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REAL-TIME ANALYSIS OF A MULTI-CLIENT MULTI-SERVER ARCHITECTURE FOR NETWORKED CONTROL SYSTEMS

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ABSTRACT

Networked control systems are control systems in which sensors, controllers, actuators, and other system components communicate over a network. In a networked control system the control loops are closed through a communication network. Implementing closed-loop control over a communication network introduces communication delays that degrade the control performance. Depending on network protocols and scheduling methods, network induced delays have different characteristics which can be constant and time varying. In a design process, the interaction of the control system with the network must be considered in order to use the communication resources effectively. This paper is an effort to analyze a multi-client multi-server architecture by observing the effects of packet delays, packet loss, and network congestion on the performance of the networked control system (NCS).This work proposes a multiple client server architecture that can be used as a real-time communication setup for possible applications in factory automation. In multi-client multi-server architectures, numbers of packet drops are reduced. Comparing with normal multi-client single-server systems, the additional servers in a multi-client multi-server architecture will ensure better handling of the traffic and considerable reduction in delay.

Keywords: delay, factory automation, networked control system, packet loss.

INTRODUCTION

The control systems in which sensors, controllers, actuators, and other system components communicate over a network are referred to as NCSs. The defining feature of an NCS is that the control and feedback signals are exchanged among the system's components in the form of information packages through a network. The functionality of a typical NCS is established by the use of four basic elements: Sensors, controllers, actuators and network. Networked control systems eliminate unnecessary wiring thereby reducing the complexity and the overall cost in designing and implementing the control systems. They can also be easily modified or upgraded by adding sensors, actuators and controllers to them with relatively low cost and no major changes in their structure.

The interaction of the control system with the network must be considered in order to use the communication resources effectively. In a networked Control System the control loops are closed through a communication network. The use of a communication network offers significant advantages in terms of reliability, enhanced resource utilization, reduced wiring, easier diagnosis and maintenance. However, implementing closed-loop control over a communication network introduces communication delays that degrade control performance.

Generally feedback control over a network in an industry consists of a client side and a server side. The communication between client and server are performed through a dedicated communication network. The client side may have some sensors and actuators. A controller will be there in the server side to provide control information according to the sensed data from the client side. There are two types of communication networks – data networks and control networks. In data networks there is usually a transmission of large data packets and the transmission rate is relatively infrequent. In control networks there is a frequent transmission of small packets that must meet timing guarantees.

In the current scenario, the number of clients or plants that need to be served is constantly growing but there is always an issue of scaling the number of servers/controllers. As the number of requests to a single controller increases, there will be a degrading effect on the performance of the control system. The focus of this paper is mainly in this area. In large industrial factories there will be large number of plants which needs to be controlled according to certain conditions and parameters. Each plant which is to be controlled is occupied with different types of sensors. The sensed values of different parameters (e.g.: temperature, strain, speed) are to be transmitted towards the controller side. In the controller side there will be a server which will provide necessary controlling information according to the received sensor data. This controller information is then transmitted towards the plants. On receiving this data, plants will undergo changes with the help of actuators.

In some higher end industrial applications plants are needed to be controlled very fast. In such cases communication between the server and clients must be very efficient. As the number of plants which is to be controlled by a single server at a time increases, the average network delay and packet loss increases. This will degrade the total control performance. Thus in a single server-multi client architecture as the number of clients increases network performance decreases.

In the case of a queue based communication system, when a client sends a packet to a server, the packet will be forwarded to that particular egress queue of the server. If there are packets already in the queue, it is stored in the queue till its turn, else it is routed immediately. Hence, as more clients try to connect to a single server, the link utilization starts to increase and the packets from different clients have to wait in the queue before being sent to that particular server. Thus the net delay increases.

The solution for this delay increase is to use multiple servers in the network instead of a single dedicated server. When multiple servers are incorporated in the controller side the number of clients which is to be controlled by a single server decreases. This will reduce the communication delay and the controller action will take place more efficiently.

RELATED WORK

Technological advancements in the field of electronics and computers brought step by step changes in NCS. The initial changes were in the area of controllers, when the analog controllers were gradually replaced by digital control, giving birth to the direct digital control. This consists of a computer/processor as the brain of the system with a direct connection between the plant and the controller. The sensors and actuators generate required signals for the plant and the controller. As the scale of control systems increased, it gave rise to a new era of control architecture known as distributed control system (DCS). In a DCS [1], majority of real-time tasks like sensing, actuation, and control are done at the process stations whereas supervisory tasks like monitoring, caution alarms, and on/off signals are done at the operator stations.

