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Automation Business
Network Certification Services

Optimizing Ethernet Networks

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Overview

The performance level of Automation and Control applications on Ethernet is such that inefficiencies due to errors, congestion, collisions and extraneous traffic must be avoided. Schneider Automation Network Certification Service Engineers, (NCSE's), are trained and equipped with the latest tools and technology to render an analysis of your network, recommend configuration changes where necessary, and perform the implementation on-site. This report outlines an example Ethernet segment analysis and reconfiguration. This example was constructed in our Network Certification Lab located in North Andover, Massachusetts. Schneider Automation provides these services to assist your migration project across a range of vendor platforms. Schneider Automation also has some unique tools to assist with analyzing and modeling your Ethernet network.

One of the challenges for Controls and Network engineers is projecting growth on a network. As SCADA, HMI and Control traffic is added, calculating the additional loads on the backbone can be challenging.

Optimizing Ethernet for IT groups has been approached in a couple of ways. One way is simply to supply much more bandwidth than is necessary and to increase server capacity to handle the increased transaction load.

Another way is to architect a solution, is to install switches with advanced features such as VLAN's and Prioritization to separate OSI Layer 2 MAC broadcasts using VLAN's, or prioritize traffic by physical port. Such switches are based upon the IEEE 802.1Q/p Ethernet Bridging standard. Also, OSI Layer 3 switches may be used to switch at OSI Layer 2 and route IP traffic at OSI Layer 3 to divide your network and broadcast domains into subnets. Layer 4 switches additionally can queue and prioritize traffic at TCP Layer 4. This of course would incur substantial additional capital cost as well as a limited number of switch choices capable of surviving in an industrial environment.

For Automation, determinism is a direct result of accurately proportioning bandwidth for fast and repeatable message transaction turnaround time.

Performance Goals

For Automation users, deterministic performance of the Ethernet fieldbus is essential for control, messaging and large data acquisition applications. Simply deploying the latest switching technologies may not ensure determinism if those features are not carefully designed. A comprehensive examination of the network communications matrix, message traffic, host protocols used, and capabilities of the infrastructure can lead to greater performance and reliability for your investment. Schneider Automation NCSE's can identify those inefficiencies that rob performance such as:

System Bottlenecks and congested message queues
Unauthorized hosts or devices on your network
Unnecessary Protocols in use
Excessive collisions, errors, and delays
Excessive Broadcast or Multicast traffic from switches, routers and PC's

Identifying and correcting problems in these areas produce a cleaner, faster and more effective network. Free of such bottlenecks, Ethernet is real-time and deterministic.

Data Collection

Onsite, Schneider Automation NCSE's collect traffic samples from different areas of the network using protocol analyzers and other tools. Hosts are identified and entered into an Ethernet modeling topology map. Protocols, frame types, message types are all sorted and analyzed for problem areas. Delta times for communications are profiled for each conversation pair. In this report, we have introduced some inefficiency to illustrate the process.

The data collection process to baseline your network can however, impose some challenges.

In a shared ethernet environment, as all Ethernet MAC frames are broadcast to all ports on all segments, an accurate picture of IP traffic and conversation pairs is developed. A single sample on a shared ethernet network for 60 seconds should reveal a pattern of virtually all traffic on the network. This makes the use of a Protocol Analyzer especially useful in a shared environment.

However, when the environment is switched, traffic is forwarded by the switches using virtual point to point circuits within the switch. This behavior minimizes the utility of a Protocol Analyzer. In a switched environment, connecting a protocol analyzer as a host on any particular port will limit its capturing ability to mostly Broadcast and Multicast traffic. Therefore, conversation traffic between controllers at Layers 3 (IP), and 4 (TCP), will bypass its ability to sample such traffic.

One remedy is to utilize Port Mirroring, available on some Ethernet switches, to replicate traffic from one port to another. The benefit is that traffic data can be collected unobtrusively by an attached protocol analyzer on the Monitoring port. However, to collect traffic samples for all network devices would be time consuming on large networks. Then, all of the packet traces would have to be correlated to get an overall view of network loading.

Another method of data collection for analysis is the use of an SNMP Manager to perform a Ping discovery and SNMP Get Request to interrogate devices. The shortcoming of using this method is that it is of value only to devices which support SNMP. If your network devices do not support SNMP, any devices found will be generic and have a limited amount of information that could be obtained from them.

Also, SNMP only works well for existing Ethernet devices. If you would like to project the addition of a number of devices, or simulate the increased traffic, SNMP may be of limited utility. An SNMP Manager can populate devices, but cannot generate a traffic load for the added devices.

Traffic and Topology Analysis

Traffic analysis reports the use of any extraneous activity that would generate excessive or unnecessary broadcast traffic such as the IPX/SPX, NetBeui or DLC Protcocols. Also multicast traffic such as RIP updates, bridge updates and PC name server requests are examined and minimized, retimed, or groomed out of the system if they are unnecessary. This traffic analysis will also report on total network activity and throughput. This sampling can also be inserted into a simulation model to study the effects of delays, collisions, errors, infrastructure device choices, port densities, and congestion.

