

Performance Evaluation of Switched Ethernet as Communication Media in Controller Networks

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Abstract: *The paper presents a simulation scenario for performance evaluation of switched Ethernet as communication media in controller networks. Ethernet is the most accepted Local Area Network technology, characterized with low price and deployment robustness. Using Ethernet instead of custom industrial communication protocol can ease the development of applications. The introduction of Fast Ethernet and micro-segmentation eliminates some of the biggest problems of using Ethernet in controller networks. This also enables integration of controller networks with the enterprise and global networks. The use of queue management discipline shows a lot of possibilities for achieving requirements for different type of services. The evaluation is by means of simulation analysis, using network simulator – NS2 as a tool. The results are used for studying the interactions in multi-tier model for distributed automation and for improving its communication performance. Some particular classes are proposed for prioritisation of different CNDEP traffic used in the multi-tier model.*

Key words: *Fast Ethernet, Embedded Communication, Simulation Analysis.*

INTRODUCTION

Ethernet is the most accepted Local Area Network technology. Its wide adoption has led to low price and robustness of deployment and has created a trend to expand its use in the factory-floor. Using Ethernet instead of custom industrial communication protocol can ease the development of applications. By using a standard TCP/IP stack on top of Ethernet, embedded systems can become widely accessible over wide area networks. This provides the base for integration of factory-floor and the enterprise network. Despite these benefits there are some requirements that must be fulfilled. The traffic in the control loop must have high priority and must always meet the deadlines. Many published works exist that have efforts to evaluate using of Ethernet in control networks. Most of them concentrate on the shared medium defined in early standard implementations. Nowadays, Fast Ethernet is more widely used than Shared Ethernet and Gigabit Ethernet is gaining popularity in offices. These standards provide not only faster communication but allow breaking collision domains using switches and impose full-duplex links. This new environment leads to new research perspectives, as published in [1, 2, 3, 4, 8, 10, 11, 12, 14].

The aim of this paper is to show the performance characteristics of switched Ethernet as communication media in controller networks through simulation using NS2 network simulator as an evaluation tool.

Motivation

The vast use of Internet in all fields of our life and the globalization of services and businesses leads to new class of applications – distributed over wide areas. The embedded systems do not stay away of this trend. Newly developed applications try to integrate the devices in the global network. Factory-floor systems are connected with the enterprise network and applications.

One way to integrate the automation systems from the factory-floor and the enterprise information systems is by the use of multi-tiered architectures [7]. Multi-tier architecture is adopted from the database systems, where business logic is separated from the presentation logic and data storage. In the multi-tier model, presented in [7], the data tier is replaced by a controller network. This leads to increased availability and security, as long as to separation of functionality. The controllers in the network communicate only with the server on the upper (service) tier, which is their adapter in the complex distributed architecture.

Implementation of the multi-tier model leads to the need of evaluation of the interaction between the tiers and in the tiers themselves. In the current paper, an evaluation of the interaction and communication in the data tier (the controller network) is proposed. In the controller network the upper layer communication protocol is CNDEP [6]. This is application layer protocol based on UDP.

Background

Ethernet has been developed for use in office networks and provides non-deterministic algorithm for media access (CSMA/CD). This 1-persistent media access method tries to provide statistically "fair" access to the channel to all nodes. The main drawback of Ethernet for control networks is its non-deterministic manner in the case of collision occurrence. When a collision is detected, all nodes must wait for a random time before continuing with transmission. This drawback can be seriously isolated by using micro-segmentation. In extreme micro-segmentation every device is isolated in its own collision domain and collisions do not occur. The use of full-duplex channels has further eliminated the concurrence for the media and every device can transmit at will. The only shared resource is the switch internal fabric. Further, the need of channel scheduling techniques for real-time traffic that was not supported in early Ethernet implementation, are now included in the standards.

Common LAN switches may have two basic modes – cut-through and store-and-forward. The first mode provides on-the-fly commutation, i.e. a packet is forwarded as fast as possible. The second mode receives the whole packet and inspects it, after that a decision is made whether to forward or drop the packet. The cut-through switches has very small latency but they can forward malformed packet because the CRC is calculated after forwarding [1].

Quality of Service (QoS) mechanisms provides the necessary level of service (bandwidth and delay) to an application in order to maintain an expected quality level. To a mission-critical application, this means guaranteed bandwidth with zero frame loss. For real-time applications, this also means guaranteed frame latency. Fine-grain control provided by QoS places a significant burden on the network infrastructure. Each device must keep an entry in its forwarding table for each flow. Class of Service (CoS) mechanisms reduce flow complexity by mapping multiple flows into a few service levels. Instead of the fine grain control of QoS, CoS applies bandwidth and delay to different classes of network services. Two common CoS mechanisms are: IEEE 802.1p – tagging (Layer 2); and Type of Service (ToS) – prioritization (Layer 3). Both provide prioritization but have their limitations. Differentiated Services (DS) is an advanced architecture of ToS. The 802.1p standard works on the MAC sub-layer and do not depend on the upper layer transport [1, 5, 13].

