USE OF GIGE VISION ETHERNET CAMERAS FOR FLIGHT TEST APPLICATIONS WITHOUT DATA LOSS

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Abstract:

As Ethernet based networks have become the dominant choice for Flight Test Instrumentation (FTI) network applications, it is also clear that Ethernet based camera integration and applications have yet to become more wide spread for system level design and integration. A significant customer base utilizes either separate video compression systems or even just stand-a-lone gopro cameras for recording purposes in an unsynchronized ways. The use of uncompressed high definition (HD) video from GigE Vision Ethernet cameras for flight test applications is a significant issue in managing the large volumes of data produced by the cameras and forwarding them to any 1000BASE-T(x) switch port without packet loss and significant delays. Of course an easy approach to overcome this issue would be to just increase the network bandwidth from 1000BASE-T(x) to 10GBASE-SR, but most FTI systems just moved to 1000BASE-T(x) in the past years and therefore changing the overall system hardware is cost prohibited. One concern has been the use of compression algorithms to reduce the required video bandwidth, with the negative side effect that the image quality reduces and end-to-end latency increases, which is not acceptable for some applications. Further, it is important that data from cameras is available to a number of different multicast consumers within the FTI network, for example workstations, recorders and telemetry systems. These video data stream also require synchronization so that they can be analyzed in post processing.

Keywords: GigE Vision, QoS, traffic shaping, port trunking, LACP, packet memory optimization, FTI

Abbreviations

CoS	Class of Service
DSCP	Differentiated Services Code Point
FCS	Frame Check Sequence
FTI	Flight Test Instrumentation
HD	High Definition
IED	Intelligent Electronic Device
IP	Internet Protocol
IPG	Inter-Packet Gap
LACP	Link Aggregation Control Protocol

MAC Medium Access Control
NIC Network Interface Card
QoS Quality of Service
RTOS Real Time Operating System
UDP User Datagram Protocol
TCP Transmission Control Protocol
ToS Type of Service

GigE Vision – the network challenge

GigE Vision is a bandwidth demanding protocol for an Ethernet network. Uncompressed bursty video data from several video cameras sent to the same video consumer could suffer from network congestion resulting in packet loss.

GigE Vision cameras

A GigE Vision camera typical sends 20 – 30 video frames per second.

A video frame can contain up to 1.3Mbyte of data (1024 x 1280 pixels, where each pixel is 8bit). This means more than 200Mbps from one GigE camera when 20 frames are sent per second. The Ethernet + UDP/IP overhead will further increase the network load, although this overhead is negligible if jumbo packets are used for the video data, since such packets can carry 10kbytes. 200Mbps is the average load, but note that the camera load can be close to full wire speed (1Gbps) if the inter-packet gap between two packets is equal to the minimum inter-packet gap (96ns) of GB Ethernet, see Figure 1 below.

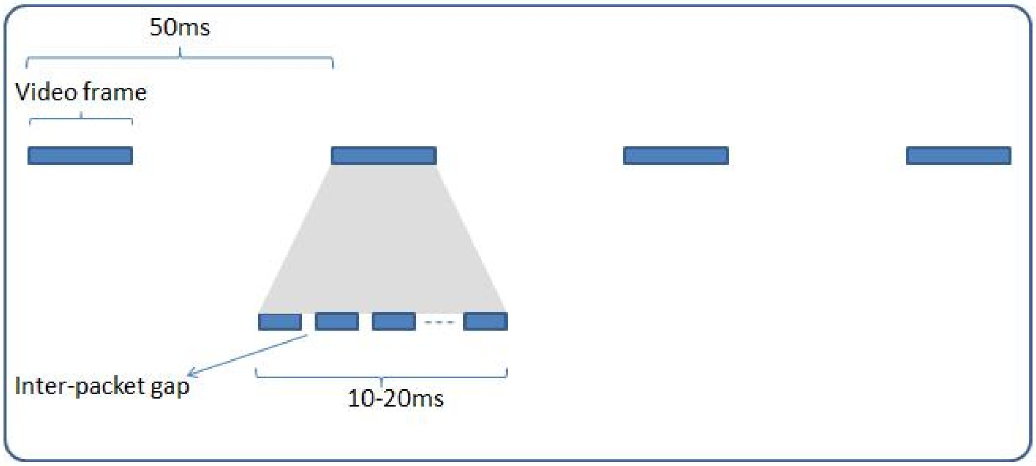


Figure 1, GigE Vision video streaming

The worst case packet burst is created when Ethernet packets of 1518 bytes are used with 20 frames per second and 1024x1280 pixels resolution, resulting in 890 packets with minimum inter-packet gap.

