTOY, BCDYEAR
7	BCDTOY, BCDYEAR, SBS

4.4.2 Time Code Words

The two time code words employed in this standard are**:**

- BCD time-of-year
- SBS time-of-day (seconds-of-day)

All time code formats are pulse-width coded. A binary (1) bit has period equal to 0.5 of the index count interval, and a binary (0) bit has period equal to 0.2 of the index count Interval. The BCD time-of-year code reads 0 hours, minutes, seconds, and fraction of seconds at2400 each day and reads day 001 at 2400 of day 365 or day 366 (leap year)[34]. The SBS Time-of-day code reads 0 seconds at 2400 each day excluding leap second days when a second may be added or subtracted. Coordinated Universal Time (UTC) is generated for all interring applications.

4.4.3 Position Identifier

Position identifiers have period equal to 0.8 of the index count interval of the respective code. The leading edge of the position identifier P_0 occur one index count interval before the frame reference point P_r and the following position identifiers (P_2, P_2...P_0) occur every following tenth bit. The repetition rate at which the position identifiers occur is always 0.1 of the time format bit rate.

4.4.4 BCD Time-of-Year Code Word

The BCD time-of-year code word consists of sub words in days, hours, minutes, seconds, and fractions of a second encoded in a binary illustration (1n 2n 4n 8n) where n=1, 10, 100, 1 k...N. Time code digit values less than N are considered zero and are encoded as a binary 0.The position identifiers earlier the decimal digits and the index count locations of the decimal digits (if present) are:

Table 4: BCD CODE Word [3]

BCD Code Decimal Digits	Decimal Digits Follow Position Identifier	Digits Occupy Index Count Positions
Units of Seconds Tens of Seconds	P0	1-4 6-8
Units of Minutes Tens of Minutes	P1	10-13 15-17
Units of Hours Tens of Hours	P2	20-23 25-26
Units of Days Tens of Days	P_3	30-33 35-38
Hundreds of Days Tenths of Seconds	P4	40-41 45-48
Hundredths of Seconds	P5	50-53

4.4.5 Control Functions

All time code formats preserve a set of bits known as control functions (CF) for the encoding of various control, identification, or other special purpose functions. The control bits may be programmed in any determined coding system. A binary 1 bit has period equal to 0.5 of the index count interval, and a binary (0) has period equal to 0.2 of the index count interval. Control function bits follow position identifier P5 or P6 establishment at index count 50 or 60 with one control function bit per index count, excepting each tenth bit which is a position identifier. The number of offered control bits in each time code format is [34]:

Table 5: IRIG Control Function

Format	Control Functions
A	27
B	27
D	9
E	45
G	36
H	9

Control functions are presently proposed for intrarange use but not for intrarange applications; therefore, no standard coding system exists. The addition of control functions into a time code format as well as the coding system in use is an individual user defined option.

4.4.6 Index Marker

Index markers occur at all index count positions which are not assigned as a reference marker, position identifier, code, or control function bit. Index marker bits have duration equal to 0.2 of the index count interval of the respective time code format.

4.4.7 Amplitude Modulated Carrier

A standard sine wave carrier frequency to be amplitude modulated by a time code is coordinated to have positive-going, zero-axis crossings immediate with the leading edges of the modulating code bits. A mark-to-space ratio of 10:3 is standard with a range of 3:1 to 6:1.

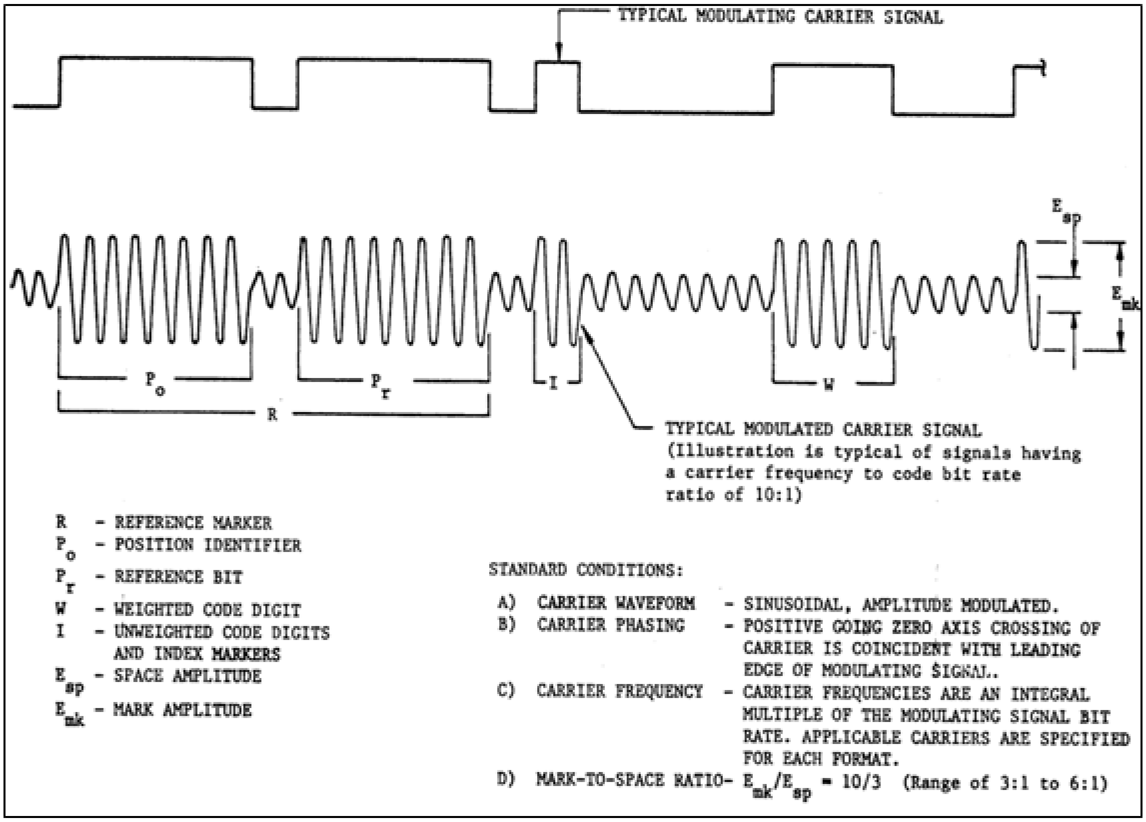

Figure 9: Signal Format [34]

4.5 IRIG-B PROTOCOL DESCRIPTION

IRIG-B time code is the most common which sends time information per second. The IRIG-B time code not only includes the information of second pulse but also includes the information of the year, day, hour, minute, and second [11].

It is serial time code, the total width of each symbol is 10ms, a time-frame period includes 100 symbols, and there are three kinds of coding of each symbol: binary "0", 1" and location identifier [34]. There are three fields: the first is time field (years, days, hours, minutes, and seconds), the seconds control function field, and the third field can respect the day time information by the use of binary symbol directly. Symbol's reference point is the pulse front; whose pulse width is 8ms; every 10 symbols have a location recognition mark. Therefore, one second has a total of 10 location identifier: P1, P2, and P3... P9, P0, the pulse width of them is 8ms; PR is the reference point for the frame; binary "1" represents that the pulse width of symbol is 5ms, binary "0" represents that the pulse width of symbol is 2ms.

4.5.1 IRIG-B Signals

IRIG-B is typically distributed as a DC level shift, pulse-width coded signal ("unmodulated IRIG-B") or as an amplitude-modulated signal based on a sine wave carrier with a frequency of 1kHz ("modulated IRIG-B"). Modified Manchester modulation is also particular in the standard but is less common. The IRIG-B coding compression methods are given in the Figure below.

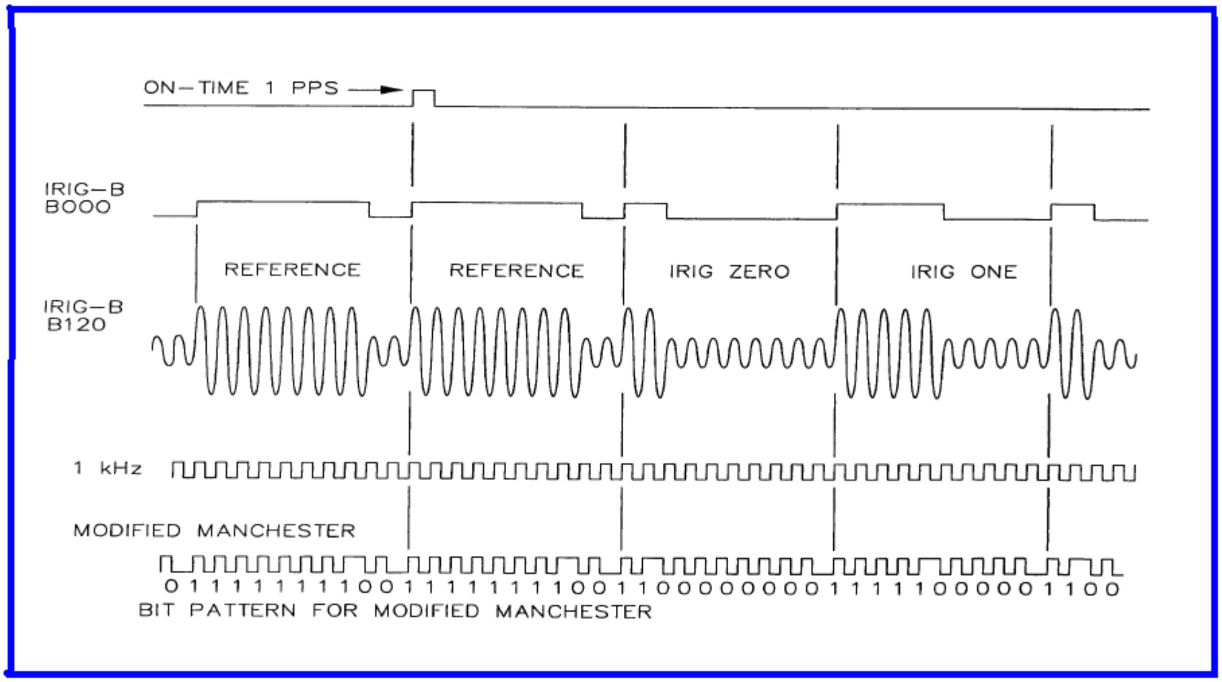

Figure 10: IRIG-B Coding Compression Method – Level shift (UNMODULATED),

The IRIG-B is 74-bit time code contains 30 bits of BCD time-of-year information in days, hours, Minutes, and seconds; 17 bits of SB seconds-of-day; and 27 bits for control functions. The BCD code (seconds sub word) begins at index count 1 (LSB first) with binary coded bits occurring between position identifier bits P0 and P5: 7 for seconds, 7 for minutes, 6 for hours, and 10 for days, to complete the BCD word. An index marker occurs between the decimal digits in each sub word to give separation for visual resolution. The BCD time code recycles yearly. The SBS word begins at index count 80 and is between position identifiers P8 and P0 with a position identifier bit (P9) between the 9th and 10th binary SBS coded bits. The SBS time code recycles each 24 hour period. The control bits occur between position identifiers P5 and P8, with a position identifier every 10 bits.

Basic symbol of B code is "0","1" and" P" symbol, and each symbol are occupied by the 10ms time. The symbol "0" and "1" corresponds to the pulse width of 2ms and 5ms and "P" symbol is the location code corresponding to the pulse width of 8ms.

The valid combinations in use for IRIG-B are: B00z, B12z and B22z.

4.5.1.1 B00z (DC level-shift IRIG-B)

B00z (DC level-shift IRIG-B) has been special for use with new equipment in substations because, even though it cannot be used for wiring runs of more than about 100 meters, it offers good timing accuracy. As long as the GPS clocks outputs are inaccessible and therefore balanced this successfully eliminates problems due to induced noise that can cause difficulties using this form of time code in sub-stations [34]. This code can also be easily transmitted over fiber. Demodulation is not necessary, so the code can be very simply received and used by connected equipment. The B00z signals are already being used for synchro-phasor timing.

4.5.1.2 B12z (Amplitude Modulated IRIG-B)

B12z (Amplitude Modulated IRIG-B) has in history been widely used. Because this modulation is a 1 KHz sine-wave, timing accuracy is essentially limited by the wave shape. This is, therefore, the least accurate of all of the IRIG-B varieties, but has been in common use because, with no DC content in the signal, it lends itself to transmission over lengthy distances. The sine-wave zero-crossing transitions have to be placed very accurately by the GPS clock (within a few microseconds of absolute UTC time), so that very good accuracy can still be obtained provided that the receiving equipment employs a reasonably difficult demodulator (e.g. PLL) to recover the timing accuracy. Sub-millisecond accuracy is reachable.

4.5.1.3 B22z (Modified Manchester IRIG-B)

B22z (Modified Manchester IRIG-B) while not yet in common apply, gives the best of both worlds. It preserve the razor sharp accuracy of B00z, using a 1Khz square wave, but with phase modulation slightly than DC level shift. With no residual DC level, it is, therefore good for driving very long distances as well. Demodulation using PLL method is relatively straight forward.

4.5.2 IRIG-B CODE CRITERION

The B-code is a pulse width encoding. Its time frame rate is 1f/s, and each code width is 10ms. One time frame period contains 100 code elements. The high is bit before the low bit. The year, day, hour, minute, and second all use BCD-code. Put the tens before ones. The time format as shown in given below Figure 11:

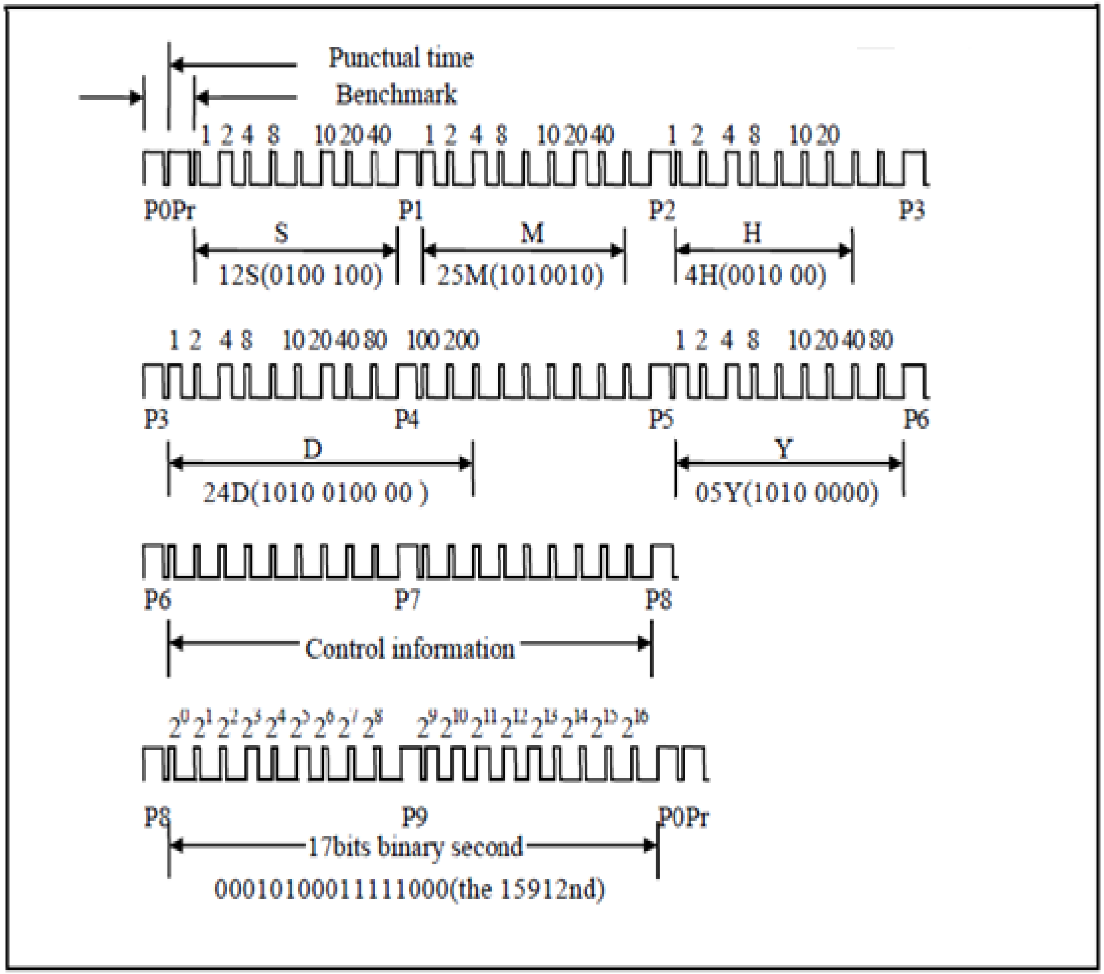

Figure 11: IRIG-B Code scheme [34]

The code element "on time" reference point is its pulse leading edge. The time frame reference mark includes a location identification mark and a adjacent reference code element and its width is 8ms; every 10 code elements have a location identification mark: P1, P2, P3,….P9, P0. These are all 8 ms width; PR is frame reference point, width is 8ms; the binary "1" is 5ms pulse width and "0" is 2ms pulse width are shown in above figure 12.

A time frame starts from the reference mark, and the constant two 8ms pulse width means a second start. The time sequence is second-minute-hour-day-year. Each occupies 7bits, 6bits, 10bits, and 8bits of information bit. The location is between P0 and P6. P6-P8, as well as other control information. P8-P0 includes second information of a day, and it occupies 17bits and uses binary. The high is bit before the low bit. The year, day, hour, minute, and second all use BCD-code. Put the tens before ones.

Essential symbol of B code is "0","1" and" P" symbol, and each symbol are occupied by the 10ms time. The symbol "0" and "1" be in contact to the pulse width of 2ms and 5ms and "P" symbol is the location code equivalent to the pulse width of 8ms .The basic symbol diagram as shown in Figure 12

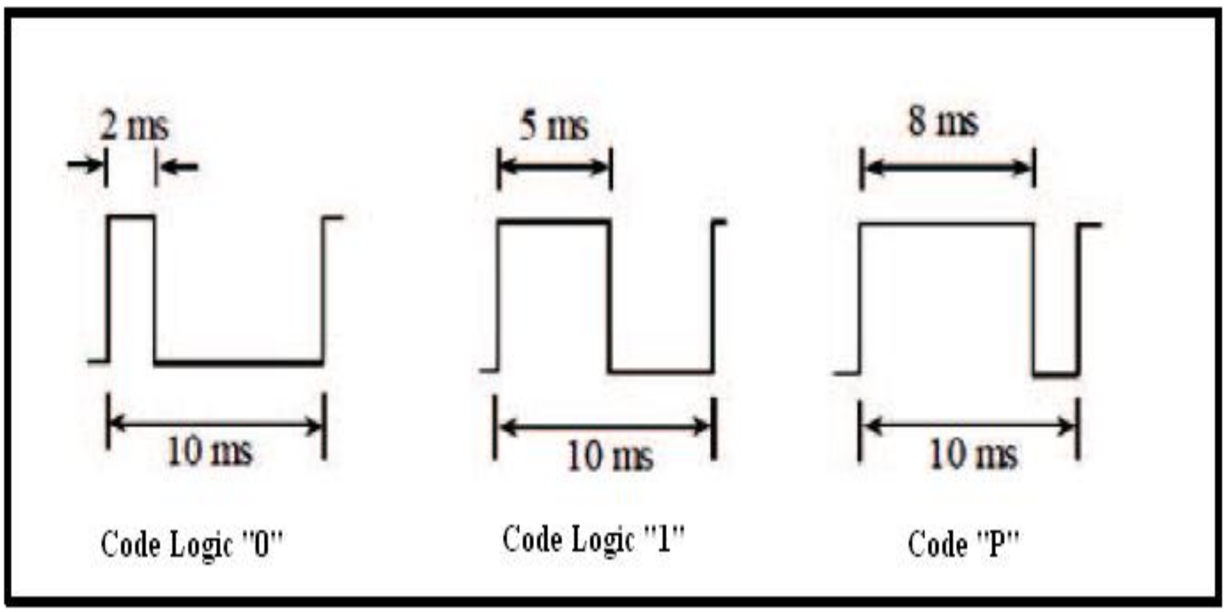

Figure 12: Sketch Graphic of IRIG-B Symbol [11]

4.5.3 IRIG-B Encoding

IRIG-B consists of 100 bits created every second, 74 bits of which include various time, date, time changes and time quality information of the time signal. Consisting of logic ones, zeros and position identifier bits, the time code give a reliable method of transmitting time to synchronize power equipment devices. There are three functional groups of bits in the IRIG-B time code: Binary Coded Decimal (BCD), Control Functions (CF) and Straight Binary Seconds (SBS). The BCD group contains time information including seconds, minutes, hours and days, recycling yearly. The BCD time-of-year code (BCD_{TOY}) reads zero (0) hours, minutes, seconds and fraction of seconds at 2400 each day and reads day 001 at 2400 of day 365, or day 366 in a leap year. The BCD year code (BCD_{YEAR}) counts year and cycles to the next year on January 1st of each year and will count to year 2099. The SBS time-of-day code consists of the total elapsed seconds, recycling daily. SBS reads zero (0) seconds at 2400 each day excluding leap second days when a second may be added or subtracted [34].

The CF group includes year, time quality, leap year, pending leap seconds and parity. Other CF bits are reserved for user-defined purposes, depending on application.

4.5.4 Leap Year/ Leap Second convention

LEAP YEAR:

The length of a year is not an even multiple of days. The year is about 365.25 days. Thus, every four years there is an extra day, February 29, provided the year is divisible by 4. Years divisible by 400 are leap years. If the year is divisible by 100, it is not a leap year. Consequently, the years 1988, 1992, 1996, and 2000 are leap years. The year 2100 will not be a leap year because it is not divisible by 400. With the addition of leap years, the calendar stays in step with the seasons.