Topology analysis, the device, media and topology criteria are collected and mapped into a model. A load can then be simulated upon the topology indicating delay times at each node and stresses within the network.

Protocol & Frame Analysis

From the traffic sample collected, analysis is performed to determine the protocols on the network and their origin. Frames are examined for proper size and construction in accordance with Ethernet II and IEEE 802.3 standards. ModbusTCP messages are also examined for correct formatting and conversation pairs. This will identify the traffic pattern associated with the devices. Frame analysis is particularly useful when troubleshooting a few devices, but of limited use to project network expansion.

Congestion, Error and Collision Analysis

From the traffic samples collected, our reports will indicate problems and potential problems in your network. In addition, we can transfer the actual traffic into our simulator, replay the actual communications on your network and further identify excessive network delay.

Modeling & Simulation

Models are constructed and analyzed in one of two ways depending on your topology and ethernet access method, switched or shared.

An inventory of devices and packet trace samples are collected to characterize your network. The model is then constructed with the criteria for each device entered into the model. The live traffic captured from a protocol analyzer can then be imported into a Modeling system to analyze the amount of UDP, TCP and other traffic as well as conversation pairs, latency, explicit point-to-point and background traffic such as broadcasts, multicasts, bridge updates (BPDU's), router updates and other services traffic.

The model is then subjected to a simulation, which will generate traffic over a predetermined period of time and produce a result, which may then be studied. The results are analyzed, and adjustments are made to the model in software. The simulation is then run again to produce potential what-if scenarios of network changes. Therefore, the impact of potential changes can be studied before an configuration changes are performed on your network.

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Simulation & Scenario Building

Once the model has been constructed and calculated, the results of model testing can indicate areas to focus on for improved throughput, as well as red flags of obvious deficiencies. Evaluating all of the facts and basing the changes on a priority basis develops a change strategy. These changes are then inserted into a duplicate model and the simulation run again to compare the findings. Once your Controls group validates the changes, an implementation schedule is drawn up and our NCSE's can implement any desired changes.

Characterization and Modeling Example

The embedded example paper is a simple network that was constructed in our Network Certification Lab to illustrate the characterization and modeling process. The outcome of modeling a switched Ethernet environment over a shared Ethernet environment is obvious to experienced Ethernet users, however, this simple model serves to illustrate the advanced analysis capabilities of Schneider Automation Network Services.

Ten Quantum PLC's were used in this test. Five of the PLC's had four IEC MSTR blocks each, with each MSTR block reading one hundred registers from five corresponding slave PLC's for a total of two thousand registers read per scan.

The initial test was performed on 10 Mbs shared Ethernet between all devices with IRL (Inter Repeater Links), between 4 hubs. A traffic sample, called a Packet Trace, was captured using a Protocol Analyzer inserted into the network and statistically evaluated. This packet trace sample was imported into our simulator and the resulting statistics, shown in the Appendices, outline the Ethernet, IP and TCP statistics for each node. Schneider NCSE's then were able to modify the existing network in a software model, thus testing similar loads in different configuration without actually "touching" the existing network. The hubs were replaced with switches, in the software model, to upgrade the network from 10BaseT to 100BaseTX operating at Full Duplex, and to eliminate the delays and retransmissions caused by shared Ethernet Collisions.

The resulting comparison illustrates the obvious performance increase using switches as shown in the Appendices.

Note: Aside from simply replacing hubs with switches, we could also have for example, separated the network into two subnets, added devices, and sized a router with an appropriate packet-forwarding performance for this application. Our databases maintain a table of common vendor devices.

Conclusion

Shown in our Appendices of our report is an inventory of the tested devices and the global statistics in a 10 BaseT environment. The packet trace sample for this and all other comparisons is 36 seconds. The traffic shown from device to device is level as all 5 Masters are reading the same amount of data, (400 registers each), from each of the 5 slaves. During our simulation the sustained Ethernet delay is 154 microseconds, not including the additional overhead to process and packetize the ModbusTCP message into an Ethernet frame.

Collision counts on Page 8 are not insignificant, and in fact not unhealthy for Ethernet, (collision recovery is a feature of CSMA/CD Ethernet). Collisions do however prevent determinism, particularly if there are 16 consecutive unsuccessful retries and the frame is discarded. Also, this inability to reproduce consistent and repeatable Round Trip Times, (RTT), is counter to determinism. Page 8 displays the MAC Layer and IP Layer statistics calculated in our model and Page 9, the TCP statistical data. Note that the bit error rate and point to point queuing delay is symptomatic of the Shared Ethernet environment as shown on Page 10.

Correspondingly, the raw statistics for the Switched 100 Mbs Ethernet model are shown on Pages 11-13 and yield reduced delays due to the absence of collisions.

