Application Note AN017

Considerations when implementing PTP in camera systems

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Abstract

Since industrial camera systems started using Ethernet for image transfer they now require PTP to have a common understanding of time for all related cameras as well as the image processing system. This application note describes the architectural considerations when adding PTP to such systems.

Typical Application Scenario

A typical industrial camera system as used for stereo vision or quality inspection is made up of two or more cameras that deliver their image data either in burst mode or as a continuous data stream to a video processing unit. Since Ethernet is used for this communication there is no common understanding of frequency or phase available in such systems. Thus, PTP is introduced in such systems either to timestamp every video image recorded to allow the video processing unit to correctly combine the video streams received from several cameras. Additionally, one might use the time as well for triggering the cameras. For this an accurate, phase-locked vsync signal (vertical sync) has to be generated in each camera.

One example is the GigE Vision standard (https://www.visiononline.org) that added with version 2.0 PTP for clock synchronization .

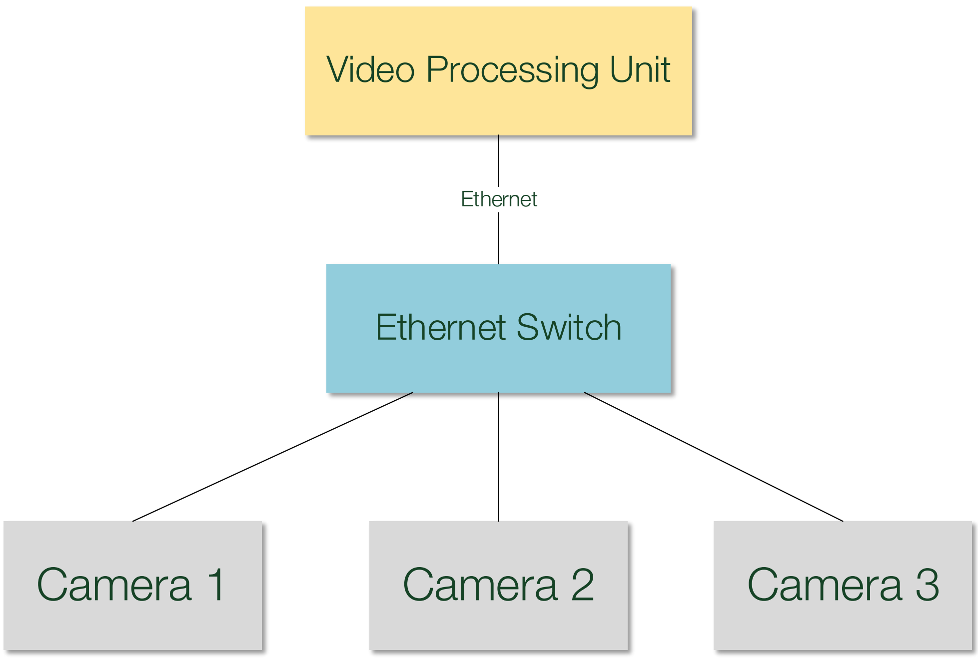

Figure 1: Typical industrial camera system

Figure 1 shows such a typical camera system. Usually the Ethernet lines of all cameras are combined into a single Ethernet connection to the video processing unit using a standard Ethernet switch. This Ethernet connection might use a higher link speed as it is used for connecting the cameras to the Ethernet switch. Alternatively the video processing unit may offer several Ethernet interfaces; one for each camera as shown in Figure 2.

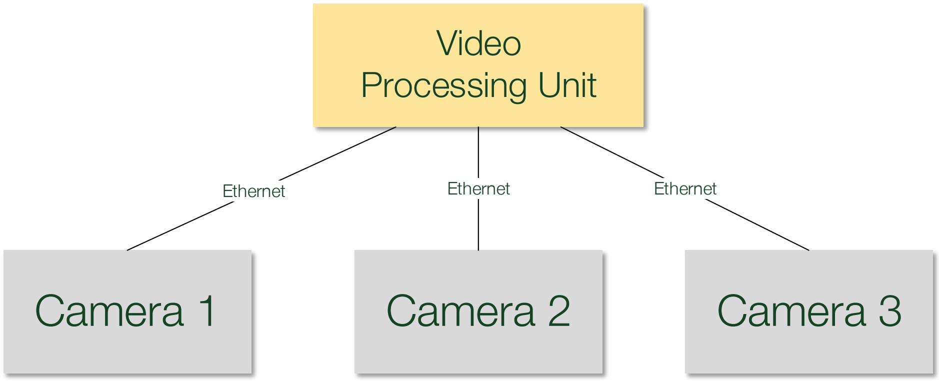

Figure 2: Industrial camera system with directly attached cameras

Communication

The following figure shows the typical communication in such scenarios. The bandwidth is asymmetrically used. The downstream (traffic from the camera to the video processing unit) requires quite large or even huge bandwidth since the video data has to be transferred. The upstream (traffic from the video processing unit to the camera) just consumes small bandwidth since only control and status information are transferred.