GigE Vision is, in most cases, based on multicast streaming when the video is supposed to be sent to more than one video consumer.

Gigabit Ethernet switches and GigE Vision

In order to avoid network packet loss, optimization of the Ethernet switches for GigE Vision applications is required, unless the Ethernet links to the video consumers have more bandwidth than the video cameras (e.g. by using 10GBASE or multiple 10GBport in a trunk on the links to the video consumers).

Switch packet memory optimization

To achieve the best possible GigE Vision switch performance the packet memory settings need to be adjusted. The packet memory settings must first of all be optimized for multicast in order to avoid that the number of multicast/video consumers has any impact on the performance. This means to utilize the allocation of shared packet memory instead of egress port packet memory allocations.

QoS and switch latency

Network latency is another important aspect to optimize the switch performance for GigE Vision applications and depends on the acceptable network latency of each of the GigE Vision video streams and if the video streams can be configured with different latency properties.
The network latency property for a given GigE Vision video stream is characterized by the allocated priority queue for the stream and the used switch scheduling mechanism.

Modern Ethernet switches have support for priority with up to eight priority queues per port, where the high priority queues are reserved for latency sensitive critical data offering best possible quality of service performance for such data. Relevant packet scheduler schemes for an Ethernet switch can be:

1. Round-robin weighting; i.e. N packets are sent from the highest priority queue (7), before N packets are sent from the second highest priority queue (6), and so on to the lowest priority queue (0), where also N packets are sent from this queue. The packet scheduler will move directly to the next priority queue in the chain if no packets are present in the given queue.
2. Strict priority scheduling; i.e. all available packets in the highest priority queue will be transmitted from the highest priority queue before any of the lower priority queues are served. Thus, packets from a queue will only be sent if all higher priority queues are empty.

Strict priority scheduling is used for switches optimized for GigE Vision in the tests described in this paper.

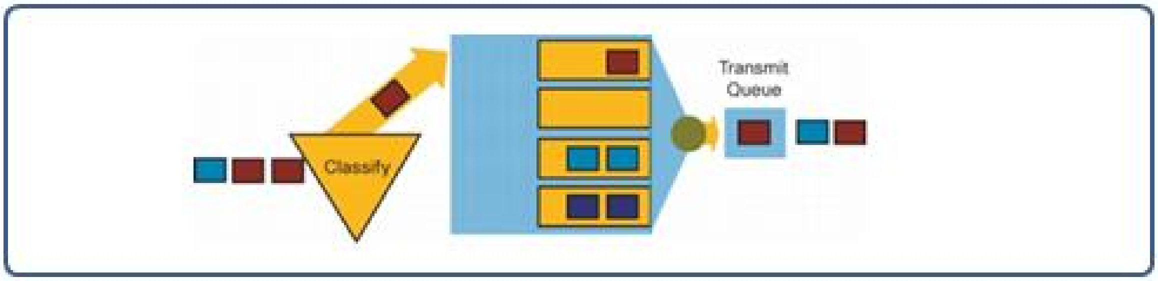


Figure 2, Priority queue scheduling

A proposal for switch configuration optimized for GigE Vision can be as follows:

- Priority queue 6 shall be reserved for video stream 1, where this stream has the lowest latency requirement of the cameras in the network
- Priority queue 5 shall be reserved for video stream 2, where this stream has the second lowest latency requirement of the cameras in the network
- Priority queue 4 shall be reserved for video stream 3, where this stream has medium latency requirement
- Priority queue 3 shall be reserved for video stream 4, where this stream has standard latency requirement

Priority queue 7 is reserved for other real-time critical, low bandwidth and non-video data.