The graphical comparison on Page 14-17 illustrates the performance differences from a shared 10 BaseT environment to a switched 100BaseTX environment operating at Full Duplex. Note that the devices used support the 100 BaseTX specification and that using 10BaseT devices in a switched environment will similarly appreciable performance gains by eliminating collisions and recovery.

What is clear on Page 14 is the substantial improvement in Ethernet and TCP/IP processing times. As the switches maintain a table of MAC addresses, TCP circuits are opened more quickly. Ethernet frame switching also eliminates the collision counts and therefore offers more repeatable, and therefore deterministic, results.

This example of simulating and projecting Ethernet performance is useful not only in terms of optimizing existing networks, but for projecting performance if growth is anticipated. The impact of traffic loading, application scan times, packet inter-arrival times and Ethernet, IP and TCP stack processing delays can aid our customers to project performance levels decisively.

Once a strategy is proven and change orders are rendered to optimize or expand your network, Schneider Automation Network Certification Engineers can provide the on-site assistance necessary to implement these changes.

Schneider Automation Network Certification Engineers can service and configure switching and routing devices from any manufacturer. Our expertise is Ethernet Network Design, Testing, Modeling & Simulation, Troubleshooting, On-site Service and Support. Our staff of Microsoft and Cisco Certified Engineers has many years of experience building networks and using the latest tools and technologies. Industrial Control over Ethernet is our specialty.

Determinism is within the realm of Ethernet as a fieldbus with proper planning, segmentation and load balancing. Fault tolerance should also not be overlooked as a measure of preserving plant productivity and uptime. Schneider Automation Network Certification Services can assist customers seeking to migrate to a deterministic Ethernet fieldbus.

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Appendix of Test Results

SCENARIO NO. 1
SHARED 10 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

Nodes Tested

Unit	Host	IPAddress	Device Description	PLC Ethernet Adapter	Link
1	Master 1	10.10.1.10	Quantum PLC	NOE 771 00	10BaseT
2	Master 2	10.10.1.20	Quantum PLC	NOE 771 00	10BaseT
3	Master 3	10.10.1.30	Quantum PLC	NOE 771 00	10BaseT
4	Master 4	10.10.1.40	Quantum PLC	NOE 771 00	10BaseT
5	Master 5	10.10.1.50	Quantum PLC	NOE 771 00	10BaseT
6	Slave 1	10.10.1.11	Quantum PLC	NOE 771 00	10BaseT
7	Slave 2	10.10.1.22	Quantum PLC	NOE 771 00	10BaseT
8	Slave 3	10.10.1.33	Quantum PLC	NOE 771 00	10BaseT
9	Slave 4	10.10.1.44	Quantum PLC	NOE 771 00	10BaseT
10	Slave 5	10.10.1.55	Quantum PLC	NOE 771 00	10BaseT

Infrastructure	Switches/Hubs Used	Manufacturer	Model	Encoding	Data Rate
	4	SA ConneXium	499NEH0410	Manchester	10 Mbs Shared
	Media	Cat 5e UTP			Half Duplex

Global Statistics *	Average	Maximum	Minimum
Ethernet Delay [1] (sec)	0.000154	0.000154	0.000154
IP Dropped Packets	0	0	0
TCP Delay [2] (sec)	0.000583	0.000583	0.000583
TCP Segment Delay [2] (sec	0.000554	0.000554	0.000554
Sampling Time [3]	36 Seconds		

* Based upon simulation model assumptions
[1] Statistical Ethernet Frame Transmission Time
[2] End-to-End TCP Message Processing Time
[3] Protocol Analyzer Capture Sample Time

SCENARIO NO. 1
SHARED 10 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

Node Statistics *	Ethernet Collision Count	Ethernet Delay [1] (sec)	Ethernet Load (bits)	Ethernet Load (average bits/sec)	Ethernet Load (average packets/sec)
Hub	4,571	N/A	N/A	N/A	N/A
Master 1	906	0.000208	2,215,968	616	1.6
Master 2	921	0.000204	2,430,976	675	1.76
Master 3	850	0.000206	2,296,736	638	1.66
Master 4	881	0.000205	2,427,632	675	1.76
Master 5	902	0.00021	2,382,912	662	1.72
Slave 1	923	0.000104	8,280,144	2,300	1.61
Slave 2	311	0.000102	9,084,672	2,524	1.76
Slave 3	884	0.000102	8,576,800	2,382	1.66
Slave 4	948	0.0001	9,074,464	2,521	1.76
Slave 5	1,016	0.000101	8,899,280	2,472	1.73