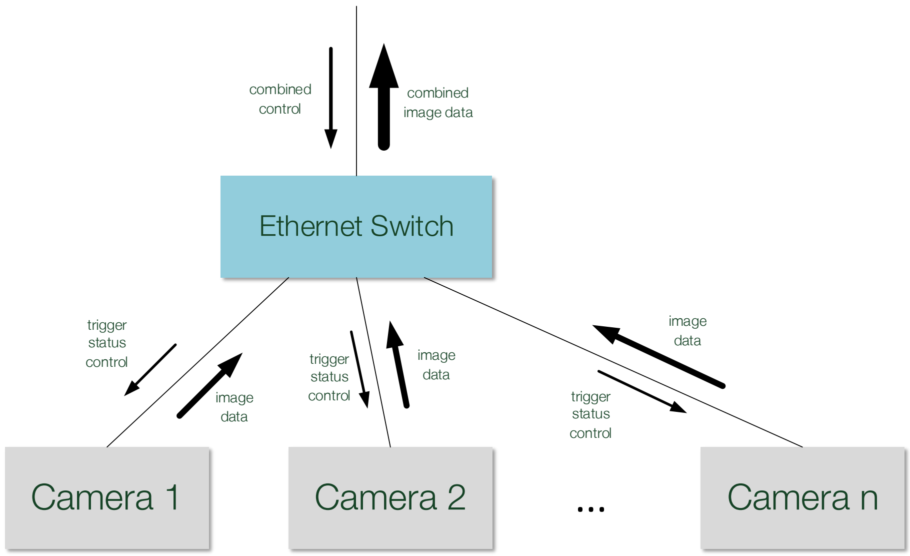

Figure 3: Application: band width requirements

The following figure shows the PTP traffic that is added to this application specific communication. The majority of the data is sent on the uplink channel that is sparsely used.

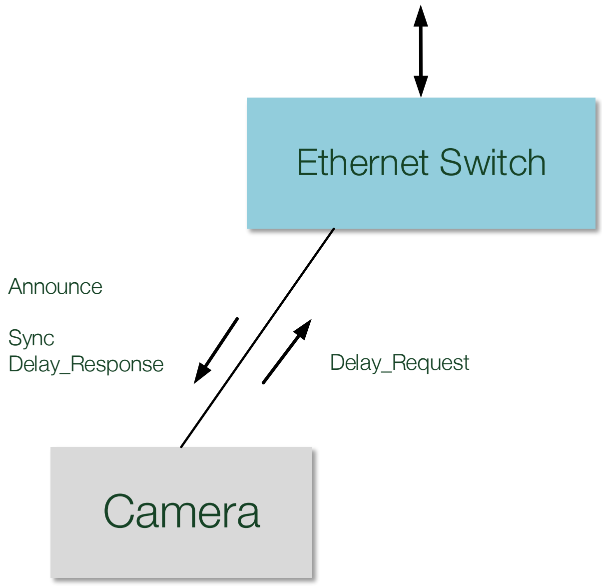

Figure 4: PTP: communication

PTP Requirements

It is important to carefully plan the design of the PTP functions in the overall system architecture in advance. Just adding a software service and changing a few components will not achieve the required accuracy.

If one wants to introduce PTP into such a camera system the following basic functions will be required.

Camera

Every camera will act as a PTP slave device only. The camera requires an IEEE1588 capable network interface; that's basically an IEEE1588 hardware clock with supporting functions as well as a timestamping unit for the Ethernet network traffic. Additionally, a PTP stack will be required as well. This PTP stack is basically the high level protocol stack that runs the high-level communication and controls the hardware functions like clock and timestamping units.

The hardware clock requires a stable and jitter-free base clock. One can simply use the Ethernet grade oscillator for this. To avoid dependencies of temperature and voltage one can choose TCXO devices. One should carefully select the TCXO type since TCXOs tend to show excessive short term jitter.

