Vision Q.400

Image Processing

Version 7.0.0.0 GigE Hints

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1. Introduction

GigE Vision technology presents several attractive advantages over competing technologies, such as:

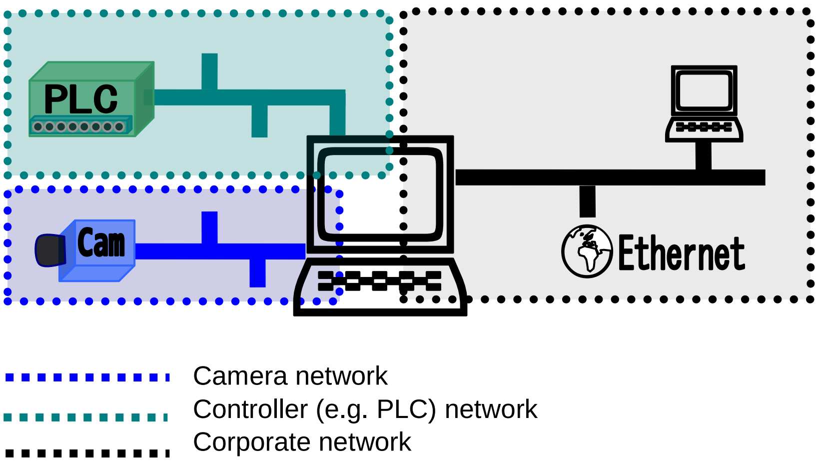
- High data rate, since it is based on Gigabit Ethernet, which has a bandwidth of up to 1000MBit/s (125MB/s) [1]
- Long distance connections with economic Ethernet cabling. Single cables of up to 100m, and this can be extended with switches and repeaters.
- Tried and tested hardware and Ethernet standards.
- Flexible configurations. Easy to add to the network.
- Common camera interface standard (GigE Vision)

However, users should be aware that despite its strengths GigE has some areas that need particular attention, especially in the area of performance and network configuration.

- High CPU load. This can be an issue if the CPU has to process camera data, however it can be reduced to a minimum through the use of filter or dedicated high performance network drivers.
- Network latency (time for packets to travel across the network) can be too high.
- Network bandwidth, particularly when multiple cameras are connected in a single network, can be exhausted. This is because the bandwidth is shared by all cameras. This can invariably lead to the situation that all the cameras are requiring bandwidth at the same time. Even a single camera, say 2 Megapixel at 32 frames per second, can demand the whole bandwidth.

With careful planning, choice and configuration of hardware, any weaknesses can be eliminated or reduced to a minimum. This document discusses the most important issues and serves as a guide to building an appropriate system network.

Ideally, a Gigabit Ethernet camera network should be separate from other networks. This is because even a single camera can saturate the bandwidth such that other network data cannot be transmitted, or packets of camera data may get lost.



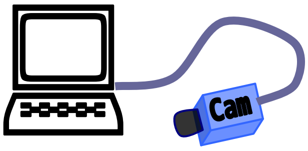
This means that for a typical configuration of a computer attached to a corporate network, at least two network adapters are required. Should network-based controllers like PLCs also be a part of the application;

[1] The available bandwidth of Gigabit Ethernet can be less, for instance on systems with on-board video as opposed to a graphics card, the bandwidth can be reduced to around 100MB/s.

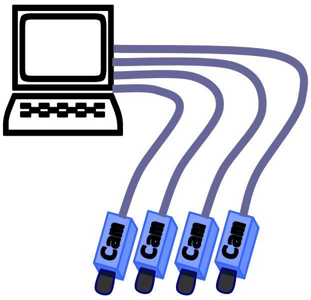
it is recommended that these also have their own network adapter, too. In this case, at least three network adapters are required.

2. Camera Network Configurations

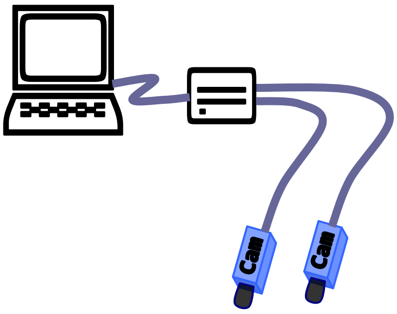
- Peer-to-Peer connection. This is the optimal connection, a single camera connected[2] directly to the network adapter. It allows the camera to utilize the whole gigabit bandwidth (125Mb/sec) and there is a minimal chance of losing any packets (ensure that the network card is running in full-duplex mode).