	IP Processing Delay [4] (sec)	IP Traffic Sent (peak packets/sec)	IP Traffic Received (peak packets/sec)	IP Traffic Dropped (average packets/sec)	IP Broadcasts (sent / received)
Master 1	0.0002	160	160	0	0 / 0
Master 2	0.0002	176	176	0	0 / 0
Master 3	0.0002	166	166	0	0 / 0
Master 4	0.0002	176	176	0	0 / 0
Master 5	0.0002	172	172	0	0 / 0
Slave 1	0.0002	161	161	0	0 / 0
Slave 2	0.0002	176	176	0	0 / 0
Slave 3	0.0002	166	166	0	0 / 0
Slave 4	0.0002	176	176	0	0 / 0
Slave 5	0.0002	172	172	0	0 / 0

* Based upon simulation model assumptions
[1] Statistical Ethernet Frame Transmission Time
[4] End-to-End IP Datagram Processing Time

SCENARIO NO. 1
SHARED 10 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

	TCP Connection Aborts	TCP Delay [5] (sec)	TCP Load (bytes)	TCP Load (bytes/sec)	TCP Load (packets)
Master 1	1	0.000665	46,152	1,282	3,846
Master 2	1	0.000661	50,628	1,406	4,219
Master 3	1	0.000662	47,808	1,328	3,984
Master 4	1	0.00066	50,580	1,405	4,215
Master 5	1	0.000862	49,620	1,378	4,135
Slave 1	1	0.000504	803,814	22,328	3,846
Slave 2	1	0.000504	881,980	24,499	4,220
Slave 3	1	0.000502	832,656	23,129	3,984
Slave 4	1	0.000501	884,144	24,560	4,216
Slave 5	1	0.000502	864,006	24,000	4,134

	TCP Segment Delay [5] (sec)	TCP Traffic Received (bytes)	TCP Traffic Received (bytes/sec)	TCP Traffic Received (packets)	TCP Connection Segment Round Trip [6]
Master 1	0.000608	803,814	22,328	3,846	0.00483
Master 2	0.000604	881,980	24,499	4,220	0.00367
Master 3	0.000606	832,656	23,129	3,984	0.00377
Master 4	0.000605	881,144	24,476	4,216	0.00403
Master 5	0.00061	864,006	24,000	4,134	0.00387
Slave 1	0.000504	46,152	1,282	3,846	0.00377
Slave 2	0.000502	50,628	1,406	4,219	0.00296
Slave 3	0.000502	47,808	1,328	3,984	0.004
Slave 4	0.000501	50,580	1,405	4,215	0.00356
Slave 5	0.000501	49,620	1,378	4,134	0.00351

* Based upon simulation model assumptions
[5] End-to-End TCP Transaction Processing Time
[6] Round Trip TCP Transaction Processing Time

SCENARIO NO. 1
SHARED 10 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

CSMA/CD Errors
(Single Shared Ethernet Collision Domain)

Device	Point to Point Bit Error Rate [7]	Point to Point Queuing Delay (sec) [8]
Master 1	0.0133	0.000053
Master 2	0.0134	0.000054
Master 3	0.0136	0.000143
Master 4	0.0133	0.000145
Master 5	0.00061	0.000054
Slave 1	0.0134	0.000143
Slave 2	0.0133	0.000145
Slave 3	0.013	0.000145
Slave 4	0.0138	0.000145
Slave 5	0.0148	0.000143

* Based upon simulation model assumptions
[7] Statistical Probability of a bit being received incorrectly. Example: A Bit Error Rate of 0.01 averages 1 bit error per 100 bits sent
[8] Represents statistical average of waiting time in the transmitters channel queue.

SCENARIO NO. 2
SWITCHED 100 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

Nodes Tested

Unit	Host	IPAddress	Device Description	PLC Ethernet Adapter	Link
1	Master 1	10.10.1.10	Quantum PLC	NOE 771 00	100BaseTX
2	Master 2	10.10.1.20	Quantum PLC	NOE 771 00	100BaseTX
3	Master 3	10.10.1.30	Quantum PLC	NOE 771 00	100BaseTX
4	Master 4	10.10.1.40	Quantum PLC	NOE 771 00	100BaseTX
5	Master 5	10.10.1.50	Quantum PLC	NOE 771 00	100BaseTX
6	Slave 1	10.10.1.11	Quantum PLC	NOE 771 00	100BaseTX
7	Slave 2	10.10.1.22	Quantum PLC	NOE 771 00	100BaseTX
8	Slave 3	10.10.1.33	Quantum PLC	NOE 771 00	100BaseTX
9	Slave 4	10.10.1.44	Quantum PLC	NOE 771 00	100BaseTX
10	Slave 5	10.10.1.55	Quantum PLC	NOE 771 00	100BaseTX

Infrastructure

No	Mfr	Model	Encoding	Data Rate
1	Simulated Switch	Advanced 10/100 Switch	MLT3 (Fast Ethernet)	100 Mbs Switched Full Duplex

Global Statistics *

	Average	Maximum	Minimum
Ethernet Delay [1] (sec)	0.0000252	0.0000252	0.0000252
IP Dropped Packets	0	0	0
TCP Delay [2] (sec)	0.000431	0.000431	0.000431
TCP Segment Delay [2] (sec)	0.000425	0.000425	0.000425
Sampling Time [3]	36 Seconds		