The 802.3x standard provides some mechanisms for flow control. The flow control can be crucial to avoid degradation in real-time communication performance. Using flow control can led to reduced network performance in some cases but when applied in the controller network it can guarantee the transmission of important frames and avoid frame loss. Flow control can be implemented on a link-by-link or end-to-end basis and allows all devices on the path to reduce the amount of data they receive. Link-by-link flow control examines only an individual link between switches or stations. When the recipient of a transmission becomes busy, it will send a signal to the directly linked transmitter. If that transmitter is not the originator of the traffic, this signal would have to be propagated back through each link in order to reach the originator of the traffic. End-to-end flow control means that the switches at each end of the link communicate to throttle back the end stations that are originating the traffic. Until this information is propagated, packets must be stored or dropped, meaning that flow control reduces, but does not eliminate, the need for buffers [1, 5]

SIMULATION SCENARIO

In this section we discuss the simulation scenarios used for the evaluation of Ethernet and CNDEP in controllers' networks. We ran a series of simulations using the topology shown on figure 1. It consists of a Transaction Server (TS), Intelligent Fast Ethernet switch and Ethernet-enabled controllers. The TS sends 'Set' and 'Get' commands to controllers and receive responses and alarm messages [6]. The following parameters are used in simulations [9]:

- 1) Queuing time (T_{queue}): is defined as the time that the message waits in the buffer at the source and intermediate nodes. For the specific case, delay in source node can be ignored and T_{queue} is defined by the time waiting in the buffers of the switch node. We influence on that time by altering the buffer sizes.
- 2) Blocking time (T_{block}): is defined as the time that the message must waits once it is ready to be send because of media concurrence and collisions. Since we assume full duplex micro-segmentation scenario $T_{\text{block}} \approx 0$ and can be ignored.
- 3) Frame time (T_{frame}): depends on the size of the data, overhead, any padding, and the bit time. It is implicitly defined in the simulations.
- 4) Propagation time (T_{pd}): depends on the signal transmission speed ($\approx 1.77 \cdot 10^8 \text{m/s}$ for UTP cables) and the distance between source and destination. For the worst case (100m distance), $T_{\text{pd}} = 0,556 \mu\text{s}$.

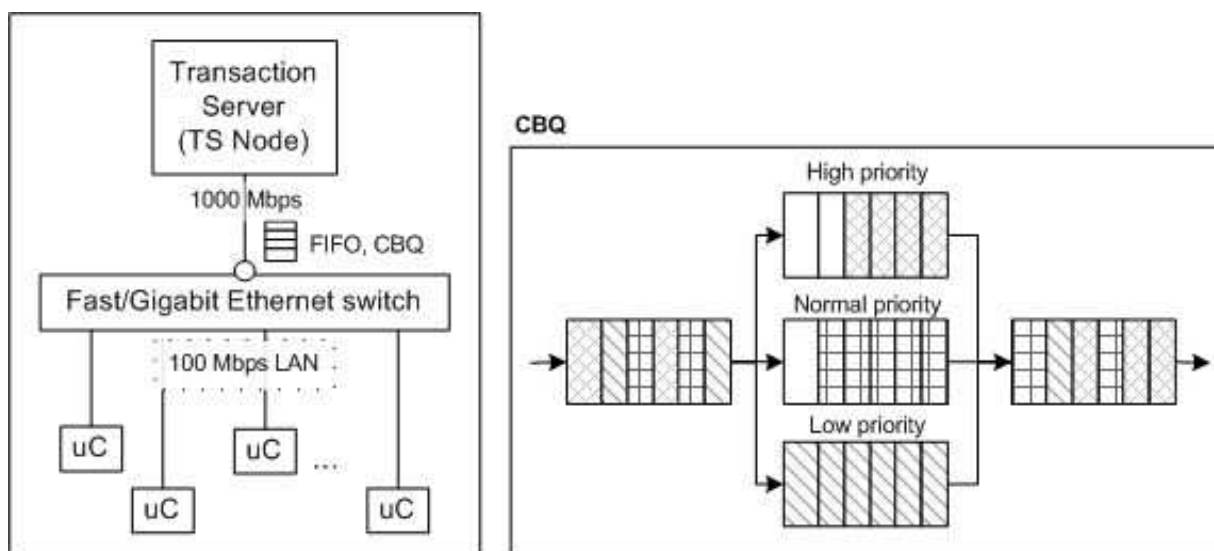


Figure 1: Controller Network Topology and CBQ with 3 classes of flows applied at the uplink switch port.