ACCUMULATED LEAP SECOND:

Since 1 January 1972, the relationship among International Atomic Time (TAI) and Coordinated Universal Time (UTC) has been given by a simple accumulation of leap seconds occurring around once per year.

At any instant (i), T_i = TAI time

U_i = UTC time expressed in seconds

$T_i = U_i + L_i$,

Where (L_i) is the accumulated leap second additions between the epoch and the instant (i).

The following table contains a reference list of the accumulated leap second additions

(L_i) between 1972.0 and 1988.0:

Table 6: Reference Lost of Accumulated Leap year

TIME PERIOD	L_i
1972 Jan 1 --- 1972 Jul 1	10.000 000 0 s
1972 Jul 1 --- 1973 Jan 1	11.000 000 0 s
1973 Jan 1 --- 1974 Jan 1	12.000 000 0 s
1974 Jan 1 --- 1975 Jan 1	13.000 000 0 s
1975 Jan 1 --- 1976 Jan 1	14.000 000 0 s
1976 Jan 1 --- 1977 Jan 1	15.000 000 0 s
1977 Jan 1 --- 1978 Jan 1	16.000 000 0 s
1978 Jan 1 --- 1979 Jan 1	17.000 000 0 s
1979 Jan 1 --- 1980 Jan 1	18.000 000 0 s
1980 Jan 1 --- 1981 Jul 1	19.000 000 0 s
1981 Jul 1 --- 1982 Jul 1	20.000 000 0 s
1982 Jul 1 --- 1983 Jul 1	21.000 000 0 s
1983 Jul 1 --- 1985 Jul 1	22.000 000 0 s
1985 Jul 1 --- 1986 Jan 1	23.000 000 0 s
1986 Jan 1 --- 1988 Jan 1	24.000 000 0 s

5 SNTP (Simple Network Time Protocol)

5.1 Introduction

The most generally used method for maintaining precise time across whole networks is an implementation of the Network Time Protocol (NTP) [8]. It is a networking protocol for distributing Coordinated Universal Time (UTC) by a method of synchronizing the clocks of computer systems over a packet switched variable-latency data networks. NTP is the oldest protocol and widely used protocol on the internet [9]. It is application layer protocol and builds on the internet protocol and UDP (user data gram protocol). Mostly it is designed to maintain Time accuracy and dependability.

NTP protocol is planned to synchronize all computer are participating within few milliseconds of UTC. This protocol mostly described in terms of client-server model. NTP protocol provides 10 millisecond time synchronization accuracy over the public internet and can also achieve one millisecond accuracy in LAN under situation [8]. The clients and servers used in the NTP have capability and possibilities over a wide range of network delays and jitter characteristics.NTP provide a solution to system time preservation problems. The client/server software enables to set up a almost safe synchronized time environment for networks of any size and complexity.

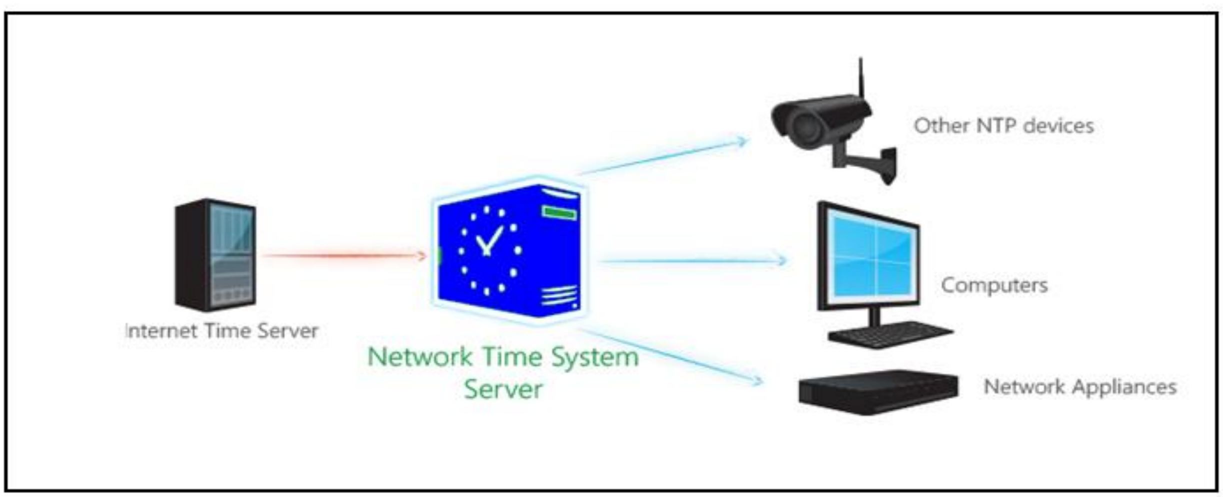

Figure 13: Network Time Protocol Communication Architecture

Network Time System allows the manufacture of a source of precise time in a corporate network environment establishing an interconnected time synchronization system for each and every device on the company network. As shown in Figure 14.

Network Time System (Server) is part of the Network Time System package used for setting up and running a devoted time server on the network. The application is accomplished of time synchronization with external NTP sources (such as GPS, clock cards etc.). Moreover, it can host the time received from an external time source for NTP/SNTP well-matched devices and non-Windows clients. Network Time System (Client) is part of the Network Time System package dependable for synchronizing time on Windows based workstations where it is installed. The application is capable of repeatedly searching for time server on the corporate network of any difficulty, from LANs to several routing networks. Setting a time server physically is also possible. Network Time System allows the creation of a custom source of precise time in a corporate network environment establishing a consistent time synchronization system for each and every machine and device on the company network

.NTP mechanism on assumption of having all the system clocks get as close as possible to the correct time[10]. NTP corrects the current time and makes sure the time is reliable on the devices and automatically adjusts for time drift on the client. When this is achieved, it allows for small network traffic and stores client clocks more constantly, even if the network is unreachable due to changes in topology or any calamity.

5.2 Network time protocol architecture

The Main purpose of NTP (Network Time Protocol) is to attach a number of primary reference sources (like GPS, Clock Cards etc.) synchronized to widely available resources such as backbone gateways and its substitute as primary time servers, use NTP between them to cross-check the clocks and moderate errors due to equipment or propagation failures. Some number of local-net hosts or Gateways, substitute as secondary time servers, runs NTP with one or more of the primary servers. In order to decrease the protocol overhead, the secondary servers allocate time via NTP to the remaining Local-net hosts. In the interest of dependability, selected hosts can be equipped with less accurate but less costly radio clocks and used for backup in case of failure of the primary and secondary servers or communication paths between them. There is no condition for peer discovery or virtual-circuit management in NTP [13]. Data reliability is

provided by the IP and UDP checksums. No circuit-management, duplicate-detection or retransmission services are provided. The service can work in a symmetric mode, in which servers and clients are identical, yet continue a small amount of state information, or in Client/server mode, in which servers require maintain no state other than that restricted in the client request [13]. A lightweight association-management capability, as well as dynamic reach ability and variable polling-rate mechanisms, is integrated only to manage the state information and reduce resource requirements. Since only a single NTP message format is used, the protocol is easily implemented and can be used in a variety of wanted or unwanted polling mechanism.
It should be accepted that clock synchronization requires by its nature long duration and multiple comparisons in order to maintain accurate timekeeping. While only a few measurements are usually enough to reliably conclude local time to within a second or so, period of many hours and dozens of measurements are required to determine oscillator drift and sustain local time to the order of a millisecond. Thus, the accuracy achieved is straight dependent on the time taken to achieve it. Providentially, the frequency of measurements can be quite low and approximately always non-intrusive.

5.3 Implementation model

The most common client/server model a client sends an NTP message to one or more servers and processes the replies as received. The server interchanges addresses and ports, overwrites certain fields in the message, recalculates the checksum and returns the message immediately. Information included in the NTP message allows the client to determine the server time with respect to local time and adjust the local clock accordingly [10]. In addition, the message includes information to calculate the expected timekeeping accuracy and reliability, as well as select the best from possibly several servers.

While the client/server model may suffice for use on local nets involving a public server and perhaps many workstation clients, the full generality of NTP requires distributed participation of a number of client/servers or peers arranged in a dynamically reconfigurable, hierarchically distributed configuration. It also requires sophisticated algorithms for association management, data manipulation and local-clock control.

Implementation model for a time-server host as well as three processes sharing a partitioned data base, with a partition devoted to each peer, and interrelated by a message passing system. The transmit process, determined by independent timers for each peer, collects information in the data base and sends NTP messages to the peers. Each message includes the local timestamp when the message is sent together with earlier received timestamps and other information from directly connected time code receivers. When an NTP message is received the offset between the peer clock and the local clock is calculated and incorporated into the data base along with other information helpful for error estimation and peer selection. A filtering algorithm described improves the estimates by discarding lower data.

The update procedure is initiated upon receipt of a message and at other times. It processes the offset data from each peer and selects the best one using the algorithms. This may involve many observations of a few peers or a few observations of many peers, depending on the accuracies required.

The local-clock process works upon the offset data formed by the update procedure and adjusts the phase and frequency of the local clock using the method. This may result in either a step-change or a gradual slew modification of the local clock to decrease the offset to zero. The local clock gives a stable source of time information to other users of the system and for following reference by NTP itself information necessary to conclude the hierarchy and manage the involvement [13]. The message transmission rate is resolute by the accuracy required of the local clock, as well as the predictable accuracies of its peers. The receive process receives NTP messages and perhaps messages in other protocols, as well as.

5.4 How SNTP works

SNTP is simple network time protocol that allows you to synchronize over the network SNTP use Server/Client mode. SNTP can work point to multipoint (broadcast) mode or point (unicast) mode. SNTP server get time from GPS clock receiving device and send time information to the client, broadcast server periodically send a message to a IP multicast group address or IP broadcast address. A SNTP unicast client sends a request to a SNTP server and waits for a replay from the server. SNTP are client of the UDP (user datagram protocol). The UDP port number allocated to SNTP 567, which should be used in both source port and destination port in the user datagram protocol header. Unicast mode as shown in Figure 15.

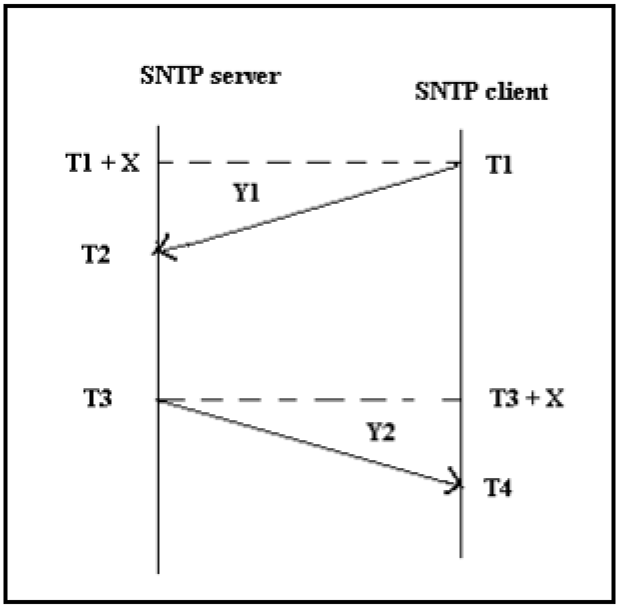

Figure 14: SNTP Synchronization [6]

In figure the originate timestamp T_1 is the time when the client send request X is the offset between the client clock and server clock.T_1 + X is the SNTP server local clock reference .Y_1 is one side delay .then its result

$T_2 = T_1 + X + Y_1$

$Y_1 = T_2 – T_1 – X$

After all the processing client send request and server send reply to the client at the T3.when the client determine the timestamp T4. T4 is the time of arrival according to its local clock. There is

$T_2 = T_4 – (T_3 – X)$

If the network delay in the two direction is same ($Y_1 = Y_2$), then offset X is calculate by given below equation

$X = (T_3 + T_4 + T_2 – T_1)/2$

Using this mathematical equation calculate the offset between client and server.

6 IEEE 1588(PTP)

6.1 Overview

IEEE 1588 PTP protocol utilize in power system protection, control, automation and data communication application employ in communication architecture [7]. Typical Ethernet –based time distribution architecture consists of reference clock, bridges, and end devices. Bridges with boundary clock functionality may also be used at interconnection points between different PTP domains or PTP profiles.

In addition to distributing global time that is appreciable to a recognized standard time source, the profile has condition for distributing global time for the cases when connectivity to recognized standard time source is lost.
The profile can be used for precise time synchronization of the devices in a substation and between substations in larger geographical area, if performance requirement of this standard are met.

The use of different physical layer communication technologies to carry Ethernet frame, and wireless technology is not precluded if they can meet performance requirement of this standard
Time distribution specified in this standard is based on the following basic statement [14]:

- all devices that contribute in time distribution maintain this standard
- All devices are in the identical time distribution domain.
- All devices have point-to-point correlation to their neighbors.
- Transmit and receive cable delay for each point-to-point correlation is assumed to be symmetrical known asymmetry in cable delay can be configured and accurate.

The use of security techniques is an important thought and, based on the application may be desirable .security extension and network engineering methods for hardening the PTP-based time distribution

Redundancy is an important consideration; some application suggests or authorization support for different time distribution technologies, all about this redundancy discuss on next chapter.

6.2 Scope

Mainly IEEE 1588 method and settings expected to enable device interoperability, robust response to network failures deterministic control of delivered time value. It specifies the preferred physical layer higher level protocol used for PTP message exchange and the PTP protocol arrangement parameters. Special concentration is to ensuring consistent and reliable time distribution with in substation, between substations and across wide geographic areas [14].

Conventionally, synchronization has been achieved using a devoted medium to convey time information, typically using the IRIG-B serial protocol it is told about this protocol in last chapter.

PTP has been designed to develop the current time synchronization of the distributed network device. PTP stands for Precision Time Protocol and Ethernet protocol described in the standards IEEE 1588 and IEC61588 for time synchronization [7]. It is a cost- capable solution and can be applied on the basis of the offered Ethernet network in a substation. IEEE 1588 applies master/slave time synchronization mechanisms and supports hardware time stamps. IEEE 1588 has two versions and they are not straight compatible. IEEE 1588 v2 is necessary for IEC61850-9-2 Process Buses.

6.3 Purpose of IEEE 1588

The purpose of the this standard is to facilities implementation IEEE 1588 for power system application require high precision time synchronization .it specifies a common subset of PTP Parameters and option to provide global time availability, device inerrability and failure management . Precision Time Protocol (PTP) is a protocol designed to synchronize real-time clocks in the nodes of a distributed system that communicate with a network [7]. The new IEEE 1588 standard precision time protocol is now a very best solution to do very accurate time synchronization in an Ethernet network. This protocol was developed by Agilent for control task and distributed instrumentation. This technique based on the work of john Edison who as chairman of the standardization committee is largely dependable for the approval of standard in November 2002. using IEEE 1588 it is achievable for the time to synchronize in the micro second range,the local actuators ,sensors and other terminal devices using the same Ethernet network that also transport the process data without such standization synchronization protocol which is defined to be used with any protocol not just Ethernet it would be probably not be possible to synchronize local clocks in terminal devices from different manufactures with the precision[7] .

There are many time synchronization protocols such as NTP, SNTP and IRIG-B do not achieve the required time synchronization accuracy in microsecond as compare to IEEE 1588.

PTP is based on the most accurate matching of times when synchronization packets are transmitted and received possible .unlike SNTP, the transmission time stamp does not need to be transmitted in the synchronization packet itself as described about this protocol in previous chapter. A PTP domain automatically configures itself using the best master clock algorithm and its is also fault tolerant.

6.4 Many industry and groups are interested in IEEE 1588

The biggest interest in Ethernet currently is found in automation ,specially motion control application .Many drive manufactures are equipping their devices with ETHERNET interfaces, but now have problems synchronizing all connected drives as precisely as possible over the network.

Several groups of the industrial sector have decided to use this protocol in their Ethernet based field busses. But interest is not only coming from the automation industry. Increasing demand of the growing out of test and measurement the origin of this protocol also early projects have been started to use IEEE 1588 for military application .Other groups which show interest are coming from telecommunication and electrical power distribution ("IEC61850- communication networks and system in substation").

6.5 How to build a PTP synchronization element

The architecture is the division of the time-critical part which is implemented in hardware and the protocol itself and is decoupled from hard real time condition the software part. Thus the protocol is running on a processor with low performance requirements [14].

In architecture of PTP synchronization element contain the hardware unit of a highly precise real time clock and the time stamp unit (TSU) it is used for to generate time stamp [14]. The software part implements the actual IEEE 1588 protocol with the required to real –time clock and the HW time stamp unit. The hardware and software component of a IEEE 1588 synchronization element.

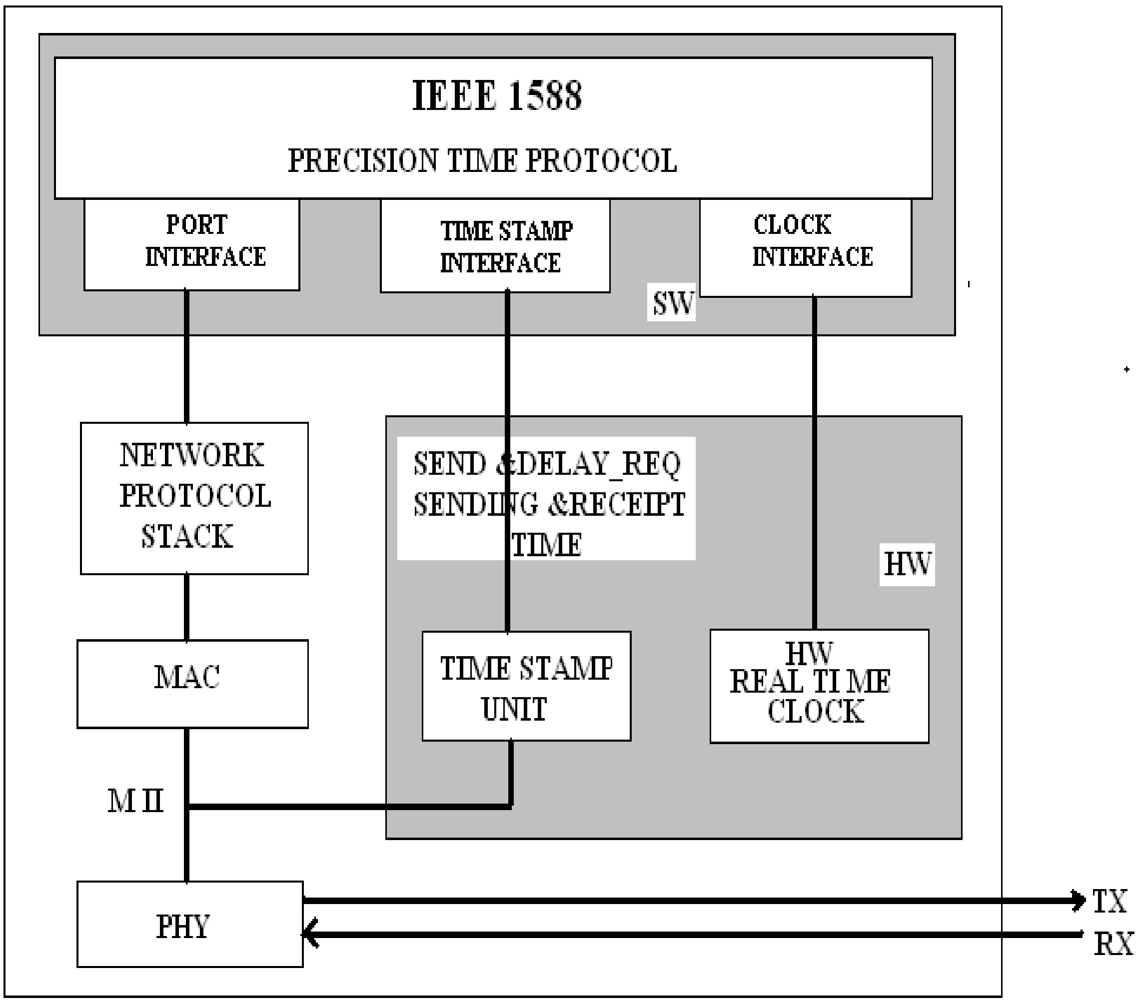

Figure 15: Synchronization Element [14]

The presented architecture supports an almost OS independent modeling of the software component; we introduced three layers with different abstraction level. The protocol layer implements the operating system independent precision time protocol .the OS abstraction layer forms the interface between PTP and the selected operating system .the function made available by the operating system –task/processor, timers, sockets etc are merged over the OS layer.