* Based upon simulation model assumptions
[1] Statistical Ethernet Frame Transmission Time
[2] Statistical Processing Time for ModbusTCP Message
[3] Protocol Analyzer Capture Sample Time

SCENARIO NO. 2
SWITCHED 100 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

Node Statistics *	Ethernet Collision Count [4]	Ethernet Delay [5] (sec)	Ethernet Load (bits)	Ethernet Load (average bits/sec)	Ethernet Load (frames)
Switch	0				
Master 1	0	0.0000357	2,216,608	616	5,773
Master 2	0	0.0000356	2,431,616	675	6,333
Master 3	0	0.0000356	2,296,096	638	5,980
Master 4	0	0.0000357	2,429,632	675	6,328
Master 5	0	0.0000357	2,383,552	662	6,208
Slave 1	0	0.0000147	8,280,144	2,300	5,780
Slave 2	0	0.0000146	9,083,712	2,523	6,337
Slave 3	0	0.0000146	8,577,120	2,383	5,987
Slave 4	0	0.0000147	9,076,384	2,521	6,335
Slave 5	0	0.0000147	8,899,280	2,472	6,210

	IP Processing Delay [6] (sec)	IP Broadcasts (sent / received)	IP Traffic Sent (peak packets/sec)	IP Traffic Received (peak packets/sec)	IP Traffic Dropped (packets)
Master 1	0.0002	0 / 0	160	161	0
Master 2	0.0002	0 / 0	176	176	0
Master 3	0.0002	0 / 0	166	166	0
Master 4	0.0002	0 / 0	176	176	0
Master 5	0.0002	0 / 0	172	173	0
Slave 1	0.0002	0 / 0	161	160	0
Slave 2	0.0002	0 / 0	176	176	0
Slave 3	0.0002	0 / 0	166	166	0
Slave 4	0.0002	0 / 0	176	176	0
Slave 5	0.0002	0 / 0	173	172	0

* Based upon simulation model assumptions
[4] Included for Comparison.
[5] Statistical Ethernet Frame Transmission Time
[6] End-to-End IP Datagram Processing Time

SCENARIO NO. 2
SWITCHED 100 MBs ETHERNET PERFORMANCE

Date Nov. 29, 2001

	TCP Connection Aborts	TCP Delay [6] (sec)	TCP Traffic Sent (bytes)	TCP Traffic Sent (bytes/sec)	TCP Traffic Sent (packets)
Master 1	1	0.000447	46,152	1,282	3,846
Master 2	1	0.000446	50,628	1,406	4,219
Master 3	1	0.000446	47,808	1,328	3,984
Master 4	1	0.000447	50,580	1,405	4,215
Master 5	1	0.000447	49,620	1,378	4,135
Slave 1	1	0.000415	803,814	22,328	3,846
Slave 2	1	0.000415	881,980	24,499	4,220
Slave 3	1	0.000415	832,656	23,129	3,984
Slave 4	1	0.000415	881,144	24,476	4,216
Slave 5	1	0.000415	864,006	24,000	4,134

	TCP Segment Delay [6] (sec)	TCP Traffic Received (total bytes)	TCP Traffic Received (average bytes/sec)	TCP Traffic Received (packets)	TCP Connection Segment Round Trip Time [7] (sec)
Master 1	0.000436	803,814	22,328	3,846	0.00483
Master 2	0.000436	881,980	24,499	4,220	0.00367
Master 3	0.000436	832,656	23,129	3,984	0.00377
Master 4	0.000436	881,144	24,476	4,216	0.00403
Master 5	0.000436	864,006	24,000	4,134	0.00387
Slave 1	0.000415	46,152	1,282	3,846	0.00377
Slave 2	0.000415	50,628	1,406	4,219	0.00296
Slave 3	0.000415	47,808	1,328	3,984	0.004
Slave 4	0.000415	50,580	1,405	4,215	0.00356
Slave 5	0.000415	49,620	1,378	4,135	0.00351

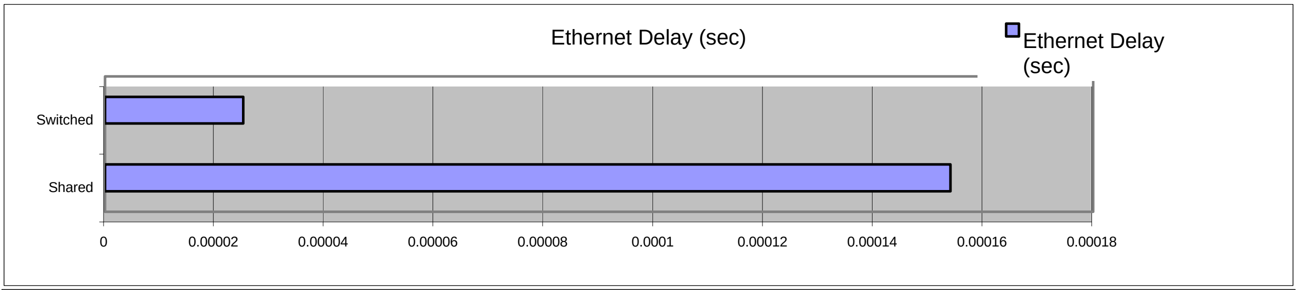
* Based upon simulation model assumptions
[6] End-to-End TCP Message Processing Time
[7] Statistical ModbusTCP Transaction Turnaround Time

