Time Synchronization and IEEE 1588v2 Solutions

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Abstract*: By knowing the issues surrounding time synchronization and the solution provided by IEEE 1588v2, a standard for network-based timing synchronization is introduced. Researchers can solve the barriers to leverage cost-effective IP networks and handle the increased bandwidth anticipated from 3G and 4G services. This paper explores the issues related to the requirements for synchronization and the solution provided by the IEEE standard.*

Keywords: *Synchronization, IEEE 1588v2, PTP client.*

1 Introduction

Synchronization in telecommunication networks is the process of aligning the time scales of digital transmission and switching equipment, so equipment operations occur at the correct time and in correct order [1]. In an industrial data network, time synchronization allows all of the different devices on that network to use a common clock to coordinate their activities. Network integrators currently have a number of different time synchronization options which are available. Time synchronization is important for any distributed system. G.Kálmán et al (2014) [1] Examined that Synchronization is a requirement also from the telecommunication side to allow use of e.g. carrier Ethernet instead of SDH. Wu and Chen (2013) [2] defined that an

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industrial data network, time synchronization allows all of the different devices on that network to use a common clock to coordinate their activities. G. M. Garnner (2008) [3] examined that synchronization requires communications between individual clocks to check whether their deviation is tolerable and whether the clock needs to be corrected. It takes time to go through the process of correcting time and maintaining the accuracy 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. IEEE 1588v2 known as Precision Time Protocol (PTP) is an industry standard clock synchronization protocol which is capable of transferring timing information over packet switched 2 networks [4]. It is widely used both in wire-line and wireless network environments due to its low cost implementations in networked measurement and control systems.

G. M.Garnner(2010) [3] investigated that IEEE 1588v2 PTP is a protocol designed to synchronize real-time clocks in the nodes of distributed system which communicate using network. This protocol is used to transport timing information across Ethernet Network and synthesize clock on the far end IEEE 1588. Ixiacom (2015) [4] examined that precision Time Protocol (PTP), defined by the IEEE 1588v2 standard, provides highly accurate timing over a packet based network by propagating frequency, phase, and time-of-day information. As service providers migrate from synchronous TDM based networks to non-synchronous Ethernet/IP, they require a cost effective mechanism that propagates timing in order to support the existing synchronous infrastructure- especially in mobile backhaul networks. Mihail L. et al (2009) [5] investigated that both accurate frequency and time distribution will be considered. Time distribution, in particular, appears to be a key issue for emerging wireless network technologies, such as Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE). Aleksic et al [6] declared that using a packet-based, event-driven simulator, which would most probably lead to a complex and less scalable implementation. T.J.Hoque (2014) [7] declared that IEEE 1588v2 PTP used to transport timing information across Ethernet Network and synthesize clock on the far end. IEEE 1588v2 PTP supports system wide synchronization accuracy in the sub-microsecond range with little use of network and local clock computing resources. 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 and their business partners.

In this paper first we introduced the Synchronization and IEEE 1588v2 definitions. Next, we found the solution of IEEE 1588v2and PTP client and its works. Finally we discussed about this solution.

2 Synchronization

The essential technology building block of today's service provider networks is synchronization [9]. The interpretation of the standard wired T1/E1, SONET and SDH networks are based upon necessitated clock control theory and PLL design. This form of synchronization signal is related to frequency. The physical layer of the transmission system provides a clock signal. Electronic circuits organizing this signal to provide the frequency accuracy, stability, phase movement control, wonder filtering and phase noise levels − specified in capacity of standards documents.

In these documents each "end customer service" has a definite set of stipulation performance. By the assorted international standard bodies this performance is explained and is well understood. There are two mobile wireless network synchronization schemes. The first one is the same as the wired networks in using the technology. This is used to provide FDD (Frequency division duplex) radio-based mobile wireless network synchronization signals for ingress/egress of data and exact radio frequency. For example WCDMA FDD is the most famous method of radio air interface used in GSM systems .The second is synchronization of TDD (Time division duplex) radio based mobile wireless networks .This radio technology takes both the frequency exactness from the above analysis in the cell network. Examples of TDD radio system are CDMA, CDMA2000 and Mobile Wimax 802.16e. The usual wired "circuit" oriented synchronization signal delivery system cannot be used as there is no phase or time connection between signal termination points on the clock distribution network,.

