Architectural Impact of FDDI Network on Scheduling Hard Real-Time Traffic

Preface

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Abstract

We examine the architectural impact on guaranteeing synchronous message deadlines in FDDI token ring networks. The FDDI network does not have facility to support (global) priority arbitration which is a useful facility for scheduling hard real-time activities. As a result, we found that the worst case utilization of synchronous traffic in an FDDI network can be far less than that in a centralized single processor system. Nevertheless, we propose and analyze a scheduling method which can guarantee deadlines of synchronous messages having traffic utilization up to 33% — the highest to date.

1 Introduction

High speed networks are vital for the support of distributed hard real-time applications. In hard real-time systems tasks must satisfy explicit time constraints; otherwise, grave consequences may result. Consequently, the messages transmitted in the network are also time constrained. In this paper, we are concerned with architectural support and its impact in scheduling messages with hard real time constraints in an FDDI network.

The basic design requirements of scheduling real-time tasks in a centralized environment (e.g., a single processor system) and scheduling real-time traffic in a communication network (e.g., a token ring network) are similar: Both are constrained by time to allocate a serially used resource to a set of processes. For scheduling synchronous (i.e., periodic) computation tasks in a single CPU environment, the objective of the scheduler is to guarantee that the deadlines of all the tasks are met. Liu and Layland [10] analyzed a fixed priority preemptive algorithm, called *rate monotonic algorithm* which assigns priorities in the reverse order of task's periods. They showed that the *Worst Case Achievable Utilization* of the algorithm is 69%. That

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is, as long as the utilization of the task set is no more than 69% the task deadlines are guaranteed to be satisfied – even in the worst circumstances.

FDDI networks do not have facility to support (global) priority arbitration. As a result, the rate monotonic algorithm cannot be directly implemented. However, the methodology for analyzing rate monotonic scheduling algorithm has a more profound significance than merely its relevance to the algorithm. This methodology stresses the fundamental requirement of *predictability* and *stability* in hard real-time environments and is therefore also befitting to other hard real-time scheduling problems. In this methodology the *worst case achievable utilization* is used as a metric for evaluating the predictability of a scheduling algorithm. That is, as long as the CPU utilization of all tasks is within the bounds, specified by the metric, all tasks will meet their deadlines. This metric also gives a measure of the stability of the scheduling algorithm in the sense that the tasks can be freely modified as long as their total utilization is held within the limit. We should adopt this methodology in our study of guaranteeing deadlines of periodic messages in an FDDI network. In particular, we should pay attention to the architectural impact on the worst case achievable utilization of FDDI networks.

The remainder of the paper is organized as follows: Section 2 will outline the characteristics of the system under consideration, i.e., the message and network models. In Section 3, we will study the architectural impact on guaranteeing periodic (synchronous) message deadlines. Section 4 contains the concluding remarks and suggestions for future work.

2 System Characteristics

We consider the network topology as consisting of n nodes connected by point-to-point links forming a circle i.e., the token ring. The overhead caused by the ring latency, which is the token walk time when none of the nodes disturb it, is denoted by τ. The usable ring utilization would therefore be $(1 - \alpha)$ [20].

Messages generated in the system at run time may be classified as either *synchronous messages* or *asynchronous messages*. We assume that there are n streams of synchronous messages, $S_1, S_2, \ldots, S_n$, one for each node in the system[1]. These n streams of synchronous messages form the synchronous *message set*, M, i.e.,

$$M = \{S_1, S_2, \ldots, S_n\}. \tag{1}$$

The characteristics of messages are as follows:

1. Synchronous messages are *periodic*, i.e., messages in a synchronous message stream have a constant inter-arrival time. We denote P_i to be the period length of stream S_i $(i = 1, 2, \ldots, n)$.
2. The *deadline* of a synchronous message is the end of the period in which it arrives. That is, if a message in stream S_i arrives at time t, then its deadline is at time $t + P_i$.
3. Messages are independent in that message arrivals do not depend on the initiation or the completion of transmission requests for other messages.

[1] This assumption can be relaxed. In [3], we show that this message model is logically and timmingly equivalent to that of the systems where a node may have zero, one, or more than one synchronous message streams.

4. The *length* of each message in stream S_i is C_i which is the maximum amount of time needed to transmit this message.

The *Utilization factor* of a synchronous message set, $U(M)$ is defined as the fraction of time spent by the network in the transmission of the synchronous messages. That is,

$$U(M) = \sum_{i=1}^{n} \frac{C_i}{P_i} \tag{2}$$

where n is the number of synchronous message streams.