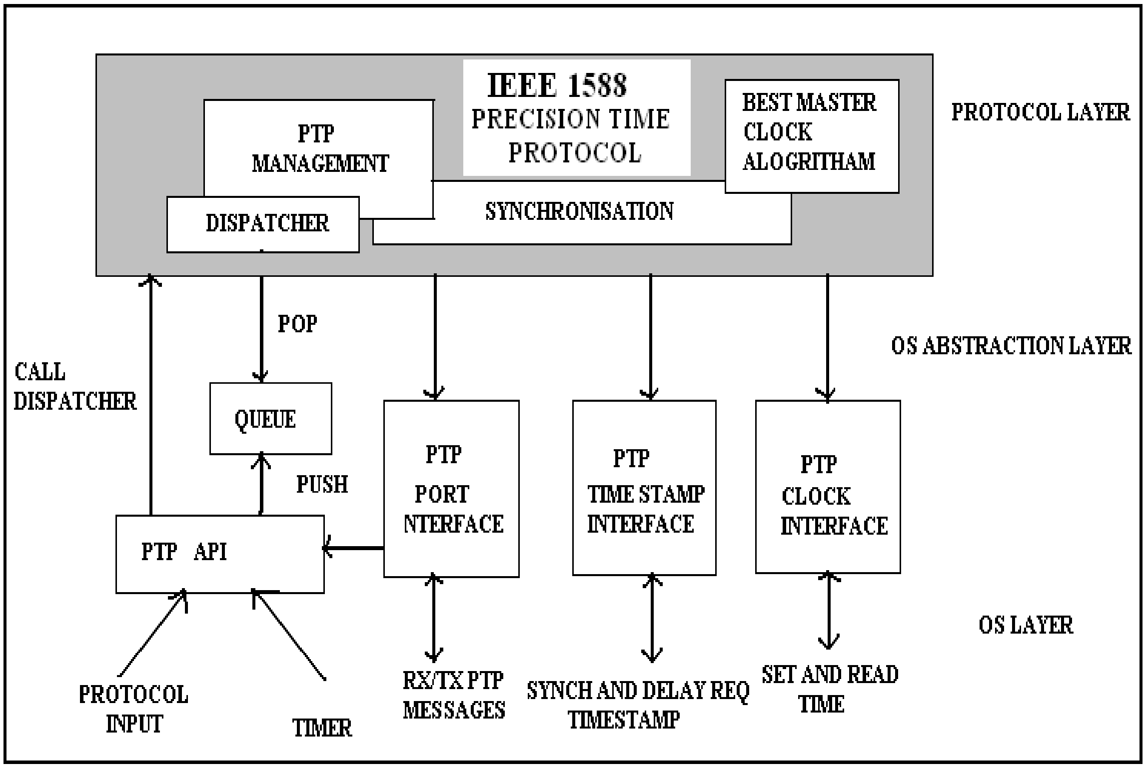

Figure 16: Interaction Diagram [14]

The highest layer implements PTP for the synchronization of clocks in a network and can be used on unusual communication element. Here is the actual intelligence located for synchronizing the individual communication elements. Contained by the protocol layer we used only ISO C, thus we can easily transfer the protocol without deep interference into the functionality on different platforms .The protocol dispatched ensures the atomic execution of function during an individual process .communication between the protocol and OS abstraction layer has been realized by queue and the defined interface given in the figure 16.

The Timestamp interface provides the precision time protocol with the sized time stamps of the sync and delay_req messages. It is depend upon the development either it is hardware unit or software unit generate the time stamp. To generate time stamp between hardware or software the best way between them is software time stamp is in OS dependent NIC (network interface card) drivers as near as possible transportation medium [14] .

The port interface is used to dispatch or receive PTP message. The IEEE 1588 massage use excluding UDP/IP multicast packets and thus make it possible to send and receive them over the socket interface of the IP protocol stack , one May be neglect due to the temporal requirements, since the time stamps are generated directly at transport medium. The input to the protocol runs over the PTP. The modular software platform made it possible for us to build implementation of this protocol window.

A pure software implementation reaches a precision of about 100us and its seems to be possible to increase this precision of better than 10us.

6.6 How IEEE 1588 Protocol work

IEEE 1588 (The Precision Time Protocol) has been designed to improve the time synchronization of distributed network device .PTP allows for synchronization of distributed time to microsecond accuracy and its implement over packet based protocol. Major focus is to implement PTP over UDP/IPV4 [14].

Version 1 of the standard IEEE 1588 published in 2002 and version 2 of the standard IEEE 1588was published in May of 2008. IEEE 1588 PTP is a networked system consists a master time and slave time. The synchronization is achieved between master and slave clock by exchanging PTP timing message, the slave time using the timing information to correct their clock according to the time of their master time.

There are two phase. The first phase is the time difference between the master and slave clock is corrected this correction is the offset measurement and second phase is the calculate delay network between master and slave time.. During offset correction the master time transmit the synchronization message (SYNC) to the default slave clock at the defined intervals (after 2 seconds)[6] .This SYNC message contain the estimated value for the exact time the message was transmitted .As shown in the Figure 18 is the offset measurement.

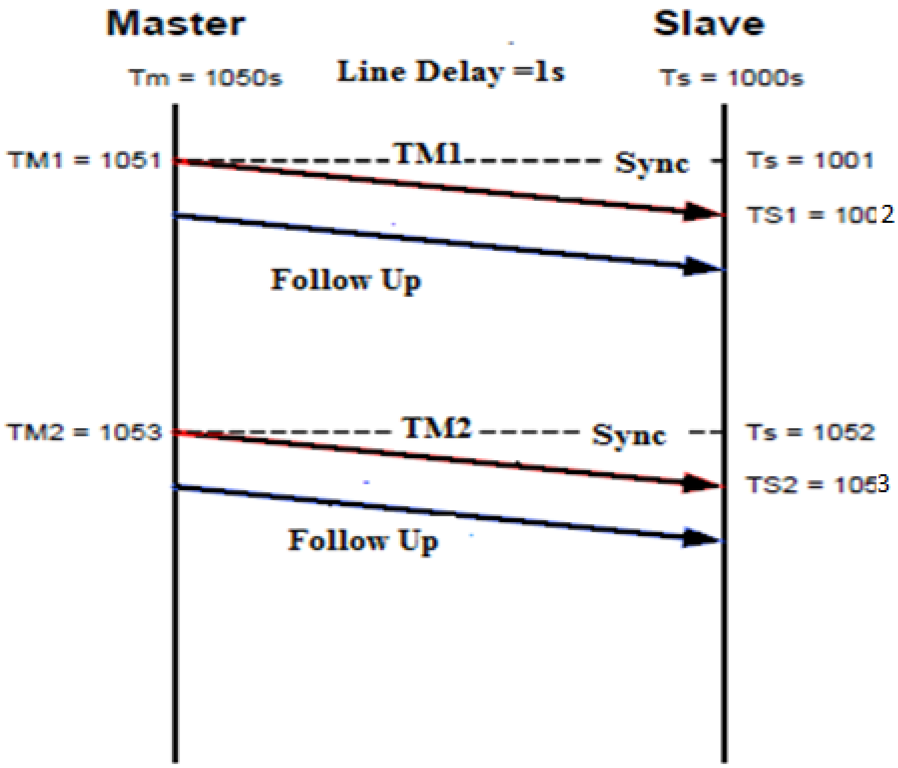

Figure 17: Offset Correction

During the offset correction ,the master clock measure the exact time of transmission TM_1 and slave time measure the exact message of reception TS_1,the master then send a second message is the FOLLOW UP message ,the exact time of transmission TM_1 is the corresponding SYNC message to the slave clock. The slave clock calculates the offset between master time (TM_1) and slave time (TS_1) by using this mathematical calculation to calculate the offset between TM_1 and TS_1 is:

OFFSET= $TS_1 – TM_1$ - delay (not yet known) (1)

=1002 – 1051 – 0 = -49

After calculating the OFFSET, then adjust the time by

Ts – OFFSET (2)

= Ts - (-49**)**

When the slave time calculates the OFFSET then slave time TS must be corrected by this OFFSET. If there were to be no delay over the transmission path between master time and slave time, both clock would now be synchronized.

The second process of the time synchronization process, the delay measurement. For this process the slave clock send a delay request packet to the master clock during the this process a determine the exact time of the transmission of the message TS_3 and the master side it generate a time stamp on the reception of the packet and sends the time of reception TM_3 back to the slave clock delay response packet 2. From the local time stamp of transmission TS_3 and the timestamp of reception provided by the master TM_3, the slave calculate the delay between slave and master, as shown in Figure 19.

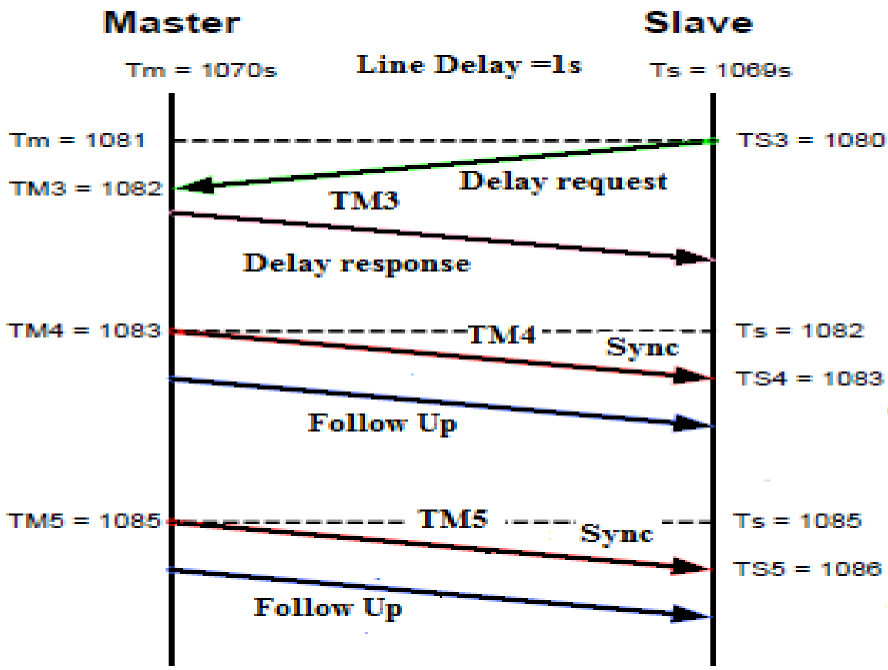

Figure 18: Delay Measurement [6]

Calculate the delay from slave side by using mathematical equation is given below

Delay = $(TS_2-TM_2) + (TM_3-TS_3)/2$ (3)

= 0 - (1082-1080)/2 = 1

After calculate the delay then again calculate the offset between the master and slave clock by using known delay

OFFSET = $TS_4 – TM_4$ – Delay (4)

= 1083 - 1083- 1 = -1

After offset is calculated adjust the time of slave clock.

Adjust Time's – offset= Ts - (-1) (5)

Using equation (5) adjust the time of slave clock, however a symmetrical delay between master and slave is important for the delay measurement and its precision. Using this synchronization process, timing fluctuation between master clock and slave clock can be eliminated.

6.7 PTP Operation

6.7.1 PTP Clocks

PTP distinguishes the following node types, as given below

- Grandmaster clock is the primary reference source within a PTP sub domain; the "ultimate source of time for clock synchronization using the PTP protocol" .The Grandmaster clock will generally have a high-precision time source, which can be a GPS reference or an Atomic clock. If synchronization is needed purely within a network and not to any external reference (such as UTC - Coordinated Universal Time), then the grandmaster clock could also free run [32].

- Ordinary Clocks (OC) have only one port (singly-attached clock), that operates either in the slave or in the master state. An ordinary clock can be configured as master-capable or slave-only. When the OC is the best clock of its sub domain, it becomes the Grandmaster Clock (GMC), its port is in the MASTER state and sends Sync messages to synchronizes all slave clocks. Otherwise, its port is in the SLAVE (or PASSIVE) state and it receives synchronization messages.

- Boundary Clocks (BC) has at least two ports that are usually in different states, exactly one port being in the SLAVE state and synchronized by a master clock while the other port is in the MASTER state and synchronize (s) a sub domain. When the BC receives a Sync message over the port in the SLAVE state, it does not forward it to the ports in the MASTER state; instead, it sends its own PTP messages, with a period that may be different from port to port. If the BC is the best clock of all sub domains, all its ports are in the MASTER state and it becomes the Grandmaster clock. Otherwise, it becomes master in each sub domain where it is the best master. It may be degraded to SLAVE or PASSIVE by a better master in its sub domain.

- Transparent clocks have been added to version 2 of the standard as an improved method of forming cascaded topologies have at least two ports which are stateless, and acts as a bridging node for all messages. A TC forwards the Sync messages it receives over one port to all its other ports and corrects the time by evaluating the peer delay and residence delay of Sync messages.

  These clocks are shown in figure 20 it is given below

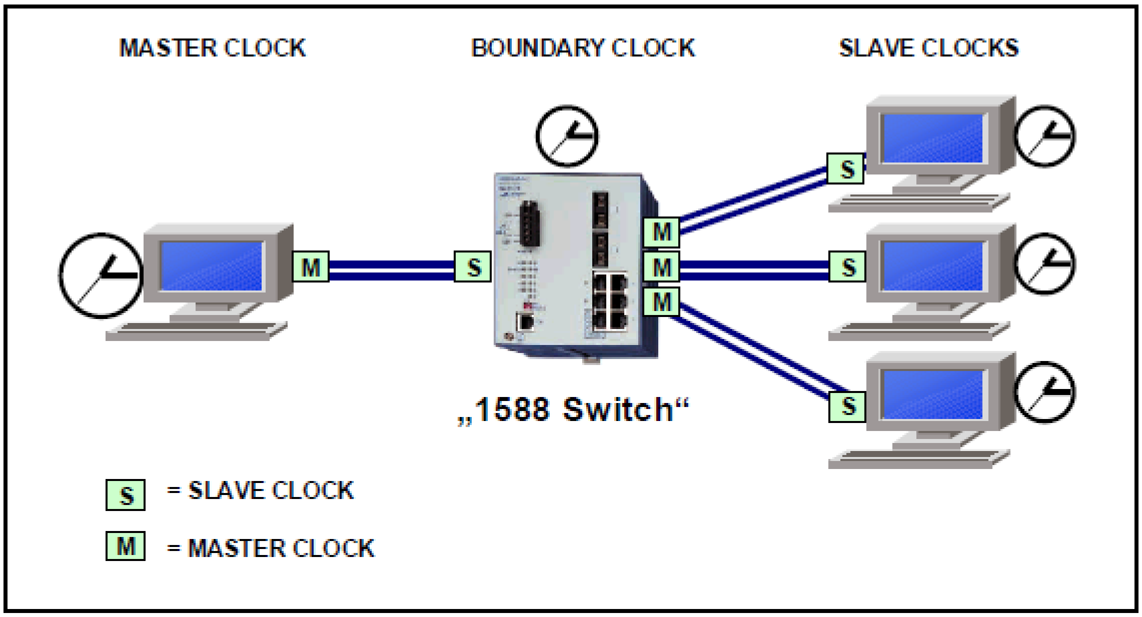

Figure 19: PTP Clocks [14]

Hybrid Clocks (HC) combine a Transparent Clock and an Ordinary Clock.

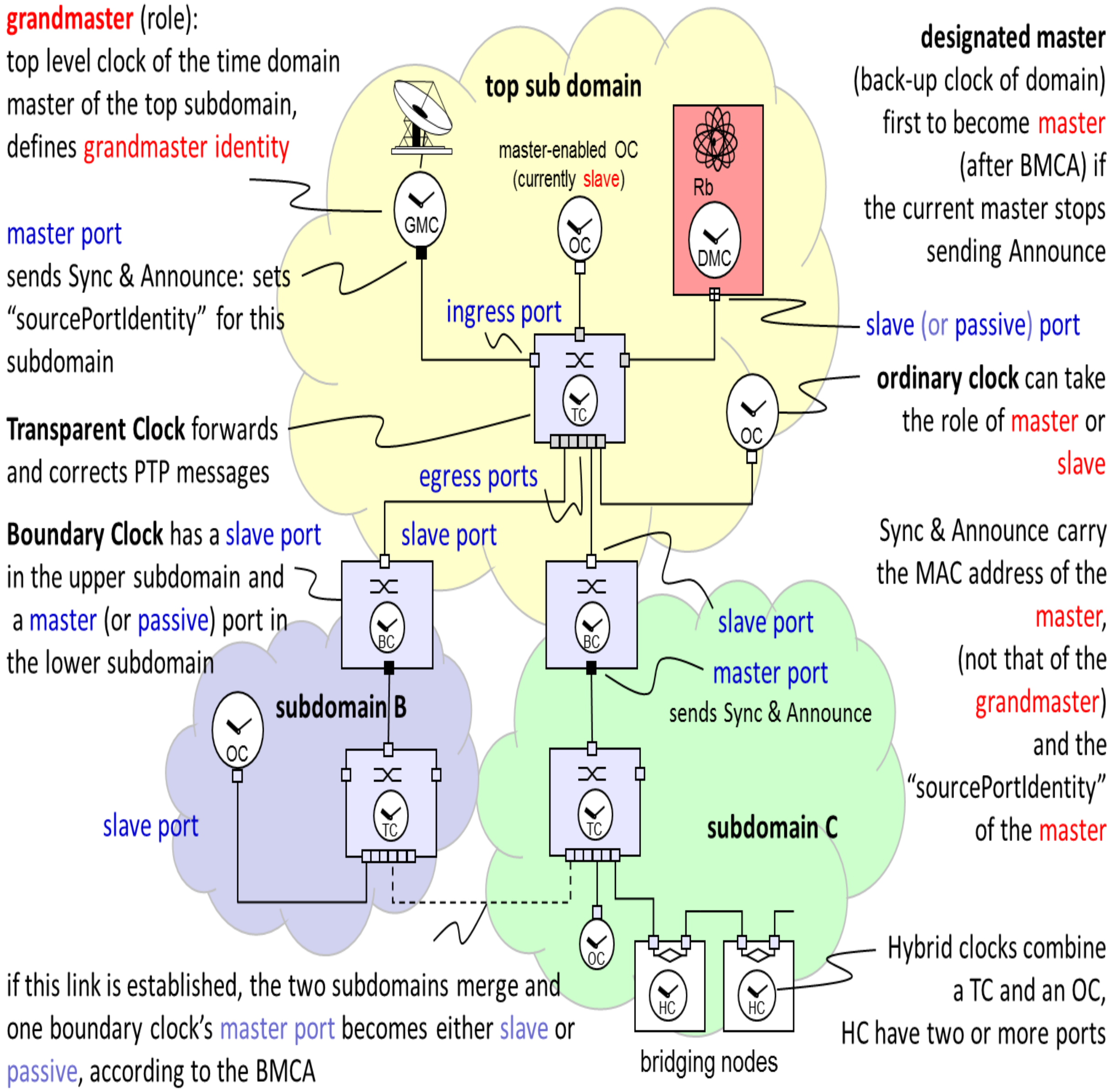

Figure 20: IEEE 1588 Time Clock [32]

6.7.1 PTP Main option

IEEE 1588 distinguishes three basic options:

- layer 2 vs. layer 3 communication,
- one-step vs. two-step clock correction,
- end-to-end, vs. peer-to-peer delay measurement,

6.7.2 Layer 2 vs. layer 3 communication

Layer 2 PTP communication transports PTP message on layer 2, relying on MAC addresses. This communication ends at a router. Layer 2 PTP defines for Ethernet at which point in a frame the time stamps is taken. Layer 2 PTP is the preferred approach for automation networks.

Layer 3 PTP communication transports PTP messages over layer 3, relying on IPv4 or IPv6 addresses (mapped to specific Layer 2 addresses). Layer 3 PTP can operate over a variety of media. The precise time-stamping relies on an unspecified physical layer support. Layer 3 PTP is the preferred approach for telecoms.

6.7.3 One-step vs. two-step clock correction,

6.7.3.1 Time correction in Sync message

The master clock (MC) multicasts periodically (e.g. every 1 s) a Sync message containing the reference time. This Sync message transits through the network over links and transparent clocks.

The Sync message suffers network delays consisting of the link delays λ between nodes and of the residence delays ρ in the transparent clocks, before it reaches the slave clocks. To correct these delays, the network components time-stamp precisely the Sync messages as they ingress and egress the devices.

The transparent clock calculates a correction including the residence time of the Sync message. There are two ways to transmit this correction: one-step correction and two-step correction, which are illustrated in Figure

- One-step correction: the transparent clock enters the value of the correction in the Sync message while it is being sent. This needs a hardware support that can modify messages on-the-fly.
- Two-step correction: the transparent clock sends the value of the correction in a subsequent Follow-up message. The hardware support is limited to the precise time-stamping of the ingress and egress frames

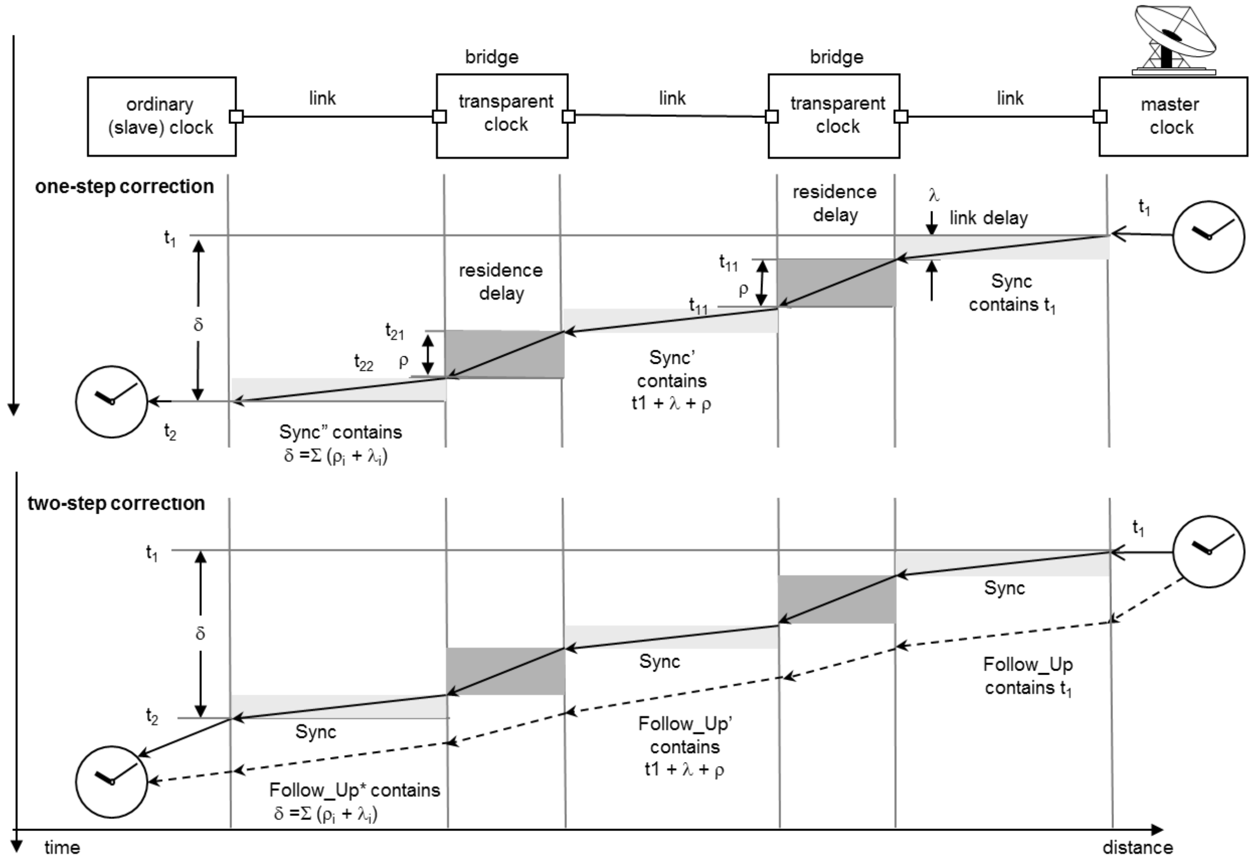

Figure 21: Propagation of the Sync Message (one-step and two-step correction) [31]

6.7.4 Two step to one step translation

6.7.4.1 Choice of method

Both one-step correction and two-step correction are possible within the same sub domain.

