Communication Response Time in P-NET Networks: Worst-Case Analysis Considering the Actual Token Utilization

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Abstract. Fieldbus networks aim at the interconnection of field devices such as sensors, actuators and small controllers. Therefore, they are an effective technology upon which distributed computer-controlled systems (DCCS) can be built. DCCS impose strict timeliness requirements to the communication network. In essence, by timeliness requirements we mean that traffic must be sent and received within a bounded interval, otherwise a timing fault is said to occur. P-NET is a multi-master fieldbus standard based on a virtual token passing scheme. In P-NET each master is allowed to transmit only one message per token visit, which means that in the worst-case the communication response time could be derived considering that the token is fully utilized by all stations. However, such analysis can be proved to be quite pessimistic. In this paper, we propose a more sophisticated P-NET timing analysis model, which considers the actual token utilization by different masters. The major contribution of this model is to provide a less pessimistic, and thus more accurate, analysis for the evaluation of the worst-case communication response time in P-NET fieldbus networks.

Keywords: real-time communication, worst-case message response time, fieldbus networks, medium access control protocols, P-NET

1. Introduction

Local area networks (LANs) are becoming increasingly popular in industrial computer-controlled systems. LANs allow field devices like sensors, actuators and controllers to be interconnected at low cost, using less wiring and requiring less maintenance than point-to-point connections (Lenhart, 1993). Besides the economic aspects, the use of LANs in industrial computer-controlled systems is also reinforced by the increasing decentralization of control and measurement tasks, as well as by the increasing use of intelligent microprocessor-controlled devices. Broadcast LANs aimed at the interconnection of sensors, actuators and controllers are commonly known as fieldbus networks.

Similarly to other types of LANs, fieldbus networks are based on a layered structure derived from the seven-layer OSI model (Day and Zimmermann, 1983). However, due to the specialized requirements that must be met, the use of a full seven-layered architecture is precluded. Since transmission of states associated with sensors and actuators across the
networks can be avoided, the network layer is not needed. The transport layer is also not needed, since as the network layer is not present, its most important functions (e.g., error control, and reliable data transfer with error recovery) can be performed by the data link and application layers, respectively. Similarly, the session layer is not needed, since its basic functions (e.g., process-to-process communications) can be performed by the application layer, and its more sophisticated functions (e.g., dialog synchronization) are not needed in the context of fieldbus applications.

Consequently, a typical fieldbus network is based on a three-layered structure—physical layer, data link layer and application layer—even if some of these layers embody functionalities similar to those found in the other four layers of the OSI reference model.

There are multiple services and protocols that can be chosen for each of those three layers. The choice depends, essentially, on the original objectives of the fieldbus designers; that is:

1. either the fieldbus is to be merely a means to simplify the wiring between devices;
2. or the fieldbus is to be the backbone of a distributed real-time computing system.

These two different points of view about fieldbuses are one of the essential reasons for the proliferation of fieldbus systems (Thomesse, 1997). Other reasons relate to the lack of a unique and generic international standard. More than 30 product names or standards appeared, as the need for fieldbus has been felt in each industrial area, and since the beginning of the 80s, the international standardization efforts have been trying to emerge in a sea populated by tens of already available products and services.

Some distinguished examples of fieldbus networks are WorldFIP (Fip, 1990), PROFIBUS (Profibus, 1992) and P-NET (P-NET, 1994). In parallel, several international standardization efforts have been, and are still being carried out. One of the most relevant resulted into the European Standard EN 50170 (Cenelec, 1996), which basically encompasses three different fieldbus profiles: WorldFIP, PROFIBUS and P-NET.

In WorldFIP, the determinism is guaranteed by a bus arbitrator, which, for periodic traffic, controls data transfers according to a static scanning table. The real-time capabilities of WorldFIP have been extensively studied (Pedro and Burns, 1997; Raja et al., 1995). PROFIBUS adopts a simplified version of the timed token (TT) protocol (Grow, 1982). Despite some differences in the TT protocol used in FDDI or IEEE802.4, for which real-time characterization have been deeply addressed (Agrawal et al., 1992; Montuschi et al. 1992 are just some examples) it is still possible to guarantee real-time behavior with PROFIBUS networks (Tovar and Vasques, 1998a, 1998b).

P-NET also offers a deterministic access. P-NET adopts a virtual token passing (VTP) scheme. Although this is not really relevant for the timing behavior of this MAC approach, it worth mentioning that, conversely to other token passing schemes, in P-NET there is no explicit token transmission between stations. The determinism is not achieved by means of controlling the token rotation time, as it happens in networks based on the TT protocol. Instead, the bounded access delay is implicitly guaranteed by the fact that at each token visit only one message request may be performed.