A priority tag according to IEEE 802.1p will be inserted into all packets received on a pre-defined GigE Vision camera port. This VLAN tag (containing priority information) will follow the packet throughout the network (from switch to switch). The tag will be removed when forwarded to a user port. This means that the 10G switch trunk ports will be configured as VLAN trunk ports when GigE Vision optimization is enabled on the switch.

Rate shaping

In addition individual rate shaping levels for the different priority queues will have a positive impact on the GigE Vision video stream latency and packet memory utilization. Rate shaping means that extra time is introduced between each packet on egress, as shown in Figure 3.

Figure 3, Rate shaping

No rate shaping shall be configured for video stream 1, i.e. the stream with lowest latency requirement, while all other video streams are subject for rate shaping on the switch to switch trunk ports.

Example of network optimization for GigE vision
The following example demonstrates …

The setup is shown in Figure 4.

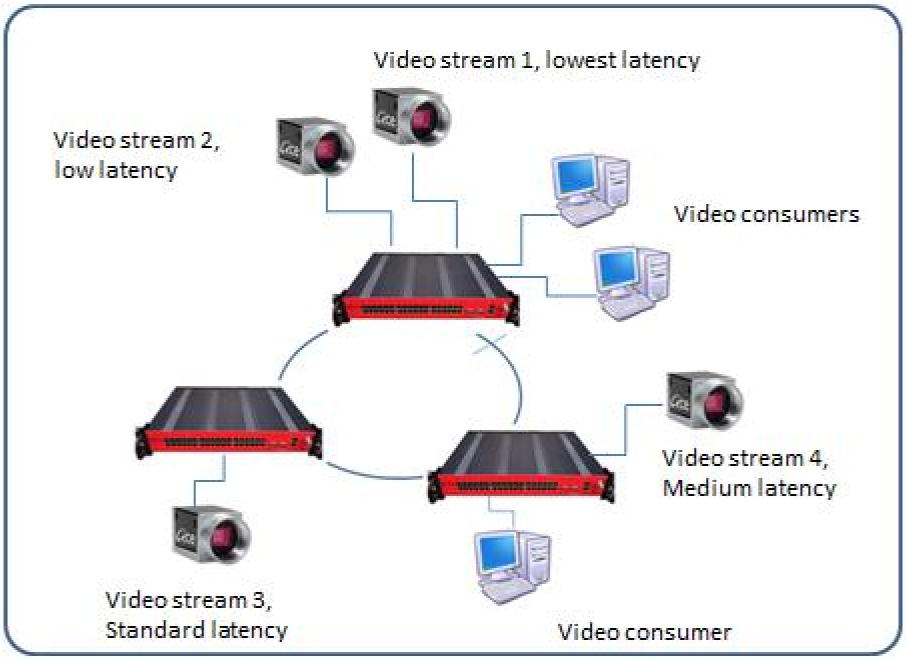


Figure 4, Network setup

Where:

- GigE Vision camera 1 – lowest possible latency
- GigE Vision camera 2 – low latency
- GigE Vision camera 3 – medium latency
- GigE Vision camera 4 – standard latency

A network tester (CM1600 FPGA switch from OnTime Networks with test FW) is used instead of cameras. This tester is able to simulate the sending of video frames with a pre-defined inter-packet gap, where the video frames from the four cameras are sent simultaneously and the inter-packet gap is set to minimum inter-packet gap for GB Ethernet in order to test the worst case scenario, where all four cameras send their data at the same time.

The tester is configured to send 1000 packets of 1458 bytes with minimum inter-packet gap.

Switch setup

The switch setup is based on having the two cameras with the low and lowest latency requirements connected to the same switch. The GigE Vision setup for this switch is as follows:

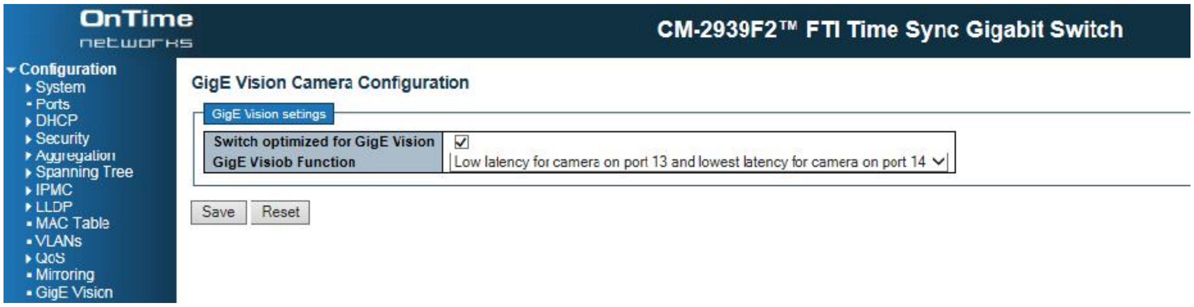


Figure 5, GigE Vision switch setup for the switch with the two low latency sensitive cameras connected

The two other cameras with medium and standard latency requirements are connected to each of the two other switches in the setup. The GigE Vision setup for each of these two switches is as shonw in Figure 6

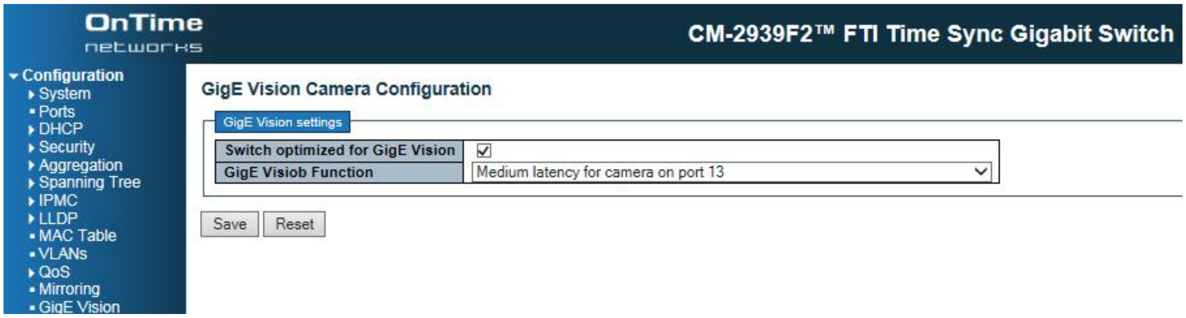


Figure 6, GigE Vision switch setup for the switch switches with the camera with medium latency requirement connected

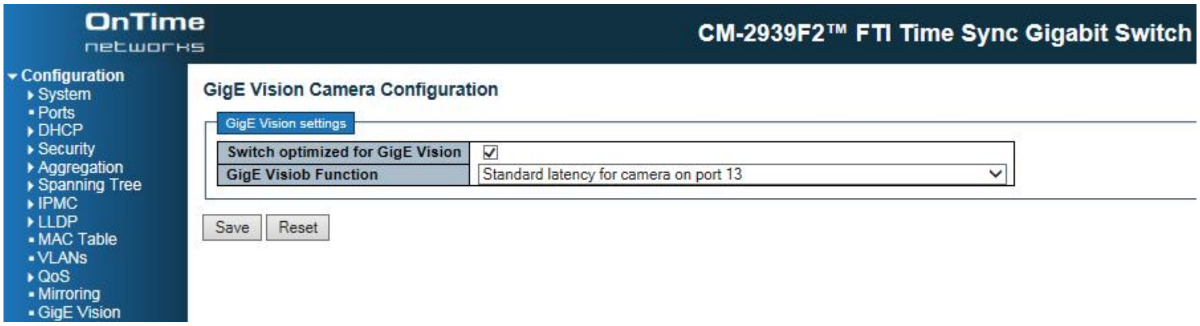


Figure 7, GigE Vision switch setup for the switch switches with the camera with standard latency requirement connected

Test results

GigE Vision Test – no optimization

Test:	GigE Vision Test – no optimization	
Category:		
Criteria for approval:	No packet loss	
Test parameters on tester	# packets	4 x 1,000 (on each test port)
	Minimum inter-packet gap	96ns
	Packet size	1458
	Speed	4 x 1000Mbps