Controller networks workloads are comprised mainly of periodical, synchronized and shorter in length messages. Constant bit rate (CBR) traffic that is close enough to that pattern is used in simulations. The rate used in simulations is one packet on every $500 \mu\text{s}$. Since we suggest integrating controller networks with enterprise networks we also assume noise traffic with Poisson distribution comprised of FTP and HTTP.

Controller networks rarely consist of more than 10-20 controllers at most. In the simulations we use from 9 to 99 controllers – increasing their number (load respectively) in runtime. That let us evaluate the performance degradation in means of throughput, delays and packet lost.

On the uplink port of the switch that connects to the TS a CBQ queue management is used (figure 1). Its implementation is based on priorities and bandwidth reservation close to the class based queuing – 802.1p. For the purpose of simulation three different priority levels are used (high, normal, and low priorities) with explicitly defined in the simulations bandwidth reservation (figure 2).

CNDEP protocol uses commands with different requirements that could be mapped to particular priority class in CBQ. The mapping could be done on usage also – for observation, alarm message or just for logging. Alarm messages are the most critical commands both in terms of time delay and successfully delivery. On the opposite side are commands like ‘GetImage’ [6] when used for logging. If they are used for real time observations, they will have stronger requirements to the delay and jitter, while packets lost are acceptable. Commands for obtaining environmental variables has different requirement depending on whether used for observation or logging. If the former is true they can accept lost packets and the last-is-best approach serves them well. It means shorter queue buffers and shorter delays respectively. If they are used for logging than the packet lost should be reduced to zero but higher delays are acceptable – longer queue buffers. Different classes can serve to differentiate between the requirements. In the simulations three general classes of CBQ are used.

SIMULATION RESULTS

For the performance evaluation of switched Fast Ethernet and CNDEP the time delay and packet loss in respect to workloads is measure, and queue lengths for three different priority classes. The workload is increased in simulation time by increasing the number of controllers (form 9 to 99). Two different queue lengths are used – unlimited size and size of 20 packets.

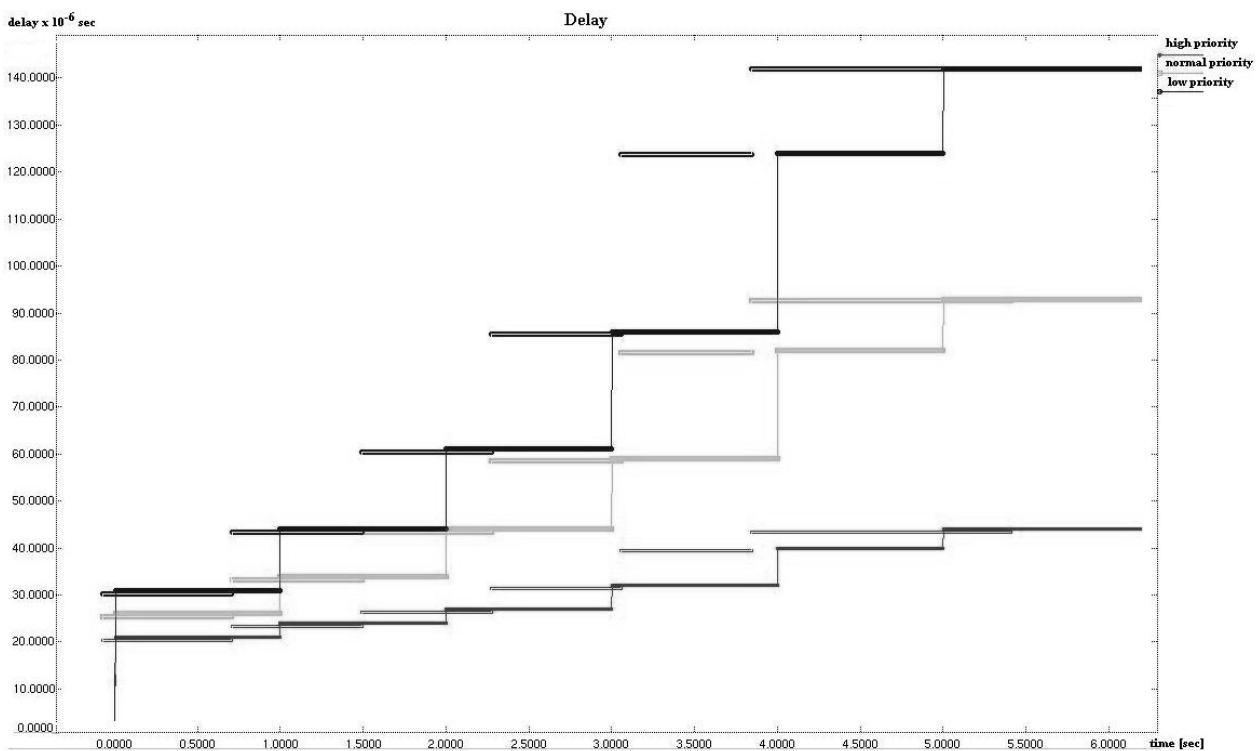


Figure 2: Message delay for three different CBQ classes and unlimited queue length.

