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Technical Report

Repeater vs. Bridge-Based Hybrid Wired/Wireless PROFIBUS Networks: a Comparative Performance Analysis

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TR-060901

Version: 1.0

Date: September 2006

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Abstract

In the last years, several solutions have been proposed to extend PROFIBUS in order to support wired and wireless network stations in the same network. In this paper we compare two of those solutions, one in which the interconnection between wired and wireless stations is made by repeaters and another in which the interconnection is made by bridges. The comparison is both qualitative and numerical, based on simulation models of both architectures.

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Abstract

In the last years, several solutions have been proposed to extend PROFIBUS in order to support wired and wireless network stations in the same network. In this paper we compare two of those solutions, one in which the interconnection between wired and wireless stations is made by repeaters and another in which the interconnection is made by bridges. The comparison is both qualitative and numerical, based on simulation models of both architectures.

1. Introduction

Most of the industrial community is very reluctant to integrate new technologies in their consolidated automation systems, either by preconception or by the lack of matureness of these technologies. When addressing communication systems for control applications, these fears become even more acute. That is why only a few fieldbus communication systems consolidated their market position, due to their technical features and also to big enterprise lobbies. From these, PROFIBUS (PROcess FIeldBUS) [1] is the most widely used, with over 15 million nodes [2] worldwide, in applications ranging from discrete-part automation to process control.

During the cellular phone and WLAN boom of the last decade, soon it became evident that wireless (radio-based) communications could leverage a whole new set of potentialities in field level control applications. Moving parts in machinery, hand-held equipment, wearable computers, transportation equipment and autonomous vehicles are just a few examples requiring wireless/mobile communications. Within this context, some commercial [3] and research solutions[4, 5] for providing the traditional PROFIBUS with wireless extensions have been proposed. Nevertheless, these solutions are quite limited either in terms of number of segments or wireless cells and in the support of mobility.

The RFieldbus architecture [6], driven by the European Project IST-1999-11316 consortium has provided a complete solution where multiple segments and multiple wireless cells (hereafter, segments and wireless cells will be referred as domains) are interconnected via Physical Layer (PhL) Intermediate Systems (operating as repeaters). This solution (validated by two field trials, one of them developed in our facilities [7]) is compatible with standard PROFIBUS, but the fact that all messages are broadcast throughout the network leads to some problems, namely no error containment between different domains and low responsiveness to failures. These facts triggered the analysis and proposal of an alternative approach where the Intermediate Systems (ISs) operate at the Data Link Layer (DLL) level as bridges [8-10]. This approach required two new protocols, one for supporting the communication between stations in different domains – the Inter Domain Protocol (IDP), and another to support the mobility of wireless stations between different wireless domains – the Inter-Domain Mobility Procedure (IDMP).

Although the bridge-based approach brings up some additional complexity, it showed up to overcome some limitations of the RFieldbus approach [11].

This paper provides a comparative performance analysis between the repeater and bridge-based architectures. In order to carry out this quantitative comparison, we have developed two simulation models which provided several sets of results showing the influence of varying several important network parameters on the network performance.

This paper is structured as follows. The PROFIBUS DLL and also the repeater and bridge-based architecture are outlined in Section 2. Section 3 describes the network scenarios which are used in Section 4 as a basis for the comparison between the two approaches, based on simulation results. Section 5 compares the two approaches in terms of responsiveness to errors. Finally, Section 6 discusses the results and presents the conclusions.

2. Repeater and Bridge-Based Architectures

2.1 Basics of PROFIBUS

The PROFIBUS DLL uses a token passing procedure to grant bus access to masters, in where the token is passed between masters in ascending Medium Access Control (MAC) address order, organizing the medium access in a logical ring.

After receiving the token, a PROFIBUS master is capable of dispatching transactions during its `Token Holding Time` (T_{TH}), which is, for each token visit, the value corresponding to the difference, if positive, between the `Target Rotation Time` (T_{TR}) parameter and the `Real Rotation Time` (T_{RR}) of the token.