The engineer is faced with two correction methods, depending on the ability of its devices. Most current commercial clocks use two-step correction to simplify implementation, but with increasing silicon support one-step is gaining ground. Since hardware support is already provided for cut-through and the handling Follow-up would only be overhead.

Devices supporting the two correction methods can be mixed in the same network if they accept both one-step and two-step clocks. If a transparent clock translates from one-step to two-step or the reverse, the two-step flag is modified in the message header.

6.7.4.2 Translation from one step to two step

A two-step clock is always able to receive one-step sync messages. A two-step node that receives a one-step Sync needs no special translation except change the mode to two-steps and generates the Follow-Up. In one method, the Sync carries the received correction field, while the Follow-up carries the sum of the residence delay and of the peer delay. Alternatively, the Sync carries the sum of the received correction field and of the peer delay, while the Follow-up carries only the residence delay. The next node will take the sum of the correction fields in the Sync and in the Follow_Up messages for correction. A one-step TC modifies the correction field of the Sync message, while a two-step TC modifies the correction field of the Follow_Up message. Therefore it is important that for any one-step translation or synchronization the sum of the Sync and Follow_Up correction field is used.

6.7.4.3 Translation from two step to one step

IEEE 1588 only foresees a one-step to two-step translation. The method described in this Clause is not part of IEEE 1588 but could be included in a next revision, since it is fully backward compatible. Figure 22 shows the translation from two-step to one-step in a chain of one-step and two-step transparent clocks between an ordinary clock (slave).

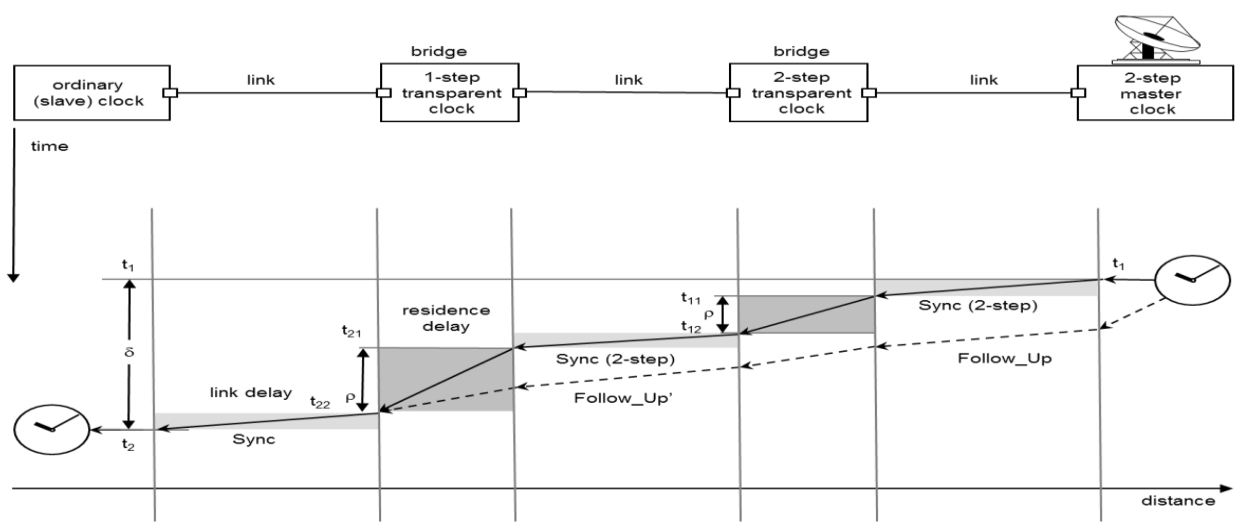

Figure 22: Two-step to One-step Translation in Transparent Clocks [31]

A one-step node that receives a two-step Sync awaits the Follow_Up before generating the one-step Sync. The one-step Sync at the egress port then carries the sum of the correction fields of the two-step Sync, of the Follow_Up, the residence delay of the node and the estimated delay to the upstream peer, as Figure 23 shows.

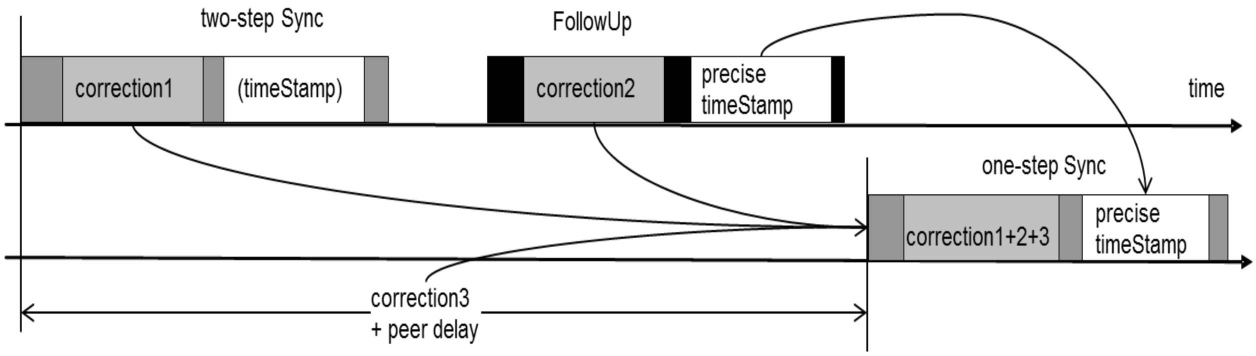

Figure 23: Two-step to one-step translation – message view [31]

6.7.5 End-to-end delay calculation

6.7.5.1 GENERAL METHOD

In all methods, the residence time of the Sync messages in the transparent clocks is computed using the local oscillator.

In end-to-end delay measurement, the transparent clocks correct the Sync or Follow_Up messages only for the residence time, but not for the link delays. The calculation of the link delay involves a call-and-reply mechanism using the DelayReq (delay request) and DelayResp (delay response) messages.

The handling of these messages is different in one-step and two-step correction.

6.7.5.2 End to End Delay Measurement with One step Correction

Each slave calculates the link delays on the path to the master by sending a DelayReq (delay request) message to the master, which responds with a DelayResp (delay response) message containing the time of reception. Both DelayReq and DelayResp cross all transparent clocks in the network. The slave awaits the Sync to compute the correction,

The master sends the Sync at time t1, the transparent clocks correct t1 by their residence timeρ. The slave receives the Sync at time t2 with the sum of the residence time correction ρms.

To calculate the end-to-end delay, the slave sends at time t3 a DelayReq to the master. The master receives the DelayReq at time t4 with the sum of the residence time corrections on the path and responds with a DelayResp that contains the received sum of the correction and the timestamp t4, as figure shows. After this exchange, the slave keeps t3, t4 and the sum of the residence times, ρsm.

One-step Transparent Clocks correct the timestamp in the DelayReq for their residence delay. They do not modify the DelayResp.

This mode therefore implies that the DelayReq takes the same path as the Sync, which requires some engineering in a layer 3 network.

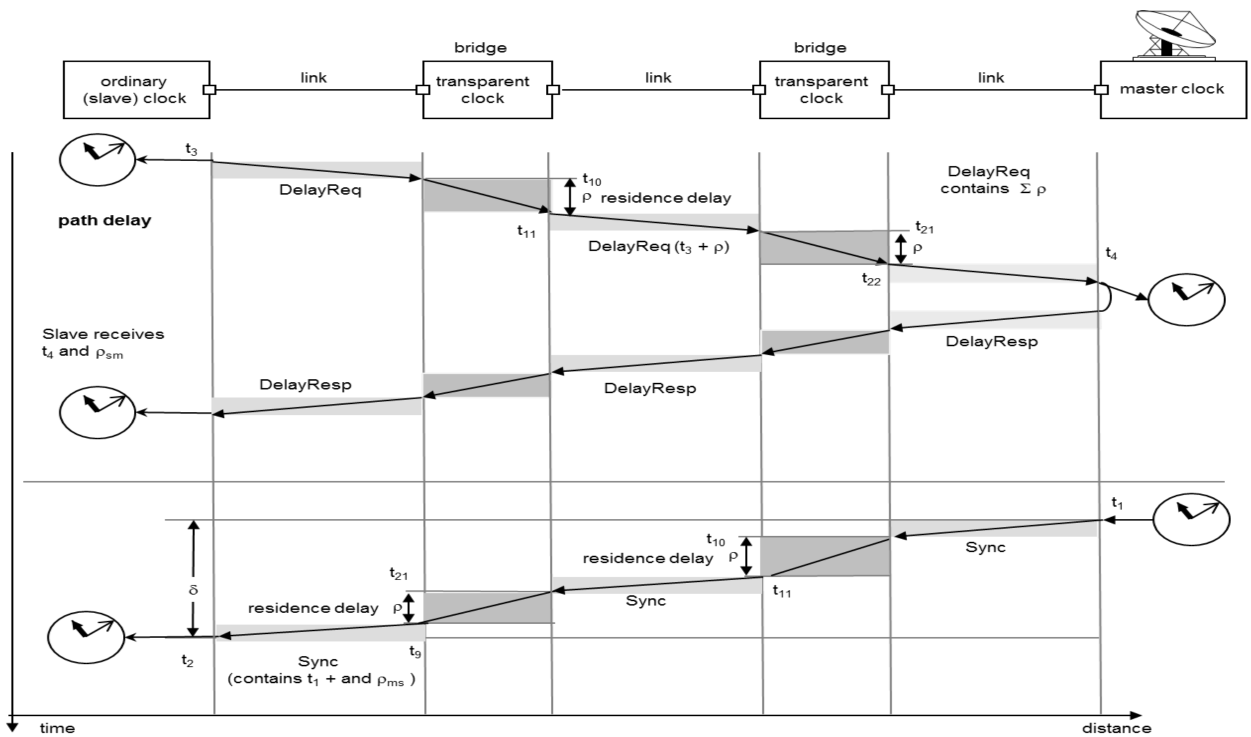

Figure 24: PTP End to End Delay Measurement with One Step Correction [32]

6.7.5.3 End to end delay measurement with two step clock correction

Two-step Transparent Clocks do not modify the Delay Req. They record the exit timestamp of the DelayReq and insert this correction when they forward the DelayResp in the opposite direction, as Figure 26 shows.

This mode therefore implies that the Transparent Clocks memorize the communicating partners and that the DelayResp takes the same path as the DelayReq, which requires some engineering in a layer 3 network.

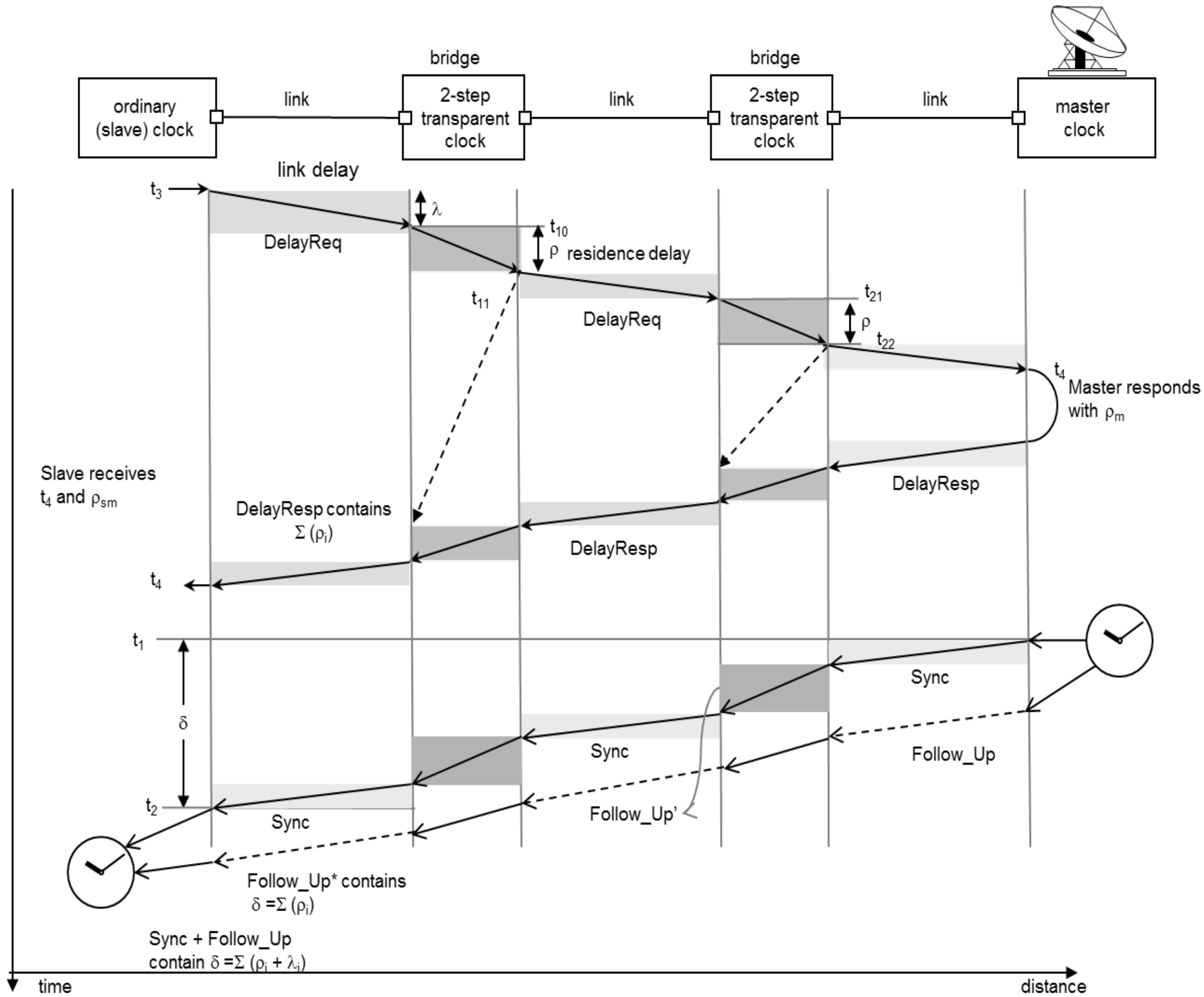

Figure 25: **PTP End to End Delay Measurement with Two steps Clock Correction [32]**

6.7.5.4 Link delay calculation by DelayReq/DelayResp

In one-step and two-step correction, the slave deduce the sum of the two line delays from the correction field δsm and ρms previously received in DelayResp and Sync

6.7.6 Peer to peer delay measurement

6.7.6.1 PTP peer to peer delay measurement with one step clock correction

Each transparent clock computes the link delay to all its neighbours be sending a time-stamped PdelayReq (peer delay request) message on its links, to which the peer responds with a time-stamped PDelayResp (peer delay response) message.

Figure shows a PTP clock distribution peer-to-peer delay measurement and with one-step correction.

To calculate the link delays, each node sends peer delay request messages (Pdelay_Req) to all its neighbours, even in the direction opposite to the current GMC since a redundant GMC may exist. The neighbour responds with a Pdelay_Resp message and the link delay over each link is calculated as:

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

In one-step clocks, each TC j adds to the received correction from clock k to its own correction (λkj + ρj) and modifies the Sync message's correction field on-the-fly, while the frame is being transmitted over the egress port, since the residence time is only precisely known when transmission started. This one-step correction requires a dedicated hardware to modify the correction field (and the checksum) of the outgoing Sync frame while the header of the message has already been transmitted.

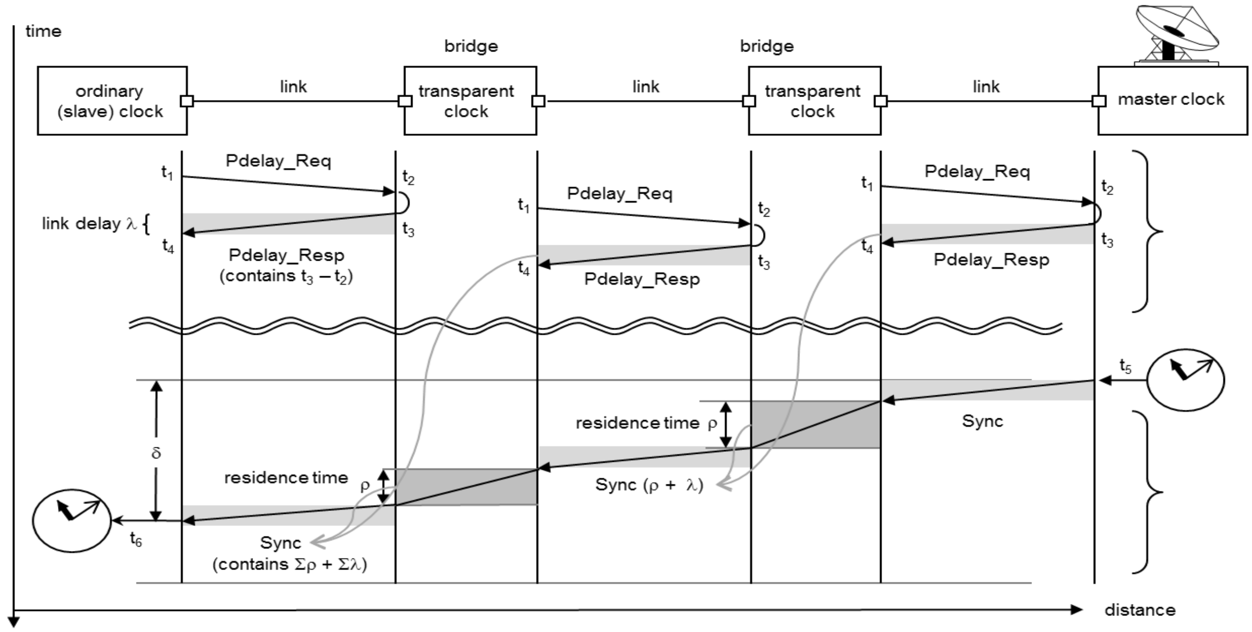

Figure 26: PTP Peer to Peer Delay Measurement with One step Clock Correction [32]

The slave clock corrects the received time t4 by the value of the correction field, which contains the sum of the residence times and the sum of the estimated link delays.

6.7.6.2 PTP peer to peer delay measurement with two step correction

To avoid a dedicated hardware for modifying the Sync message on-the-fly, a two-steps clock records the precise time at which the Sync was received, forwards the Sync message without modification (but announcing a Follow_Up message) and records the precise time at which the Sync was sent. There exist dedicated PHY chips that time-stamp messages within a few ns, so sending the Sync message is not time-critical, it can be done by a CPU.

The two-step TCs calculates the correction field as the sum of the ingress Sync correction, the residence delay and the (previously measured) peer delay and sends a Follow_Up message as Figure shows. The same scheme applies to the calculation of the peer delay.

The receiver assumes that Sync and Follow_Up messages are paired; they have the same PTP sequence number.

A two-step Pdelay_Resp / PdelayResp_Follow_Up improves over one-step Pdelay_Resp since it transmits the values of t2 and t3 individually and therefore allows discovering errors in the synchronization, as described in IEEE 1588.