For the unlimited queue length, the messages experience a longer delay for all three CBQ classes as expected. However, this results in no message loss (Table 1) and thus is suitable for logging services. For shorter queue length the delay is much smaller, but the message lost increase seriously. The results are shown on figure 2 and figure 3.

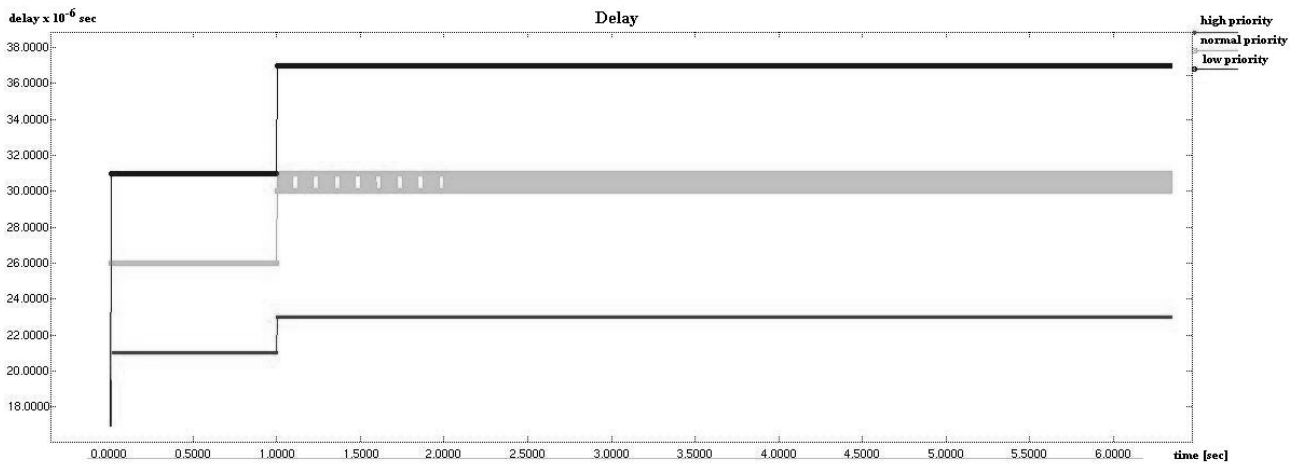


Figure 3: Message delay for three different CBQ classes and short queue length.

Table 1 shows the ratio between successfully received and unsend (dropped) messages in relation to the size of the queue buffer. The results measured are for three different priority CBQ classes.

Table 1: Received vs. Dropped message in relation to queue length.

		Queue Buffer Size							
		queue buffer = 5pkts		queue buffer = 20pkts		queue buffer = 30pkts		queue buf = 1000pkts	
		packets	bytes	packets	bytes	packets	bytes	packets	bytes
High Priority	received	119943	25188030	119943	25188030	119943	25188030	119943	25188030
	dropped	86975	18264750	4990	1247500	0	0	0	0
Normal priority	received	119943	25188030	119943	25188030	119943	25188030	119943	25188030
	dropped	92974	19524540	27989	5877690	1999	419790	0	0
Low Priority	received	125940	26447400	125940	26447400	125940	26447400	125940	26447400
	dropped	98971	20783910	33986	7137060	7996	1679160	0	0

CONCLUSIONS AND FUTURE WORK

The presented simulation scenarios are used for evaluation of a Fast Ethernet as a communication media for distributed embedded systems. The scenarios are based on a real multi-tier system for distributed automation. The results show that using Fast Ethernet switches with 802.1p implemented on them is a very good choice for building controller networks. Using different priority queues and bandwidth reservation, the time-critical traffic can meet its deadlines. The calculated delay and jitter for the high priority traffic is small enough to satisfy the demands of the real-time applications. The very low error rate for the high and middle priority traffic shows that there is no need of complex transport and using UDP is adequate for such class of applications. The results also show some parameters' boundaries for the examined network, like number of controllers in a single network and queue buffer size, and can be used as base for determination of the number of priority classes and mapping of traffic and classes.

ACKNOWLEDGEMENTS

The presented work is supported by National Science Fund of Bulgaria project – “**BY-966/2005**”, entitled “Web Services and Data Integration in Distributed Automation and Information Systems in Internet Environment”, under the contract “**BY-MI-108/2005**”.

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