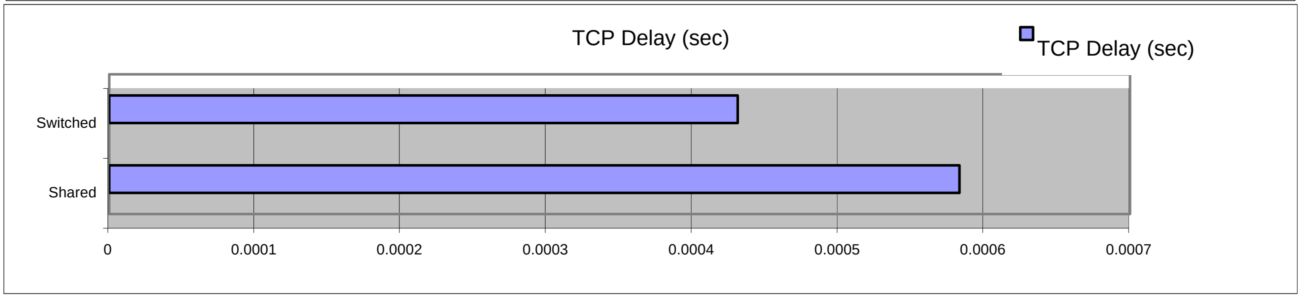
Date Nov. 29, 2001

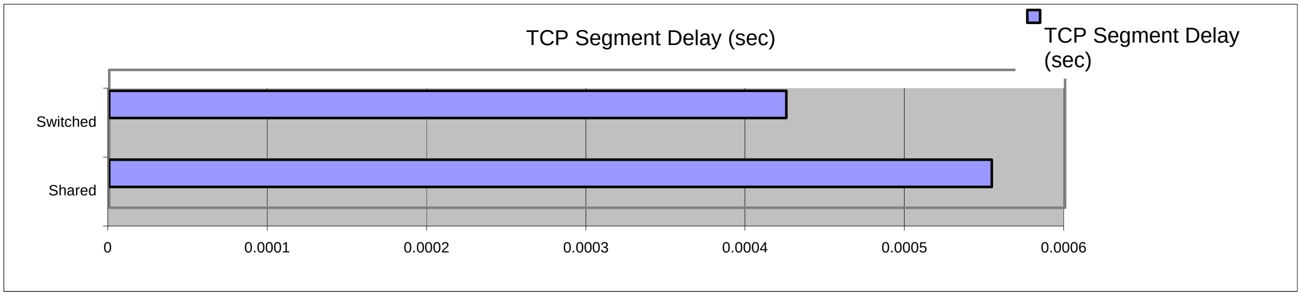
SCENARIO COMPARISON
10 MBS SHARED VS. SWITCHED 100 MBs ETHERNET PERFORMANCE

Global Comparison *

	Shared	Switched
Ethernet Delay (sec)	0.000154	0.0000252
TCP Delay (sec)	0.000583	0.000431
TCP Segment Delay (sec)	0.000554	0.000425