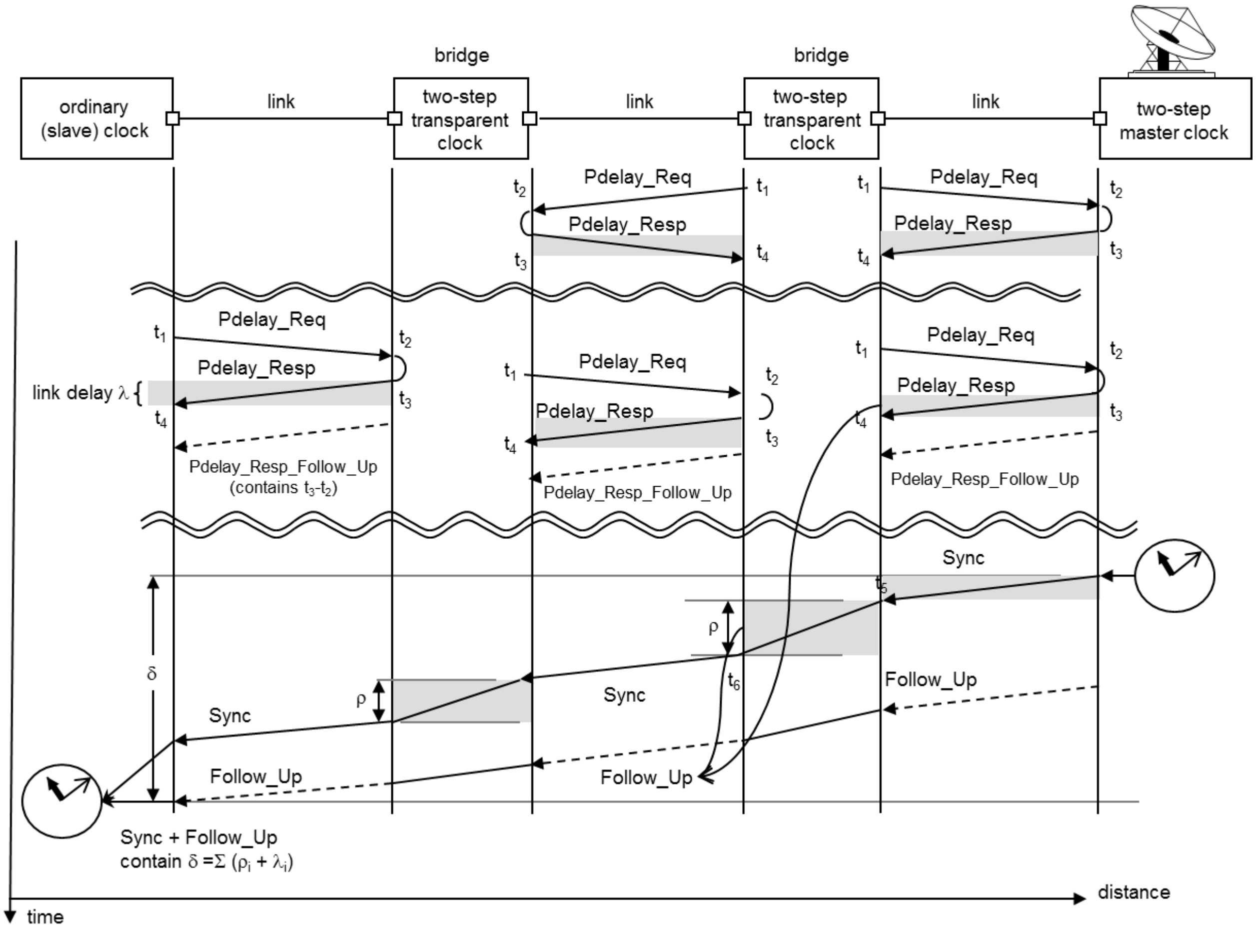

Figure 27: PTP Peer to Peer Delay Measurement with Two Step Clock Correction [32]

A combination of two-step Pdelay with one-step is in principle possible, since the two-step flag applies to the messages individually, but is not currently specified. In view of a possible revision of IEEE 1588, the receiver should watch the two-step flag of the received Pdelay_Resp or Sync messages to know if a PdelayResp_Follow_Up or Follow_Up is expected. Also, IEEE 1588 should define a time-out for a Follow_Up to be received, in case of unreliable Links.

6.8 Implementation and analysis of IEEE 1588 PTP Time synchronizing design of bay level in digital substation

In previous chapter discuss all about digital substation .We know that the digital substation divide in three level from top to bottom is station level , Bay level and Process level. The Time synchronization information of the bay level device can be derived from the process level.

In the IEC 61850 of the process of the process level devices required highest time synchronization accuracy in microsecond range. But in bay level device doesn't require high time synchronization accuracy we get the highest time accuracy by implementing IEEE 1588 PTP protocol. It provides microsecond accuracy so we can implement this protocol in the digital substation.

6.9 IEEE 1588 PTP comparison to other protocol

The Precision Time Protocol arose out of a need for greater synchronization over networks, particularly Ethernet. Several different research institutions were working in parallel to develop an improved method to NTP which is currently the most common network synchronization protocol. Several of these research projects were incorporated into or have provided improvements to IEEE 1588.

Table 7: Compression between Different Types of Time Synchronization Protocol

	PTP	NTP	GPS	IRIG-B
Spatial Extent	A few subnets	Wide area	Wide area	Local
Communications	Network	Internet	Satellite	Dedicated
Target accuracy	Sub-microsecond	Few milliseconds	Sub-microsecond	Sub-microsecond
Style	Master/Slave	Peer ensemble	Client/server	Client/server
Resources	Small network message and computation footprint	Moderate network and computation footprint	Moderate computation footprint	Small computation footprint

6.9.1 IEEE 1588 solves these problems by:

- Using an Ethernet network to propagate the timing signals, eliminating the extra cabling requirements of IRIG-B
- Using mechanisms that increase accuracy by accounting for switching time and peer to peer propagation delays that occur as the timing signals traverse the network.
- Using 'transparent clocks' in Ethernet switches that eliminate the need for end-to-end delay measurement, reducing traffic congestion and eliminating switch jitter.

The most important features introduced in IEEE 1588 v2 that correct the above problems are Peer-to-Peer Path Delay Measurement and Transparent Clock mode

7 Network Redundancy Protocol IEC62439

7.1 OVERVIEW

Recent advancements in power utility automation use Industrial Ethernet which provides stronger adaptability, high efficiency and more function. In many applications it is necessary to have network with zero recovery time, when any fault or an error is occur. To full fill the requirement of drop-out fault- tolerance in this application field so there are different method in which with some redundancy, the communication is recovered from fault in the network the recovery takes some time for this solution so there are different method in which with some redundancy [1], IEC 62439 series studied are several alternatives of redundancy but only two of them provide zero time recovery. These two Ethernet redundancy mechanisms are parallel redundancy protocol (PRP) and high availability seamless protocol (HSR) [18] .These two redundancy protocol are compatible with Ethernet, and they provide bump less redundancy .high availability [21], zero recovery time, by introducing two independent path to send information duplicated from source to destination, so that in case of fault no information is lost, when duplicated frame that arrive to destination must be discarded.

7.2 Network Redundancy Protocol

Standard series specify two redundancy protocol designed to provide seamless recovery in case of single failure of bridge in the network. They are based on the scheme- Duplication of LAN, duplication of transmitted information. These two different classes of network redundancy:-

- Parallel redundancy protocol is standardized as IEC 62439-3 Clause 4.
- High availability seamless redundancy protocol is standardized as IEC 62439-3 Clause 5.

These two standardization was started to fulfill the dependability and real time requirement of demanding application. Such as substation automation and motion control. They provide zero recovery time in case of failure [19] .HSR and PRP are simply the implementation of double mode node in hardware.

7.3 Parallel Redundancy Protocol

PRP is a method to provide redundancy in Ethernet network .the concept mainly introduce double LAN network, where source and destination connected to each other via independent two LANs. In case any fault happen in one of the network the communication is continue over the network or without loss of information. As shown in Figure 28.

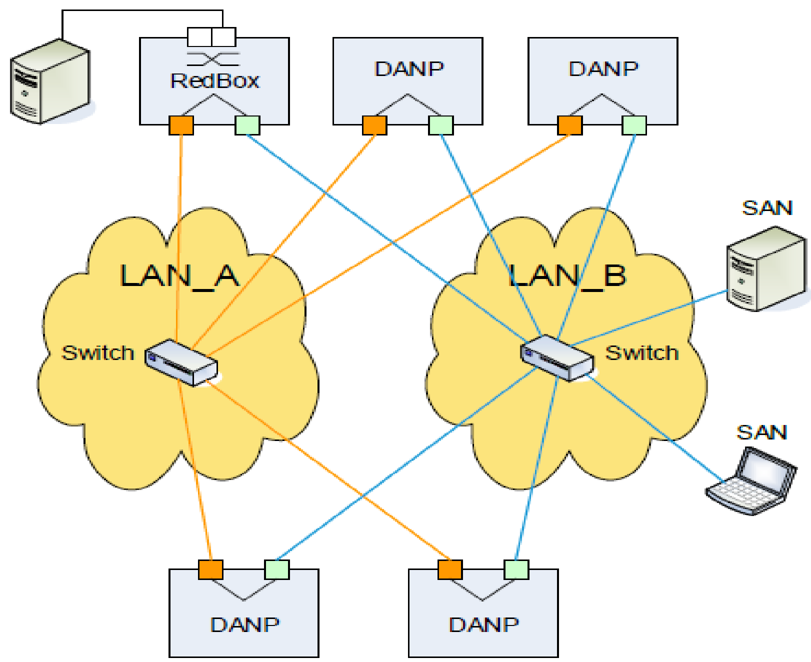

Figure 28: PRP Network

The main element are linked to the two network doubly attached node with (DANP), which duplicate information and send it through the two different LAN. All PRP nodes connected via two separate network LAN_A & LAN_B both constructed using non-aware PRP Ethernet switch. All messages are sent to both network and target device drops the duplicate frame that arrive later .in PRP network there can also be SAN (single attached node) that connect to only one of LANs. A red box is a device that connects non-PRP nodes to the redundant PRP network. In the DANP node structure each node has two ports that operate in parallel and that are attached to the same upper layer of the communication stack through the LRE (link redundancy entity) as shown in Figure 29.

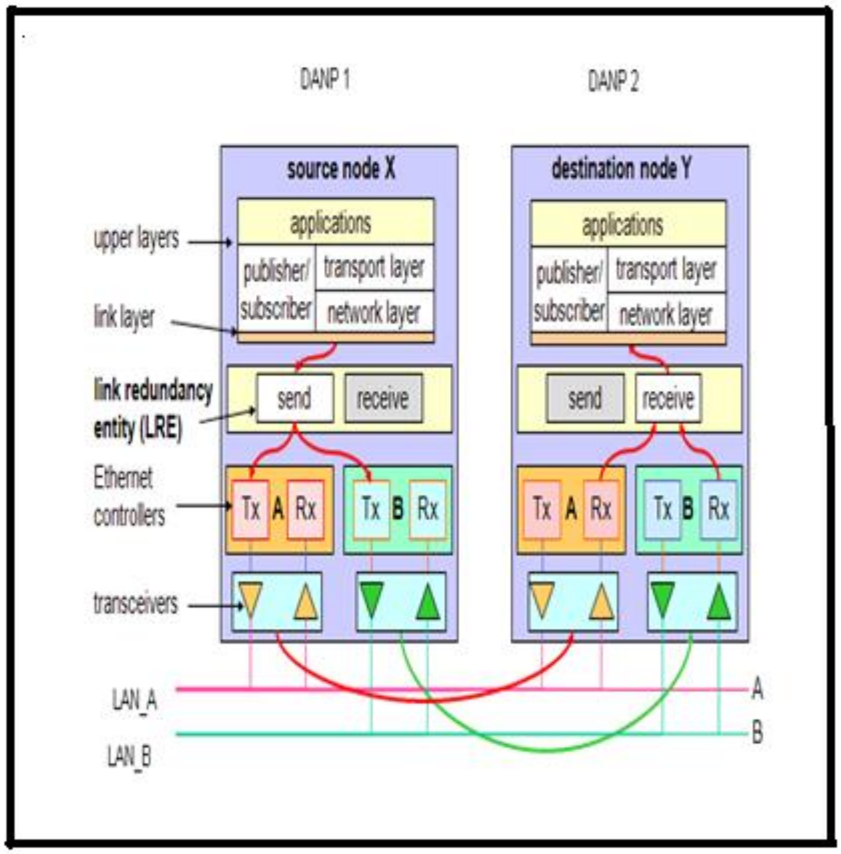

Figure 29: PRP with two DANs communicating [20]

PRP can also be used as an easy to apply but powerful solution to improve the transmission behavior of unreliable and diverse transmission media such as a wireless radio [25][26] .Basic communication between two DANPs, the LRE present centre between upper layer and network adapter, so the upper layer network adapter ,so the upper layer are unaware of redundancy .The LRE mainly has two tasks one is handling of duplicate and management of redundancy. When receiving a frame from the node's upper layer. Then the LRE appends to the frame a RCT (Redundancy check trailer) which contain a sequence number and sends the frame through both its ports at the same time. These two duplicate frame transit through the two LAN with different delays but ideally they arrive at nearly same time at the destination node [20] .PRP could be tunneled over arbitrary networks via a suitable tunneling protocol [28] [29][30]

At the destination side when its receive frame from the network the LRE forward the first frame of a pair to its node's upper layer and discard the duplicate frame when it is arrive. It removes the RCT if required. Checking and management of redundancy of the presence of other DANPs then the LRE periodically Sends PRP supervision frame and can evaluate the PRP supervision frame sent by other DANPs.

7.4 High Availability Seamless Redundancy Protocol

Clause 5 describe to implement a high availability seamless redundancy (HSR), retaining the PRP property of zero recovery time, this redundancy protocol can be applicable to any topology, in particular rings and rings if rings topology, HSR nodes have two ports too, double attached node with HSR. Each HSR nodes having two ring ports they are interconnected by full duplex links, as shown in Figure 30[19].

The source DANH sends a frame passed from its upper layer, by add an HSR tag to indentify frame duplicate and then sends the frame over each port A-frame and B-frame .and then at destination DANH receive two identical frames from each port (A-frames and B-frame) within a certain interval, before passing the frame to its upper layer it remove the HSR tag of the first frame and discard duplicate frame [20].

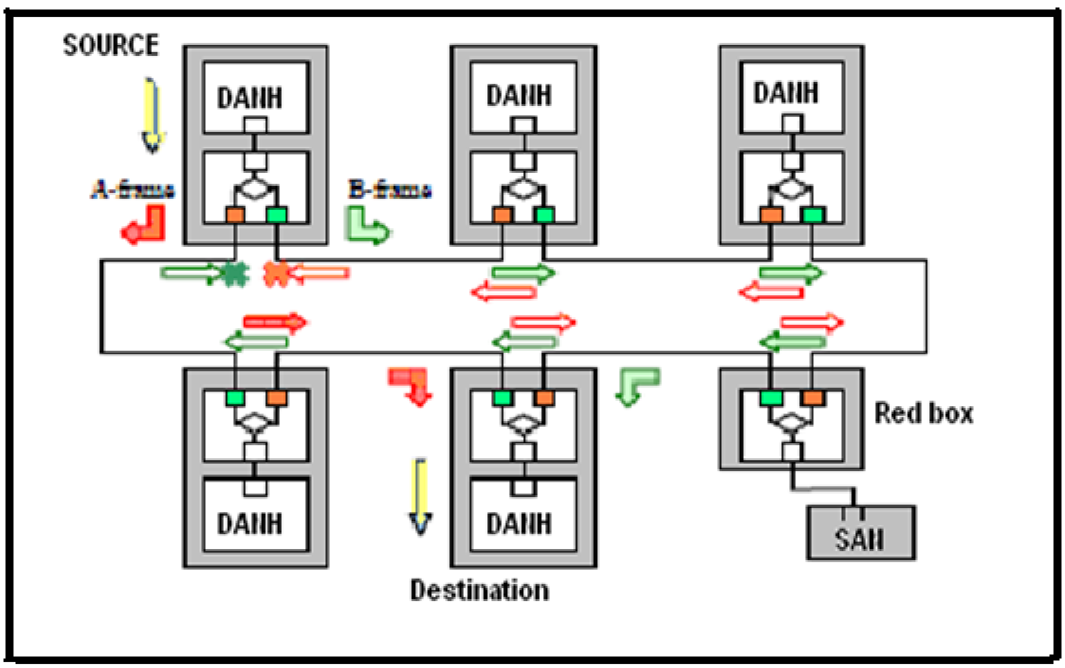

Figure 30: HSR Network [19]

These two frames (A-frame and B-frame) in the ring carry the HSR tag, inserted by the source, which contain a sequence number using this sequence number easily, indentify the duplicate frame. HSR node operation .the upper layer send a frame to LRE which generate the duplicate frame and send each frame to simultaneously over port A and port B 1, 2. , and the switching logic forward frame one port to other port(3,4) but except (5,6) ,at the receiver side the LRE receiver receive the both frame and keeps the first frame and discard the duplicate frame[18] .Each node of HSR has the same MAC address on both ports, each node operate with same IP address for both ports.

7.5 FRAME identification of HSR and PRP

In HSR and PRP the way to know if a frame has been seen before is remembering the frame that arrived to nodes , in order to do that frame must be easily indentified .In this protocol append extra information to Ethernet frame and using this and address of the frame the frames can easily indentified. In HSR frame HSR append a HSR tag after address.

In PRP frame PRP append a trailer RCT (redundancy control trailer) the end of the frame. In HSR, Path ID indentifies the HSR regular frame direction .In PRP LAN ID indicate the network through the frame sent. In HSR and PRP have 16-bit sequence number. Every node has a sequence counter where value is increment every time a HSR/PRP frame is send. The field sequence is filled with the value of the sequence counter each time a frame is duplicated and appends trailer/tag to be sent so that the two copies sent the same sequence number. LSDU size is 12 bits, size of the link service data unit. PRP-1 suffix and ETHER type both are 16 bits. Append in PRP/HSR frame.

The sequence number is common to both frame generated from original frame delivered from upper layer and to send through the two different path by each node then ,those frame can indentified by using source address and sequence number, so that nodes store this information to circulating frame and discard duplication[19]. This is a method used to identify the frame.

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7.6 Recovery Time

Recovery time is the most important factor for the network redundancy protocol .it ability of fault tolerance performance. Recovery time is time from the fault factor to the time when the network region is required communication function in presence of the fault [24]. The recovery time include the two elements which is given in below:-

a) Fault detecting
b) Link switching time

Fault detecting is calculated by using this mathematical algorithm:

$$T_r = T_d + T_s \qquad (1)$$

Here T_r is recovery time, T_d is fault detecting, Ts is link switch time for the single network or Dual network redundancy protocol detecting of link fault it is depend on sending and receiving of the frame. When the different sequence number of two frame reach to the maximum value, the receiver link redundancy entity (LRE) consider that failure is occur in the local adapter so fault detecting time is:

$$T_d = Max\_Seq\_Diff * T_{smi} \qquad (2)$$

Where T_{smi} is time interval of the frame Max_Seq_Diff is the Maximum value the sequence number difference .when the failure is detect then LRE immediately called link switch algorism for the link switching time and is calculated by using this formula:

$$T_s = T_{path} + T_{send} + T_{rec} \qquad (3)$$

Where T_{send} and T_{rec} are the processing of the sending and receiving LAN redundancy entity, T_{path} is the frame delivery through the link.

In parallel redundancy protocol receive data frame which is based on the principle of first come and first reserved. If one LAN is fails and then Data frame is missing, the duplicate data frame is transmitted in another LAN will be processed and forward to upper layer therefore then recovery time is zero.

7.7 Data Analyzing of HSR and PRP

For experiment of the data analyze of the recovery time is composed of the two DAN (Double attached node) and SAN (Single attached node), DAN work as redundancy node of sender and receiver based on EPA (Ethernet for plant control automation) .protocol .as shown in Figure 31 and 32. The sender sends the packet to the receiver by using redundancy path in every 10 ms .by using the equation number (1), recovery time can be measured [23].

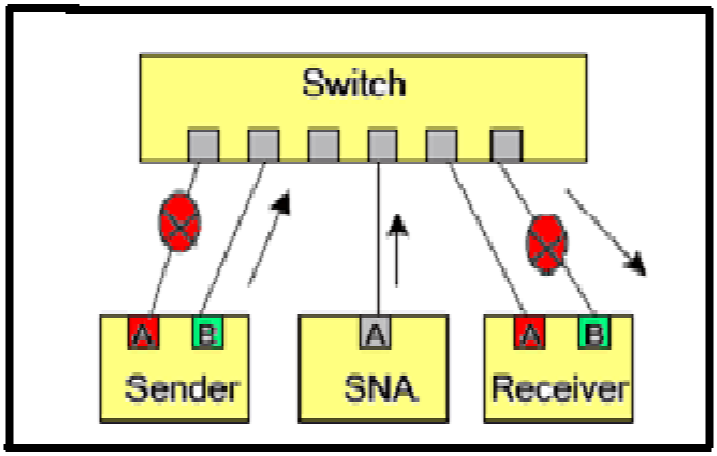

Figure 31: Single LAN Redundancy Protocol [20]

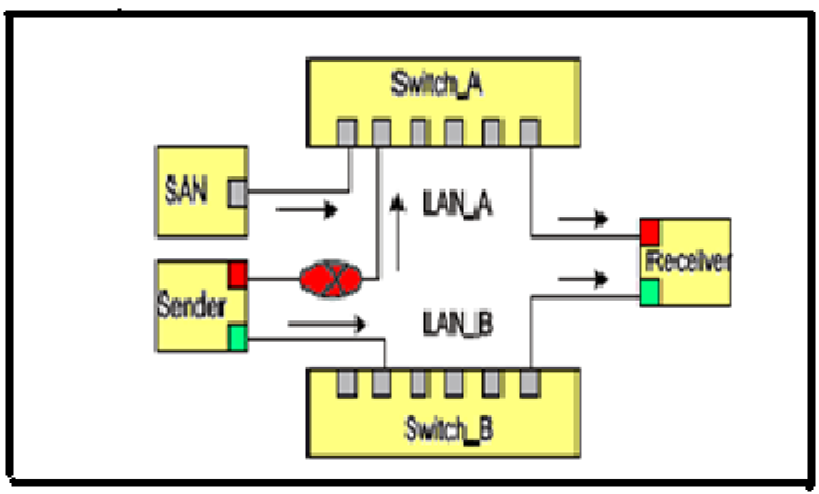

Figure 32: Double LAN Mode Redundancy Protocol [20]

The experiment describe as follow, whenever a frame each the end node then receiver will records the receiving time then the difference between this time value from that of previous received frame is recorded in $Time_{[n]}$ [23] . During the testing , a link failure is produced by cutting off the cable ,at this time the value of $Time_{[n]}$ indicate the fault time T_f after complete the testing, the average value of the element in array $Time_{[n]}$ is T and this is the normal interval of each frame.ao recovery time formula is :

$T_r = T_{f\,=}\, T$ (4)

For testing to Single LAN redundancy protocol the max difference value of sequence number is fix value ,during the test the Max_Seq_Diff is set to 4ms and then T_{smi} is set to 8msfor Single LAN mode redundancy protocol the fault detection time is calculated by using equation (2) ;

$T_d = Max\_Seq\_Diff * T_{smi}$ (5)

$T_{d\,=}$ 4ms * 8ms = 32ms

The value of T_{path} is a 40 us in a switched Ethernet .T_{send} and T_{rec} 15us through experiment, so calculate the switching time by using this given below equation :

$T_s = T_{path} + T_{send} + T_{rec}$ (6)

T_s = 40us + 15 us + 15us = 70 us

After all these calculate the recovery time by using equation (1):

$T_r = T_d + T_s$

T_r = 32ms + 0.07ms = 32.07ms

Now using equation (4) we can find out recovery time:

$T_r = T_f - T$

T_r = 42 -10 = 32ms

The graph is draw between fault recovery times versus average recovery time as shown in Figure 33.