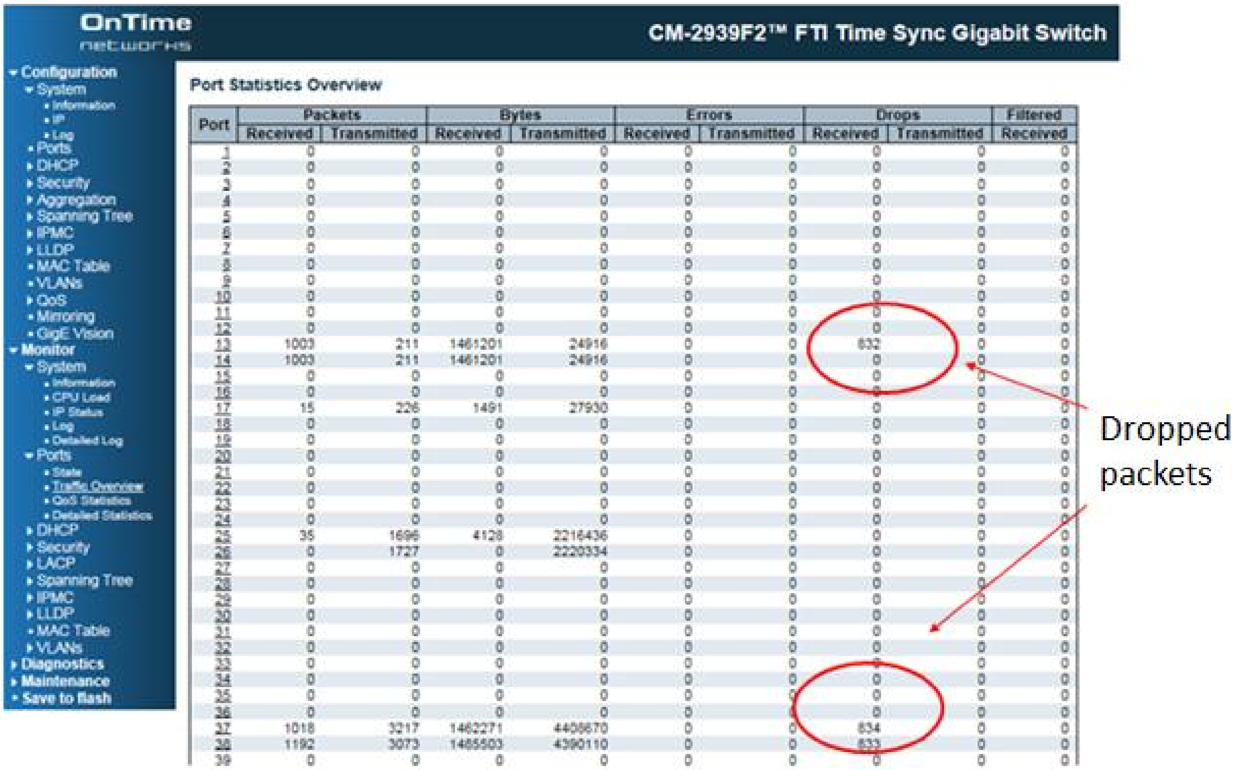
The packet performance test setup is shown in Figure 4.

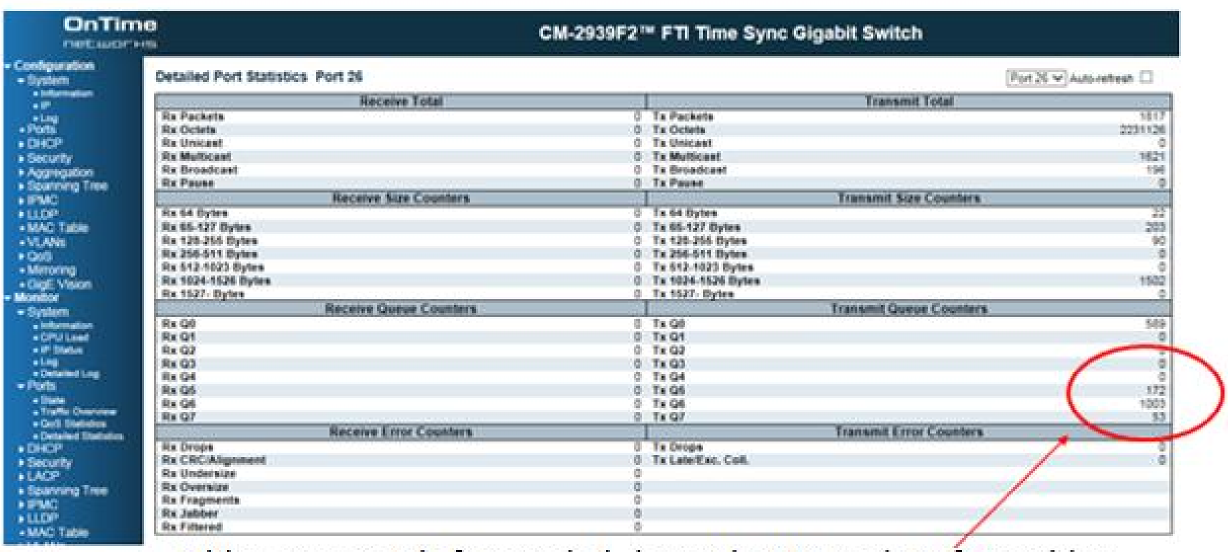
Test procedure:

1. Configure tester and each of the three switches for no GigE Vision optimization.
2. Start tester.
3. Inspect the switch packet statistics and verify that the number of sent packets to each of the multicast consumers are 4 x 1000 packets

Test conduct log:

Test nu	Description	Result
1	Configure each of the three switches for no GigE Vision optimization	-
2	Start tester.	-
3	Switch packet statistics shows that all packets from video stream 1 are forwarded correctly, but only 172 packets from video stream 2 and none from video stream 3 and 4. See Figure 8 below.	**Not passed**





Video stream 1 is forwarded , but only 172 packets from video stream 2 and none from stream 3 and 4

Figure 8, GigE Vision – No optimization, Test Result

GigE Vision Test –optimization

Test:	GigE Vision Test – optimization	
Category:		
Criteria for approval:	No packet loss	
Test parameters on tester	# packets	4 x 1,000 (on each test port)
	Minimum inter-packet gap	96ns
	Packet size	1458
	Speed	4 x 1000Mbps

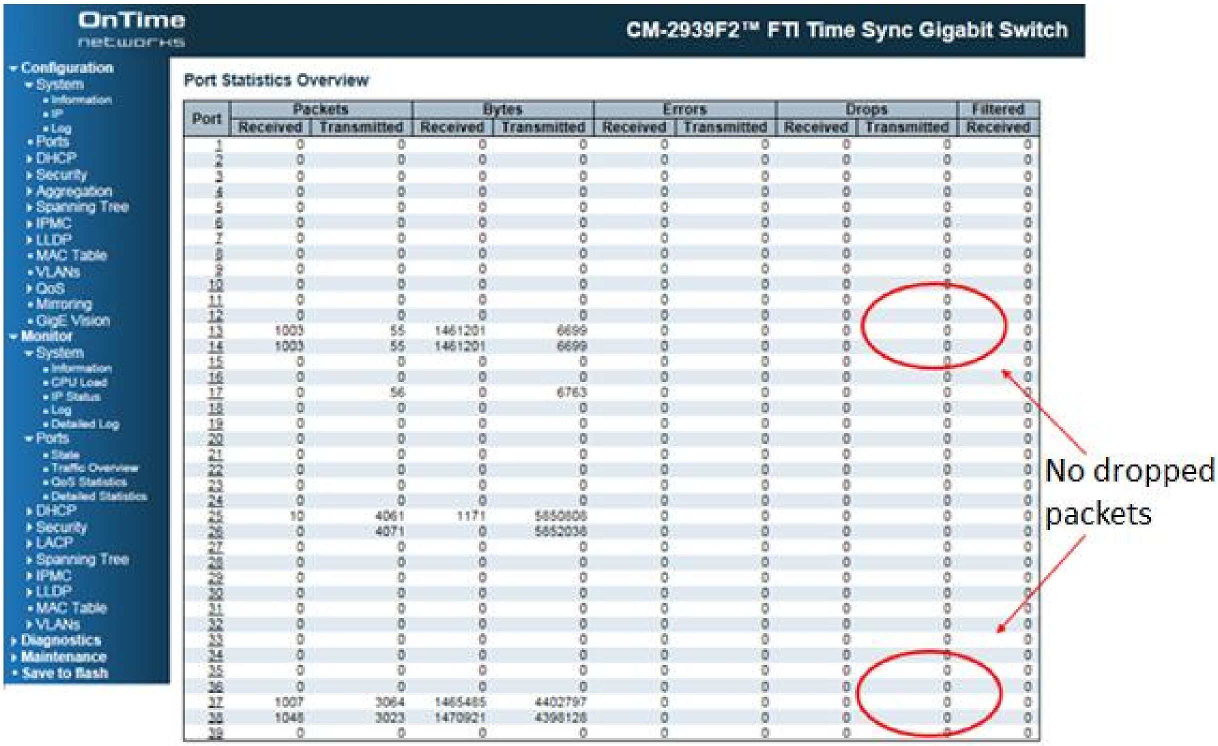
The packet performance test setup is shown in Figure 4.