3 Impact on Guaranteeing Periodic Messages

Scheduling (i.e., control of message transmission) in an FDDI network is implemented in its MAC layer by a *timed token protocol* which was proposed by Grow in [5]. In this protocol, messages are segregated into separate classes: the *synchronous* class and the *asynchronous* class. The idea behind the timed token protocol is to control the token rotation time. At network initialization time, a protocol parameter called *Target Token Rotation Time* (TTRT) is determined which indicates the expected token rotation time. Each station is assigned a fraction of the TTRT, known as *synchronous capacity* [2], which is the maximum time a station is permitted to transmit its synchronous messages *every time* it receives the token. Once a node receives the token, it transmits its synchronous message, if any, for a time no more than its allocated synchronous capacity. It can then transmit its asynchronous messages only if the time elapsed since the previous token departure from the same node is less than the value of TTRT, i.e., only if the token arrived earlier than expected. In this way, the time elapsed between any two consecutive token visits at a particular node (i.e., the token rotation time) is bounded. In [7, 16], Johnson and Sevcik formally proved that when the network operates normally, the token rotation time between two consecutive visits to a node is bounded by $2 \cdot TTRT$.

Although the bounded token rotation time property provides a necessary condition for guaranteeing all the periodic message to meet their deadlines, it is inadequate. A node may be unable to complete the transmission of a synchronous message before its deadline since insufficient synchronous capacity may be allocated to the node. Thus, for a given network model[3], whether or not a set of synchronous message can be guaranteed is dependent upon the allocation of the synchronous capacities to the nodes. We have analyzed the performance of FDDI networks with several synchronous capacity allocation schemes. The results can be briefly summarized as follows:

Full Length Allocation Scheme. With this scheme, the synchronous capacity allocated to a node is equal to its total time required for transmitting its synchronous messages, i.e.,

$$H_i = C_i. \tag{3}$$

This scheme attempts to transmit a synchronous message arriving at a node in a single turn *rather than* splitting it into chunks and distributing its transmission evenly over its period P_i. Although the

[2] Some other synonymous terms that researchers use are: *Bandwidth allocation* [20], *Synchronous allocation* [6], *Synchronous bandwidth assignments* [7], *High Priority token holding time* [13], etc.

[3] In terms of parameter values of n – the number of nodes, τ – the token walk time, and TTRT – the target token rotation time.

synchronous capacity allocated is sufficient, we have found [3] that in an FDDI network, the worst case achievable utilization of synchronous traffic can asymptotically approach 0% if this allocation scheme is used.

That is, for any given $\epsilon > 0$, there exists a message set M such that $U(M) \leq \epsilon$ and the deadline of some message in M cannot be met when the synchronous capacities are allocated using the Full Length Scheme.

Equal Partition Allocation Scheme. In this scheme, the usable portion of TTRT is divided equally among the n nodes for allocating their synchronous capacities, i.e.,

$$H_i = \frac{TTRT - \tau}{n}, \tag{4}$$

where n is the number of nodes in the system.

For this scheme, we also showed that the worst case achievable utilization of synchronous traffic can asymptotically approach 0% [3].

Normalized Proportional Allocation Scheme. With this scheme, the synchronous capacity is allocated according to the normalized load of the synchronous message on a node, i.e.,

$$H_i = \frac{C_i/P_i}{U}(TTRT - \tau), \tag{5}$$

where $U = \sum_{i=1}^{n} C_i/P_i$.

Let α be the ratio of the ring latency τ to the target token rotation time (TTRT). We obtained in [3] that the worst case achievable utilization of an FDDI network is $\frac{1}{3}(1-\alpha)$ when the Normalized Proportional Allocation Scheme is utilized.

From the results of our analysis, the architectural impact of the FDDI network on guaranteeing synchronous message deadlines is evident. Implementing the optimal rate monotonic scheduling algorithm requires the support of global priority arbitration. Without such facility, the worst case achievable utilization cannot be as high as that achieved on centralized systems.

Nevertheless, the FDDI network does provide means to control message transmissions through appropriate settings of the protocol parameters like synchronous capacities of the nodes. Improper settings of these parameters can result in worst case achievable utilization of 0% while appropriate settings can guarantee the deadlines of synchronous messages with utilization up to 33%. To the best of our knowledge, no other method has been reported to achieve a better utilization. Hence, this allocation scheme should be recommended for use in hard real-time FDDI token ring networks.

4 Future Work

Currently we are investigating issues in the design and implementation of an optimal synchronous capacity allocation scheme. An optimal scheme should always guarantee a message set if there exists another allocation scheme which can do so. Clearly, the optimal scheme has the highest worst case achievable utilization. We are also working on multi-link ring networks where more than one link can connect two neighboring nodes. With this architecture, we would like to study the network performance in the context of the worst case achievable utilization.

