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# Development of Test Ethernet Network for Use in NPP

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**ABSTRACT—**
With growing internet using demands, the need of services at various scales of Quality of Service (QoS) has made appropriate classification of these types of services mandatory. Therefore, the Switched Ethernet Architecture has been proposed for NPP at various scales of services. Switched Ethernet are the composition of nodes with Ethernet switches. Switch receives a frame through transmission line from a source station, and checks the reception line of destination station for idleness. If the reception line is idle, the switch transmits the frame. Otherwise, the switch stores the frame into its buffer and waits until the reception line becomes idle. In addition, if several frames with the same destination address are received at the switch simultaneously, the switch stores frames to the buffer and then sends frames to the destination one by one. Here a solution is proposed adding a transport control layer over a test setup. Switched Ethernet gives stable performance. Traffic loading on one link does not affect the performance of other links. Traffic loading on one link does not affect the performance of other links. If two or more nodes are sending data towards a node, the receiving buffer of switch for receiving node may overflow and loss of frames takes place.

**Keywords**—Switched Ethernet; Transport control Layer; Test set up

## INTRODUCTION

Nuclear Power Plants (NPPs) have continued to generate electric power for many decades. In the control systems of a NPP, the control network connects various sub-systems and makes communication between them possible. When using a control network in NPP, its reliability, complexity and hard real time specifications must be considered. For safety critical systems, incorrect and delayed operations can lead to loss of life or other catastrophes. Therefore, safe and stable operation of a control network is very important for a control system used in nuclear power plants. These systems are having more sensors, actuators, and controllers. As number of devices in a system grows and the functions of the system need to be more complex, these devices need to exchange more and more amount of data among them in rapid manner. So, two requirements i.e. high bandwidth and determinism are becoming critical requirements of control network in advanced control systems. Many existing networks used as a control network, like MIL-1553B [7], Device Net [8], CAN [9], WorldFIP [10] or AS-Interface [11] have either low bandwidth or are complex in operation. MIL-1553B protocol is a deterministic protocol with centralized control. It supports
Exhaustive diagnostic test for error conditions. But this network supports 1 Mpbs bandwidth and maximum 31 numbers of nodes which make it inadequate as a control for a system that needs higher bandwidth. Token

bus (used in ControlNet) protocol is also a deterministic protocol that provides high throughput and efficiency. In this protocol, token is passed to each node in a cyclic manner which makes it deterministic in operation. But when number of nodes increases, additional delay to wait for token is added to each node and maximum time spends in passing the token between nodes. Table 1 summarizes the difference among several networks used in control systems.

TABLE I. **COMPARISON AMONG CONTROL SYSTEM**

| Networks → / Parameters ↓ | MIL-1553 B | CAN | Control Net | AS-Interface | World FIP | 100base Tx Ethernet |
|---|---|---|---|---|---|---|
| Data rate (Max) | 1 Mbps | 1 Mbps | 5 Mbps | 167 Kbit/s | 5 Mbps | 100 Mbps |
| Max Length (Meter) | 100 (Approx) | 100 | 1000 | 300 | 5000 | 205 |
| Max. Data Size (byte) | 2 | 8 | 504 | 4 bits | 256 | 1500 |
| Min. Data Size (byte) | 2 | 8 | 7 | 4 bits | 0 | 46 |
| Minimum Overhead per message | 20 to 80 bits + 4 bits per data frame | 47 bits | 7 bytes | 16 bits | 12 bits per data frame | 26 bytes |
| Communication Method | Master/Slave | CSMA AMP | Token Bus | Master/Slave | Master/ Slave | Multi Master |
| Nodes (Max.) | 32 | 127 | 99 | 31 | 256 | No Limit |
| Network Management | Bus controller, Status word | Error controll & Emergency Message | Token Passing | Master - Slave | Bus Arbitrator | -NA- |

Switched Ethernet (100baseTx) is a better choice for real-time control systems because:

1. One pair of wire is dedicated to each direction of communication for each node, so no possibility of occurrence of collision.
2. CSMA/CD is shut off [2], means any node can transfer any time without even listening to the media.
3. Each pair is having 200 Mbps bandwidth [2], so adequate amount of bandwidth available.

