Final Year Report - Investigation into the Precision Time Protocol

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Abstract

Abstract goes here

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Acronyms

BMC Best Master Clock

CSAC Chip Scale Atomic Clock

CSMA/CD Carrier Sense Multiple Access with Collision Detection

GM Grandmaster

GPS Global Positioning System

IEEE Institute of Electrical and Electronic Engineers

ITU International Telecommunication Union

LAN Local Area Network

NERC North American Electric Reliability Company

NTP Network Time Protocol

PPS Pulse per Second

PTP Precision Time Protocol

PTPd PTP Daemon

SA Security Association

SNTP Simple Network Time Protocol

TDEV Time Deviation

UTC Coordinated Universal Time

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1 Introduction

In a few important applications there is a requirement for high accurate clocks. These clocks mmay be used for either an actual timestamp, such as in the telecommunications industry, or a way to synchronise processes, as is what happens in the automotive industry. Multiple clocks will be used in these applications, and thus they all should be synchronised, but also be accurate.

In some applications it is not feasible to have a high accuracy atomic clock (or Chip Scale Atomic Clock (CSAC)) due to space or cost constraints. If this is not possible, then a Global Positioning System (GPS) receiver could be used and time can then be synchronised to the accurate clocks onboard the GPS satellites. Using high accuracy clocks like the ones mentioned would help to reduce any clock accuracies.

There are two types of clock inaccuracies when synchronising clocks. Firstly they may have started at a different time relative to the others, and adjusting for this is called offset correction. The second effect is that clocks do not necessarily run at exactly the same speed. Therefore clocks need to be continuously adjusted, which is called drift correction. The amount of drift correction required depends on the quality of the clock. Appendix **??** shows a table of clocks and their corresponding accuracies.
The following industries are examples that would require highly accurate clocks.

Automation Industry
: Processes will need to be synchronised exactly, and can only be if their clocks are in sync with one another. If clocks are in sync then processes can also be separated away from communication between each machine and the processing of the control commands. [**?**]

Power Transmission
: Time synchronisation is very important in the power transmission industry. An example of a situation where timing would have mitigated an event from occurring is the North American blackout in August 2003 [**?**]. It made it difficult for the investigation team to be able to sort through the data received when the timestamps were gathered from an inaccurate clock. From the events of this blackout a regulation was put in place to define a minimum absolute accuracy for timestamped data. The adoption of the North American Electric Reliability Company (NERC) Standard PRC018-1 in 2006 [**?**] made it a requirement for any substation in the USA to log data to a minimum accuracy. The timestamped data must be accurate to within 2ms relative to Coordinated Universal Time (UTC).

Telecommunications
: In telecommunications, timing protocols are considered when networks need to be synchronised or if mobile base stations need synchronisation pulses. With the increase in GPS jamming, systems such as 4G must rely on other timing methods in case GPS is affected.

All of the industries mentioned above could feasibly use GPS for a highly accurate timing reference. But if there is an issue with the system, for example a jamming incident, then there will be some major consequences should timing drift out of line. It is known that jamming of GPS receivers is becoming more common (REFERENCE) and thus an alternative method of time synchronisation should be used. [reference]

One way of realising this is by using a distributed timing system, such as Network Time Protocol (NTP) or Precision Time Protocol (PTP). This would allow for nodes to be able to synchronise their clocks with a much more accurate time source without having to rely on GPS

1.1 How NTP Works

This is a technology originally designed in 1985 and is used to synchronise clocks over a packet switched network. It is able to achieve synchronisation with UTC within a few milliseconds, but can maintain sub-millisecond accuracy on a Local Area Network (LAN) if ideal conditions are met. Errors due to different packet routes or network congestion can decrease this accuracy by 100ms or more. [**?**]

NTP uses a client-server hierarchy split into "Stratums". Figure 1 on the next page shows the Stratums numbered from 0 to 3.

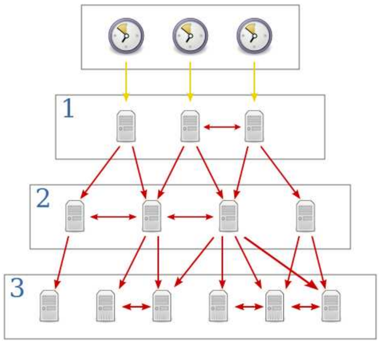

Figure 1: NTP Network Hierarchy [?]

