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Switched Ethernet with Multiple Client-Server Architecture in Real Time Networked Control System Applications

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Abstract: ***The importance of real-time communications at the device level in a factory automation setup is a widely researched area. It is an effort to experimentally verify if Ethernet can be used as a real-time communication standard in a factory automation setup, by observing the effects of packet delays, packet loss, and network congestion on the performance of a networked control system. The NCS (Network control system) experimental setup used here involves a boiler operation real-time feedback control of multiple plants connected to one or more controllers over the network. A Multi client–multi server architecture on a local area network was developed using user datagram protocols the communication protocol. As the link utilization increased beyond the threshold, employing an additional server in the NCS reduced average packet delays and also overcame the negative effects of Ethernet's flow control mechanism. This paper experimentally verifies that a multiple-client–server architecture based on switched Ethernet can be used as a real-time communication standard for possible applications in factory automation, to reduce the packet delays and ease the flow mechanism.***

Keywords: Client–server architecture, link utilization, net-work control system, real-time system, switched Ethernet.

1. Introduction

The framework of an NCS with a single controller is shown in Fig.1 In this setup, the communication link between the controller and the plant has to compete with the traffic from other controllers and applications on the network. Industrial communications has come a long way from a dedicated point-to-point connection to optical wireless systems. However, the high costs of hardware and incompatibility of multiple-vendor systems have become barriers in its acceptance.

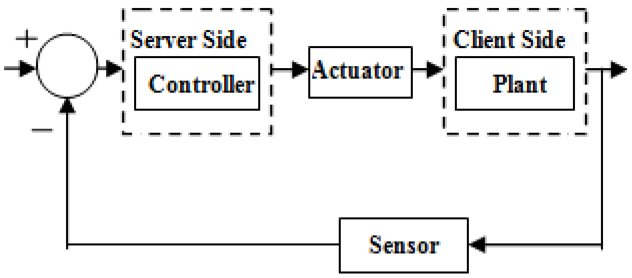

Figure 1: Feedback control over a Network

Recently, the computer network standard IEEE 802.3 ethernet has come up as an alternative for real time NCS. The advancements in Ethernet have made it possible to employ it in factory automation systems at the cell and the plant levels.

Ethernet has been studied extensively with a Poisson traffic model in different simulation models. However, in a real-time scenario, the traffic is mostly bursty in nature. Mazraani and Palkar found that as long as the network utilization did not reach a particular threshold behavior of the Ethernet remained the same under bursty conditions.

They also observed that as the utilization increased beyond a threshold, packet delay, queue lengths, and packet loss increased drastically. To address the issues of non determinism, network architectures based on switching have gained significance. Switches are network devices that operate at the data-link layer interconnecting various hosts.

Contrary to a shared architecture, in switched network architectures, frames are sent only to the addressed nodes reducing the number of collision domains considerably leading to a better handling of the traffic and considerable reduction in delay. In this research, a similar switched Ethernet network is used. The experimental setup including the hardware, software, and communication network is elaborated in experimental setup. The devel-opment of the MC–MS architecture is as follows.

A) Multi-Client-Server Architecture

Ethernet allows up to 1024 hosts per multi segment, there is always a physical limitation on the number of clients that a single server can handle. As the number of clients being served by a single server is increased, the communication is not only affected by network-induced delays, but also by the delays caused due to the processing time at the server. If the plants connected to the clients have a high sampling frequency, then it burdens the server with heavy timing requirements. To overcome these challenges multi server architecture as shown in Fig.2 was developed.