In spite of these advantages, guaranteed time bound cannot be promised with this network because:

1. If too much traffic is moving towards an output port of switch, congestion can occur there.
2. If too much traffic is moving towards the switch and switch is too slow to process all traffic, congestion can occur at input ports of switch. Frames can also be lost due to buffer overflow of switch in both conditions.
3. The processing and queuing delay of frame in switch can lead to non-deterministic behaviour under different loading conditions. The increasing number of switches between nodes, make it worst.
4. Packet lost or corrupted due to logical error and electrical noise.

**ETHERNET NETWORKS**

Ethernet, often referred as IEEE 802.3 developed for data communication among computers in the early 1973s by Institute of Electrical and Electronics Engineers (IEEE), to operate with a data rate of 2.94 Mbps using a CSMA/CD protocol. Success with that project attracted early attention and led to the 1980 joint development of the 10-Mbps Ethernet version-1.0 specification by three company consortium: Digital Equipment Corporation, Intel Corporation, and Xerox Corporation. The draft standard was approved by the 802.3 working group in 1983 and was subsequently published as an official standard in 1985 (ANSI/IEEE Std. 802.3-1985). Since then, a number of supplements to the standard have been defined to take advantage of improvements in the technologies and to support additional network media and higher data rate capabilities, plus several new optional network access control features. In first generation of Ethernet networks thick coaxial cable was used as backbone. In such networks maximum segment length is 500 meters; maximum total diameter is 2500 meters and transmission speed is 10Mbps. The present generation of Ethernet standards uses twisted-pair wiring or fibber-optic cables in a star network topology. Nowadays, Fast Ethernet (100 Mbps) and Gigabit Ethernet (1Gbps) [2] are running successfully.

Basically, Ethernet includes a shared transmission medium such as a twisted pair cable or coaxial cable and a multi-port hub. All devices on the network use the same share media for communication. The network nodes are connected to each other through hub using cables in a star-like or a bus-like topology. In the conventional Ethernet, hub is a passive device that broadcasts whatever it receives from source, as shown in Figure 2.1. Ethernet uses a broadcast access method called CSMA/CD in which each node notices all messages. Each node can access the network and can send message anytime using CSMA/CD.

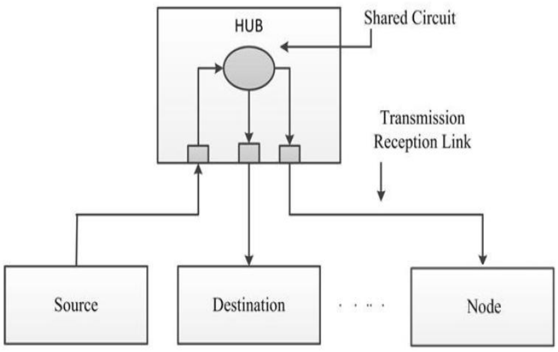


**Figure 2 Conventional Ethernet**

## SWITHED ETHERNET NETWORK

With the advent of Ethernet switch, a new generation of Ethernet networks evolved. The Ethernet nodes along with Ethernet switches are defined as Switched Ethernet networks.

This topology supports two primary mechanisms: micro-segmentation and full duplex communications. With micro-segmentation, each device is isolated in its own segment. All cables are point to point, from one station to a switch and vice versa. This feature renders a full duplex operation possible on each cable without any collision. So in Switched Ethernet, collisions are completely eliminated.

A typical method of switching technology is store and forward method [12] as shown in Figure 2.4. In this figure, switch receives a frame through transmission line from a source station, and checks the reception line of destination station for idleness. If the reception line is idle, the switch transmits the frame. Otherwise, the switch stores the frame into its buffer and waits until the reception line becomes idle. In addition, if several frames with the same destination address are received at the switch simultaneously, the switch stores frames to the buffer and then sends frames to the destination one by one. Table 2 summarizes the difference between conventional Ethernet and Switched Ethernet networks.