- Multiple cameras to multiple network adapters. This is the preferred configuration when multiple cameras are required. Like the peer-to-peer connection, each camera can utilize its own full gigabit bandwidth. Packet loss should be minimal, as long as the computer's CPU can process the data.



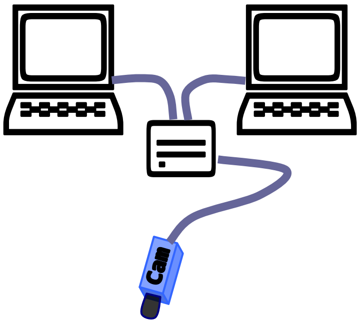
- Multi cameras to single adapter via a switch. Ensure that the combined bandwidth of the cameras does not exceed the capacity of the single network adapters. Also, a good quality switch will help to reduce the overhead of collisions.



If the combined bandwidth of the cameras exceeds 1000Mb/s, it may be possible to obtain a workable application by implementing flow control techniques. This will reduce the chance of the cameras sending data simultaneously.

[2] Gigabit Ethernet supports automatic cable recognition, so it does not matter whether a crossover or standard Ethernet cable is used to connect the camera

- Single or multiple cameras serving multiple hosts. In this seldom-used configuration, one of the hosts is responsible for triggering the camera. More than one host though can process the image data. The camera has to be configured to send multi-case packets to a range of addresses.



3. Network Adapter Choice and Configuration

It is vital to use an appropriate Network Adapter (NIC) and highly recommended is an NIC that uses the Intel Pro 1000 chipset and the PCIe[3] bus.

Always ensure that the Network driver is up-to-date.

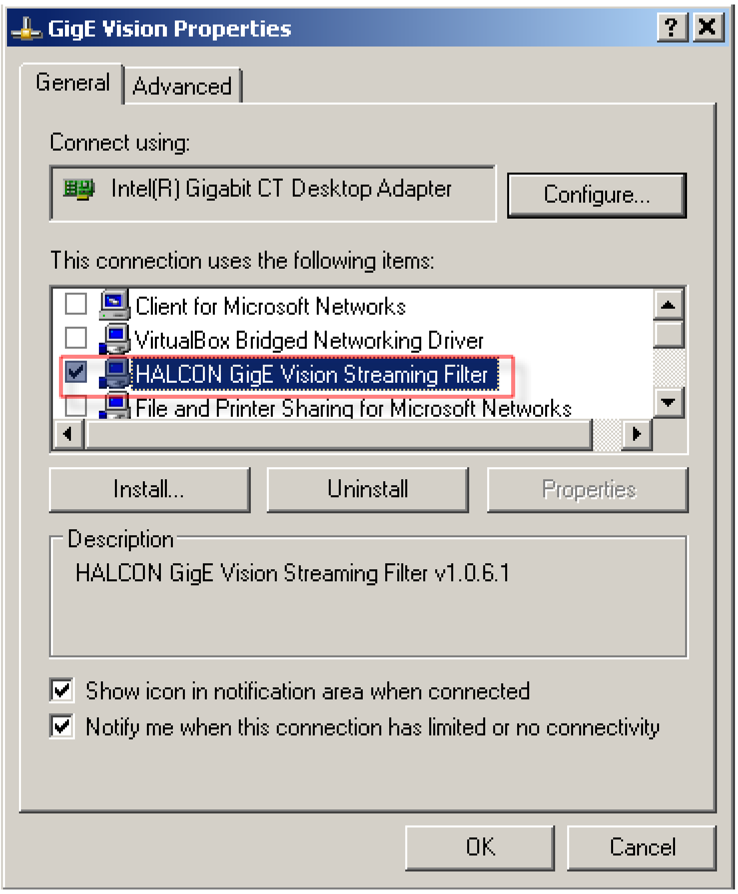
With the correct choice of NIC, the following settings should be correctly configured. Note that the settings recommended here are for a GigE camera network. A controller (PLC) network, as possibly used in a GigE application, would generally use default network settings.