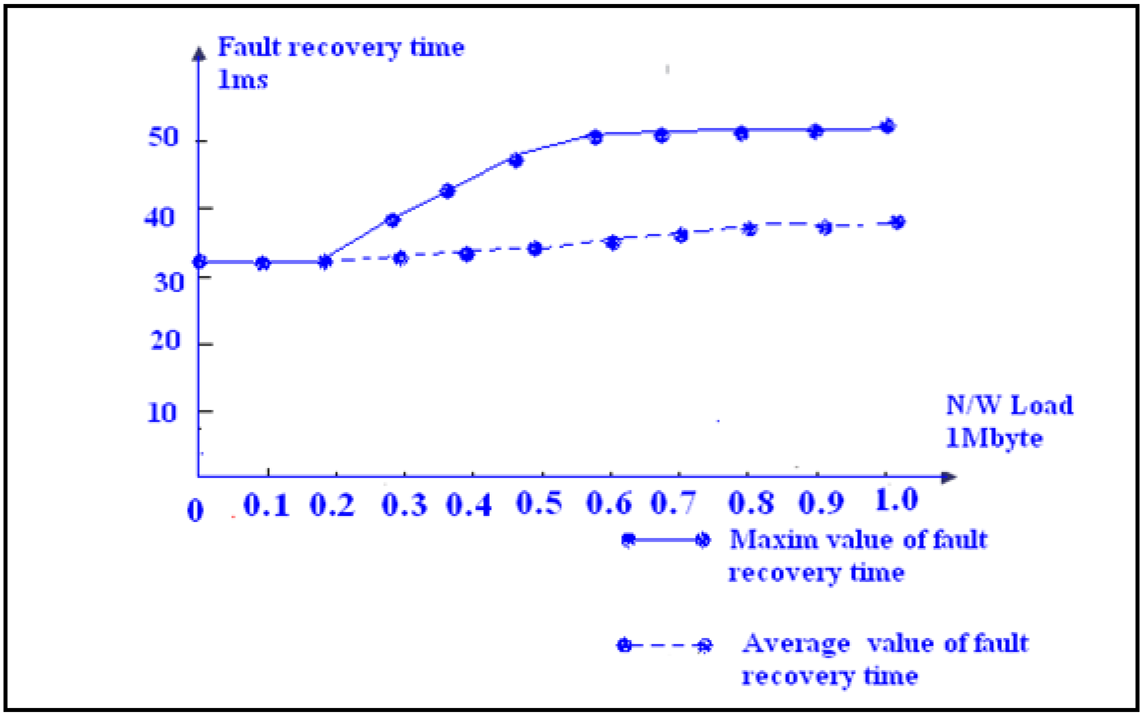

Figure 33: Recovery Time of Single LAN Mode Protocol Network

For Dual-LAN redundancy protocol, set the Max_Seq_Diff is set to1ms and T_{smi} is set to 4ms.the value of fault detecting time is:

T_d = 1ms * 4ms = 4ms

For calculating of link switching time of Dual network redundancy protocol, the value of T_{path} is 30 us in switched Ethernet, T_{send} and T_{rec} is less than 10us through testing so switching time is:

T_s = 30us + 10us + 10us = 50us

So theory value of Dual LAN of recovery time is

$T_r = T_d + T_s$

T_r = 4ms + 0.05ms = 4.05ms

Now using equation (4) we can find out recovery time:

$T_r = T_f - T$ = 14 – 10 = 4ms

The graph is draw between fault recovery times versus average recovery time as shown in Figure 34:

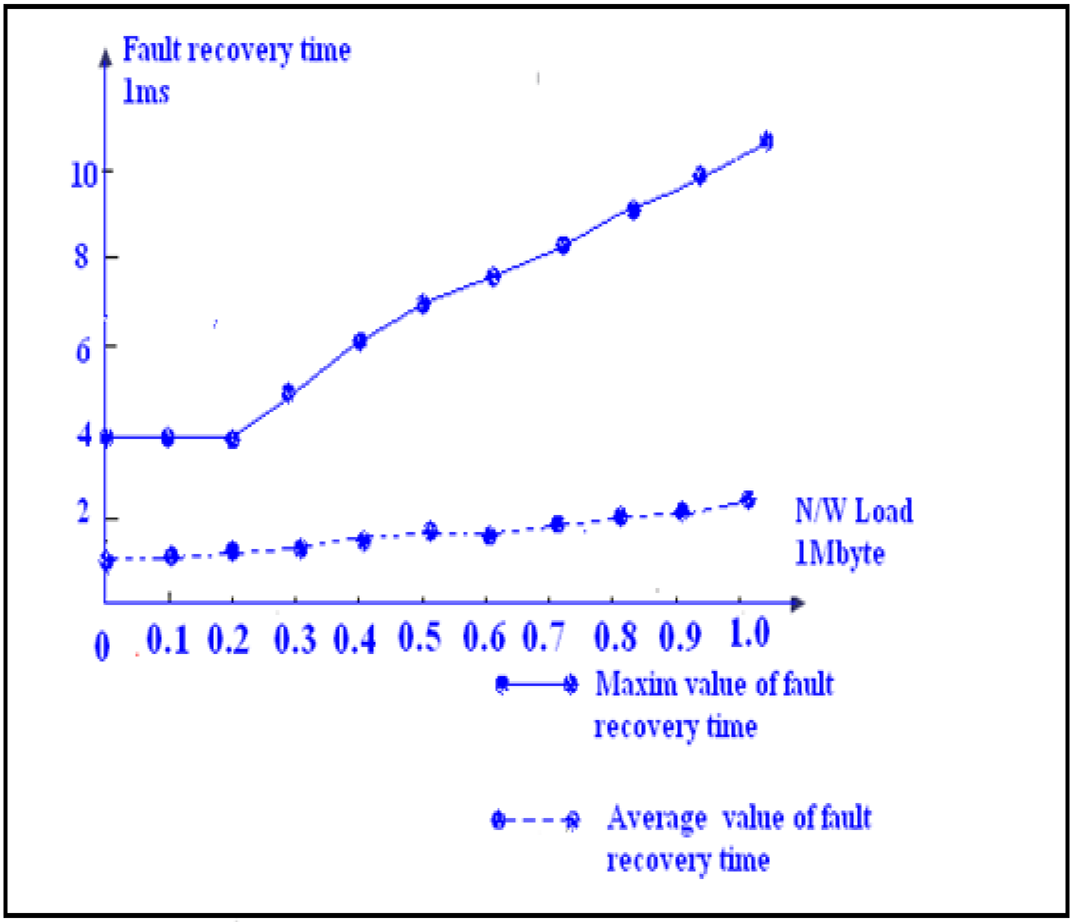

Figure 34: Recovery Time of Dual LAN Mode Protocol Network

For Dual LAN parallel mode redundancy protocol recovery time is zero [23] .The graphs is draw between fault recovery times versus average recovery time as shown in Figure 35.

Using equation (4) then recovery time is:

$T_r = T_f - T$

$T_r = 10 - 20 = 0$

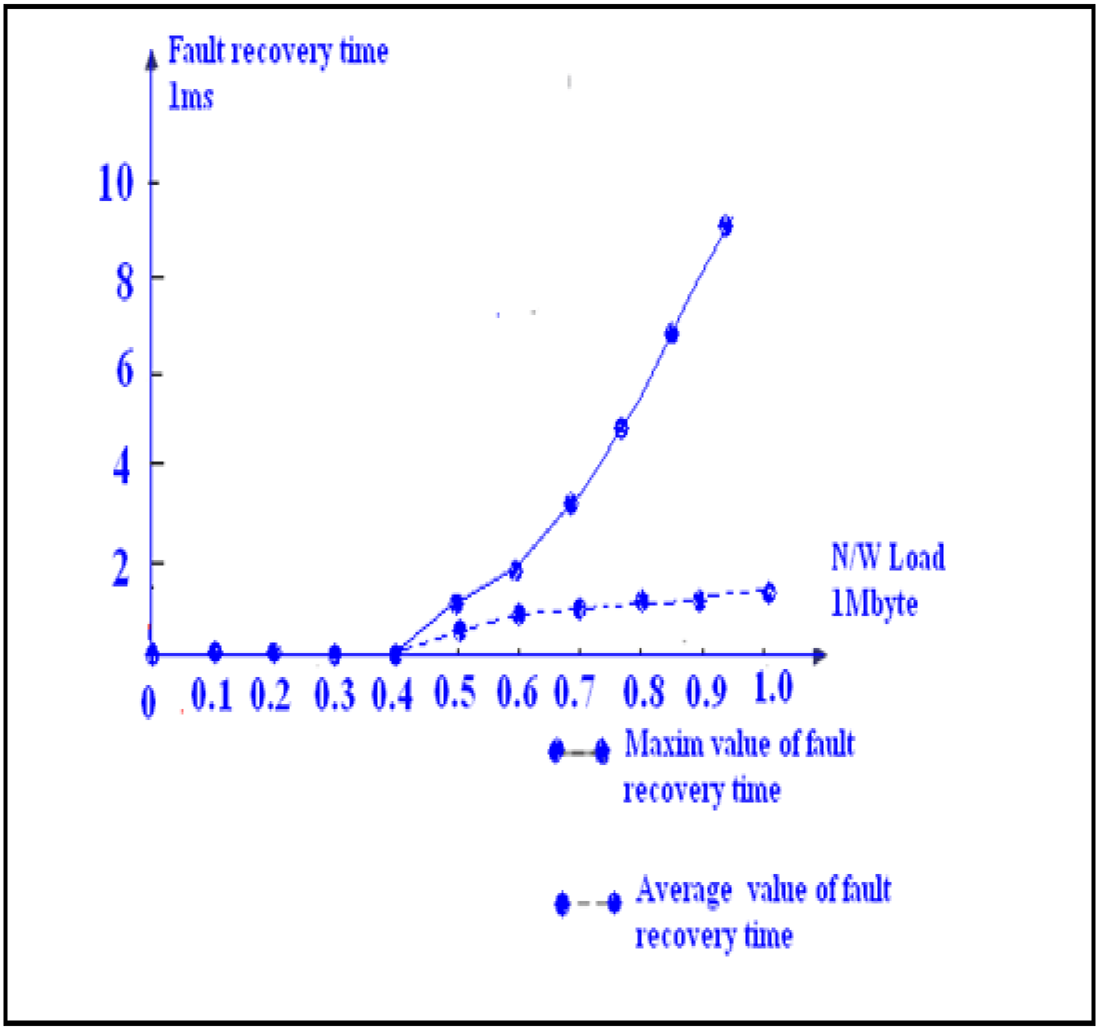

Figure 35 : Recovery Time Dual LAN Parallel mode Protocol Network

In figure 31 and 34 we see that if network load is less than 0.2 Mbps then it does not affect the recovery time but if network load is more than 0.4 Mbps than the recovery time value is getting bigger.

8 Case study – clock synchronization with SEL-2401 satellite – synchronized clock

8.1 INTRODUCTION

Some Time computer clock is drift. Many network services require the computer on the network to share the same accurate time to the network. So for this NTP is the best method providing the accurate time to the one computer to another through a network. Mainly it is internet protocol used to synchronize the clock of computer to using time reference clock. Its provide accuracy in microsecond.

In this case study we used a SEL-2401 clock as reference clock for time synchronization with NTP. This clock provides time synchronization accuracy in ±100 ns. For more discuses about this clock firstly we know that about what is reference clock. A reference clock is some device or machinery that spits out the current time. The special thing about these things is accuracy: Reference clocks must be accurately following some time standard. The reference clock are provide accurate time. Mainly this time broadcast by national standard agencies like GPS receiver that get the time from the satellite [32].SEL 2401 is GPS receiver clock its give a time in UTC standard . UTC (Universal Time Coordinated) is an official standard for the current time. The UTC have the main components like Universal means that the time can be used everywhere in the world, its mean that it is independent from time zones like it is not same as local time . To convert UTC to local time, one would have to add or subtract the local time zone and other component is coordinated means that several institutions contribute their estimate of the current time and UTC is built by combining these estimates.

8.2 SEL-2401

SEL-2401 satellite synchronized clock like a GPS receiver clock it’s provide the following feature:-

- Accuracy: - Apply for synchrophasor, relay event correlation, and other high-accuracy timing needs. Demodulated IRIG outputs with accuracy of ±100 ns average (±500 ns peak) meet requirements for existing and future timing applications.
- Reliability: - Apply in harsh environments. Meets IEEE C37.90 and IEC 60255 protective relay surge and environmental standards.
- Low Cost, High Function:- Provides demodulated IRIG-B time code with time-quality values Preset daylight time for European Union (EU) and United States (USA), plus a custom **DST** command provides automatic advance and return for daylight (summer) time anywhere in the world.

The main advantage that this clock also provides an unmodulated IRIG-B output. All information about IRIG-B in detail is available in chapter 4.

Figure 36 : GPS Receiver Clock [5]

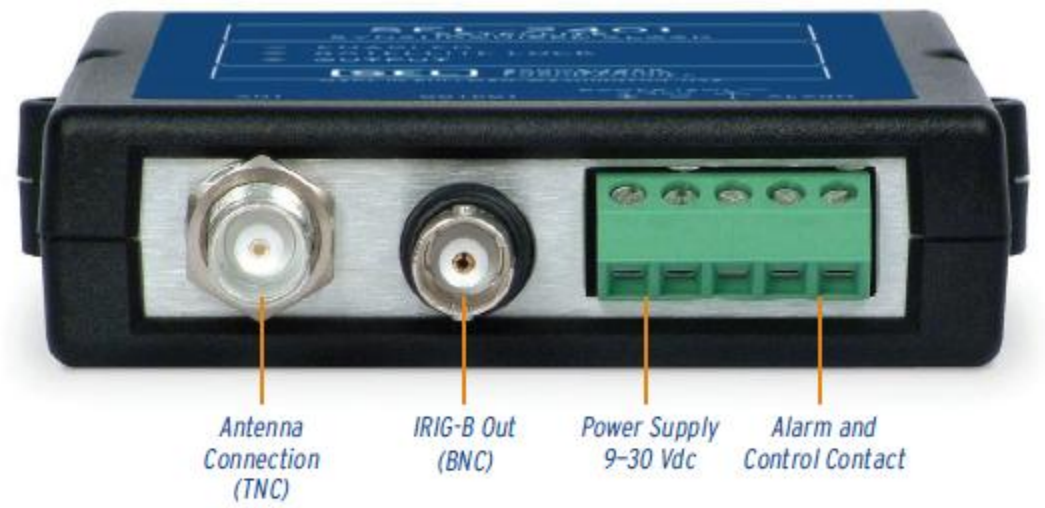

Figure 37: SEL-2401 Functional Overview Bottom [33]

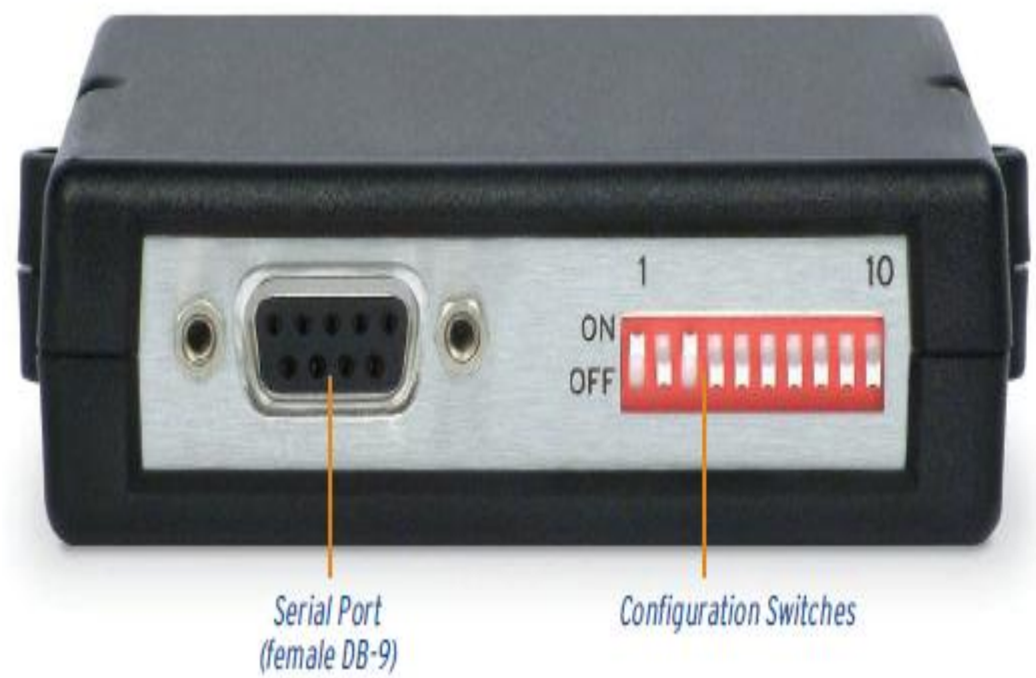

Figure 38: SEL-2401 Functional Overview top [33]

The SEL-2401 has three statuses indicate LED. These indicators that annunciate the status of the clock describe in given table below:-

Table 8: Status LEDs Indicator

LABEL	**COLOR**	**DESCRIPTION**
ENABLED	GREEN	All SELF TEST PASSED
SATELLITE CLOCK	GREEN	CLOCK IS TRACKING FOUR OR MORE SATELLITES
OUTPUT	GREEN	CLOCK IS OUTPUTING ACCURATE TIME ±100 MICROSECOND AVERAGE

Figure 39: LED Status Indicator [33]

8.2.1 Setting and Command

All settings for the SEL-2401 are performed through control switches {DIP (dual inline package) located on the top end of the device shown in Figure 40. The switch are label SW1 through SW10 The switch setting information are given below in table

Table 9   Control Switch (DIP) Settings and Function

<u>**SWITCH**</u>	<u>**FUNCTION**</u>
1	ON = Password protection disabled (only use to reset password when lost) OFF = Password protection enabled
2	ON = ALARM output does not include loss of satellite lock OFF = Adds loss of satellite lock to ALARM output
3	IRIG-B output format ON = extended IEEE C37.118 IRIG-B000 format OFF = standard IRIG-B002 format
4	ON = add to UTC OFF = subtract from UTC
5	ON = 8 hour increment OFF = subtract from UTC
6	ON = 4 hour increment OFF = subtract from UTC
7	ON = 2hour increment OFF = subtract from UTC
8	ON = 1 hour increment OFF = subtract from UTC
<u>**SWITCH**</u>	<u>**FUNCTION**</u>
9	ON = 1/2 hour increment OFF = subtract from UTC
10	ON = add to UTC OFF = Daylight-Saving Time (DST)

We can control the time format with using control switch SW4 through SW9 .The clock output is given UTC standard time. When all the switches is off position .if we want to set the local time firstly we need to set the appropriate offset from UTC time. We can add or subtract the time by setting the switch then get the local time. Always set the time to the local region standard time like according to daylight saving time this setting is done by setting SW10.

8.2.2 Serial port communication

SEL-2401 clock has one RS-232 serial port .the fixed serial port settings are given below in table

Table 10 Serial Port Configuration

Data rate	9600bps
Data bits	8
Stop bits	1
parity	none
Port time out	15 minutes

When we want to communicate personal computer with SEL 2401 through a serial port then we used serial cable for connection. Proper interfacing through integrated circuit MAX 3232 which is multi channel RS-232 line driver/receiver having ±15kV ESD protection Serial cable image shown in figure 40.

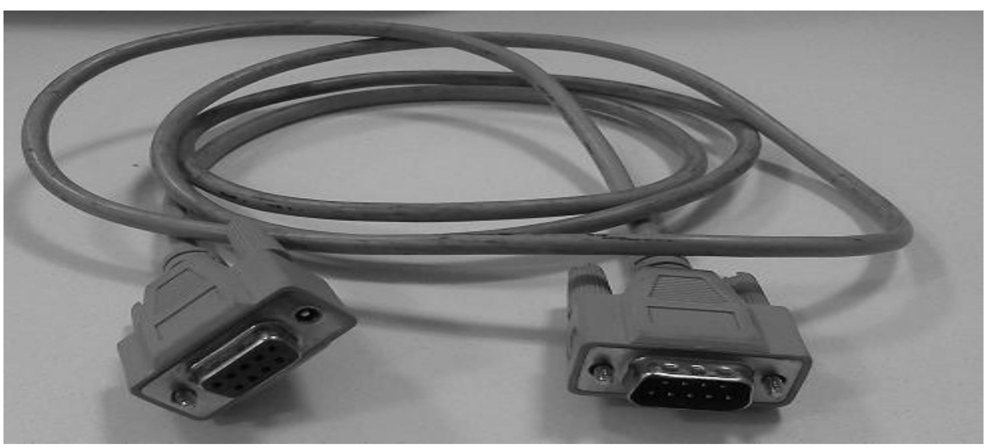

Figure 40: Serial Cable used for Connection between Personal Computer with SEL-2401 Module [32]

8.2.3 SEL-2401 communication port Command

SEL ASCII COMMAND

BX Command:

The **BX** commands give the ability to control and format time broadcasts from the serial port These broadcast commands allow a way to synchronize a remote PC or RTU through a serial connection. The broadcast commands have the format BX with one parameter X.

X can have one of the following values:

0 = Deactivates broadcast mode

1 = Activates broadcast of ddd: hh:mm:ss

5 = Activates broadcast of l YY ddd: hh:mm: ss.000

6 = Activates broadcast of ddd: hh:mm:ss q

8 = Activates broadcast of YYYY: ddd: hh:mm:ss q

L = Configures B1, B5, B6 and B8 broadcasts to send local time

U = Configure B1, B5, B6 and B8 broadcasts to send UTC time

CON command:

The **CON** command forces the ALARM contact closed one or more times, beginning at a specified time, and with a specified duration. This command implements a precise alarm clock function with an accuracy of ±0.5 ms, and a Pulse length that you set.