TABLE II. **CONVENTIONAL ETHERNET VS SWITCHED ETHERNET**

TABLE III.

| Parameters | Conventional Ethernet | Switched Ethernet |
|---|---|---|
| Standard | IEEE 802.3 | IEEE 802.3x |
| Networking Device | Hub | Switch |
| Topology | Bus | Star |
| Mode of Operation | Half Duplex | Full Duplex |
| Collision | Part of Network | Does not occurs |
| CSMA\CD | Strictly followed | Completely shut off |
| Multiple Convertation | No Possibility | Supports |
| Different Speed per Segment | No Possibility | Supports |
| Bandwidth per node | X for XbaseY standard | 2*X for XbaseY standard |
| Flow Control | By upper layer only | Supports |
| Channel Capture | Possibility | No possibility |
| Late Collision | Possibility | No possibility |

## SOLUTION BASED ON MODIFYING ETHERNET HARDWARE

These solutions falls in different categories as explained below:

### *A.* Modifying Nodes

Carrier Sense Multiple Access/Deterministic Collision Recovery (CSMA/DCR) defined in [18] consist a binary tree of colliding nodes based on hierarchy of priorities. Whenever collision occurs lower priority nodes voluntarily cease contending for the bus and higher priority nodes try again. This process is repeated until successful transmission occurs. The drawback of such scheme is worst case transmission delay can be much higher than the average transmission delay. Solution proposed in [6] implemented a traffic shaper which directly interacts with MAC controller. The main drawback in both cases is firmware must be modified, so commercially available hardware is not useful.

It is the average of the delay ((received time)-(sent time)) of every data packet travelling into the network.

### *B.* Modifying Switch

EtheReal [19] project was to build scalable real time switches that support bit rate reservation. However, EtheReal is throughput oriented which means there is no or limited support of real time communication [5]. Solution proposed in [5, 20] used an intelligent switch in which, they implemented Early Deadline First (EDF) scheduling [20] as traffic shaper which delivers the frames based on deadline. However, the use of such intelligent switches is limited in control systems.

## SOLUTION BASED ON ADDING TRANSPORT CONTROL LAYER OVER ETHERNET

These solutions falls in different categories as explained below:

### *C.* Token Passing

This method consists on circulating a token among the stations. Only the station currently holding the token is allowed to transmit and the token holding time is bounded. This scheme is still not very efficient due to the bandwidth used by the token and induces large jitter in the periodic traffic due to variations in the token holding time. Furthermore, token losses generally impose long periods of bus inaccessibility. RETHER protocol [21] is based on this scheme.

### *D.* TDMA

In this case, stations transmit messages at predetermined is joint instants in time in a cyclic fashion. This approach requires precise clock synchronization and does not lend itself well to dynamic changes in the message set because the communication requirements are distributed and thus, changes must be done globally. On other hand, it uses the bus bandwidth efficiently since there are no control messages beyond those to achieve clock synchronization.

### *E.* Virtual Time Protocol

Virtual time protocol [24] tries to reduce the number of collisions on the bus while offering the flexibility to implement different scheduling policies. When a node wishes to transmit a message it waits for a given amount of time counting from the moment the bus became idle. This amount of time is calculated according to the desired scheduling policy. When that time expires, and if the bus is still idle, the node tries to transmit the message. If a collision occurs, then there is another node with a message with the same tolerance. This kind of approach has some important drawbacks:

1. Performance highly dependent on the proportional constant value used to relate the waiting time with the scheduling policy.
2. Worst case transmission time is much higher than average transmission time.

### *F.* Traffic Shaping

This approach is based on the fact that if bus utilization is kept low, the probability of collisions is also low. Therefore, if the network average load is kept below a given threshold and bursts of traffic are avoided, a given probability of collisions can be obtained. One implementation of this technique is given in [23]. Major drawback of this approach is that all the guarantees are statistical; it cannot be guaranteed a priori that a specific message can be transmitted within a specific time interval. Therefore this approach is not well suited to support hard real-time traffic.