- **Link Speed & Duplex** should be set to "Auto Negotiation".
- **Jumbo Packets (or Jumbo Frames)** should be turned ON. This setting means that data is transmitted more efficiently in larger packets. This results in far fewer interrupts, thereby reducing CPU utilization and increasing throughput. Note that for Jumbo Packets to function correctly, all devices on the data path (i.e. switches) should support and be configured to forward Jumbo Packets of the same size.
  In the network adapter's properties dialog, set the value for the Jumbo Packet setting to 9014 Bytes, or the largest value supported across the network. Typically, the default value will be much smaller or set to "Disabled".
- **TCP/IP Checksum Offload** settings should be switched ON. These settings (often split into IPv4, TCP and UDP settings) reduce CPU utilization by allowing the adapter to perform checksum verification.
- **Receive Buffers** defines the number of receive buffers used to store received packets and should be set to the highest possible value. A typical maximum is 2048 bytes.
- **Interrupt Moderation Rate** alters the number of interrupts sent to the CPU. Setting this to the highest possible rate ("Extreme") will reduce the CPU utilization. The price to pay is slightly more latency in handling packets; however this is generally not a problem with large packets.
- **Flow Control** should be disabled.
- **Adaptive Inter-Frame Spacing** should be set OFF, which is the default. It is only applicable to half-duplex networks.

3 The PCI bus is seldom suitable for GigE, since its available bandwidth is too low (33MHz x 32 bit = 128.9MB/s) and is not entirely available. PCIe is much faster and provides multiple point-to-point channels for simultaneous data transfer.

4. Network Adapter Driver: Minimizing CPU Load with a Filter Driver

The large data amounts associated with GigE cameras can cause the computer's CPU to overload. This CPU utilization can be greatly reduced by using either a dedicated network card driver or a universal filter driver. The latter is generally the preferred method, since dedicated network card drivers provide minimal extra benefit. The filter driver concept manipulates image (video) data and network services separately and is supported by any network card.



The setup for the GigE version of Vision P400 will always install a universal filter driver[4]. There is no configuration needed for the driver, it just needs to be activated for each network interface. All network interfaces will have the driver enabled after installation. Should a network card be installed or upgraded after installing Vision P400, you should ensure that the filter driver is activated for that particular card.

It is also highly advisable to disable network services that are not required by the cameras network adapter. For example, the "Client for Microsoft Networks" and "File and Printer Sharing for Microsoft Networks" in the diagram above should be disabled – **only the "Halcon GigE Vision Streaming Filter" and the "Internet Protocol (TCP/IP)" should be enabled**.

[4] During installation of the filter driver, network interfaces will be temporarily disabled. This means that connections will also be temporarily closed.

5. Disabling the Firewall

Disable the Windows firewall for the network adapters used for image acquisition. If the firewall is not disabled, image acquisition may not be possible, or an application timeout may occur.
Image acquisition performance is affected by the presence of a firewall. However, discovery and setup of a camera is not. So a camera may appear to function correctly while being configured; but, until the firewall is disabled, image acquisition may fail. A firewall can be disabled for an individual network adapter without it being disabled for the whole system. If firewall settings are set by a group policy, the assistance of a system administrator may be required.

To disable the firewall on Windows XP:

1. Open the Windows Firewall control panel.
2. Click the “Advanced” tab.
3. Disable the firewall for the Local Area Connections that correspond to the network adapters you are using for image acquisition.
4. Click [OK].

If a network adapter receives an update or modification, the firewall may have to be disabled again. For example, this may happen if the filter driver is turned on or off.

6. Network Cables

Cables rated at CAT5e or higher are required. For long distances, category 6/6a is preferred. In environments with high electromagnetic interference, shielded cables (S/STP) are required. The maximum cable length of 100m can be extended with switches.

Ensure that cables are not bent to an extreme or exposed to an environment for which they were not intended.
Do not exceed the maximum recommended length for your cable type. Shorter lengths often provide better results.

7. Installation of Network Adapters

If you install new network adapters or reinstall a network adapter, you have to ensure that all information about adapters currently not installed in the system is removed from the device manager.

The Device Manager displays only non-Plug and Play devices, drivers, and printers when you click **Show hidden devices** on the **View** menu. Devices that you install that are not connected to the computer (such as a Universal Serial Bus [USB] device or "ghosted" devices) are not displayed in Device Manager, even when you click **Show hidden devices**.