In a supervisory control system, the client/user system stays outside the control loop and is used to mainly monitor the control experiment. Srivatsava [2] designed an Internet-based supervisory control system where the user can monitor the process, from anywhere on the Internet. With further advances in computer technology and networking, the operator is not just an observer but a full-fledged controller. When the components of a networked control system (NCS) like sensors, actuators, and controllers are distributed and the feedback control loop is closed via a common communication channel, it is defined as an integrated communication and control system (ICCS). Communication protocols were developed with respect to specific industries. Building automation control network (BACnet) developed by American society of heating, refrigeration and air conditioning (ASHRAE) [3] became a standard of communication for commercial and government buildings, and campus environments. Like Ethernet and Arcnet, BACnet can also be operated on a RS-485 twisted pair [3]. Controller Area Network (CAN) [4] is designed jointly by Bosch, Philips, and Intel primarily for the automotive industry. This standard mainly focuses on the data link layer, making it more of a serial communication bus than a network protocol. In industrial communication networks, Profibus and Factory instrumentation protocol (FIP) are categorized as field bus protocols. Profibus is a broadcast protocol operated in a Master/Slave architecture, and was developed by six German companies and five German institutes in 1987[5]. Profibus is based on token passing mechanism with an ability to support high-priority and low-priority messages.

Ethernet is a contention-based protocol that works on carrier sense multiple accesses with collision detection (CSMA/CD) for data transmission. In this mechanism there is no central bus controller that arbitrates the channel; every node acts as a self-arbiter, by listening to the channel for any ongoing transmissions and transmitting only when the channel is idle. Even after transmitting the packet, the sender keeps listening to the channel for any collisions and if detected, the colliding stations back off and wait for a random amount of time before trying to retransmit. Ethernet was invented at Xerox PARC during 1974, Metcalfe and Boggs [6] did a simple analysis on this experimental 3 Mbps Ethernet. They observed that the throughput of a network is a function of packet length and network load (in terms of output of the buffer). Mazraani and Parulkar [7] found that as long as the network utilization does not reach a particular threshold the behavior of the Ethernet remains the same under bursty conditions. They also observed that as the utilization increases beyond a threshold, packet delay, queue lengths and packet loss increase drastically. To address the issues of non-determinism, network architectures based on switching have gained significance.

Ethernet is by far the most widely used LAN technology today, connecting more than 85 percent of the world’s LAN connected PCs and workstations. Ethernet refers to the family of computer networking technologies covered by the IEEE 802.3 standard, and can run over both optical fiber and twisted-pair cables. Over the years, Ethernet has steadily evolved to provide additional performance and network intelligence. This continual improvement has made Ethernet an excellent solution for industrial applications. Recognizing that Ethernet is the leading networking solution, many industry organizations are porting the traditional field bus architectures to Industrial Ethernet. Industrial Ethernet applies the Ethernet standards developed for data communication to manufacturing control networks. Industrial Ethernet networks that use intelligent switching technology can offer a variety of advantages compared to traditional industrial networks. The technology can be deployed using a switched Ethernet architecture and has proven successful in multiple critical applications in different markets. By providing a scalable platform that can accommodate multiple applications, Ethernet-based automation systems can increase flexibility and accelerate deployment of new applications in the future. At the same time, Ethernet delivers the network security, performance, and availability required to support critical manufacturing applications.

MULTICLIENT- MULTISERVER ARCHITECTURE

A multi client single server system shown in Figure-1 consist of a single server which provides the necessary control information for multiple clients attached to it through some communication network. When a particular

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client needs a service from the server it will send a request to the server. On receiving the request the server will provide the necessary service. As more clients try to connect to a single server, the link utilization starts to increase and the packets from different clients have to wait in the queue before being sent to that particular server. Thus the net delay increases. This will degrade the performance of the total system.

A solution for reducing such network induced delay is to accommodate extra servers in to the network in the controller side. When number of servers increases the number of clients being serviced by a single server at a time decreases. This will reduce the network congestion and induced delay. Figure-2 shows a multi client multi server system having two servers and two clients.

In order to analyze the effect of adding additional servers to a single server multi client system the two architectures were simulated in network simulator 2.Two wired network architectures of SS-MC system and MS-MC system are configured in network simulator 2. The multi client single server architecture used for simulation has a single server connected to ten different clients. The communication protocol used for the simulation is user datagram protocol (UDP).The multi client multi server system used for simulation have three servers and ten clients. Here first two servers have to provide service for three clients each. The third server will provide services for remaining four clients.

