THE INFLUENCE OF INTER-DOMAIN MOBILITY ON MESSAGE STREAM RESPONSE TIME IN WIRED/WIRELESS PROFIBUS-BASED NETWORKS

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Abstract: In previous works we have proposed a hybrid wired/wireless PROFIBUS solution where the interconnection between the heterogeneous media was accomplished through bridge-like devices with wireless stations being able to move between different wireless cells. Additionally, we had also proposed a worst-case timing analysis assuming that stations were stationary. In this paper we advance these previous works by proposing a worst-case timing analysis for the system's message streams considering the effect of inter-cell mobility.

Keywords: Fieldbus, Wireless, Real-time, Industrial Automation

1 INTRODUCTION

In the past years several solutions have been proposed for extending the capabilities of fieldbus networks to encompass wireless support [6-7, 9]. PROFIBUS (acronym for PROcess FIeld BUS) is a natural candidate to support such an ensemble, especially due to its market penetration and range of covered applications.

The Multiple Logical Ring (MLR) concept was introduced and discussed in [2], and further detailed in [3-4], where a bridge-based approach (thus, layer 2 interoperability) was outlined. In such an approach, each logical ring is comprised of stations that communicate via a unique medium – a domain, which can be wired or wireless. The Inter-Domain Protocol (IDP) supports the communication between stations in different domains, and the mobility of wireless stations between different wireless domains is based on the Inter-Domain Mobility Procedure (IDMP). These protocol extensions provide essential compatibility with legacy PROFIBUS technologies.

In [8], we proposed a worst-case timing analysis for transactions supported by the IDP, considering that wireless stations were stationary. In [10], that work has been applied to calculate the latencies associated with the IDMP evolution.

In this paper, we advance that previous work by analysing the impact of the IDMP on the worst-case response time (WCRT) of message streams, considering that wireless stations can move between different wireless domains.

The rest of this paper is organized as follows. In Section 2, the main concepts related to bridge-based hybrid wired/wireless PROFIBUS architectures, including the ones related to the MLR approach, are briefly presented. Then, in Section 3, we briefly present the timing analysis of the latencies associated to the mobility procedure (IDMP), which is then used in Section 4 to derive analytical formulations for the WCRT of message streams in a system allowing inter-cell (domain) mobility. Finally, in Section 5, we draw some conclusions.

2 SYSTEM ARCHITECTURE AND PREVIOUS RELEVANT WORK

2.1 Basics of the PROFIBUS protocol

The PROFIBUS Medium Access Control (MAC) protocol uses a token passing procedure to grant bus access to masters. After receiving the token, a PROFIBUS master is capable of processing transactions during its token holding time (T_{TH}), which, for each token visit, is the value corresponding to the difference, if positive, between the target token rotation time (T_{TR}) parameter and the real token rotation time (T_{RR}). For further details, the reader is referred to [5].

A transaction (or message cycle) consists on the request or send/request frame from a master (the initiator) and of the associated acknowledgement or response frame from a master/slave station (the responder). The response must arrive to the master before the expiration of the `Slot Time` (T_{SL}), a master parameter.

In order to maintain the logical ring, PROFIBUS provides a decentralized ring maintenance mechanism. Each PROFIBUS master maintains two tables – the *Gap List* (GAPL) and the *List of Active Stations* (LAS), and may optionally maintain a *Live List* (LL).

The GAPL consists of the address range from 'This Station' address until 'Next Station' address, i.e., the next master in the logical token ring. Every time the

Gap Update Timer (T_{GUD}) expires in a master, it starts checking the addresses in its GAPL. This is accomplished by inquiring (at most) one master on the GAPL per token visit. If a new master replies, then the requesting master passes the token to this new master and updates its 'Next Station' address. Otherwise, the requesting master continues its operation. In the MLR approach, this mechanism is used for enabling the mobility of wireless master stations, as detailed later.

The LAS is a list of all the masters in the logical ring, and the LL contains all active stations (both masters and slaves).

2.2 Basics of the MLR approach

Our hybrid wired/wireless fieldbus network is composed of wired and wireless stations. Communication is based on the PROFIBUS protocol, and the communication between different domains is supported by special-purpose bridges supporting the Inter-Domain Protocol (IDP) [4]. Fig. 1 illustrates an example network.