A master station that sends an Action Frame (the first frame transmitted in a transaction) is said to be the initiator of a transaction, whereas the addressed one is the responder (a master or a slave). In PROFIBUS, slaves operate only as responders, thus have no communication initiative. A transaction (or message cycle) consists in the request frame from the initiator and of the associated acknowledgement or response frame of the responder. The acknowledgement (or response) must arrive before the expiration of the `Slot Time` (T_{SL}), otherwise the initiator repeats the request a number of times defined by an internal DLL variable called `max_retry_limit`. The `Station Delay of Responder Time` (T_{SDR}), is the time required by a responder before transmitting a reply frame.

The `Idle Time` is a period of inactivity that is inserted by master stations between two consecutive message cycles. PROFIBUS allows the setting of two different idles times: T_{ID1} and T_{ID2}. The first is inserted after an acknowledgement, response or token and the second after an unacknowledged request frame. In the remaining of this paper we will refer simply to `Idle Time` or T_{ID} in both situations.

Fig. 1 illustrates the previous concepts in a network composed of two masters (M1 and M2) and one slave (S1). M1 receives the token and waits T_{ID} before sending a request frame to S1. S1 receives the frame, processes its payload and it transmits a response frame after T_{SDR}. M1 receives the response frame and assuming that T_{TH} has expired, it waits T_{ID} before transmitting the token frame to M2. After receiving the token, M2 waits T_{ID} before transmitting a request frame to S1. If, at this time, S1 does not reply, then after expiring T_{SL}, M2 makes another retry (assuming that the `max_retry_limit` parameter is set to 1). After the second retry, M2 passes the token to M1 (note that T_{TH} has expired).

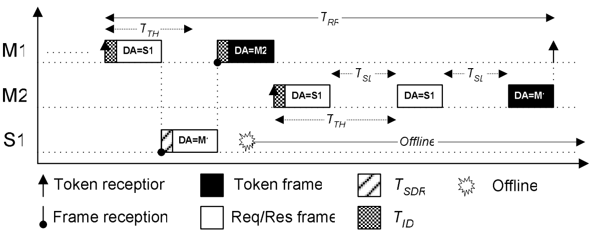

Fig. 1 – Timing parameters

2.2 Repeater-based Architecture (RFieldbus)

In the repeater-based approach (Fig. 2) the wireless stations are standard PROFIBUS stations, using a modified PhL. In such a network, all messages are relayed through Base Stations (BS) which operate in cut-through mode as a wireless repeater, using two radio channels, one to receive frames from the wireless stations (the uplink channel), and another to transmit frames to wireless stations (the downlink channel). Each adjacent BS (e.g. BS1 and BS2 in Fig. 2) must use a different set of radio channels. Only this kind of configuration allows the mobility of wireless stations between different domains.

In the repeater-based approach, the ISs operate essentially as repeaters, that is, they receive frames from the wired domain, modify their PhL frame format and transmit those frames to the wireless domains and vice-versa. Actually, the frame formats and the bit rates of the wired and wireless domains are different. The wireless PhL frames include additional preamble and header fields. Additionally, each DLL character is coded for PhL transmission using 8 or 11 bit, for wireless and wired frames, respectively. The result of these characteristics is that queuing delays may appear at the ISs.

A solution to the problem relies on the manipulation of the PROFIBUS DLL T_{ID} parameters [12], by inserting an additional idle time before a master starts the transmission of a request frame. In this way, it is guaranteed that the repeater output queues do not increase in an undesirable way, compromising the real-time performance of the system. Another consequence is that the setting of the T_{SL} parameter must be made in accordance with the new values for the T_{ID} parameter.

The mobility mechanism is based on the role of a specific master station – the `Mobility Master` (MM). This master is responsible for periodically triggering the mobility management procedure by broadcasting a special frame – the `Beacon Trigger` (BT). The reception of this frame causes the BSs to start transmitting `Beacon` frames in their radio channels and wireless mobile stations start assessing the quality of all radio channels. The mobile stations assess the quality of the radio channel using the functionalities provided by their PhL and change to the best radio channel detected.