To work around this behavior and display devices when you click **Show hidden devices**:

1. Click **Start**, point to **All Programs**, point to **Accessories**, and then click **Command Prompt**.
2. At a command prompt, type the following command , and then press ENTER:

   set devmgr_show_nonpresent_devices=1
3. Type the following command a command prompt, and then press ENTER:

   start devmgmt.msc
4. Troubleshoot the devices and drivers in Device Manager.

   NOTE: Click **Show hidden devices** on the **View** menu in Device Managers before you can see devices that are not connected to the computer.
5. When you finish troubleshooting, close Device Manager.
6. Type **exit** at the command prompt.

   Note that when you close the command prompt window, Window clears the **devmgr_show_nonpresent_devices=1** variable that you set in step 2 and prevents ghosted devices from being displayed when you click **Show hidden devices.**

If you are a developer or power user and you want to be able to view devices that are not connected to your computer, set this environment variable globally:

1. Right-click **My Computer**.
2. Click **Properties**.
3. Click the **Advanced** tab.
4. Click the **Environment Variables** tab.

5. Set the variables in the **System Variables** box.

NOTE: Use this method only for troubleshooting or development purposes, or to prevent users from accidentally uninstalling a required device that is not connected to the computer (such as a USB device or docking station that is not connected to a laptop computer).

8. Switches

If switches are required in the network, they should be appropriate and correctly configured. The Jumbo frames feature should be supported and turned ON. Also, the link speed should be set to 1Gbs and full duplex. "Power over Ethernet" (PoE) support is required if the cameras are of that type.

9. Camera Configurations

To achieve optimal results in image transfer, several Ethernet-specific factors need to be considered when using GigE Vision cameras.

Packet Size and Maximum Transmission Unit (MTU):

Network packets can be of different sizes. The size depends on the network components employed. When using GigE Vision®- compliant devices, it is generally recommended to use larger packets. On the one hand the overhead per packet is smaller, on the other hand larger packets cause less CPU load.
The packet size of UDP packets can differ from 576 Bytes up to the MTU.
The MTU describes the maximal packet size which can be handled by all network components involved.
In principle modern network hardware supports a packet size of 1500 Byte, which is specified in the network standard. However, so-called "Jumboframes" are on the advance as Gigabit Ethernet continues to spread. "Jumboframes" merely characterizes a packet size exceeding 1500 Bytes.

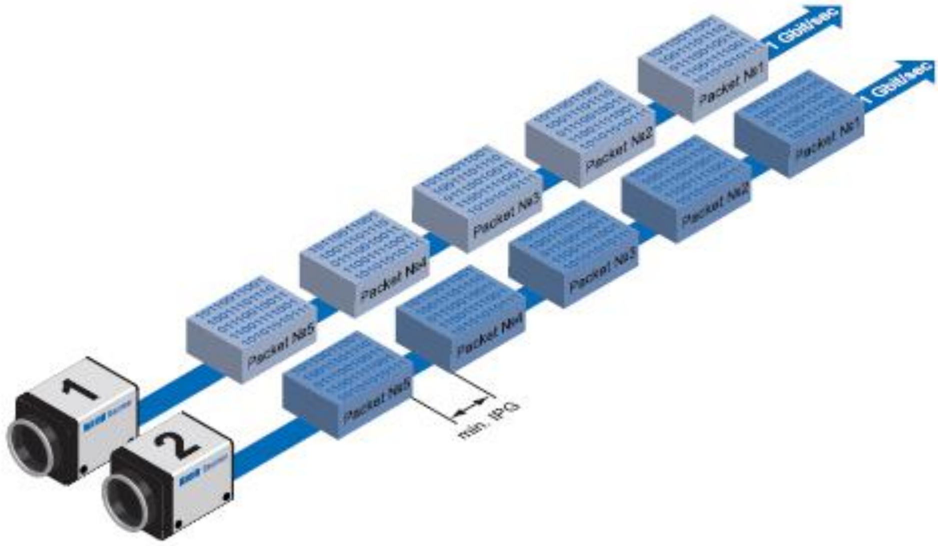
Vision P400 calculates the MTU internally, and displays it in the camera's "Advanced Settings" property page as "Max Camera Packet Size".
Thus using Vision P400 the term "packet size" in the following sections refers to this "Max Camera Packet Size".