Test procedure:

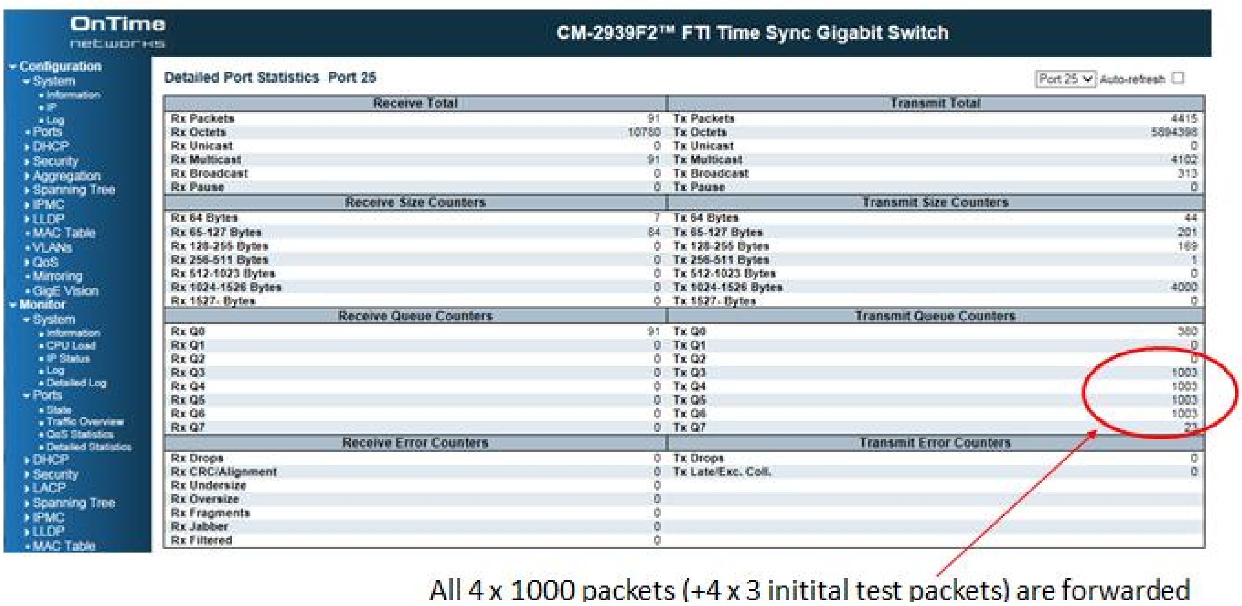
1. Configure tester and each of the three switches for no GigE Vision optimization.
2. Start tester.
3. Inspect the switch packet statistics and verify that the number of sent packets to each of the multicast consumers are 4 x 1000 packets

Test conduct log:

Test nu.	**Description**	**Result**
1	Configure each of the three switches for GigE Vision optimization	-
2	Start tester.	-
3	Switch packet statistics shows that all packets from video stream 1, 2, 3 and 4 are forwarded correctly, see Figure 9 below.	**Passed**



Port	Packets Received	Packets Transmitted	Bytes Received	Bytes Transmitted	Errors Received	Errors Transmitted	Drops Received	Drops Transmitted	Filtered Received
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	1003	55	1461201	6699	0	0	0	0	0
14	1003	55	1461201	6699	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
17	0	56	0	6763	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	10	4061	1171	5850808	0	0	0	0	0
26	0	4071	0	5852038	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	1007	3064	1465485	4402797	0	0	0	0	0
38	1048	3023	1470921	4398128	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0