Ethernet Switch

A standard Ethernet switch introduces unpredictable delays onto the packets. Additionally, the residence time will be every now and then excessively large; even some 10 milliseconds can be observed. While this behavior does not affect the layer 2 or Layer 3 communication it will affect the PTP accuracy one can achieve.

PTP defines Ethernet switches with special functions to overcome these limitations; these are called “End-to-End Transparent Clocks”. Transparent clocks measure the residence time of specific PTP packets onto the switches and add this information into special fields within the PTP packets. This enables the algorithms to consider the current switch residential delays in the computations.

Video Processing Unit

The video processing unit usually acts as a PTP master device. Alternatively a dedicated Grandmaster may be attached to the Ethernet Switch as shown in the following figure:

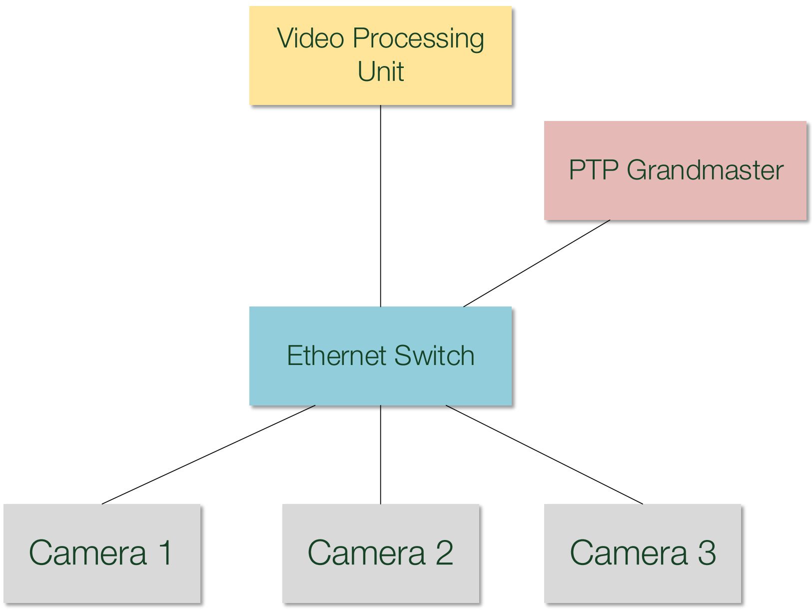

Figure 5: Industrial camera system with dedicated PTP Grandmaster

The video processing unit basically requires the same infrastructure as the camera. If the unit acts as a PTP master a high-stability oscillator is required; we generally recommend OCXO devices for this purpose.

PTP Communication

The Grandmaster sends an ANNOUNCE message with the announce rate and a SYNC message with the sync rate to all slaves. Additionally, the Grandmaster answers the DELAY REQUEST messages with the delay request rate of every PTP slave (i.e. every camera) by sending DELAY RESPONSE messages.

Every camera sends DELAY REQUEST messages with the delay request rate to the Grandmaster.

Although the sync rate and delay request rates may be independently chosen they are typically identical. Only the downstream messages (traffic from the camera to the video processing unit) is in these systems of importance since this traffic interferes with the high bandwidth image data stream. Upstream traffic (from the video processing unit to the camera) do not cause any issues since this communication channel is typically not loaded at all.

The typical announce rates are one per second. The sync rate defines the number of measurements of the path delay from the PTP master to the PTP slaves. Note, that usually IPv4 communication using UDP protocol will be used for PTP communication. Thus, messages might be dropped by any network device if it is heavily loaded. Sync rates shall be chosen in a way to balance the traffic load versus averaging multiple measurements. Sync rates may be selected in the range of 8 per second to 32 per second.

Downstream Traffic

The length of a DELAY REQUEST message (IPv4) is 90 bytes. Thus the downstream bandwidth required for every camera is

$f_{slave\_down} = 90 * 8 * f_{DelayRequest}$ bit/s = $720 * f_{DelayRequest}$ bit/s

Assuming a delay request rate of 8 the required bandwidth is 5760 bit/s. At the interface of the PTP master this is summed up by the number n of PTP slaves (i.e. cameras) in the system.