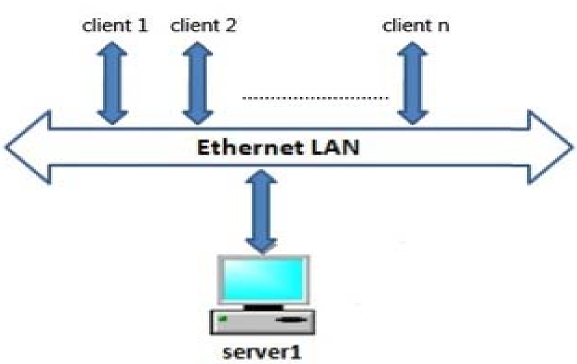


Figure-1. Multi-client single server architecture.

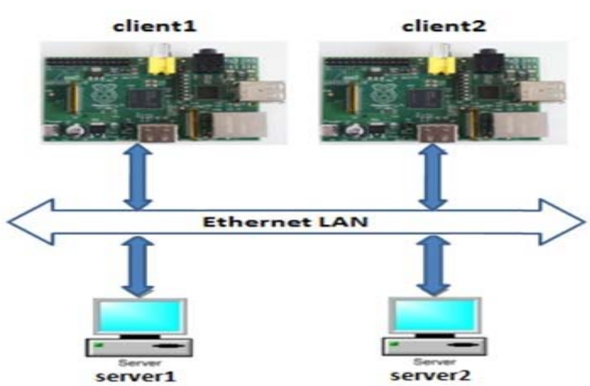


Figure-2. Multi-client multi server architecture.

SIMULATION RESULTS

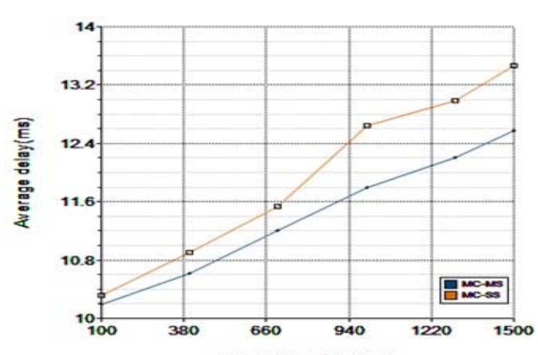
Network Simulator (Version 2), widely known as NS2, is simply an event driven simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2. In general, NS2 provides users with a way of specifying such network protocols and simulating their corresponding behaviors.

Here in this paper simulations are done in NS2 to analyze the multi-client multi-server architecture and multi-client single-server architecture. The multi-client single-server architecture configured for simulation have ten clients and a single server connected using user datagram protocol. Packets are generated in the client side and forwarded to the server side. After receiving the packets from a client, the server will send the control packets towards the client. The multi-client multi-server architecture configured for simulation have ten clients and three servers.

The simulation parameters are kept same for both architectures. The links used for connection are duplex in nature and have a drop tail type queuing. Various simulations were performed by varying packet lengths and packet rates. The average delay and packet loss for each simulation are then calculated using awk programming. The two architectures were compared using the simulation results and the results were plotted. By keeping the packet rate constant packet length is increased from 100 bytes to 1500 bytes in steps of 300 bytes for every simulation. Simulations were also performed by varying packet rates by keeping the packet lengths constant. The average delay and packet drops are measured for each simulation and plotted for comparison.

Increasing the Packet Length While Keeping the Packet Rate Constant

To analyze the effect of packet lengths in the performance of the two architectures a set of simulations are performed by varying packet length for a fixed packet rate. Figure-3 shows the results obtained after different simulations in both multi-client multi-server and multi-client single-server architectures.



(a)

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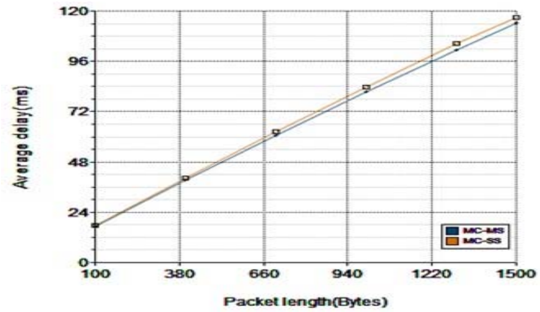


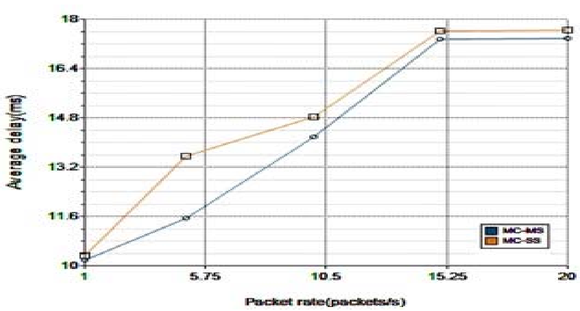
(b)

Figure-3. Average delay (ms) VS packet length (bytes) (a) 1 packet/s (b) 20 packets/s.