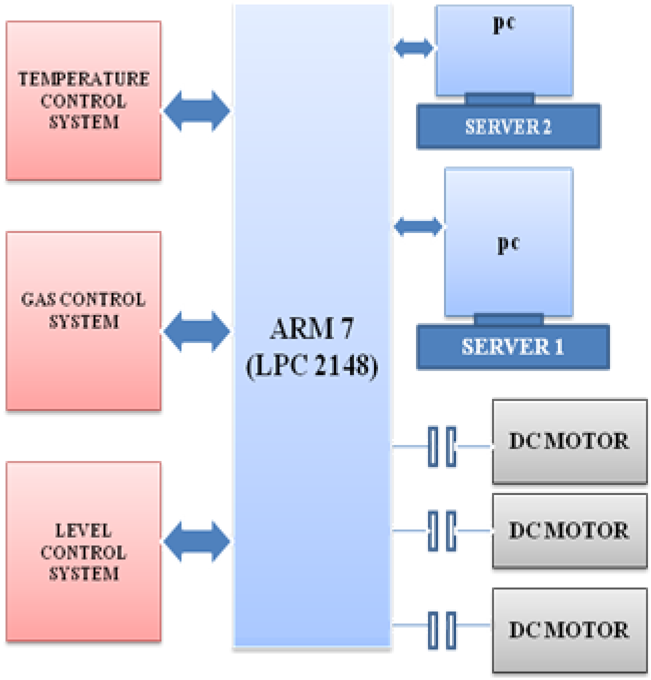

Figure 2: Block Diagram of Multi-Client-Server Architecture

A Multi server architecture improves the scalability of an NCS by giving the flexibility for a client to connect to a server based on the network load. In this research, the architecture is developed with the approach that the server can accept or reject clients based on the load, and the rejected client can automatically send a new request to a different server. The server decides solely based on the client's identification number. The previously developed architecture satisfies our needs because we are mainly concerned about the performance evaluation of an NCS under varying loads in an MC–MS scenario.

B) Experimental Setup

It includes cluster node 1 and cluster node 2.cluster node 1 as temperature control system and cluster node2 as gas control system. We use switched Ethernet at the server node for MC-MS architecture.

- **Cluster Node 1:** DC temperature control system is used as one of the cluster node for multiple clients in our test bed. The objective of a dc motor system is to control the temperature of the system at a certain threshold level.The dc motor system consists of five AMAX 26 dc motors connected to temperature sensor. A National Instruments (NI) AT89S52 board is connected at the controller node for data acquisition. The encoders are the sensors that send temperature signal outputs in terms of celsious and the controller sends back the control input as a pulse width modulation (PWM).
- **Cluster Node 2:** Dc gas control system is the second cluster node for this experiment.It includes SEN1327 gas sensor, Adc for data acquisition and pic as controller**.** The objective of this dc motor is to control the gas at certain threshold level.
- **Cluster Node 3:** Level Control system is the third cluster node for this experiment.It consists of a Level Sensor inorder to measure the displacement of the fluid and solenoid valve inorder to control the inflow and outflow of the fluid.
- **Server Node:** The server node includes Switched Ethernet, RJ45 for connecting the ARM board to the Router where Router helps to connect with the pc using the IP address.Switched Ethernet provides multi client-server networking. Ethernet Link is used for receiving the signal at server node.Pc is for monitoring the output.
- **Hardware and Software Used:** ARM Processor, Adc,Temperature sensor, Level sensor, Solenoid Valve, Gas sensor, Router, Rj 45 connector, Serial to Ethernet converter,, DC motor,Relay,Personal computer, Keil compiler, Embedded c, Proteus Simulator, Visual Basic6.0

2. Experimental Analysis

In Network multi server architecture for the two cluster nodes improves the scalability of an NCS by giving the flexibility for a client to connect to a server based on the network load. In this research, the architecture is developed with the approach that the server can accept or reject clients based on the load, and the rejected client can automatically send a new request to a different server. The server decides solely based on the client's identification number. This experiment includes cluster node 1 and cluster node 2 as its clients.

Our MC–MS client-rejection algorithm is as follows:

1) The server program starts and waits for requests from clients.
2) A client initiates a connection by sending a sensor packet with sensor signal values and an identification number.
3) The server checks for the identification number and decides whether it has to serve the client or not.
4) If it is found eligible for service, the server program selects the control loop relevant to the client and executes the sensor-control communication.
5) If it is found not eligible, the server sends a control packet with the control signal equal to "0." In a normal scenario the control signal is always found to be offset from zero. So, when the client receives a perfect "0" control signal, it considers it as the "reject" packet. The client then selects a different server and proceeds on with Step 2.

A general overview of the client-rejection process is illustrated in Fig 3. DC motor 1 is attached to Client and dc motor 2 is attached to Client 2. In this setup, Server 1 is programmed to accept only slower clients like Client 2 that is operating at low sampling frequency. So, when Client 2 sends a request, it gets accepted by Server 1 whereas the request from Client 1 to Server 1 gets rejected. Based on the client-selection–rejection algorithm, Client 1 sends a new request to Server 2. Because Server 2 is programmed to accept faster clients like Client 1, the request gets accepted as illustrated.