$f_{master\_down} = n * 720 * f_{DelayRequest}$ bit/s

Upstream Traffic

The length of a SYNC message (IPv4) is 90 bytes, the length of a DELAY RESPONSE message is 100 bytes and the length of an ANNOUNCE message is 110 bytes. Thus the upstream bandwidth required for every camera is

$f_{slave\_up} = (90+100) * 8 * f_{Sync} + 110 * 8 * f_{Announce}$ bit/s =

$= 1520 * f_{Sync} + 880 * f_{Announce\ bit/s}$

Assuming a sync rate of 8 and an announce rate of 1 the required bandwidth is 13040 bit/s.

System Considerations

When adding PTP to industrial camera systems one has to plan the traffic for both bandwidth and latency. Since the downstream channel is typically heavily loaded the PTP DELAY REQUEST messages sent to the PTP master for measuring the actual delay might be excessively delayed or even dropped. If the packets experience an asymmetrical delay on upstream and downstream the accuracy will be degraded. PTP can inherently not deal with asymmetric delays on the paths. If the packets are dropped measurements cannot be performed which will again degrade the accuracy. The PTP stack running in the camera has to have a very good clock servo filtering algorithm to deal with this measurement environment.

If your camera does not continuously deliver video data in your application and thus not continuously load the downstream channel one can decide to stop PTP measurement while the video data is transmitted and put the system in a holdover mode. In the gaps between sending video data PTP measurement is turned on again. For this one requires a good short-term stable local oscillator to ensure that the clock does not drift too far away during the holdover period without an active control loop.

syn1588® for Camera Systems

Several syn1588® products can support you on all levels to implement the required PTP functions in industrial camera systems.

- syn1588® PTP Stack
- syn1588® PCIe NIC
- syn1588® Gbit Switch
- syn1588® Clock_M IP core

syn1588® for Camera

For the IEEE1588 capable network interface we supply the syn1588®Clock_M IP core as a building block for the cameras. We also have 1G/10G/25Gbit Ethernet MACs with IEEE1588 timestamping units available. For the PTP software functions of the camera we offer the syn1588® PTP Stack which can run on most (embedded) processor and operating system.

syn1588® for Ethernet Switch

The syn1588® Gbit Switch is a 8+1 port End-to-End Transparent Clock offering outstanding PTP performance.

syn1588® for Video Processing Units

For the IEEE1588 capable network interface we supply the syn1588® PCIe NIC as a building block for the video processing units. Note, that the syn1588® PCIe NIC is optimized for maximum PTP performance, i.e. maximum accuracy. The NIC is not optimized to achieve maximum bandwidth.

If one has to combine both maximum bandwidth near the physical limits of the Ethernet line we suggest to split the network function of PTP and video traffic. Use a standard (server) NIC optimized for high throughput for the video traffic and the syn1588® PCIe NIC for providing high-accuracy PTP function.

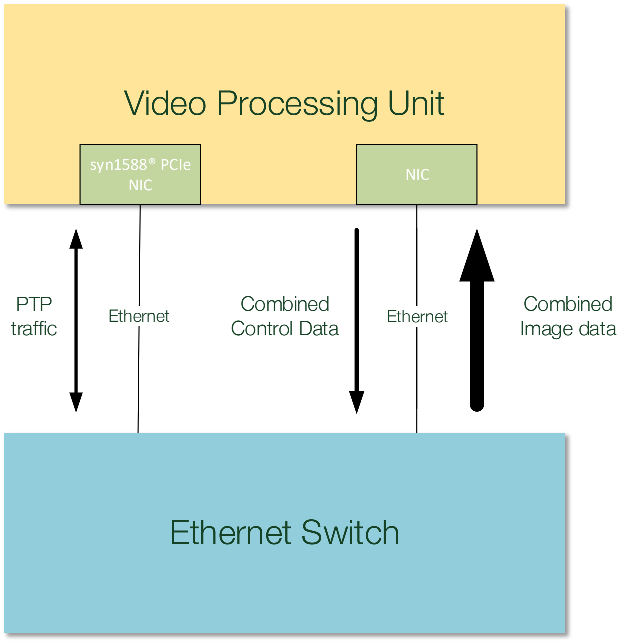

Figure 6: Separated NIC for video data and PTP traffic

For the PTP software functions we offer the syn1588® PTP Stack which can run on most processor and operating system.

What about PTP Grandmasters?

Oregano Systems does not offer PTP Grandmasters although we provide Grandmaster vendors our syn1588® technology. If one requires a PTP Grandmaster we generally recommend products from Meinberg Funkuhren (https://www.meinbergglobal.com). Please check their website for further details.

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