All four mobile wireless network synchronization demands require having an inter base station associated timing reference. This is important to guarantee carriage channel adjustment for hand off and guard band protection. Requirement for 3GPP identified FDD systems is frequency accuracy better than 50ppb (parts per billion). The 3GPP TDD systems require an inter base station time adjustment 2.5μs to 10μs and 50ppb frequency accuracy (Diamond,

2008).

3   IEEE 1588v2

T1/E1 circuit-based technologies are devoted to the individual services. The costs of service delivery show an important barrier to profitably providing higher bandwidth service offerings by considering the scale of billions of circuits around the world. For example 40%of the total operating charge for a mobile wireless operator can be consumed up by these circuits. This Market pressure is driving the move to the distributed resource of packet based Ethernet backhaul. The cost per megabit ratio contrast of T1/E1 circuit against Ethernet based packet backhaul averages 6 to 1. Understanding the desire of the service provider to shift to the cheaper Ethernet transport is easy with these metrics.

Moving towards a packet-based transport network set the challenge of providing the level of synchronization requirements specified in the 3GPP, 3GPP2(LTE) and IEEE 802.16e(WiMax) specification [10]. One solution to this problem "the broadcast of the clock information over a packet network" is omitting the need for alternative mechanisms, such as GPS prohibitively expensive oscillators placed at the receiving nodes .This provides considerable cost saving in network rig as well as in steady installation and preservation. This synchronization solution broadcasts timing packets, which flow along the same paths with the data packets reducing the cost of synchronization and shortening execution. The IEEE 1588v2 protocol is fully adaptable with all Ethernet or IP networks to deliver frequency and phase or time resolution rivaling a GPS receiver.

4   The solution of IEEE 1588v2

4.1   The solution

For today's data center and financial applications, IEEE 1588 Precision Timing Protocol (PTP) is a very promising timing solution. It's originally designed for distributed measurement and control network, later on has been successfully deployed in many large telecommunication networks worldwide in last several years due to the benefits it provides below:

● Spatially localized systems with options for larger systems

● Packet based timing distribution and synchronization

● Nanosecond to sub-microsecond accuracy

● Low administrative operation, easy to manage and maintain

● Provisions for the management of redundant and fault-tolerant systems

● Low cost, low resource use, works well for both high-end and low-end devices

4.2   IEEE 1588v2 Precision Time Protocol Overview

IEEE 1588 PTP is a high-precision time synchronization protocol for distributed communication systems. IEEE standardizes it in 2002 known as IEEE 1588v1 and later on updated it in 2008 known as IEEE 1588v2. The protocol enables heterogeneous systems which include clocks of various inherent precision levels, resolutions, and stability to synchronize with a grandmaster clock. IEEE 1588v2 PTP supports system wide synchronization accuracy in the sub-microsecond range with little use of network and local clock computing resources. The following sections introduce the main components of IEEE 1588v2 technology and its terminology. A good understanding of the IEEE 1588v2 protocol will help you to design a robust PTP timing solution for your data communication network.

4.3   PTP Clocks

IEEE 1588v2 PTP is a packet-based two-way message exchange protocol for synchronizing a local clock with a primary reference clock (a grandmaster clock) in hierarchical master-slave architecture [11]. The type of PTP clock used depends on the function performed by the PTP node in the network:

● Ordinary clock: This clock type has a single PTP port in a domain and maintains the time scale used in the domain. It can be a master clock or a slave clock. For example, if the grandmaster clock is an ordinary clock, a PTP slave on the server will be an ordinary clock, too.

● Boundary clock: This clock type has multiple PTP ports in a domain and maintains the time scale used in the domain. It can be a master clock on one PTP port and simultaneously a slave on another port on the same PTP node. This feature is very useful when you need to make PTP work in different domains or translate from a different medium (for example, a network that uses time-division multiplexing [TDM] and a packet network).

● Transparent clock: This type of clock measures the time taken for a PTP event message to transit the device and provides this information to clocks which are receiving this event message.

Two transparent clocks are introduced in IEEE 1588v2: end-to-end transparent clocks and peer-to-peer transparent clocks.

● End-to-end transparent clock: This type of transparent clock supports the use of the end-to-end delay measurement mechanism between slave clocks and the master clocks. Because the end-to-end transparent clock does not calculate link propagation, it will not terminate PTP messages, and it should work with a delay request-response mechanism between master and slave clocks.