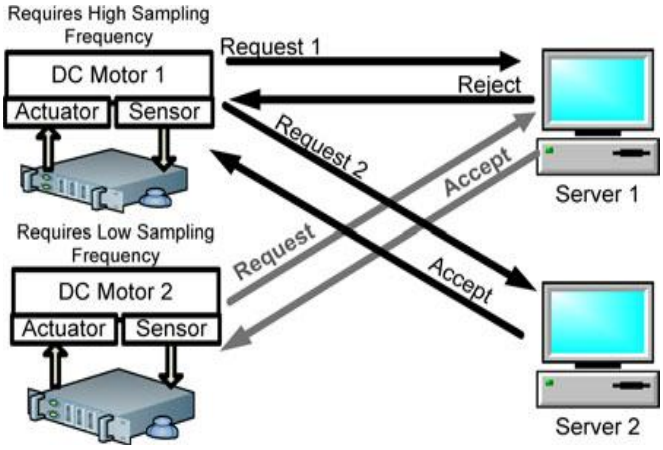

Figure 3: Illustration of Client Rejection Algorithm

Although the connection re-quests between the clients and servers are known previously, the motivation behind the client-rejection algorithm is to accommodate the dynamics of increasing network utilization and load. It is to be noted that the client rejection happens only during the starting of the connection process. From the experiments, it is found that the delay introduced between the client rejection and new server selection is in the order of 0.5 ms. This delay is both negligible and is worth the investment to have a congestion-free NCS.

3. Experimental Results

Parameter Analysis: Experiments were designed to provide maximum coverage by considering one of the parameter such as packet length increase while keeping packet rate constant.It is found that in each round of experiments, the packet rate was fixed, and the packet length was increased for every consecutive iteration. The packet length was increased from 100 bytes to1500 bytes in steps of 300 bytes generating a total of eight data points for every experiment. A total of six experiments were conducted by increasing the packet rate from 9000 to 14,000 packets/s in steps of 1000 packets/s. Hence, a total of 48 data points were generated in this test. This testing method verifies a scenario of non-real-time network utilization and it is shown in Fig.4

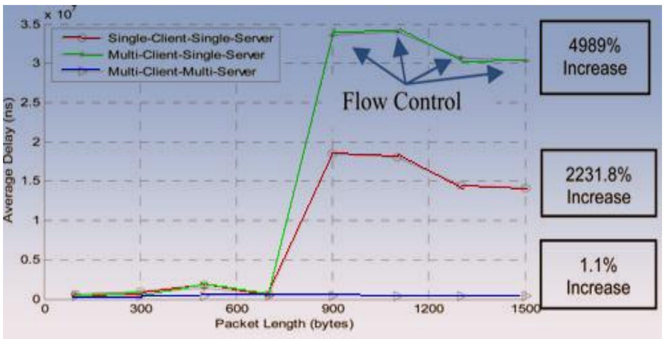

Figure 4: Performance Comparision of SC-SS, MC-SS, MC-MS

4. Simulation Output in Proteus

Fig.5 shows ciruit for the Multi server - Multi client architecture based Boiler Operation. It consist of three control systems such as boiler, level and gas control system.The main objective of a dc motor system is to control the temperature, level of water and gas leakage in the system at a certain threshold level through relay.when any one control system goes beyond threshold level the motor stops running and it is indicated to the user.

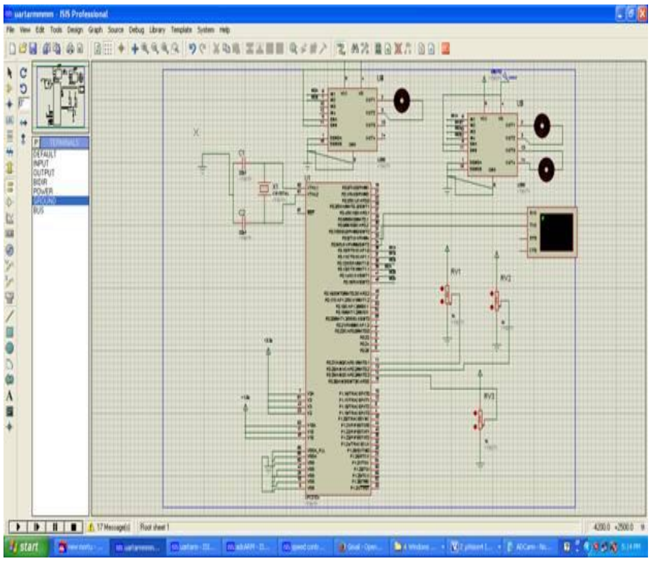

Figure 5: Simulation circuit in proteus software

5. Conclusion

Over all it verifies that a multiple client– server architecture based on switched Ethernet can be used as a real-time communication standard for possible applications in factory automation, by observing the effects of packet delays, network congestion, and packet loss on the performance of a networked control system.A multiclient–multiserver is experimentally verified using simulation software and the output is considerably accurate and faster due to the usage of switched ethernet.The very low error rate for the high and middle priority traffic shows that there is no need of complex transport and using ethernet is adequate for such class of applications.The future efforts will focus on controller design for NCS,which can differ significantly from the design of traditional centralized control systems and it includes conducting experimental studies of using specific algorithms in real time,as the basis for future message scheduling and control algorithm designs for NCSs inorder to overcome the negligible delays.

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