*G.* **Master Slave**

In this case, all ordinary stations (slaves) in the system transmit messages only upon receiving an explicit command message issued by one particular station called master. This approach supports relatively precise timeliness, depending on the master, but introduces a considerable protocol overhead caused by the master messages. However, this approach gives a promising way to achieve hard real time constraints with average throughput and flexibility. RTCC [24] is based on this approach. Table 3 comparing various protocols with real time parameters:

TABLE IV. **PROTOCOL COMPARISON**

| Parameters → / Protocols ↓ | Determinism in Worst Case | Clock Synchronization | Change in Hardware | Bandwidth Utilization | Collision Possibility | Speed (bps) |
|---|---|---|---|---|---|---|
| CSMA/DCR | Doubtful(1) | No | Yes | Low(2) | Yes | 10M |
| RETHER | Good | Yes | No | Low(3) | No | 100M |
| TDMA | Good | Yes | No | High | No | 10M |
| Virtual Time | Doubtful(1) | Yes | No | Low(2) | Yes | 100M |
| Traffic Smoothing | Doubtful(1) | No | No | Low(2) | Yes | 10M |
| RTCC* | Good | No | No | High | No | 10M |

**TEST SETUP**

Figure 4.15 is showing the connections of hardware devices used for this project.

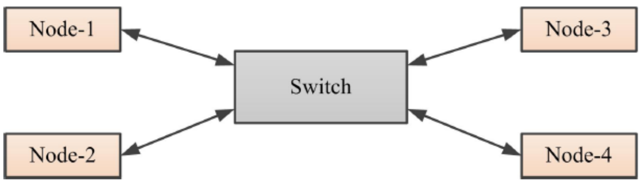


**Figure 4.15: Test-Setup**

1. Node-1 (Laptop Computer)
   Processor - Intel Core 2 duo, 1.83 GHz
   RAM - 1 GB
   Ethernet Controller - 10/100 Mbps
2. Node-2 (Laptop Computer)
   Processor - Intel core-i5, 2.4GHz
   RAM - 6 GB
   Ethernet Controller - 10/100 Mbps
3. Node-3 (Laptop Computer)
   Processor - Intel Core 2 duo, 1.83 GHz
   RAM - 1 GB
   Ethernet Controller - 10/100 Mbps
4. Node-4 (Laptop Computer)
   Processor - Intel core-i3, 2.2GHz
   RAM - 1 GB
   Ethernet Controller - Ethernet Controller - 10/100 Mbps
5. Switch
   Index 8 Port 10/100M switch
6. Cable used for connection
   Cat-5e UTP (Unshielded Twisted Pair) cable

## TEST RESULT

### *H.* Message Cmpletion Delay for Data frame Size

Figure 4.16 is showing the slave-to-slave message completion delay for different Frame sizes. This delay includes two command frames, two status frames and one data frame. Figure shows up to 512 bytes of data frame size, the delay in increasing sharply and after 512-bytes the delay is increasing gradually. Figure 4.17 is showing the comparison between slave-to-slave message completion time of MIL-1553B and designed algorithm. According to the figure, for small data size (1-8 bytes) MIL-1553B network is still giving better performance. However after that, as data size increases, the delay in MIL-1553B networks increases much faster with respect to Ethernet network designed using algorithm.