Fig. 2 depicts an example repeater-based network scenario.

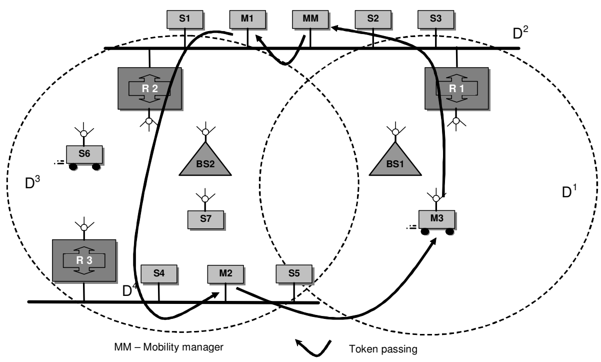

Fig. 2 – Repeater-based approach network scenario

The network comprises four domains: two wired domains {D^2 and D^4} and two wireless domains {D^1 and D^3}. Three Repeaters {R1, R2 and R3} interconnect the domains. The wireless communications are relayed by two BSs {BS1 and BS2}. The network also comprises three wired masters {M1, M2 and MM}, one mobile wireless master {M3}, five wired slaves {S1, S2, S3, S4 and S5}, one stationary wireless slave {S7} and one mobile wireless slave {S6}.

For the scenario depicted in Fig. 2, Fig. 3 shows a timing diagram which illustrates the delays that occur in a message cycle between master M3 and slave S1, which belong to domain D^1 and domain D^2, respectively. These delays are due to the internal delay of the repeater. Also, a repeater can only start transmitting in one domain after assuring that the transmission is done without gaps, therefore the transmission of a frame can only be started after knowing the incoming frame length, at a time that assures its transmission without gaps. Additionally, each message cycle also requires the use of the inserted idle time technique proposed in [12].

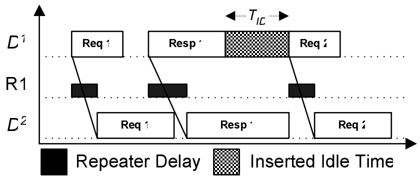

Fig. 3 – Relaying example for the repeater-based approach

Finally, it is important to note that one of the main characteristics of the repeater-based approach is that it creates a “broadcast” network where the token rotates between all masters in the network (as depicted in Fig. 2), and all messages are received by all stations in the network.

2.3 Bridge-based Architecture

In the bridge-based approach, the wireless stations (masters and slaves) have the same functionalities as defined in Section 2.2, but the communication between different domains is supported by bridges, implementing the Inter-Domain Protocol (IDP) [10]. Fig. 4 illustrates an example network, which is equivalent to the network depicted in Fig. 2.

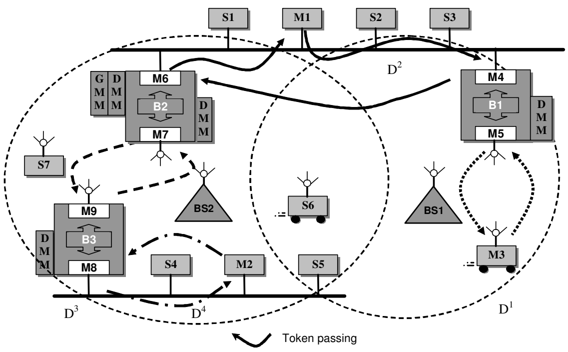

Fig. 4 – Bridge-based approach network scenario

In this example scenario, three bridge devices are considered: B1, B2 and B3. Each includes two modified PROFIBUS masters (denoted as `Bridge Master` (BM)) implementing the required protocol extensions. In our system, the network has a tree-like topology, and bridges perform routing based on MAC addresses. As in the repeater-based approach, all wireless communications are relayed through BSs.