The clock command is the following format:

CON ALARM [C] [xxxxx.xx] [[yyyy-mm-dd] [Thh:mm:ss.ff]][P[dd] [Thh:mm:ss.ff]].

STA command:

The **STA** command displays the clock status.

DST command:

The **DST** command shows the custom daylight-time setting that the clock uses to automatically advance and return local time by one hour.

TIM Command:

TIM command to either view the current local time or to manually set the time if no satellite lock is available. This command is useful for either testing roll-over date or time values for downstream devices or for areas where a satellite lock is not available. The **TIM** command will respond with the local time in hours, minutes, and seconds **(hh:mm:ss**).

UTC command:

UTC command, the SEL-2401 responds with the UTC Date, time, and local time offset in the following format (ISO 8601:2000):

YYYY-MM-DDThh:mm:ss±HH:NN

UTC format are given below

YYYY = UTC Date Year (2000–9999)

MM = UTC Date Month (01–12)

DD = UTC Day of the Month (01–31)

T = Literal Time Separator

hh = UTC Time Hours (00–23)

mm = UTC Time Minutes (00–59)

ss = UTC Time Seconds (00–60)

±**HH =** Local Time Hours Offset including Daylight-Saving Time (–15 to +16)

NN = Local Time Minutes Offset (00 or 30)

The **UTC *n*** command repeats the UTC time output for *n* times at the starting of each second. A special case of this command is **UTC 0** which outputs UTC time continually until the communications port receives any valid ASCII character.

These all are sel-2402 communication command and using these command synchronize the clock of personal commuter and remote terminal unit (RTU)

8.3 Clock synchronization of personal computer with SEL-2401 satellite –synchronized clock

SEL-2401 Module is used to provide time synchronization to remote PC and RTU. .it broadcasting the time through serial port .so in this given Figure 41 personal computer which is connect to the SEL-2401 module through serial cable .the GPS antenna connect to the SEl2401 module, and it must be installed in accordance with national electric code. The antenna should be located low and close to the control house roof.

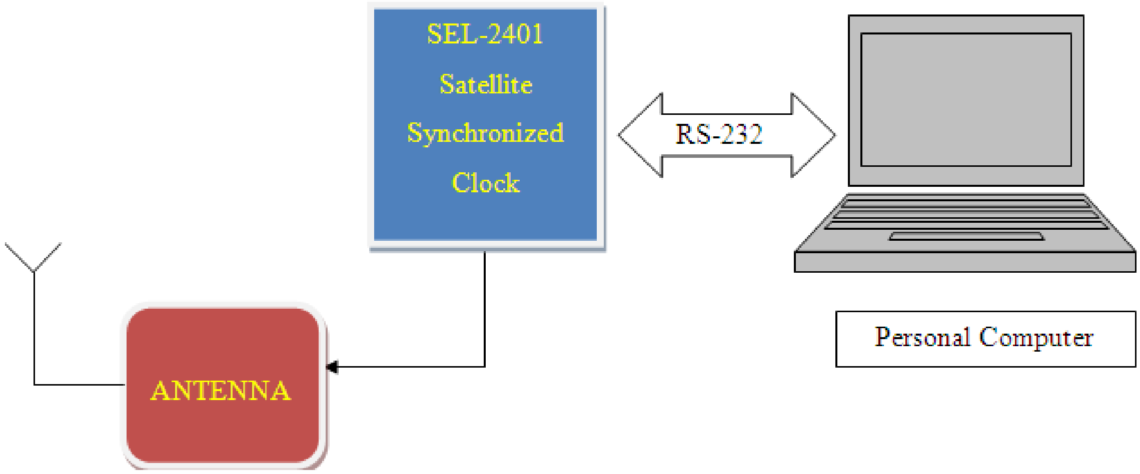

Figure 41: Block Diagram of Testing Module

When Connect SEL-2401 to PC its require SEL 5860 clock software for a accurate computer time , and this requires MICROSOFT .NET 2.0 and it also work with Microsoft window 2000, XP and 2003 server.

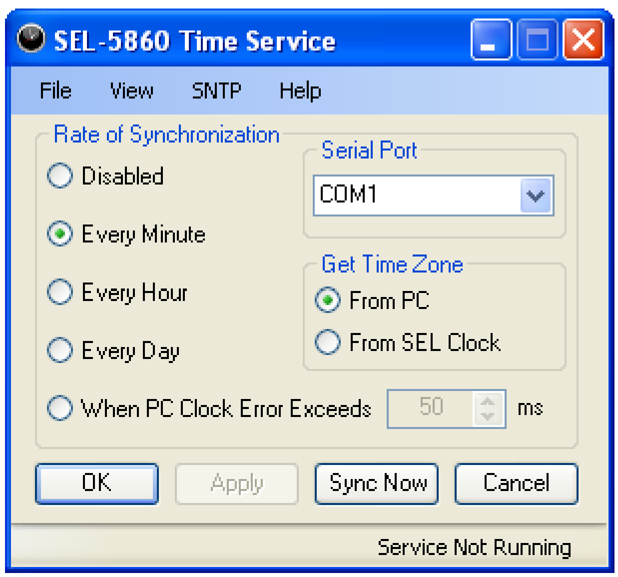

Figure 42: SEL 5860 Time Service Software

Software shall be required to communicate with the clock. Standard PC-compatible terminal emulation programs, such as HyperTerminal, shall be sufficient to establish communication, provide commands and settings, and download data. The clock shall support the capability to provide date and time to a PC or computer via a communications link using accessory software. The clock shall also provide an ASCII time output on the serial port.

9 RESULT

Result of testing of communication OF SEL-2401 module with PC is shown here.

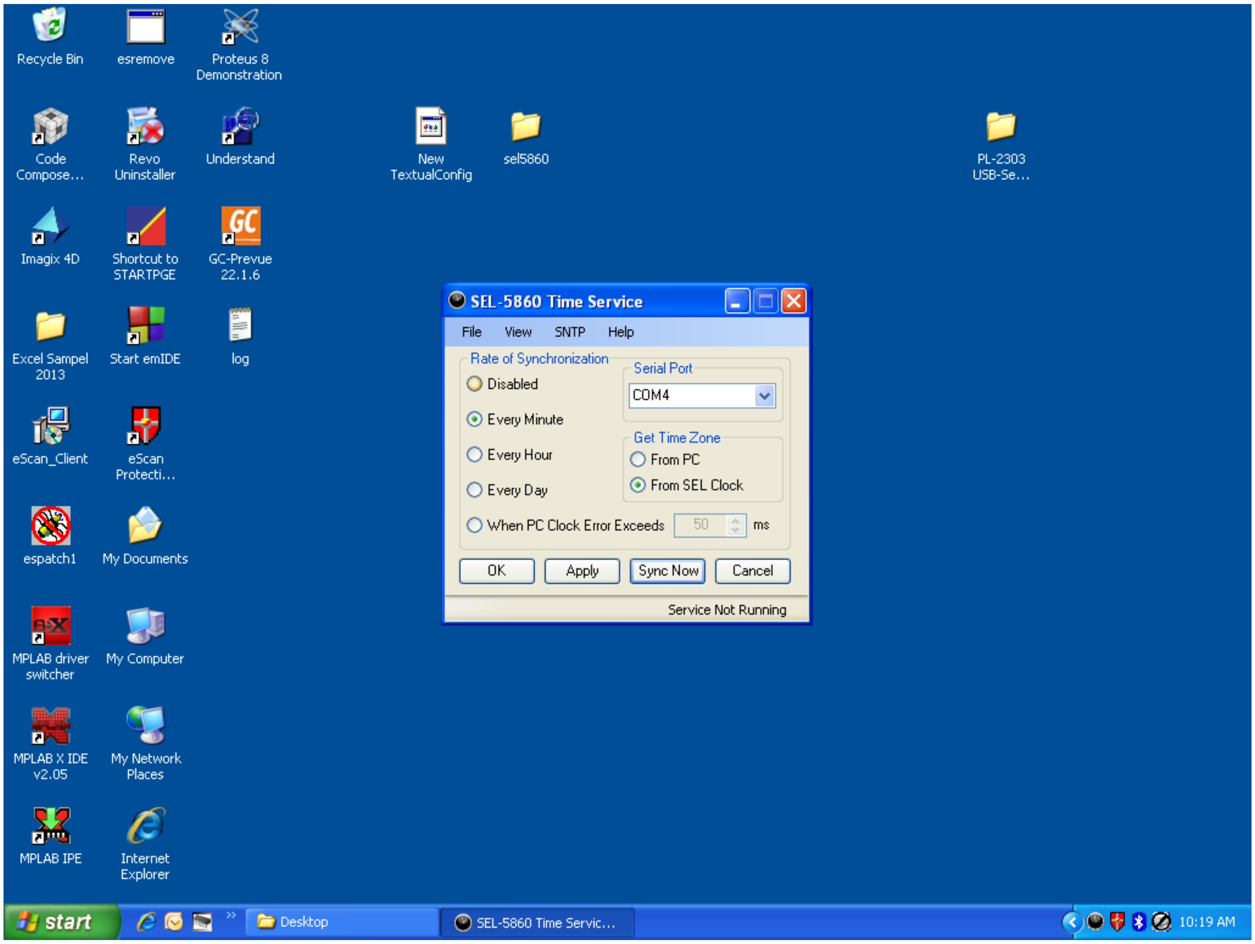

Figure 43: SEL 5860 Software Installed in Windows XP

To establish the connection between sel-2401 and personal computer then we require SEL-5860 software. This software installed in windows XP. SEL 5860 time service window is shown in Figure 43 but SEL5860 time service currently it's not in running stage shown in Figure 43. Using this software we synch the personal computer time automatically in nanosecond accuracy when SEL5860 time service is running. We test here how using this software sync the time of PC and make this PC act as server.

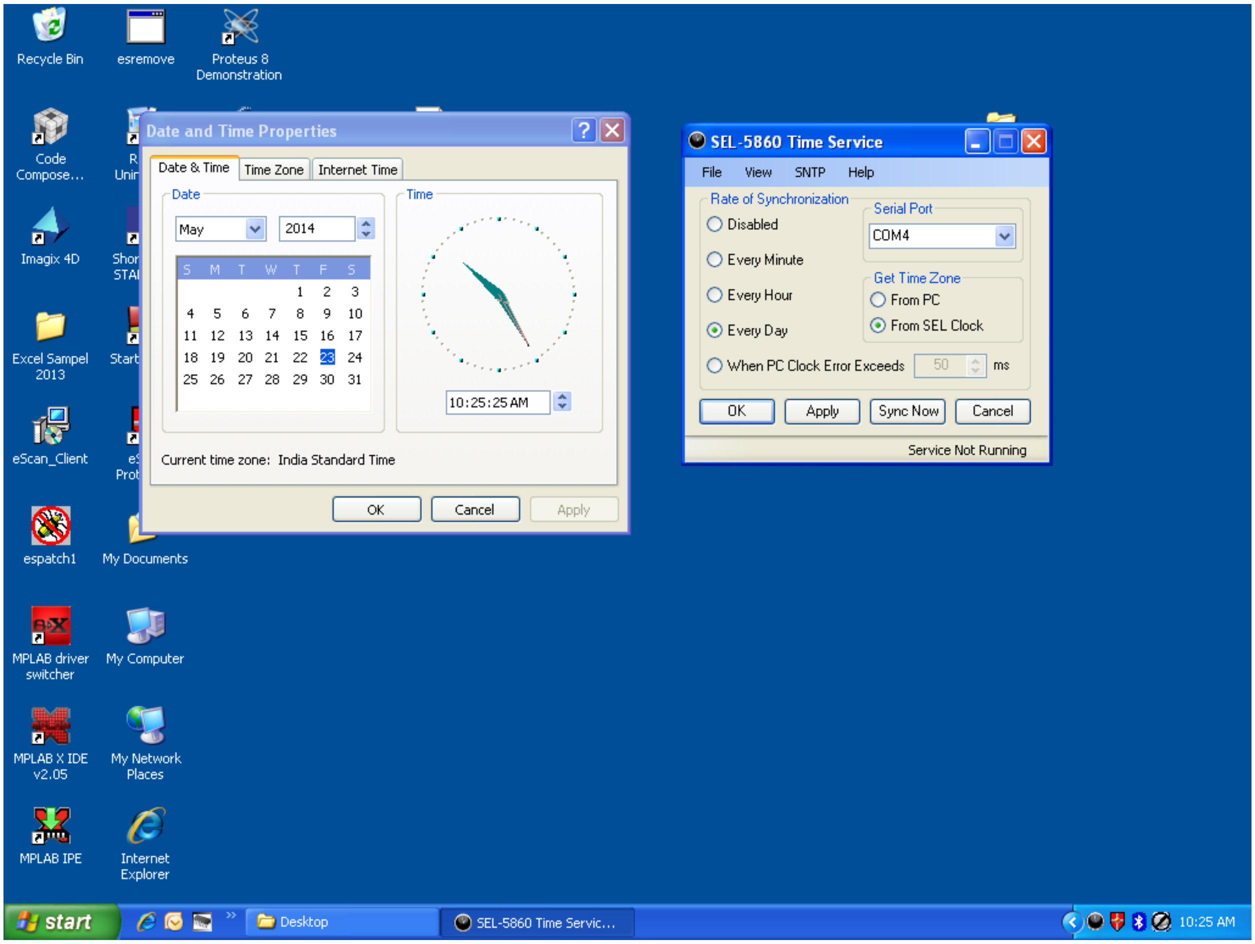

Figure 44: Window of Date and Time Properties & Window of SEL 5860

In Figure 44 the date and time properties window are open for firstly check the currently time of the personal computer and also in fig check that the SEL 5860 service is not running position. Here firstly set the correct time of the PC for check that SEL 2401 module is working or not. In figure 44 set the time of pc but currently sel5860 service are not running. we change the PC time or date its shown in figure 45 here also SEL 5860 service are not running so it not sync the time of pc if we change it .when service its running of SEL5860 time service its automatically sync the time of personal computer according to the SEL 2401 GPS .receiver its shown time in ASCII code.

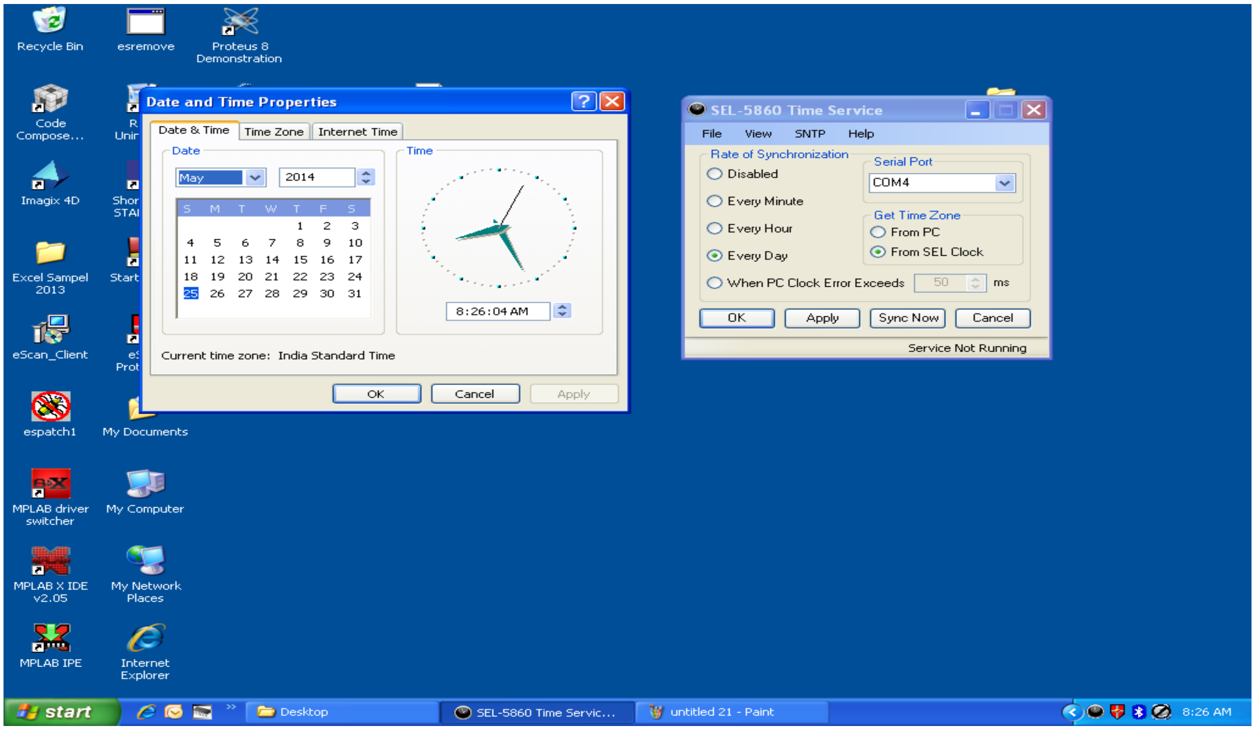

Figure 45: Change the Date and Time Properties of the Personal Computer

When service is running of time service it’s automatically sync the time of personal computer. Are shown in figure 45

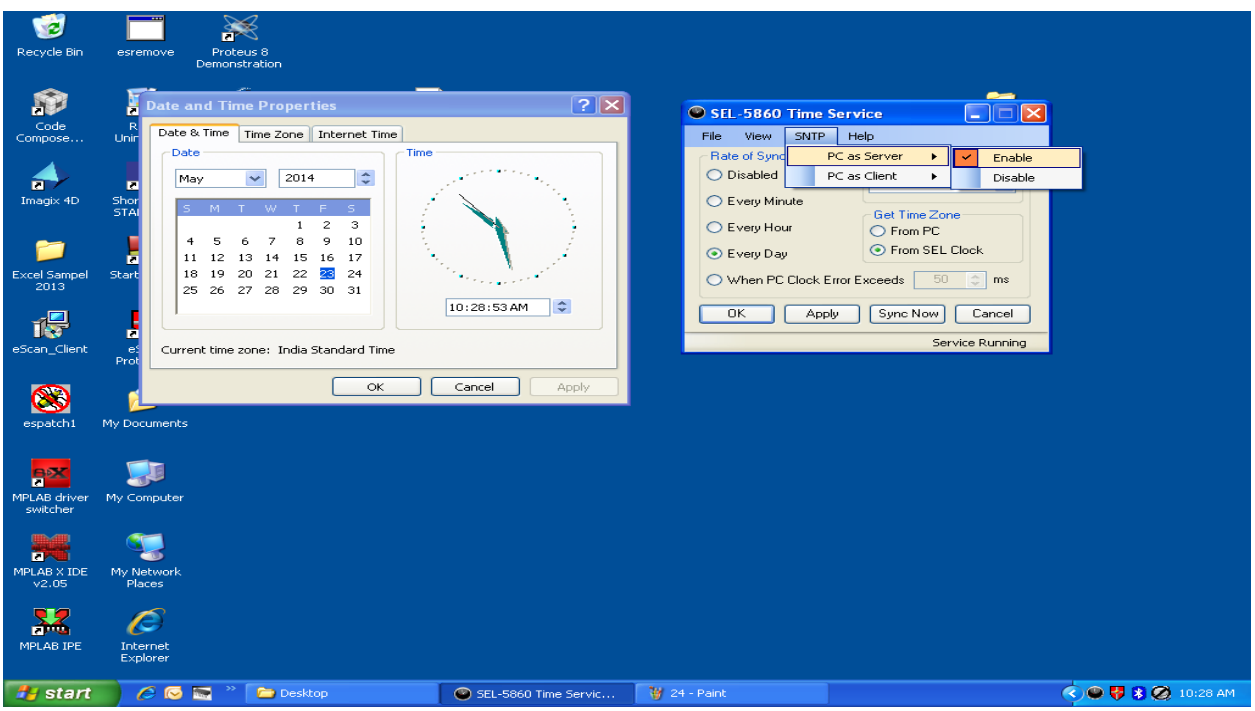

Figure 46: Make PC as SNTP Server after Time Sync of the PC

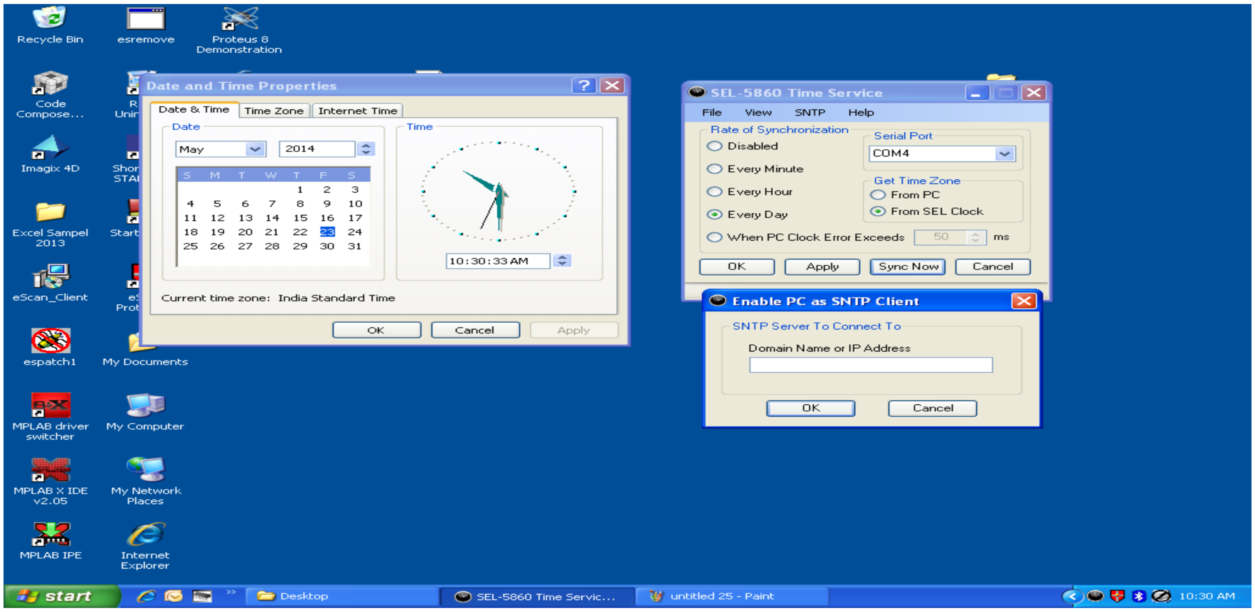

Figure 47: Enable PC as SNTP client

Hyper terminal is a program that include with every version of the window operating system hyper terminal tool allow you to communicate directly with your personal computer to SEL 2401 module through this you can reset the module configuration and diagnose command. Using hyper we can connect and communicate SEL 2401 with personal computer directly.