The reference clocks located in Stratum 0 are high precision such as atomic clocks or they use GPS synchronisation. The clocks in Stratum 2 will base their time off of the clocks in Stratum 1. A number of the clocks in Stratum 1 will be used for time synchronising each clock in Stratum 2. This is done so that the time is more accurate and robust. Within a Stratum, clocks may also synchronise for sanity checking to ensure that all clocks within a Stratum are accurate between each other. Any layers below Stratum 2 will mirror the same algorithm, and there can be up to 15 layers. Stratum 16 is reserved for clocks that are not synchronised with NTP [?].
Simple Network Time Protocol (SNTP) is used in applications which do not require a high timing accuracy. It does this by ignoring drift values. Therefore it is recommended that SNTP is only used in the higher Stratums [?]. The SNTP specification is part of the NTP specification, cited here [?].
Issues arise when synchronising time over a packet switched network where sub millisecond accuracies are required. PTP was developed as a successor to the existing NTP standard which aims to reach sub millisecond accuracies. Meeting this value of accuracy is very difficult however with a traditional Ethernet network.

When standard switches are used, the packet delay between two nodes is indeterminate. This may be because the packet route from A to B changes depending on network load, or a packet may be held in a switch for an unspecified amount of time whilst working with other data. Therefore this is undesired for PTP as this packet delay must be taken into account when working out the clock offset. Specific timing switches can be used which will prioritise PTP packets, but these may not be available in existing networks or be too expensive to be suitable.

1.2 How PTP Works

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When standard switches are used, the packet delay between two nodes is indeterminate. This may be because the packet route from A to B changes depending on network load, or a packet may be held in a switch for an unspecified amount of time whilst working with other data. Therefore this is undesired for PTP as this packet delay must be taken into account when working out the clock offset. One part of this project will be to investigate the extent of this variation in packet delay on an ethernet network.

There are a few important elements of how PTP works in order to be able to start the project. These are: general PTP operation, the Best Master Clock (BMC)

2 Best Master Clock (BMC)

2.1 Project Description

This project aims to investigate PTP performance on a heavily used Ethernet network, and to attempt to quantify PTP performance using packet metrics.
There are also some deliverables as part of the Final Year Project. These include: an interim report, a log book, a final year report and a poster. These deliverables, along with the sub tasks involved in order to complete them have been detailed in the Gantt chart, as seen in Appendix **??**.

The following project objectives have been identified:

Learn about PTP and other work in relation to the protocol
This stage would occur at the beginning of the project to understand how PTP works. This is important so work can then be carried out to investigate PTP performance on a network.

Collect PTP Data
In parallel with the above, PTP data can be collected. This will be monitoring the performance of PTP across the network as well as how using multiple types of grandmaster/slaves affect the performance. Different clock locations in the network will also be considered.

Implement some packet metric scripts
To be able to understand the performance of the network, some packet metric scripts will be created. A suitable language will be chosen once this part of the project begins.

Determine packet performance using these scripts
Multiple window sizes and types of metric will be used to quantify network performance.

Test Chronos' equipment and provide feedback
As Chronos has provided this project with some equipment, this equipment will also be thoroughly tested and any information gathered can be passed to them once the project is completed.

3 Literature Review

With the following objectives and tasks in mind, a literature review was performed with some suitable documentation: mainly packet metric related, but also on cryptographically signing PTP packets.

The reports below will be discussed in some detail:

Definitions and terminology for synchronization in packet networks [?] A standard regarding different packet metrics that could be used in order to try and quantify network delay.

Prevention of Packet Collisions [?] A journal article describing an algorithm that aims to prevent packet collisions in an Ethernet network.

3.1 Definitions and Terminology for Synchronisation in Packet Networks [?]

The first paper defines a number of definitions and terms when dealing with Packet Synchronisation. The areas of interest in this report were packet metrics which are found in Appendix I3 and I4. These can be split into three sections: Packet Selection Methods, Packet Metrics without Pre-filtering, and Packet Metrics with Pre-filtering.