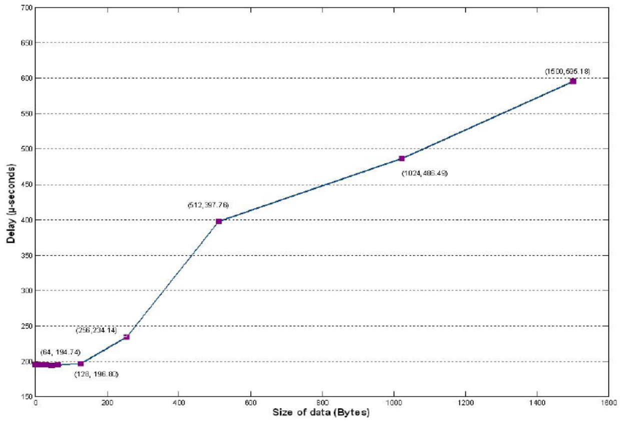


**FIGURE 4.16: MESSAGE COMPLETION TIME**

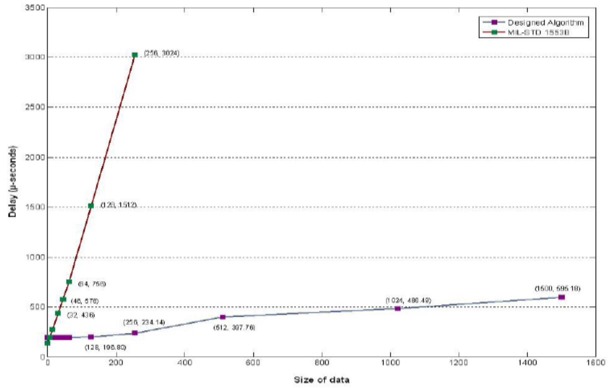


**Figure 4.17: Algorithms comparison with MIL-1553B**

### *I.* Message Cmpletion Delay for Data frame Size

Figure 4.18 is showing the slave-to-slave one message completion time for different numbers of data frame of frame size 64 bytes with two command frames and two status frames. Figure is showing linear and deterministic characteristic for any number of data frames.

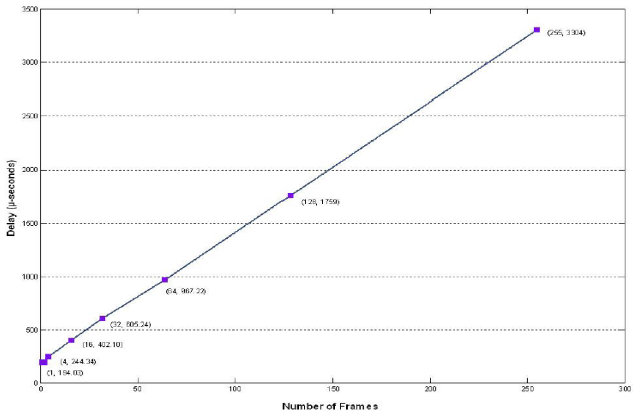


**Figure 4.18: Effect of number of frames on message completion**

### *J.* Maximum Bandwidth

Figure 4.19 is showing the distribution curve while computing the maximum bandwidth supported by this algorithm. To compute maximum bandwidth message completion time for one slave-to-slave is computed by keeping data frame size to 1499 bytes and number of data frames to 255. Time for such 10000 messages completion is measured and their distribution is as shown

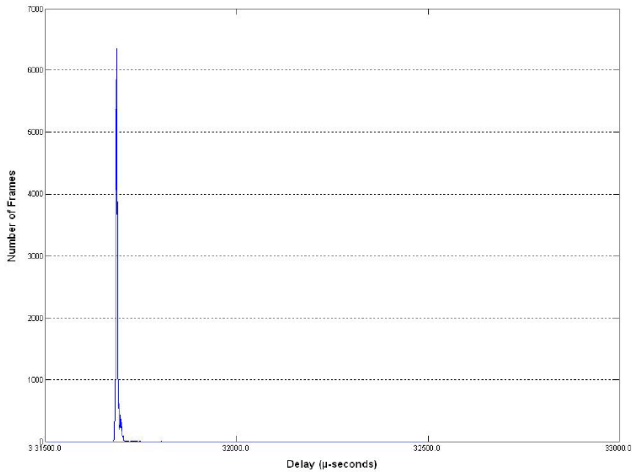


**Figure 4.19: Maximum bandwidth**

Total number of data bits = 3057960 bits
Average message completion time = 31387 micro-seconds
Maximum message completion time = 32491 micro-seconds
So, Maximum bandwidth = 94.11 Mbps (For maximum message completion time)

## CONCLUSION AND FUTURE WORK

This paper has presented many types of network scenarios under normal conditions Switched Ethernet gives stable performance. Traffic loading on one link does not affect the performance of other links. If two or more nodes are sending data towards a node, the receiving buffer of switch for receiving node may overflow and loss of frames takes place. In any frame error condition, the corrupted frame is not forwarded by switch. Adding a master-slave based real time layer over Switched Ethernet makes the network deterministic.
The delays introduced by adding developed algorithm is acceptable for control system applications. Master-slave based architecture is an effective and flexible solution to achieve deterministic behaviour. The setup can be tested with more number of devices and in nosier environment. Error diagnostic feature can also be added to developed algorithm to take more Appropriate action in error conditions.

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