* Based upon simulation model assumptions

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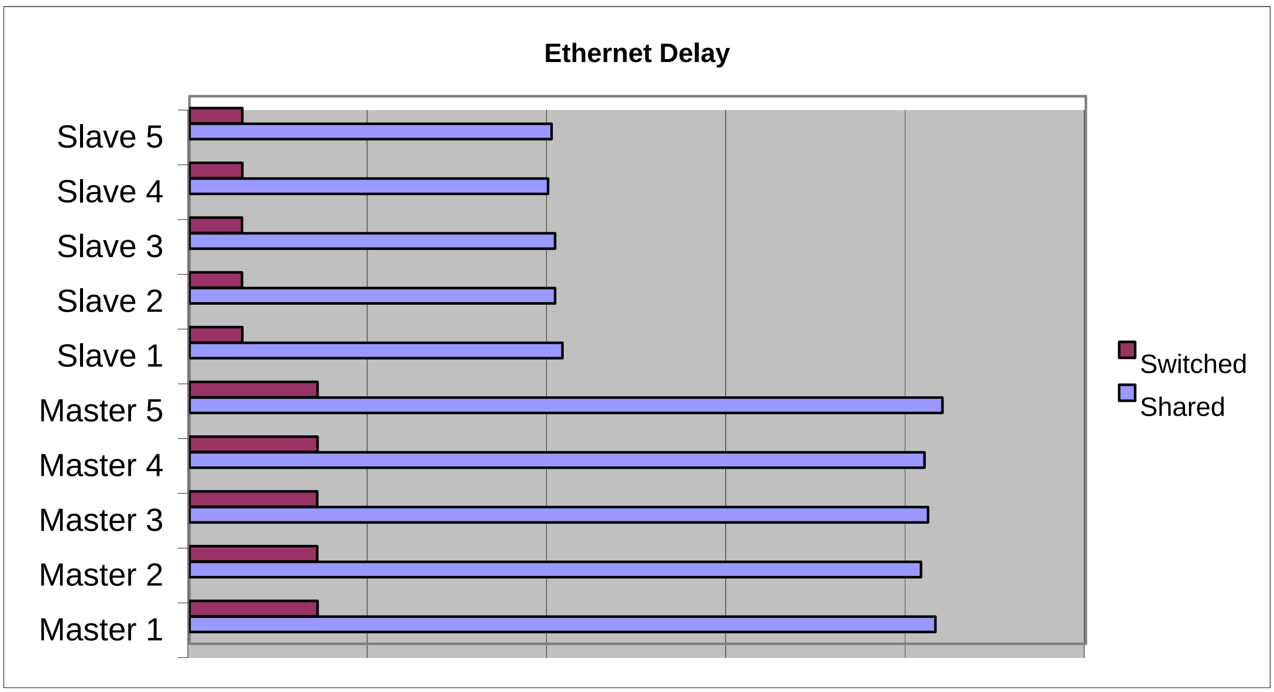
SCENARIO COMPARISON
10 MBS SHARED VS. SWITCHED 100 MBs ETHERNET PERFORMANCE

Node Comparison

Ethernet Delay*
(sec)

	Shared	Switched
Master 1	0.000208	0.0000357
Master 2	0.000204	0.0000356
Master 3	0.000206	0.0000356
Master 4	0.000205	0.0000357
Master 5	0.00021	0.0000357
Slave 1	0.000104	0.0000147
Slave 2	0.000102	0.0000146
Slave 3	0.000102	0.0000146
Slave 4	0.0001	0.0000147
Slave 5	0.000101	0.0000147