In the example, each wired/wireless domain has its own logical ring, therefore four different logical rings exist: {(M5→M3), (M1→M4→M6), (M7→M9), (M8→M2)}.

A consequence of this approach (also referred as Multiple Logical Ring (MLR) approach) is that when a master issues a PROFIBUS request addressed to a station in another domain (an Inter-Domain Request), it will not receive an “immediate” response from the responder. The IDP protocol specifies that when an initiator makes an Inter-Domain Request (a standard PROFIBUS request addressed to a station belonging to another domain), only one of the BMs belonging to the initiator’s domain (denoted as BM_{ini}) codes the frame using the IDP and relays it. The decision either to receive or discard the frame is based on a `Routing Table` (RT) contained in the BMs. Then, this Inter-Domain Request frame is relayed by the bridges until reaching BM_{res} (the last BM in the path, i.e., the BM belonging to the responder’s domain). The BM_{res} decodes the original request frame and transmits it to the responder, which can be a standard PROFIBUS-DP station. The response (referred as Inter-Domain Response frame) is again coded using the IDP and routed back until reaching BM_{ini}, where it will be decoded and stored. The IDP assumes that the initiator’s Application Layer (AL) periodically repeats the same request (using the `service.req` primitive) until receiving the related response. Note that the AL of PROFIBUS-DP has this behaviour.

It is assumed that slaves read their inputs periodically, updating data structures in their DLLs, using the PROFIBUS `Service_upd.req` primitive.

Assuming the network scenario of Fig. 4, Fig. 5 illustrates the handling of a transaction between master M3 and slave S6. Such kinds of transactions are classified as Inter-Domain Transactions (IDT). Transactions between stations in the same domain are referred as IntrA-Domain Transactions (IADT).

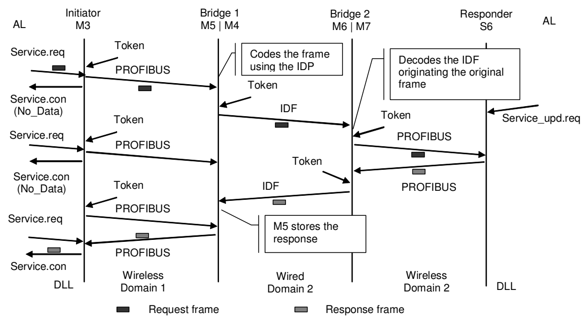

Fig. 5 – Inter-Domain Transaction (IDT) example

The bridge-based architecture requires a more sophisticated mobility procedure than the repeater-based approach, because a mechanism to support stations joining/leaving the logical rings is required. In this mechanism, called the Inter-Domain Mobility Procedure (IDMP) [8], one master in the overall system implements the global mobility management functionality – the `Global Mobility Manager` (GMM), which periodically triggers the IDMP. In each domain, one master controls the mobility of stations belonging to that domain – the `Domain Mobility Manager` (DMM). Finally, each BM implements specific mobility services.

The IDMP evolves through 4 phases, for insuring that the procedure will not generate errors, that the network inaccessibility periods are minimal and that the mobile wireless stations are able to evaluate all wireless radio channels and switch to the best one seamlessly. These characteristics insure that the influence on the latencies for IADTs is minimal in relation to the situation in which the IDMP is not active, as demonstrated in [12].

It is important to stress that the mobile PROFIBUS stations use standard PROFIBUS mechanisms to register themselves in a new logical ring (wireless domain). For further details the reader is referred to [8].

3. Description of the Network Scenarios

In order to carry out a comparative performance analysis between the repeater and bridge-based approaches, two simulations tools have been developed using the OMNet++ framework [13]. The Bridge-Based Hybrid Wired/Wireless Network Simulator [14] and the Repeater-Based Hybrid Wired/Wireless Network Simulator [15].

The network scenarios depicted in Fig. 2 and Fig. 4 were used to compare the performance of the two approaches. These scenarios are referred to as network base configuration. The T_{TR} parameter has been set to 300 bit times, according to the formulations proposed in [16]. The maximum number of DLL retries (`max_retry_limit`) parameter has been set to 1.