Interpacket Gap:

Upon starting the image transfer of a camera, the data packets are transferred at maximum transfer speed (1 Gbit/sec). In accordance with the network standard, Baumer employs a minimal separation of 12 Bytes between two packets. This separation is called "interpacket gap" (IPG). In addition to the minimal IPG, the GigE Vision® standard stipulates that the IPG be scalable (user-defined).

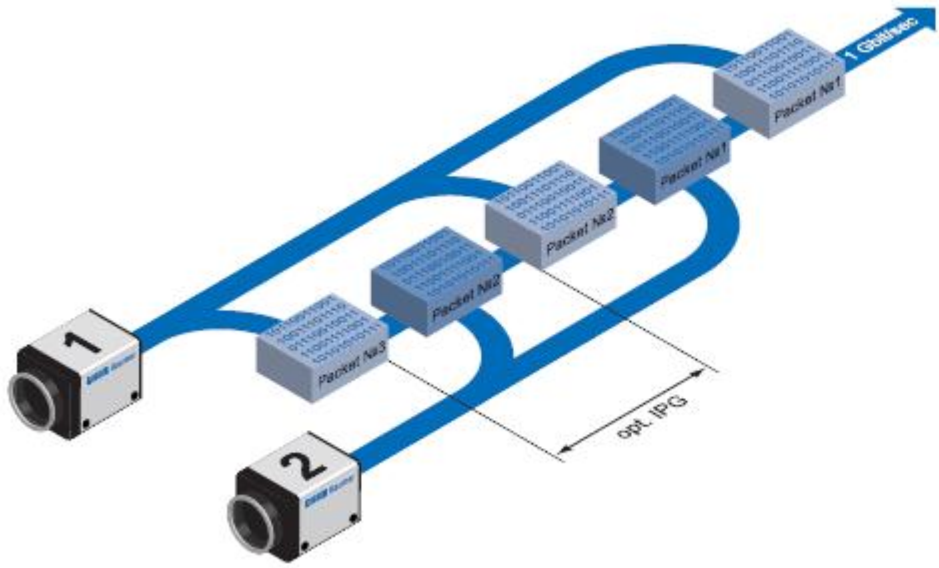
Setting the IPG to minimum means every image is transferred at maximum speed. Even by using a frame rate of 1 fps this leads to a full load on the network. Such "bursts" can lead to an overload of several network components and a loss of packets. This can occur, especially when using several cameras.

In the case of two cameras sending images at the same time, this would theoretically occur at a transfer rate of 2 Gbits/sec. The switch has to buffer this data and transfer it at a speed of 1 Gbit/sec afterwards. Depending on the internal buffer of the switch, this operates without any problems up to n cameras (n ≥ 1). More cameras would lead to a loss of packets. These lost packets can however be saved by employing an appropriate resendmechanism, but this leads to additional load on the network components.



A better method is to increase the IPG (for two cameras) to a size of *optimal IPG = packet size + 2 × minimal IPG*

In this way both data packets can be transferred successively (zipper principle), and the switch does not need to buffer the packets.



For more than two cameras the optimal IPG is calculated as *optimal IPG = ((packet size + minimal IPG) * (number of cameras – 1)) + minimal IPG*