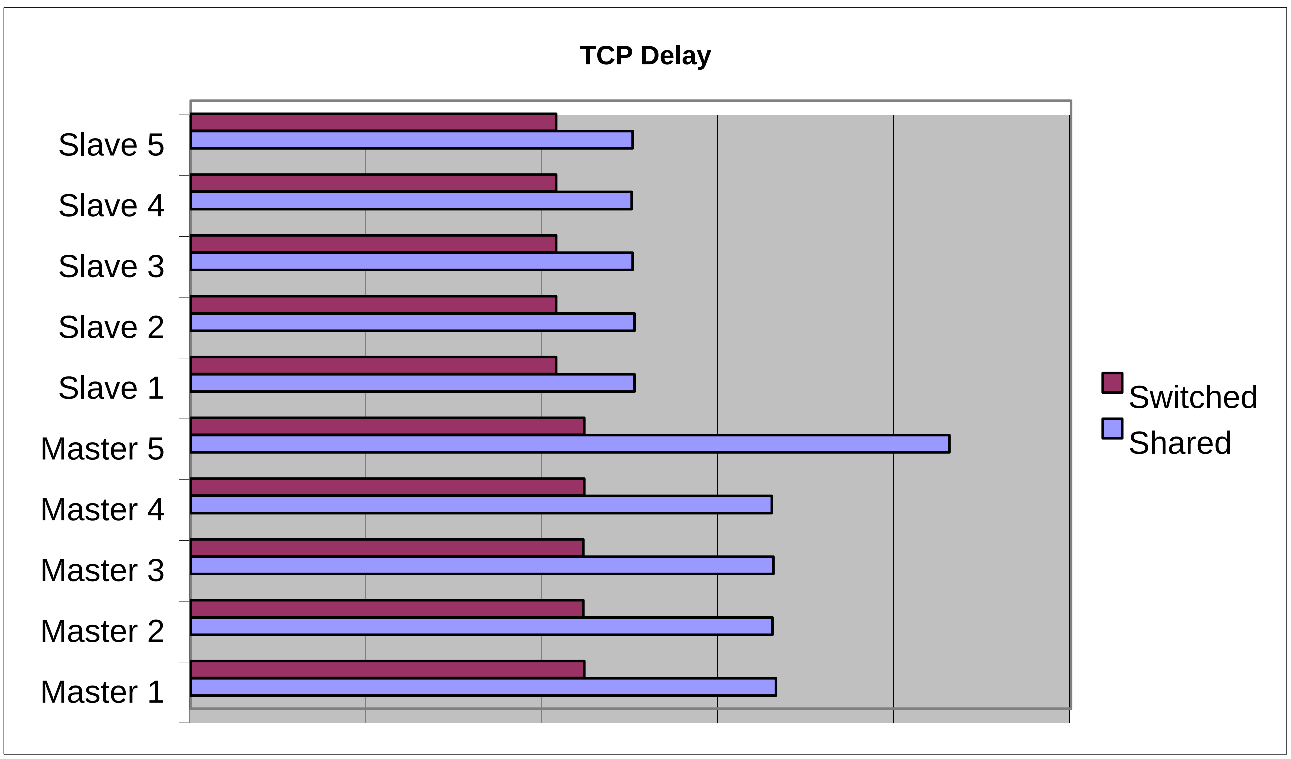


* Based upon simulation model assumptions

SCENARIO COMPARISON
10 MBS SHARED VS. SWITCHED 100 MBs ETHERNET PERFORMANCE

TCP Delay *
(sec)

	Shared	Switched
Master 1	0.000665	0.000447
Master 2	0.000661	0.000446
Master 3	0.000662	0.000446
Master 4	0.00066	0.000447
Master 5	0.000862	0.000447
Slave 1	0.000504	0.000415
Slave 2	0.000504	0.000415
Slave 3	0.000502	0.000415
Slave 4	0.000501	0.000415
Slave 5	0.000502	0.000415

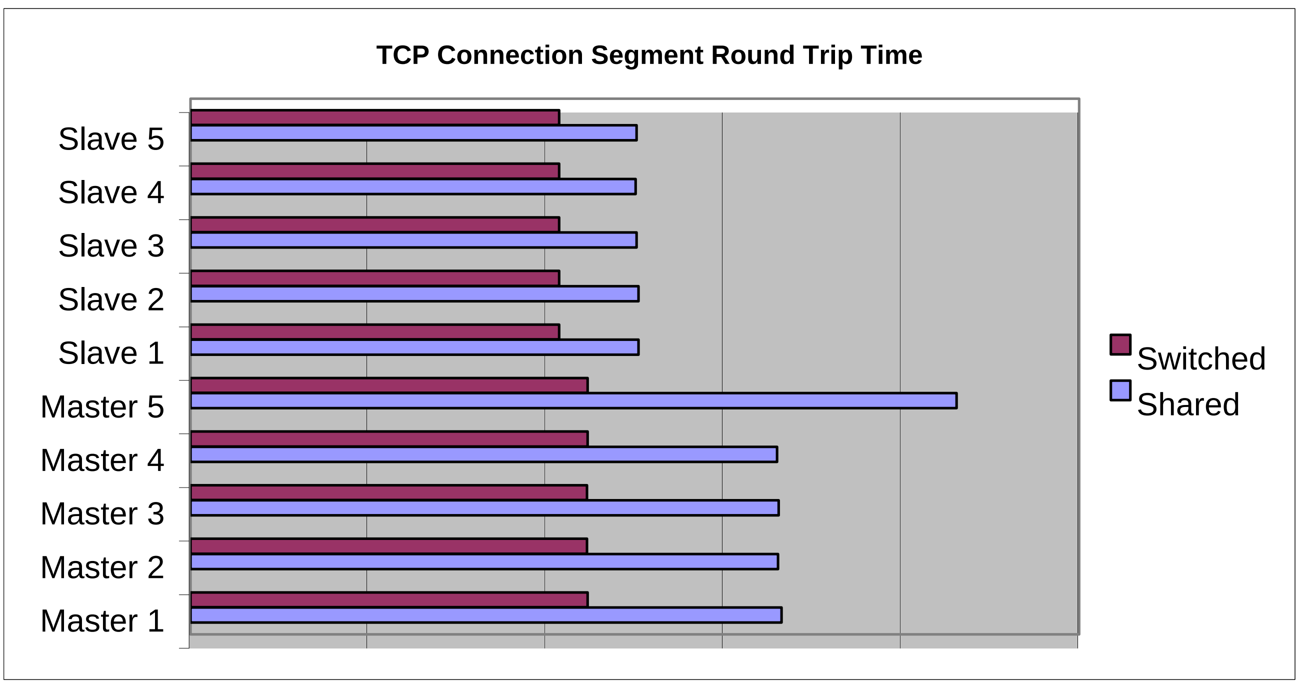


* Based upon simulation model assumptions

SCENARIO COMPARISON
10 MBS SHARED VS. SWITCHED 100 MBs ETHERNET PERFORMANCE

TCP Connection
Segment Round Trip *
(sec)

	Shared	Switched
Master 1	0.000665	0.000447
Master 2	0.000661	0.000446
Master 3	0.000662	0.000446
Master 4	0.00066	0.000447
Master 5	0.000862	0.000447
Slave 1	0.000504	0.000415
Slave 2	0.000504	0.000415
Slave 3	0.000502	0.000415
Slave 4	0.000501	0.000415
Slave 5	0.000502	0.000415



* Based upon simulation model assumptions