References

[1] *FDDI Token Ring Media Access Control.* draft proposed — ANSI Standard X3T9.5/83-16. rev. 10, Feb. 28. 1986.

[2] *FDDI Token Ring Station Management*, draft proposed — ANSI Standard X3T9.5/84-49. rev. 2.1, April 16, 1987.

[3] G. Agrawal, B. Chen, W. Zhao, and S. Davari, "Achievable Utilization of Timed Token Medium Access Protocol for Hard Real-Time Synchronous Messages," *Technical Report, Computer Science Dept., Texas A & M University* , Oct. 1991.

[4] S. Davari and S. Dhall, "An on-line algorithm for real-time tasks allocation", *Proc. IEEE Real-Time Systems Symposium*, pp 194-200. Dec. 1986.

[5] R. M. Grow, "A Timed Token Protocol for Local Area Networks", *Proc. Electro/82, Token Access Protocols*, May 1982.

[6] R. Jain, "Performance Analysis of FDDI Token Ring Networks: Effect of Parameters and Guidelines for Setting TTRT," *IEEE LTS*, pp. 16-22, May 1991.

[7] M. J. Johnson, "Proof that Timing Requirements of the FDDI Token Ring Protocols are Satisfied", *IEEE Trans. Commun.* vol. COM-35. no. 6, pp. 620-625, June 1987.

[8] J. F. Kurose, M. Schwartz, and T. Yemini, "Controlling Window Protocols for Time-constrained Communication in a Multiple Access Environment," *Proc. IEEE Int. Data Communication Symp.* 1983.

[9] C. C. Lim, L. Yao, and W. Zhao, "A Comparative Study of Three Token Ring Protocols for Real-Time Communications", *IEEE Conf. on Distributed Computing Systems*, pp. 308-317, Arlington, Texas, May 1991.

[10] C. L. Liu and J. W. Layland, "Scheduling Algorithms for Multiprogramming in a Hard Real Time Environment," *J. ACM*, Vol. 20, no. 1, 1973, pp. 46-61.

[11] A. K. Mok and M. L. Dertouzos, "Multiprocessor Scheduling in a Hard Real-time Environment". *Proc. Texas Conf. Computing Syst*, Nov. 1978.

[12] J. Ng and J. Liu, "Performance of Local Area Network Protocols for Hard Real-Time Applications", *IEEE Conf. on Distributed Computing Systems*, pp. 318-326, Arlington, Texas, May 1991.

[13] J. Pang and F. A. Tobagi, "Throughput Analysis of a Timer Controlled Token Passing Protocol under Heavy Load", *IEEE Trans. on Communications*, Vol. 37, No. 7, pp. 694-702, July 1989.

[14] K. Ramamritham, "Channel Characteristic in Local Area Hard Real-Time System." *Computer Networks and ISDN Syst.* Vol. 13, No. 1, Jan. 1987.

[15] F. E. Ross, "An Overview of FDDI: The Fibre Distributed Data Interface," *IEEE Journal on Sel. Areas in Comm.*, pp.1043-1051, Vol. 7, Sept. 1989.

[16] K. C. Sevcik and M. J. Johnson, "Cycle Time Properties of the FDDI Token Ring Protocol," *IEEE trans. Software Eng.*, Vol. SE-13, No. 3, pp. 376-385, 1987

[17] L. Sha and J. B. Goodenough, "Real-Time Scheduling Theory and Ada*," *IEEE Computer*, April 1990., pp. 53-62.

[18] K. G. Shin and C. Hou, "Analytic Evaluation of Contention Protocols used for Real-Time Systems," *Proc. IEEE Real-Time Systems Symp.*, Dec 1990.

[19] J. K. Strosnider, J. Lehoczky and L. Sha. "Advanced Real-Time Scheduling using the IEEE 802.5 Token Ring," Proc. IEEE Real-Time Systems Symp., pp. 42-52, Dec 1988.

[20] J. N. Ulm, "A timed token ring local area network and it's performance characteristics," *Proc. Conf. Local Computer Networks*, Feb. 1982, pp. 50-56.

[21] W. Zhao and K. Ramamritham, "Virtual Time CSMA Protocols for Hard Real-Time Communications", *IEEE Transactions on Software Engineering*, SE-13(8):938-952, Aug 1987.

[22] W. Zhao, J. A. Stankovic and K. Ramamritham, "A Window Protocol for Transmission of Time Constrained Messages", *IEEE Trans. Computers*, 39(9):1186-1203, Sept. 1990.