Once a hyper terminal open it will automatically prompt we can create a new connection if not exist if no connection exist we can click file/ new connection to create a new connection. in the port property show that set a port speed that match the SEL 2402 after choose communication parameter that match the device SEL 2401 parameter like 8 data bits , no party bits ,one stop bit and hardware flow control.

When hyper terminal connect to SEL 2401 we can check in using which command its give the data.

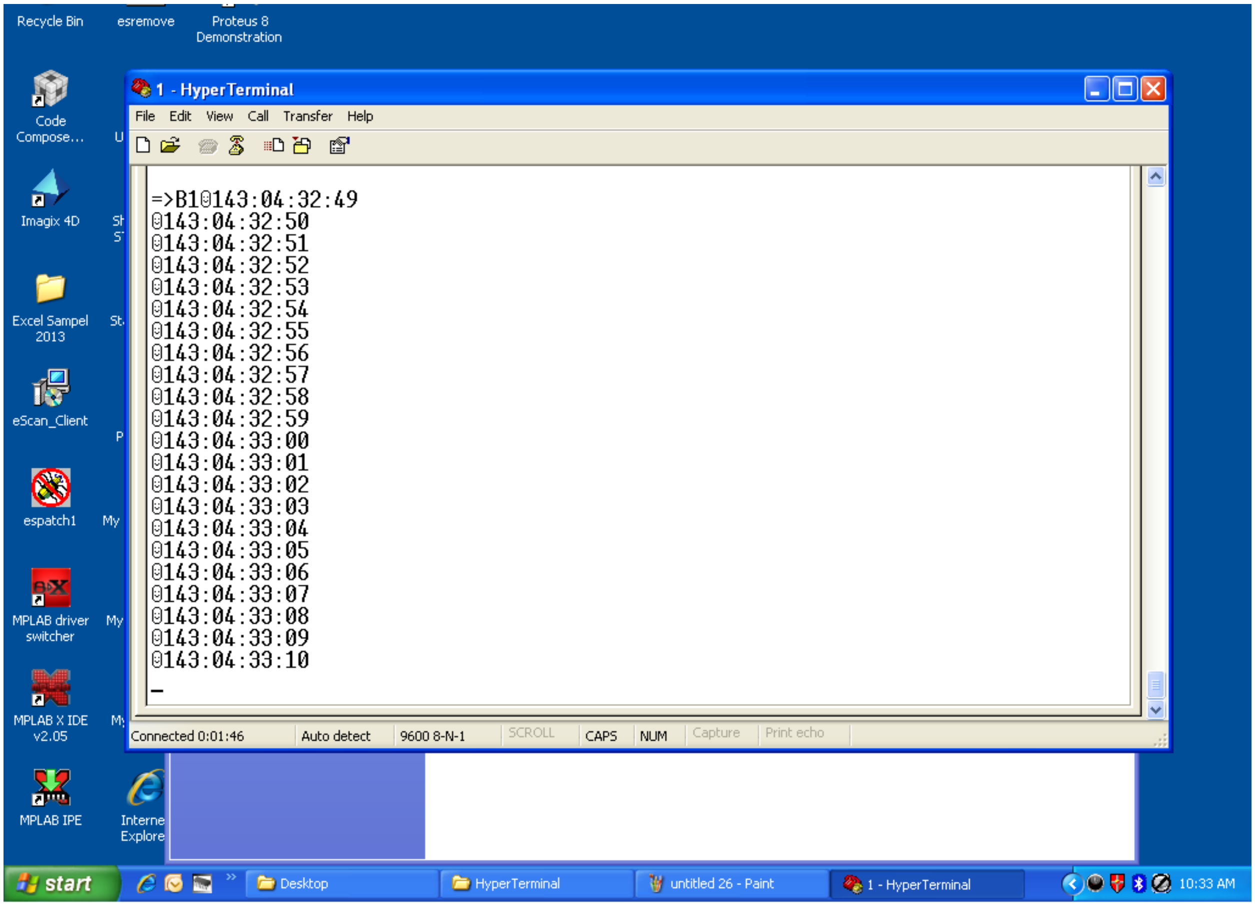

Figure 48: Issue B1 command

Here in figure 48 the default access level => prompt indicates SEL 2401 is connected to the Personal computer are working. Firstly enter the button then => Prompt are shown then USE **BX COMMAND** second but it give the time format in UTC format.

These broadcast commands allow a way to synchronize a PC through a serial Connection. In figure 48 show that If we B1 command is issued, then the Satellite-Synchronized Clock will enter time broadcast mode and respond with ddd:hh:mm:ss once per second. Note that any time the broadcast commands are issued they are not echoed to the screen. its show the time code in ASCII code format.

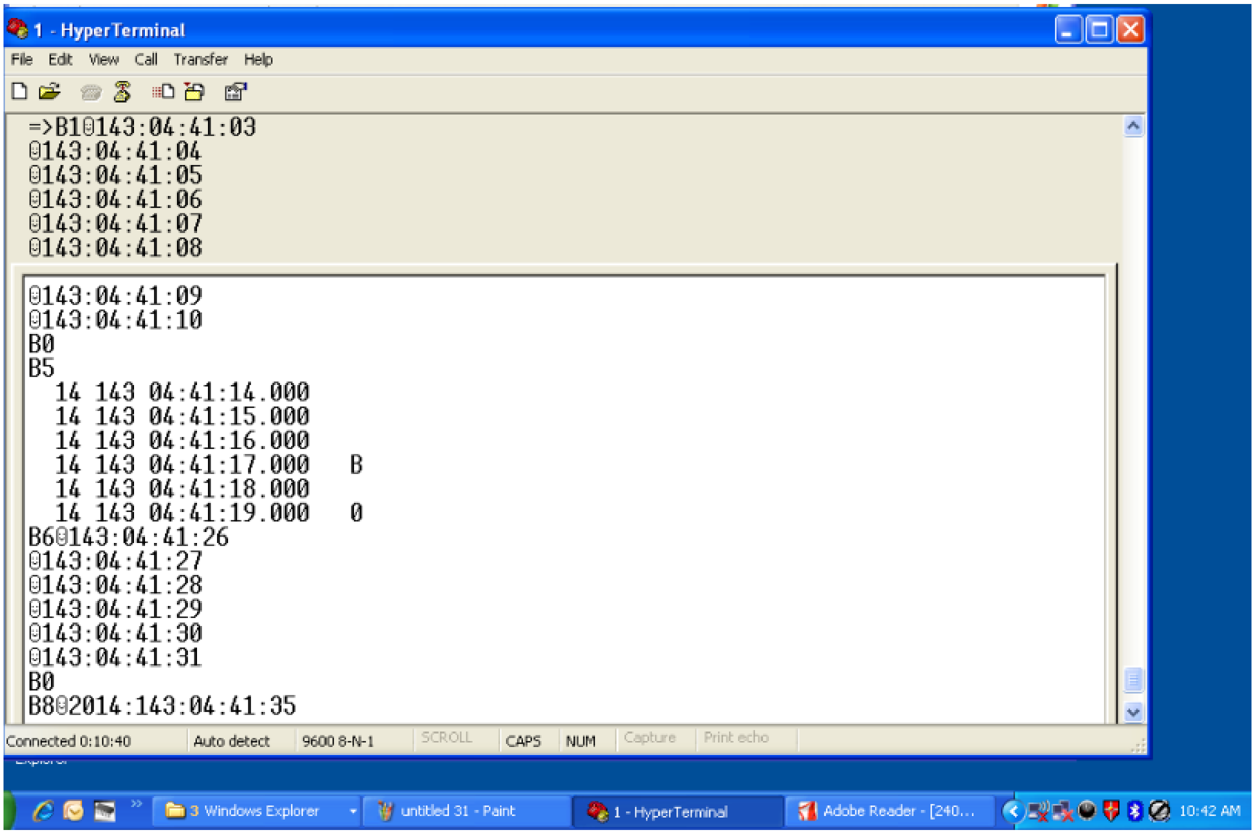

Figure 49: Issue B1 , B0, B5 , B8 ,B6 Command for Broadcasting time code in different Format

If the **BO command** is issued, then the Satellite-Synchronized Clock Deactivates broadcast mode Shown in fig 52 .When **B5** command is issued then the Satellite-Synchronized Clock will enter time broadcast mode and respond Activates broadcast of l YY ddd:hh:mm:ss.000 this format like (**14 143 04:41:14:000)** also shown in figure 49 .

When **B6** command is issued then the Satellite-Synchronized Clock will enter time broadcast mode and respond Activates broadcast of ddd:hh:mm:ss q in this format like (**0143 :04:41:14:000)** it also broadcast the time in this format in every second but it give the time format in UTC Format. B8 command is issued then the Satellite-Synchronized Clock will enter time broadcast mode and respond Activates broadcast of YYYY:ddd:hh:mm:ss q like **(2014:143:04:41:35)** broadcast this time in every second.

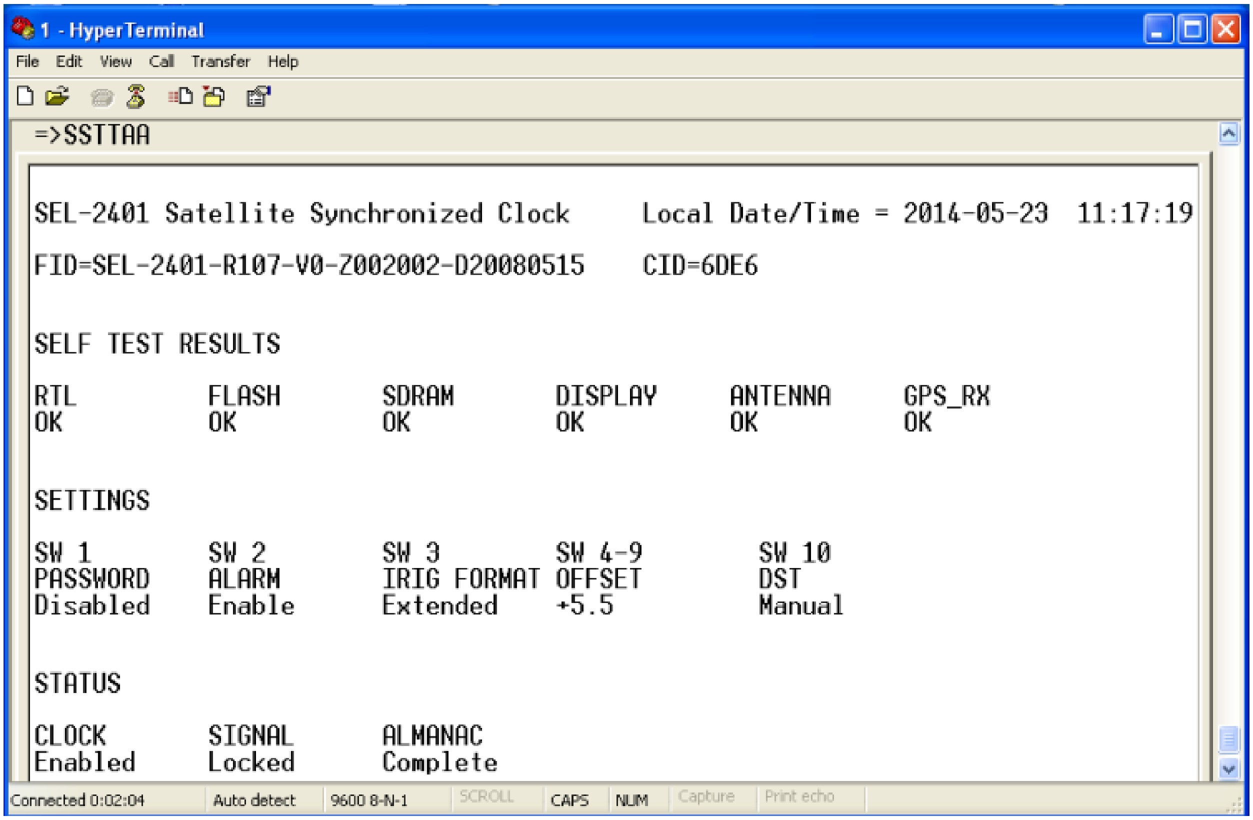

Figure 50: Issue STA Command for Clock Status

Here in figure 50 show that when we **STA** command is issued then it displays the clock status of the SEL-2401 Satellite Synchronized Clock. Using this command we set the settings of the clock also check the settings. And also we get the all information about this clock like flash, Display, antenna status easily we get. By Using the STA command. Practically here test the status of SEL-2401 clock.

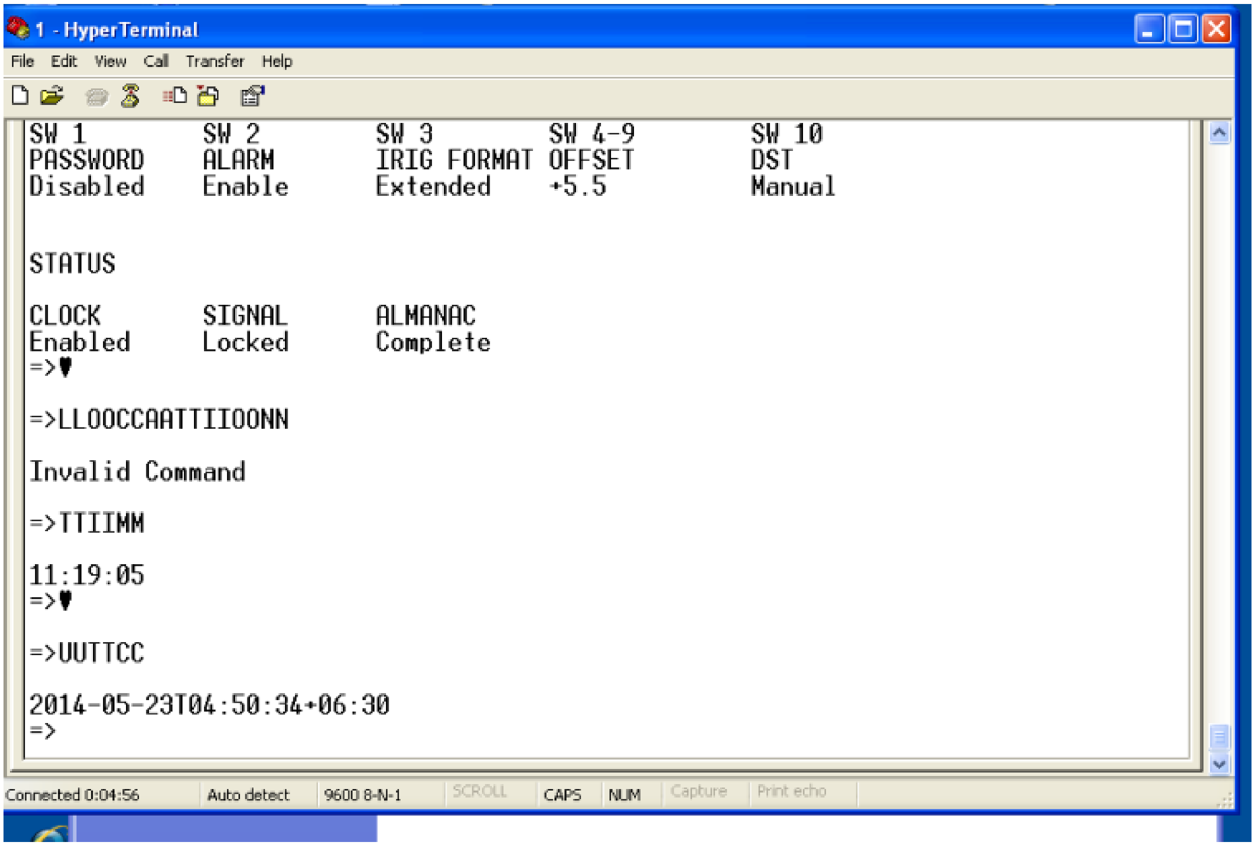

Figure 51: Issue TIM and UTC Command

Here when issued **TIM** command then its view the current local time is shown in figure 51 Or we can manually set the time if no satellite lock is available. This command is useful for either testing roll-over date or time values for downstream devices or for areas where a satellite lock is not available. The **TIM** command will respond with the local time in hours, minutes, and seconds (hh:mm:ss). Manually setting **TIM** is only allowed after cycling power or if the clock is currently not synchronized. Once the date and time are manually set the clock will not synchronize to the current date and time even if the clock picks up satellite lock. To clear the manual date and time either cycle power or issue the **TIM C** command.

When issued **UTC** command then SEL-2401 responds with the UTC date, time, and local time offset in the following format (ISO 8601:2000) are also shown in figure 51.

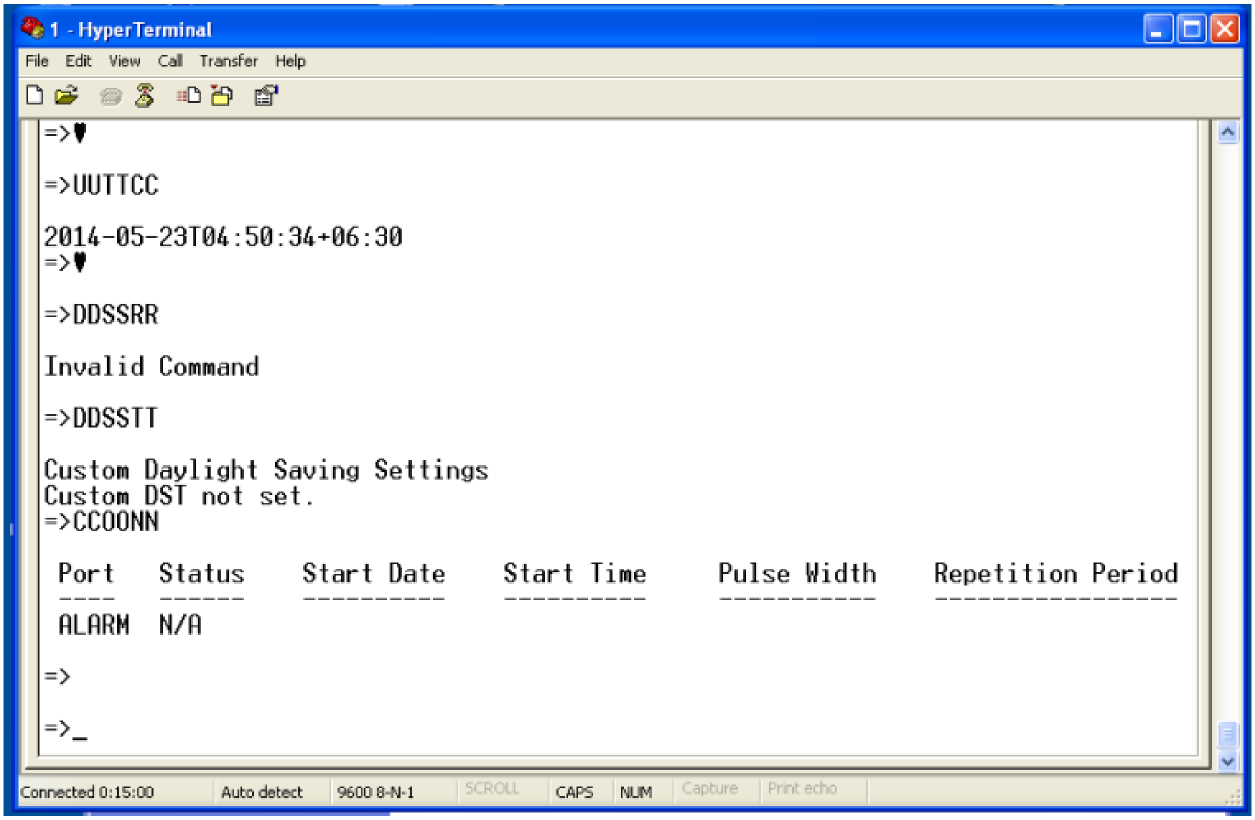

Figure 52: Issue DST and CON Command

When issued the **DST** command then its show the custom daylight-time setting that the clock uses to automatically advance and return local time by one hour is shown in figure 52. And when CON command is issue then it forces the ALARM contact closed one or more times, beginning at a specified time, and with a specified duration. This command implements a precise alarm clock function with an accuracy of ±0.5 ms, and a pulse length that we set.

10 CONCLUSION

In the present thesis different Time synchronization technologies have been studied .On the basis of study and analysis, it has been found that IEEE 1588 Provides the best accuracy up to 1 microsecond, SNTP provides accuracy in 10 millisecond , IRIG-B provides accuracy in 1 millisecond and GPS provides accuracy up to 10 microsecond. The proposed system reduces the design complexity, low cost and better time synchronization. Among the above protocols two are Ethernet based protocols, which are SNTP and IEEE 1588. These protocols provide stronger adaptability, high efficiency and microsecond time synchronization accuracy. It is also necessary to have a network with Zero recovery time, when any fault or error is occur. So to fulfill the requirement of drop out fault tolerance, two Network Redundancy protocol were studied and analyzed. These are standardized by IEC 62439 and are Parallel redundancy protocol (PRP) and High seamless availability protocol (HSR). The proposed study showed that these protocols recovered the fault in the network and provides bump-less redundancy and zero recovery time. As the result, performance is stabilized and Time synchronization maintained.

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