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Engineering PROFIBUS networks with heterogeneous transmission media

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Abstract

A significant number of process control and factory automation systems use PROFIBUS as the underlying fieldbus communication network. The process of properly setting up a PROFIBUS network is not a straightforward task. In fact, a number of network parameters must be set for guaranteeing the required levels of timeliness and dependability. Engineering PROFIBUS networks is even more subtle when the network includes various physical segments exhibiting heterogeneous specifications, such as bus speed or frame formats, just to mention a few. In this paper we provide underlying theory and a methodology to guarantee the proper operation of such type of heterogeneous PROFIBUS networks. We additionally show how the methodology can be applied to the practical case of PROFIBUS networks containing simultaneously DP (Decentralised Periphery) and PA (Process Automation) segments, two of the most used commercial-off-the-shelf (COTS) PROFIBUS solutions. The importance of the findings is however not limited to this case. The proposed methodology can be generalised to cover other heterogeneous infrastructures. Hybrid wired/wireless solutions are just an example for which an enormous eagerness exists.

Keywords: Fieldbus networks; PROFIBUS; Interoperability in heterogeneous networks; Real-time communications

1. Introduction

1.1. Context and structure of the paper

Industrial communication systems have suffered significant changes over the last 20 years or so. Local Area Networks (LANs) have substituted point-to-point communications, initially triggered by big savings in wiring and maintenance costs. The increasing decentralisation of measurement and control tasks, as well as the increasing use of intelligent microprocessor-controlled devices in industrial computer-controlled systems triggered the proliferation of fieldbus networks. A fieldbus network is a specific type of LAN aimed at the interconnection of sensors, actuators and controllers in applications ranging from discrete manufacturing, process control, building automation and in-vehicle control.

Current fieldbus technologies provide real-time, reliable and cost-effective solutions for industrial automation systems. Standard and commercial-off-the-shelf (COTS) fieldbus networks such as PROFIBUS [1], P-NET [1], WorldFIP [1], Foundation Fieldbus [1] or Ethernet/IP [2] offer a panoply of application software packages, functionalities, devices and networking interoperability solutions that make these technologies important building blocks for e-Manufacturing approaches [3].

Typically, industrial automation applications undergo process reengineering, and the underlying communication systems must be adapted and extended accordingly, rather than totally replaced. Industrial communication systems must therefore cope with the need for interoperability between heterogeneous technologies. Although modern

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industrial information technologies may play an important role in facilitating the integration and interoperability of applications, this is only profitable if industrial communication infrastructures are still able to provide crucial characteristics, such as timeliness or reliability.

It is in this context that we consider the problem of supporting distributed real-time applications with heterogeneous fieldbus networks. Specifically, we consider the case of fieldbus networks being composed of profiles exhibiting heterogeneous physical layer specifications. We exercise this problem for the most widely used fieldbus – PROFIBUS, with over 14 million nodes installed worldwide [4], namely considering a scenario involving a heterogeneous PROFIBUS-DP/PA network.

Setting up a single segment PROFIBUS network for supporting real-time distributed applications is, by itself, a non-trivial task. There is the need to compute and set a number of relevant network parameters in order to guarantee bounded message response times, among other system requirements (e.g. [5–9]).

Engineering PROFIBUS networks is even more subtle when the network includes various physical segments exhibiting heterogeneous characteristics, such as bus speed or frame formats. An intuitive solution for the interconnection of the heterogeneous physical segments is using intermediate systems operating at the physical layer level. For simplification, these intermediate systems are labelled as repeaters, and the overall system would then result in a "broadcast" network, where every node listens to every transmitted message (Fig. 1).

This approach triggers an important media adaptation problem to be solved. Since the network segments may exhibit different bit rates and different physical layer frame formats, messages may experience unbounded and unpredictable delays (introduced by repeaters' operation). This may be unacceptable for real-time distributed applications.

This paper presents an innovative solution for this media adaptation problem, which relies on the insertion of additional inactivity (idle) periods before the transmission of every request frame (by a master node) in order to guarantee bounded and predictable message response times. PROFIBUS nodes can be masters or slaves, but only master nodes have initiative to start a message transaction.

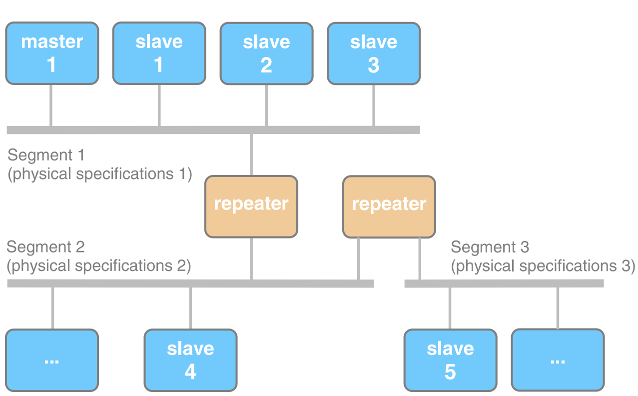

Fig. 1. "Broadcast" network with heterogeneous physical media.

A message transaction usually comprises a request from a master node and an immediate response/acknowledgement from the addressed slave node.

The minimum values for the above mentioned inactivity periods must be computed according to a number of network (e.g. bit rates) and node (e.g. message length) parameters. Then, the standard PROFIBUS Idle Time parameters must be set in every master, prior to run-time. While this may seem a trivial approach, the optimal solution requires a thorough timing analysis, which will be reasoned out throughout this paper.

The remainder of the paper is structured as follows. Section 1.2 overviews related scientific works and COTS technologies. Then, the characteristics of the PROFIBUS Data Link and Physical Layers that are relevant to the context of this paper are presented in Section 2. Section 3 states the problem and outlines the solution. In Sections 5 and 6, a methodology to properly set the PROFIBUS Idle Time and Slot Time parameters, which is a solution to the problem, is discussed and proposed. For this purpose, we use the analytical models (for the repeaters and physical media) early proposed in Section 4. Section 7 instantiates the application of the proposed methodologies to an example scenario involving a heterogeneous PROFIBUS-DP/PA network. Finally, Section 8 draws some conclusions about this work.

1.2. Related work

The heterogeneity of current and future industrial communication systems brings up interoperability problems. Therefore, there is the need to provide the appropriate mechanisms to achieve full interoperability between nodes belonging to different types of networks, such as Fieldbus, Industrial Ethernet and Wireless Local Area Networks (WLANs). We consider the heterogeneity of industrial communication networks due to the coexistence of fieldbus and higher level networks, dissimilar fieldbus networks and separated domains of the same fieldbus network. In all these cases, interoperability is mandatory and must be achieved through the use of appropriate interconnecting devices acting as repeaters, bridges, routers or gateways. This section outlines some related research efforts and commercially available products.

Nowadays, many companies supply solutions for interconnecting field-level networks and higher level networks, mainly motivated by the enormous trend towards Internet access to the factory floor. The "I can access anything from anywhere" concept is definitely driving new strategies to tackle the communication requirements of the modern factory. Most fieldbus manufacturers provide gateways to Ethernet TCP/IP, permitting the access to process data over the Internet (e.g. Siemens, Hilscher, Deutschmann Automation) AEG/Schneider, HMS and Bihl&Wiedemann provide Internet (TCP/IP on top of Ethernet) gateways to several types of fieldbus (e.g. ControlNet, PROFIBUS DP, Interbus, CANopen, AS-I, ModBus).