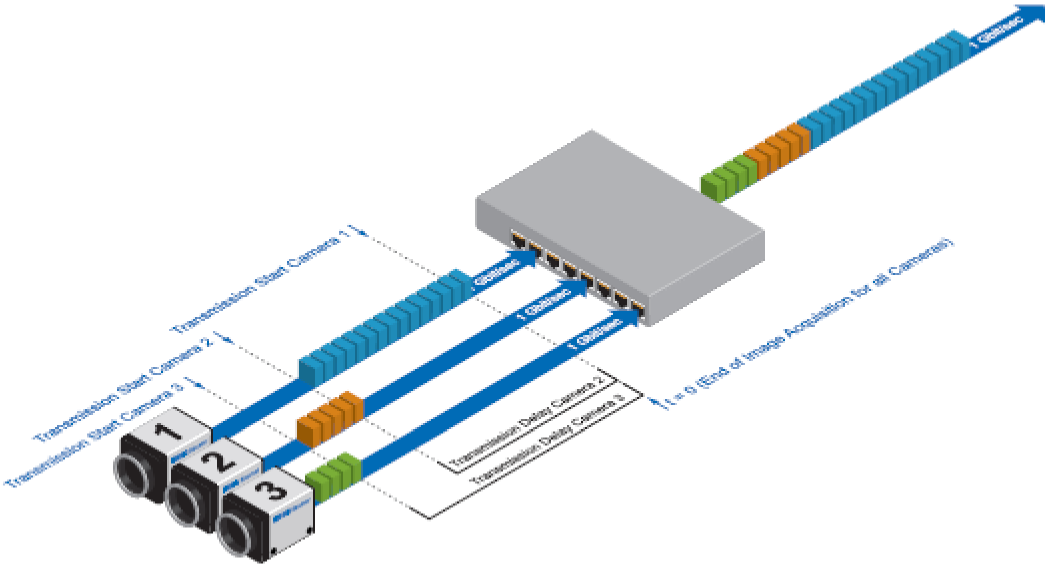
Transmission Delay:

This feature is, as described here, only supported by the cameras, which are supported by Vision P400 by default.

Another approach for packet sorting in multi-camera operation is the so-called Transmission Delay.

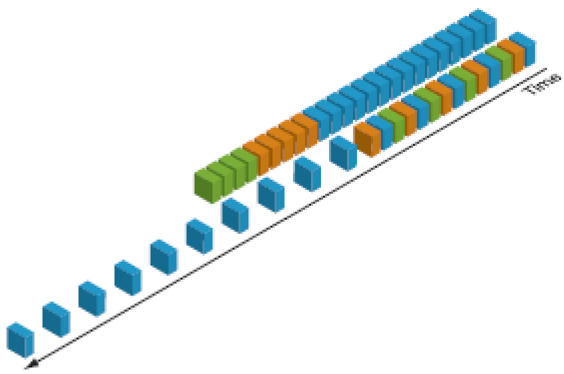
Due to the fact, that the currently recorded image is stored within the camera and its transmission starts with a predefined delay, complete images can be transmitted to the PC at once.

The following figure should serve as an example:



For the image processing three cameras with different sensor resolutions are employed.
Due to process-related circumstances, the image acquisitions of all cameras end at the same time. Now the cameras are not trying to transmit their images simultaneously, but – according to the specified transmission delays – subsequently. Thereby the first camera starts the transmission immediately – with a transmission delay "0".

As previously stated, the transmission delay feature was especially designed for multicamera operation with employment of different camera models. Just here an significant acceleration of the image transmission can be achieved:



In the above example, the employment of the transmission delay feature results in a time saving – compared to the approach of using the interpacket gap – of approx. 45% (applied to the transmission of all three images).

In general, the transmission delay is calculated as (all the cameras are triggered simultaneously, n > 1):

$$t_{TransmissionDelay(Camera\ n)} = t_{exposure(Camera\ 1)} + t_{readout(Camera\ 1)} - t_{exposure(Camera\ n)} + \sum_{n\ 3}^{n} t_{transferGigE(Camera\ n-1)}$$

The sensor resolution and the readout time ($t_{readout}$) can be found in the Technical Data Sheet (TDS) of the camera.

The exposure time ($t_{exposure}$) depends on the current camera settings.

The resulting data volume is calculated as follows:

Resulting Data Volume = horizontal Pixels × vertical Pixels × Pixel Depth

The transfer time ($t_{transferGigE}$) for full GigE transfer rate is calculated as follows:

Transfer Time (GigE) = Resulting Data Volume / 1024^3 × 1000 [msec]

As an example with three cameras, the above formula results in the following transmission delays:

$t_{TransmissionDelay(Camera\ 1)} = 0$

$t_{TransmissionDelay(Camera\ 2)} = t_{exposure(Camera\ 1)} + t_{readout(Camera\ 1)} - t_{exposure(Camera\ 2)}$

$t_{TransmissionDelay(Camera\ 3)} = t_{exposure(Camera\ 1)} + t_{readout(Camera\ 1)} - t_{exposure(Camera\ 3)} + t_{TransmissionDelay(Camera\ 2)}$