We have assumed that the time required by a slave to answer a request frame (T_{SDR}) can be modelled stochastically using a triangular distribution function with apex at 70 bit times and extremes at 11 and 100 bit times (*triang*(*11, 70, 100*)). This distribution has been chosen since the triangular distribution function is a rough model when there is no data available about the real distribution function [17]. Henceforth the following notation for the triangular distribution function *triang(minimum, apex, maximum)*, will be used.

The domains bit rates are equal to 1.5 Mbit/s, 2 Mbit/s and 0.5 Mbit/s, for D^2, $\{D^1, D^3\}$ and D^4, respectively. The internal delay of the ISs is equal to 30 µs and the mobility procedure is triggered every 200 ms.

3.1 Repeater-Based Scenario

The repeater-based approach requires the specific setting of the T_{ID} and T_{SL} parameters, which depend on the maximum size of the frames relayed by the repeaters, the number of repeaters in cascade and the bit rate in each medium. These parameters and the parameters related to the `Beacon` message were calculated with the help of the RFieldbus System Planning application, which is described in [18]. Table 1 presents the values for these parameters in each domain.

Table 1 – Repeater-based domain parameters

Domain	T_{ID1} (bit)	T_{SL} (bit)
D^1 and D^3	1952	3562
D^2	1337	267
D^4	100	890

In this approach the setting of the T_{ID2} parameter on the `Mobility Master` (2677 bit times) must be made differently in relation to the remaining stations in the network. This is because after transmitting the `Beacon Trigger` message this master enters into an inactivity period for the duration of the channel assessment period, which allows the wireless mobile stations to assess the quality of the other radio channels.

Additionally, a repeater always introduces a minimum inactivity period between two consecutive frames being forwarded. This value, the minimum idle time (T_{IDm}), has been set to 100 bit times.

3.2 Bridge-Based Scenario

One of the main advantages of the bridge-based approach is that the network parameters can be set independently for every domain, wired or wireless.

The timing parameters have been set according to the recommendation of the PROFIBUS standard [1], therefore the T_{ID} and the T_{SL} parameter have been set to 100 and 115 bit times, respectively.

3.3 Message Streams

A message stream is a periodic sequence of message cycles, related for instance, to the reading of a sensor. Each message stream associates an initiator (a master) with a responder (usually a slave). The notation S_i^x is used to identify a message stream *i* from an initiator station *x* (e.g. S_1^{M1} is the first message stream of master M1).

The set of message streams presented in Table 2 tries to illustrate some probable transaction scenarios in the network. The message streams are specified as tuples (destination address, request frame length (in bytes), response frame length (in bytes) and priority).

Table 2 – Message streams

Stream	Parameters	Stream	Parameters
S_1^{M1}	(S1, 15, 20, high)	S_2^{M2}	(S6, 15, 20, high)
S_2^{M1}	(S2, 15, 20, high)	S_1^{M3}	(S4, 15, 20, high)
S_3^{M1}	(S5, 15, 20, high)	S_2^{M3}	(S6, 15, 20, high)
S_1^{M2}	(S3, 15, 20, high)	S_3^{M3}	(S3, 15, 20, high)

As an example, S_1^{M1} and S_2^{M1} are IADTs between master M1 and slaves S1 and S2, respectively. S_3^{M1} is an IDT between master M1 and slave S5. S_2^{M3} is an IDT between a mobile wireless master and wireless slave S6.

3.4 Operational Characteristics Assumptions

A PROFIBUS standard master is usually a dedicated device composed by a communication module (mostly in hardware) and a CPU module running the control software. Therefore, master stations used in our simulation have been modelled according to the following operational characteristic assumptions:

– the variability of the master timing parameters is usually reduced, as confirmed by experimental measurements [18];

– it is expected that the clocks of the master stations in the system may have some drift between them;

– the masters are not synchronised between them.