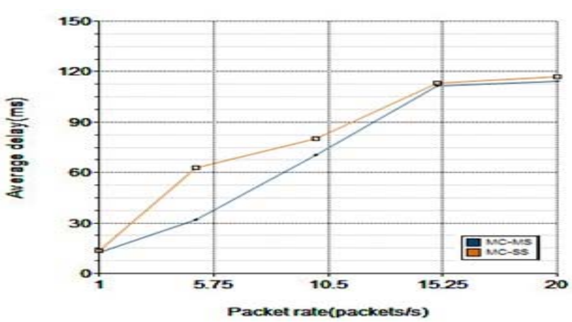
For the first simulation, packet rate is fixed to 1 packet/s. The average delay in this scenario is calculated by varying packet length from 100 bytes to 1500 bytes. For the second simulation packet rate is fixed to 20packets/s and packet length is varied from 100 bytes to 1500 bytes. Simulations are performed for both multi-client multi-server and multi-client single-server architectures and results are compared.

Increasing the Packet Rate While Keeping the Packet Length Constant

To analyze the effect of packet rate in the performance of the two architectures a set of simulations are performed by varying packet rate for a fixed packet length. Figure-4 shows the results obtained for multi-client multi-server and multi-client single-server architectures.



(a)

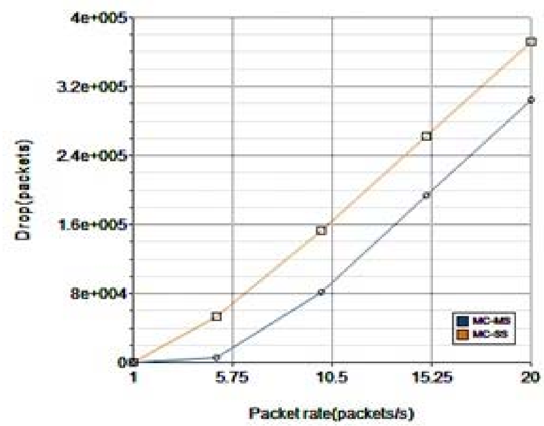


(b)

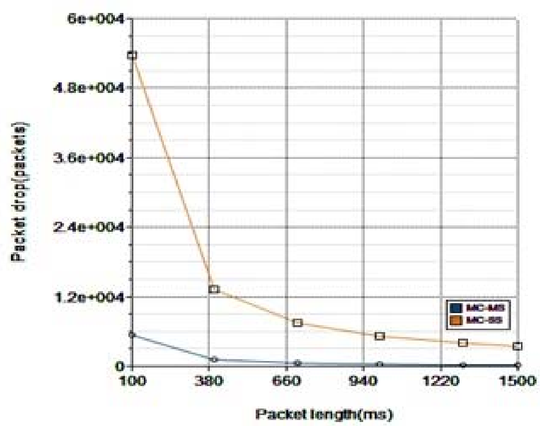
Figure-4. Average delay (ms) VS packet rate (packets/s) (a)100bytes(b)1500bytes.

For the first simulation, packet length is fixed to 100 bytes. The average delay in this scenario is calculated by varying packet rate from 1 packet/s to 20packets/s. For the second simulation packet length is fixed to 1500bytes and packet rate is varied from 1 packet/s to 20packets/s. Simulations are performed for both multi-client multi-server and multi-client single-server architectures and results are compared.

To analyze the effect of packet rate on packet drop, number of dropped packets is calculated for different packet rates. This can be done by counting the dropped packets in the trace file for each simulation. Similarly to analyze the effect of packet length on packet drop, number of dropped packets are calculated for different packet lengths. The obtained results are shown in Figure-5.



(a)



(b)

Figure-5. (a) Packet drop vs. packet rate (packets/s) (b) Packet drop vs. packet length (bytes).

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Table-1. Average delay and drops in SS-MC and MS-MC systems.