● Peer-to-peer transparent clock: This type of transparent clock, in addition to providing PTP event transit time information, provides the propagation delay of the link connected to the port which receives the PTP event message. The peer delay mechanism is used to compute the mean path delay and clock offset between two peer-to-peer transparent clocks.

4.4   Best Master Clock Algorithm

Best Master Clock Algorithm (BMCA) is used to select the master clock on each link, and it ultimately selects the grandmaster clock for the whole PTP domain. It runs locally on each port of the ordinary and boundary clocks to compare the local data sets with the received data from announce messages to select the best clock on the link. BMCA also runs the state decision algorithm to determine the PTP port states.

BMCA compares the following attributes from Announce messages with the precedence described here:

● Priority1: A user-configurable variable from 0 to 255; lower values takes precedence

● Clock Class: Defines the traceability of the time or frequency from the grandmaster clock

● Clock Accuracy: Defines the accuracy of a clock; lower values take precedence

● Offset Scaled Log Variance: Defines the stability of a clock

● Priority2: A user configurable variable from 0 to 255; lower value takes precedence

● Clock Identity: An 8-byte number typically in IEEE-EUI64 format to uniquely identify a clock

By changing the user-configurable values, network administrators can influence the way that the grandmaster clock is selected. BMCA provides the mechanism that allows all PTP clocks to dynamically select the best master clock (grandmaster) in an administration-free, fault-tolerant way, especially when the grandmaster clocks changes.

4.5   PTP Master-Slave Clock Hierarchical Topology

In an IEEE 1588v2 PTP network, the master-slave hierarchical clock topology needs to be established in a PTP domain before clock synchronization occurs. This tree-like topology is similar to spanning tree, the grandmaster clock is most accurate clock in this clock hierarchy system and is the root of the tree so every PTP slave clock synchronizes to it. In the PTP network, every port of the ordinary and boundary clocks examines the contents of all PTP announce messages received on the port, and then each port runs an independent PTP state machine to determine the port status. Using BMCA, Announce messages, and the data sets associated with the ordinary or boundary clock, the PTP port can be determined to be in one of the following three states:

● Master: The port is the source of time on the path served by the port.

● Slave: The port synchronizes with the device on the path on the port that is in the master state.

● Passive: The port is not the master on the path, nor does it synchronize with a master.

Usually IEEE 1588v2 relies on underlying networking protocols to eliminate loops, but IEEE 1588v2 also has the built-in mechanism to break a loop based on the BMCA state machine on each PTP node. The BMCA helps in ensuring that a single master port is selected on each segment.

4.6   Clock Synchronization Process

When the master-slave clock hierarchy is established, the clock synchronization process starts. The synchronization is achieved through a series of messages exchanged between master and slave clocks as shown in Figure 2 and outlined here.

1. The master clock sends the Sync message. The time when the Sync message leaves the master is time-stamped as t1, which can be embedded in the Sync message itself (one-step operation) or sent in the Follow up message (two-step operation).

2. The slave receives the Sync message; t2 is the time that the slave receives the Sync message.

3. The slave sends the Delay Request message, which is time-stamped as T3 when it leaves the slave and time-stamped as T4 when the master receives it.

4. The master responds with a Delay Response message that contains time stamp t4 [12].
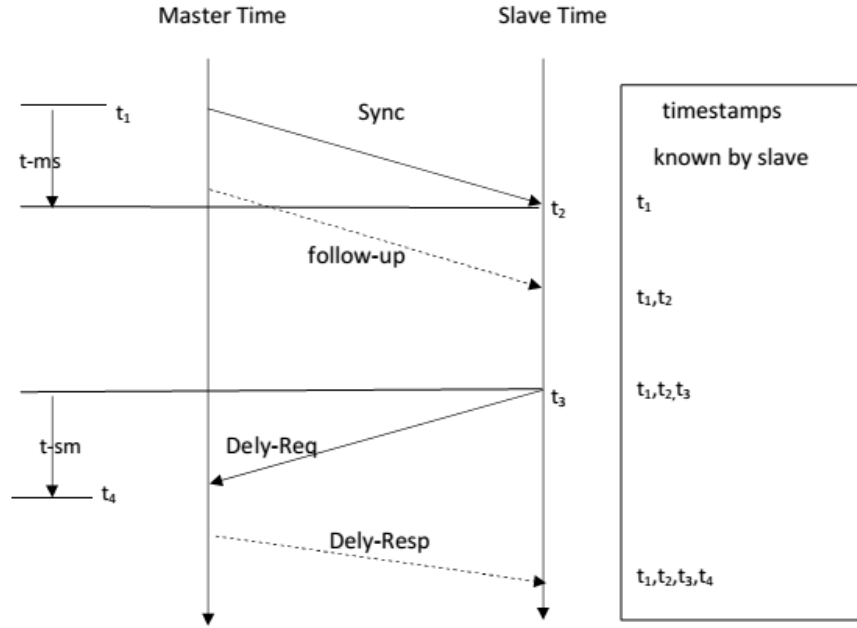
Figure 1. Clock Synchronization Process [3]