These assumptions were applied to the simulator by setting the offset of the message streams and its period using probabilistic variables.

The simulation results have been obtained as the aggregate result of 100 runs, each with 120 s of duration and using a different seed value, in order to improve the randomness of the data. Additionally, since the response time depends on the messages stream period, the simulations have been made independently for each master's message stream set:

– for the master to whom we want to perform the measurements, the message stream periods were set to a constant value;

– for the other masters, the message streams parameters were set using a triangular distribution function.

4. Performance Analysis

In this section, we present and analyse some simulation results upon variation of some network parameters: bit rate, ISs internal delay and maximum frame size. The results are presented using response time histograms or graphics of the maximum measured response time.

The message streams used on the comparison between these two approaches were S_1^{M1}, S_1^{M2} and S_3^{M3}; one IADT and two IDTs, respectively, where S_3^{M3} involves mobile stations.

A problem that occurred during the simulations, with some parameter setting, is that the network enters into saturation since the network is used beyond its maximum throughput. Therefore, in the bridge-based scenario, the period of the message stream being measured has been set to 8 ms with no initial offset. The period and initial offset of the other message streams have been set using *triang*(7.8, 8, 8.2) and *triang*(0, 7.8, 8), respectively. In the repeater-based scenario, the period of the message streams had to be adjusted for every case, using the minimum values before the network enters into saturation, as detailed along the following subsections.

4.1 Base Configuration Results

This subsection discusses the results obtained using the base configuration described in Section 3. In the repeater-based approach, the period of the message streams being measured has been set to 40 ms with no initial offset. The period and the initial offset of the other message streams has been set using *triang*(38, 40, 42) and *triang*(0, 38, 40), respectively.

Fig. 6 shows a histogram of the measured response time values for S_1^{M1} in both scenarios. Note that, in the legend of this and on remaining figures in this paper, a R or a B before the message stream symbol (RS_i^k and BS_i^k) specify that the values are related to the repeater-based or to the bridge-based architecture, respectively.

In the repeater-based scenario, the minimum response time (MinRT) value is equal to 1.16 ms and the maximum response time (MaxRT) value to 10.32 ms.

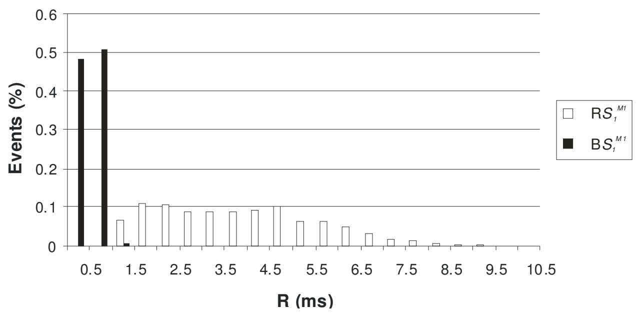

Fig. 6 – Response time for the message stream S_1^{M1}

In the bridge-based scenario, the MinRT value and the MaxRT value of message stream S_1^{M1} are 0.33 and 3.11 ms, respectively. Nevertheless, it is important to note that 99.9% of the events have a response time value smaller than 1.50 ms. In this scenario, S_1^{M1} benefits from the smaller setting of the T_{ID} parameters as well as from the traffic segmentation resulting from the use of bridges. The first reduces the message cycle duration, while the second reduces the traffic within domain D^1.

Fig. 7 depicts a response time histogram for the message stream S_1^{M2} in both scenarios.