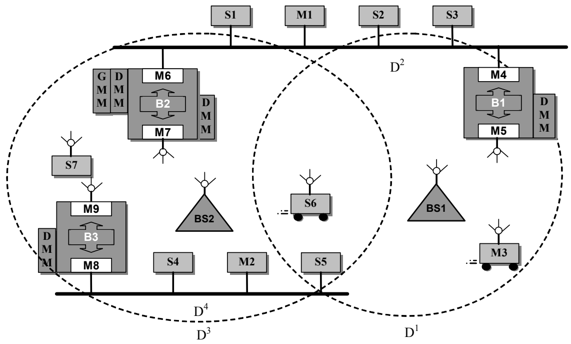

Fig. 1 – Hybrid wired/wireless PROFIBUS network

In this example, the following set of wired PROFIBUS masters (M) and slaves (S) are considered: M1, S1, S2, S3, S4 and S5. Additionally, the following set of wireless stations is considered: M3, S6 and S7. From this last set, only M3 and S6 are referred as Mobile Wireless Master/Slave station, therefore being capable of moving inside a wireless domain and between them (using the IDMP). Station S7 is referred as Domain Resident Wireless Master/Slave Station since it is stationary in a single domain. These wireless stations are standard PROFIBUS stations equipped with a radio front-end containing specific wireless extensions (as defined in RFieldbus [1]). Three bridge devices are considered: B1, B2 and B3. Each includes two modified PROFIBUS masters (denoted as Bridge Masters (BM)) implementing the required protocol extensions. In our system, the network has a tree-like topology, and bridges perform routing based on MAC addresses.

All wireless communications are relayed through base stations (BS), operating in cut-through mode. Each BS uses two channels to communicate with the wireless stations, one to receive data from the wireless stations (the uplink channel) and another to transmit data to the wireless stations (the downlink channel). Each adjacent BS (e.g. BS1 and BS2) must use a different set of radio channels. In the example each wired/wireless domain has its own logical ring, four different logical rings exist: {(M5 → M3), (M1 → M4 → M6), (M7 → M9), (M8→M2)}.

2.3 The Inter-Domain Protocol (IDP)

A consequence of the MLR approach is that when a master makes a PROFIBUS standard request addressed to a station in another domain (an Inter-Domain Request), it will not receive an "immediate" response from the responder. The IDP [4] proposes some protocol extensions suitable for handling such kind of transactions – Inter-Domain Transactions (IDT).

The IDP protocol specifies that when an initiator makes an Inter-Domain Request, only one of the BMs belonging to the initiator's domain – denoted as BM BM_i, codes the frame using the IDP, and relays it. The decision, either to receive or discard the frame, is based on a routing table contained in the BMs. Then, this Inter-Domain Request frame is relayed by the bridges until reaching bridge master BM_r (the last bridge master in the path). This bridge decodes the original request frame and transmits it to the responder, which can be a standard PROFIBUS-DP station. The response (referred as IDT Response frame) is again coded using the IDP and routed back until reaching BM BM_i, where it will be decoded and stored. The IDP assumes that the initiator Application Layer (AL) periodically repeats the same request until receiving the related response. During this period we refer to the state of the IDT in BM_i as a pending or open IDT. In Fig. 2, we illustrate this behaviour for a transaction between M3 and S7 in the example illustrated in Fig. 1.

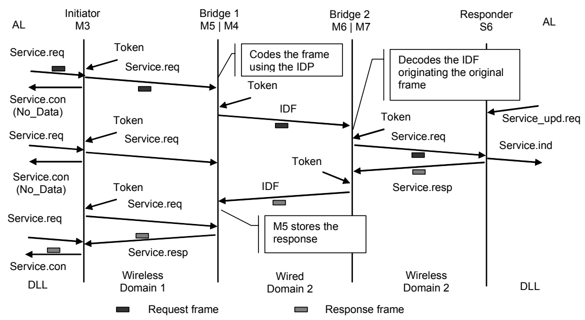

Fig. 2 – Inter-Domain Transaction (IDT) example

Note in Fig. 2 the several AL repetitions made by M3. Additionally, it is assumed that slaves read their inputs periodically, updating data structures in their DLLs, using the PROFIBUS *Service_upd.req* primitive.

2.4 Inter-Domain Mobility Procedure (IDMP)

The main objective of the inter-domain mobility procedure (IDMP) is to ensure that a wireless mobile station is able to change from one wireless domain to another, whenever it detects an adjacent wireless domain with a better signal quality. The IDMP is a hierarchically managed procedure, where one master in the system (the *Global Mobility Manager* (GMM)) is responsible for periodically starting the IDMP and