Packet Rate	Packet Length	Avg.Delay		Drop	
		SS-MC	MS-MC	SS-MC	MS-MC
1	100	10.32	10.19	0	0
	400	10.9	10.62	0	0
	700	11.54	11.21	0	0
	1000	12.64	11.79	0	0
	1300	12.98	12.21	0	0
	1500	13.46	12.58	0	0
20	100	17.65	17.38	372173	304281
	400	40.11	39.23	92781	75512
	700	62.28	60.6	52878	42841
	1000	83.64	81.52	36922	29775
	1300	104.3	101.23	28321	22734
	1500	117.01	114.32	24499	19605

The results obtained for various simulations in multi-client multi-server and multi-client single-server architectures are shown in Table-1. In order to further analyze relations between packet rate, packet length, and average delay a three dimensional graph is plotted using the simulation results. The two architectures are compared in terms of average packet delay using the three dimensional view. Figure-6 and Figure-7 shows the three dimensional graphs plotted using the simulation results.

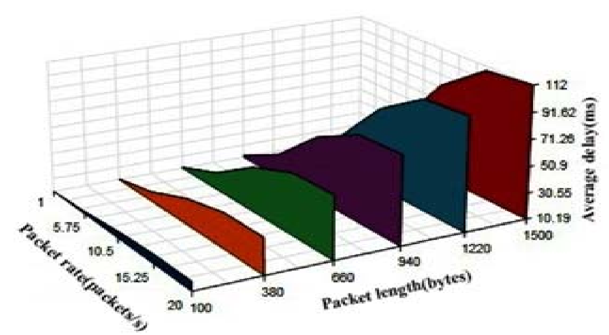

Figure-6. Multi-client multi-server architecture.

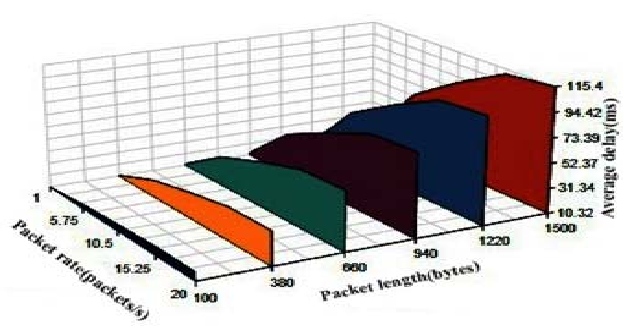

Figure-7. Multi-client single-server architecture.

CONCLUSIONS

Various simulations in network simulator 2 were performed to analyze the effect of additional server in network induced delays and packet losses. Multi client multi server system showed better performance in terms of delays and drops as compared to normal single server system. Network induced delays increases with increase in packet rate and packet length. Packet drops decreases with increase in packet length. For a fixed packet rate performance of multi server system is more effective at higher packet lengths. Multi server system is more effective in the case of packet drops at lesser packet lengths.

Overall, the MC–MS architecture performed better than other architecture because it could overcome the effects of network load and was unaffected by major packet losses. As long as the load on the network is kept below the maximum threshold of link utilization, the NCS showed excellent performance. However, in a real-time scenario a 100-Mbps high speed Ethernet network is seldom loaded to its maximum capacity. Based on the earlier observations, it is evident that multi-client multi-server systems hold a great potential for possible applications in factory automation.

REFERENCES

[1] Y. Halevi and A. Ray. 1988. “Integrated Communication and Control Systems: Part IAnalysis,”ASME Journal of Dynamic Systems, Measurement and Control, Vol.110, No. 4, pp. 367−373.

[2] A. Srivatsava. 2003. “Distributed Real-time Control via Internet,” M.S Thesis, Texas A&M University.

[3] J. Nilsson. 1998. “Real-time Control Systems with Delays,” Ph.D. Thesis, Lund Institute of Technology, Lund, Sweden.

[4] J. P. Thomesse. 2005. “Fieldbus Technology in Industrial Automation,” Proceedings of the IEEE, Vol. 93, No. 6, pp. 1073−1101.

[5] G. Olsson and G. Piani. 1992. Computer Systems for Automation and Control,Englewood Cliffs, NJ: Prentice-Hall.

[6] R. Metcalfe and D. R. Boggs. 1976. “Ethernet: Distributed Packet Switching for Local Computer Networks,” ACM Communications, Vol. 19, No. 7, pp. 395−404.

[7] T. Y. Mazraani and G. M. Parulkar. 1992. “Performance analysis of the ethernet under conditions of bursty traffic,” in Proc. IEEE Global Telecommun.Conf., Orlando, FL, Vol. 1, pp. 592–596.