3.1.1 Packet Selection Methods

There are two main methods of selecting packets when calculating a packet metric: either using a selection technique at the same time as the packet metric calculation, or as a pre-processing technique before the metric calculation is performed.

Packet selection, when integrated with the calculation, is very useful when the behaviour of a network is to be determined with respect to its packet delay variation. This is because it provides a generic method that is independent to a particular slave clock implementation [?]. This packet selection method is also known as a Class B metric.

The other method uses a pre-processing technique which preselects packets from a time window. By doing this the process will average out any inconsistencies in the delays, thus resembling a clock running in steady state. Therefore this method is more suitable when trying to specify network limits. This is known as a class A metric).

There are four examples of packet selection methods that are mentioned in the recommendation report. These are: Minimum Packet Selection Method, Percentile Packet Selection Method, Band Packet Selection Method and Cluster Range Packet Selection Method. These will be discussed in turn and will be implemented.

3.1.2 Packet Metrics without Pre-filtering

The first packet method technique discussed is Time Deviation (TDEV). It is used to specify network wander limits for timing signals and can also be used for packet data
TDEV can be applied to both integrated and pre-processed packet selection methods.

The implementation equations are quoted in the reference. The approximation equations were used when implementing the functions.

3.1.3 Packet Metrics with Pre-filtering

The other method is using pre-filtering before the metric is calculated. An averaging function is applied to the set of data, but care must be taken to not over-filter the input. This filtered packet sequence can then applied to the metrics mentioned previously in the report. Prefiltered metrics are useful as they can help specify network limits.

3.2 Other Relevant Reading

There was other relevant reading performed in the first week of the project to do with cryptography and how packet collisions can be prevented. -cryptography ?

4 Project Methods

Based on the objectives mentioned previously, the project can be split into three distinct sections:

Data Collection This part of the project will involve collecting PTP timing data on the university network. It will consist of using a number of different clock types and locations on the network.

Packet Methods This section will mainly involve the implementations of the packet metric scripts based on the referenced report above. Focus on the implementation will be made in this section rather than the metrics themselves.

Calculating/Analysing Results Once the metrics have been implemented fully, there needs to be some supplementary scripts written to process some of this data.

Securing PTP Considerations As PTP is inherently an unsecure system, there will be some work into investigating how PTP could be secured from rogue hosts on the network.

Methods to reduce Packet Collisions Due to the way Ethernet networks work, there is a high probability of packet collisions. Thus it would be useful to investigate, based on the results collected above, ways to reduce these packet collisions.

5 Data Collection

The first step to perform with this part of the project is to work out what hardware is available. The following hardware was identifed as being available to use for the duration of this project.

- Hardware Grandmaster - Chronos TimePort [**?**]
- Hardware Slave - Chronos Syncwatch [**?**]
- Hardware Slave - Beaglebone Black []
- Software Grandmaster - PTP Daemon (PTPd)
- Software Slave - PTPd

5.1 Hardware - Timeport [?]

5.1.1 Description

The Chronos CTL4540 Timeport is a low powered portable device that is able to maintain its time to a high accuracy when disconnected from a synchronisation source. It is able to maintain accuracy within a couple hundred nanoseconds without needing to be connected to GPS. It also has an internal LiPo battery. This enables the device to be used to transport and measure time.

With the above features in mind, it is thus suited for a number of markets, including the power industry and telecommunication network operators. It can also be used to correct for any time errors caused by any cabling or equipment.

Typical methods of doing this would involve using a Caesium atomic clock [REF] or setting up a GPS attenna and connecting this to some other equipment. The TimePort is best suited over these two operaitons because it is much lower power and much more transportable than an atomic clock. It also removes the requirement of GPS equipment.

Appendix **??** shows the full specifications of the CTL4540 TimePort. Below are a few labelled photos of the clock.
The difference between the release TimePort and the TimePort that will be used in this project is that the firmware on the TimePort is bleeding edge. With that in mind time needs to be allocated to allow for any issues that the clock may have. The university has close links with Chronos thus it should be straightforward to either get our issues solved or to receive a new TimePort.

This clock will mainly be kept in the same position on the network and will acct as a Grandmaster.

(a) Chronos TimePort Outside

Figure 2: Chronos TimePort Labelled Diagrams