Therefore, the clock offset (the difference between the master and slave clocks) can be calculated as follows:

$$\text{Offset} = t2 - t1 - \text{mean Path Delay} \qquad (1)$$

IEEE 1588 assumes that the path delay between the master and slave clocks is symmetrical, so the mean path delay is calculated as follows:

$$\text{Mean Path Delay} = ((t2 - t1) + (t4 - t3))/2 \qquad (2)$$

Now the slave clock can synchronize with the master clock [13]. The preceding steps show the fundamentals of the clock synchronization process between the master and slave clocks. The same concepts apply when the PTP transparent clock is added to the communication path, but the message resident time (the time taken for a PTP event message to pass the transparent clock device) and link delay propagation time will be used to adjust the overall clock offset and mean path delay [14].

4.7 PTP Messages

All PTP communication is performed through message exchange, including BMCA and the clock synchronization process discussed earlier. IEEE 1588v2 defines two sets of messages: general messages and event messages. General messages do not need accurate time stamps. They include: Announce, Follow Up, Delay Response, Pdelay Response Follow Up, Management and

Signaling. Events messages need to be accurately time stamped. They include: Sync, Delay Request, Pdelay Request and Pdelay Response.

As previously discussed, Sync, Delay Request, Follow Up, and Delay Response messages are used in the master-slave clock synchronization process. The Pdelay Request, Pdelay Response and Pdelay Response Follow Up messages are used to calculate the link delay between two transparent clocks. The Management messages are used to query and update the PTP data sets maintained by the clocks. The Signaling messages are used for communication between clocks for all other purposes. The PTP event messages use User Datagram Protocol (UDP) destination port number 319; general messages use UDP destination port 320.

4.8   Components of PTP enabled Network

Typically a PTP-enabled data network consists of 3 key components: grandmaster, PTP client and PTP-enabled switch acting as boundary clock or transparent clock. The following sections will give a brief overview of other two key components: grandmaster and PTP client.

4.9   Grandmaster with Precise Time Source

Every IEEE1588 PTP network needs a grandmaster to provide high precision time source. By now the most economical method to obtain the precise time source for the grandmaster is via GPS. GPS can provide +/- 100ns accuracy when it is installed and operated properly. PTP grandmaster's built-in GPS receive will convert the GPS timing information to PTP time information, typically UTC. Then the UTC time will be delivered to all PTP clients in such a way we explained before.

4.10   PTP Client

It is essential for PTP client to be installed on servers, network monitoring and performance analysis devices or any other devices that want to use the precise timing information provided by PTP, usually it is an ordinary clock. There are two kinds of clients: pure software PTP clients and hardware-assistant PTP clients. The PTP software clients implement IEEE 1588 PTP stack in software and is available from many vendors, there is also an open source version for Linux distribution. The hardware-assistant PTP client typically is a PCI-E bus

card with a dedicated on-board chip to process the PTP packet; It also provides additional clocking output, such as 10Mhz, 1PPS, and IRIG-B timing code [15].

IEEE1588v2 systems enhance small amount of extra traffic to the network load but they have the following advantages:

- They work in the data direction, the most superfluous and recessive part of the network, resulting in "always on" operation.
- Multiple transportation paths reducing superfluous clock system costs.
- A single synchronization session is usage for all base station traffic.
- Support systems in mobile networks, where Circuit Emulation Service (CES) is employed to carry both TDM traffic (2G) and ATM traffic (3G).
- Support for any common packet-based transport (for example IP RAN).
- Configurable packet rates for network conditions to sustain resolution (e.g. packet rate <1 pps to>1,000 pps)

5   Conclusions

IEEE1588 PTP provides a reliable, highly accurate distributed time synchronization solution for today's networks, which require nanosecond or sub-microsecond accuracy. PTP is easy to implement with very little administrative effort and can tolerate network and clock failure with built-in fault-tolerant mechanisms.

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