Receive Total		Transmit Total	
Rx Packets	91	Tx Packets	4415
Rx Octets	10780	Tx Octets	5894398
Rx Unicast	0	Tx Unicast	0
Rx Multicast	91	Tx Multicast	4102
Rx Broadcast	0	Tx Broadcast	313
Rx Pause	0	Tx Pause	0
Receive Size Counters		**Transmit Size Counters**	
Rx 64 Bytes	7	Tx 64 Bytes	44
Rx 65-127 Bytes	84	Tx 65-127 Bytes	201
Rx 128-255 Bytes	0	Tx 128-255 Bytes	169
Rx 256-511 Bytes	0	Tx 256-511 Bytes	1
Rx 512-1023 Bytes	0	Tx 512-1023 Bytes	0
Rx 1024-1526 Bytes	0	Tx 1024-1526 Bytes	4000
Rx 1527- Bytes	0	Tx 1527- Bytes	0
Receive Queue Counters		**Transmit Queue Counters**	
Rx Q0	91	Tx Q0	380
Rx Q1	0	Tx Q1	0
Rx Q2	0	Tx Q2	0
Rx Q3	0	Tx Q3	1003
Rx Q4	0	Tx Q4	1003
Rx Q5	0	Tx Q5	1003
Rx Q6	0	Tx Q6	1003
Rx Q7	0	Tx Q7	23
Receive Error Counters		**Transmit Error Counters**	
Rx Drops	0	Tx Drops	0
Rx CRC/Alignment	0	Tx Late/Exc. Coll.	0
Rx Undersize	0		
Rx Oversize	0		
Rx Fragments	0		
Rx Jabber	0		
Rx Filtered	0		

Figure 9, GigE Vision – Optimization, Test Result

Discussion

GigE Vision is a bandwidth demanding application with bursty behavior. The GigE Vision load example described in this paper is based on forwarding GigE Vision multicast data to several GigE Vision multicast consumers, where all video producer and consumer links are based on gigabit Ethernet. The consumer gigabit links are the potential bottle necks in the system.

An obvious solution in order to avoid bottle necks for such consumer links is to use 10 gigabit links for each GigE Vision consumer. However, most video systems just moved to 1000BASE-T(x) in the past years and therefore changing the overall system hardware is cost prohibited.

Port trunking according to LACP for Ethernet defined in IEEE 802.1AX and IEEE 802.1aq is another solution that can be considered in order to solve the bandwidth challenge. Several gigabit ports can be combined in one trunk for each GigE Vision consumer. The problem with this alternative is limited support for multiple NICs on the GigE video consumer platforms.

Another solution that can be considered in order to reduce the overall video bandwidth is to use compressed video. This may, however, have the negative side effect that the image quality reduces and the end-to-end latency will increase, which is not acceptable for some applications

The network latency for the GigE video cameras used in this test is based on strict priority scheduling. That means that the video stream configured for minimum latency will be forwarded through the network with worst case latency of only a few µs, where this latency mainly consist of store-and-forward delay of an Ethernet packet of 1500 bytes per network hop and minimal, if any, packet queuing delay. The worst network latency for the video camera with the second lowest latency requirement will mainly depend on the video frame size of the camera with the lowest latency requirement. That means that a queuing delay up to 10ms can be introduced for the camera with the second lowest latency requirement if video data from this camera is sent to an egress port where also video data from the camera with lowest latency is sent.

The other video stream will be further delayed if these data are sent to video consumers receiving both video from the camera with the lowest and second lowest latency requirements.

This QoS concept can of course be changed. It is, however, considered to be better to use strict priority scheduling since such a configuration will make sure that a full video frame with a given QoS level will be fully forwarded before other video frames with lower priorities are forwarded to the same video consumer.

Conclusion

This paper has demonstrated how optimization of switch packet memory, QoS and rate shaping techniques can be used in order to handle up to four GigE vision cameras with an aggregated data rate close to full wire speed of the video consumer links without packet loss.