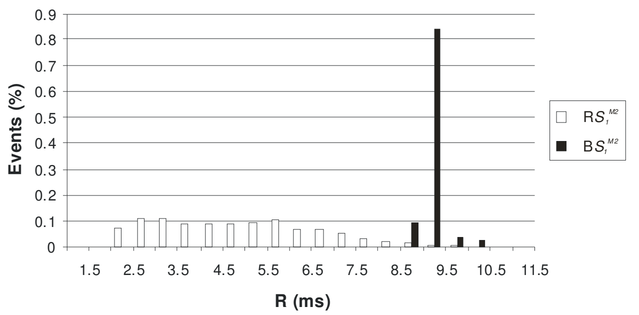

Fig. 7 – Response time for the message stream S_1^{M2}

The MaxRT values for S_1^{M2} are similar for both scenarios (11.15 ms and 11.01 ms for the repeater-based and the bridge-based scenarios, respectively) but the MinRT values are much smaller in the repeater-based scenario (1.25 ms) than in the bridge-based scenario (8.95 ms).

In the repeater-based scenario, the histogram for S_1^{M2} is similar to the histogram of S_1^{M1} as it would be expected, since the use of repeaters creates a broadcast network.

In the bridge-based scenario, the timing behaviour of message stream S_1^{M2} is different than for S_1^{M1}, since S_1^{M2} is an IDT. Therefore, such kind of transaction requires that the initiator performs at least one AL retry before obtaining a response (meanwhile stored at the BM_{ini} (BM M8)). The period of this message stream is equal to 8 ms, and consequently the MinRT value in the bridge-based scenario is greater than 8 ms.

The response time histogram of message stream S_3^{M3} is shown in Fig. 8.

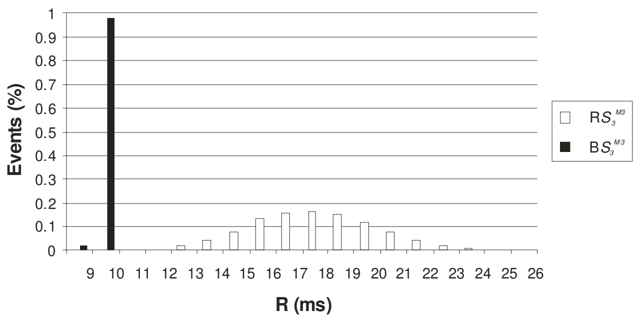

Fig. 8 – Response time for the message stream S_3^{M3}

The results for message stream S_3^{M3} in the repeater-based scenario can be a bit surprising in comparison to the case of S_1^{M2}. In this case, the MinRT value (11.91 ms) and MaxRT value (25.46 ms) are much higher than for S_1^{M1} and S_1^{M2} on the same scenario. The main reason for these results is due to the simulation model in which message stream S_3^{M3} is always queued in third place on M3 output queue. Therefore, frames related to the message stream S_3^{M3} have to wait for the transmission of frames related to the other two message streams in which the initiator is M3. This mode of operation is similar to the typical operation of a Programmable Logical Controller (PLC) running PROFIBUS.

In the bridge-based scenario, the MaxRT value for message stream S_3^{M3} (17.59 ms) is also higher. This result is due to M3 requiring three AL repetitions (in this specific case) of the request before retrieving a response from its BM_{ini}. Nevertheless, the cases when there are three repetitions only happened in 0.000003% of the events and the response time of 99.9% of the measured values are smaller or equal to 10.5 ms.

If message stream S_3^{M3} had been queued in first place instead of third, the results obtained were, in the repeater-based scenario, equal to 1.33 ms and 10.39 ms, for MinRT and MaxRT, respectively. In the bridge-based scenario the results would be equal to 8.22 ms and 11.13 ms, for MinRT and MaxRT, respectively. From this results we conclude that the message streams queuing order has much higher influence in the repeater-based scenario than in the bridge-based scenario, due to the fact that the duration of a single transaction in the repeater-based scenario is much higher.

In the following subsections, we will analyse the network timing behaviour when certain network parameters are varied.

4.2 Variability of the MaxRT as a Function of the Bit Rate

This subsection analyses how the setting of different bit rates in some network domains affects the timing behaviour of the two architectures. For this purpose, the results presented were obtained by varying the bit rate in domain D^4.

Fig. 9 compares the MaxRT values of the two scenarios for messages streams S_1^{M1} and S_3^{M3}, assuming the base configuration described in Section 3 and by varying the bit rate in D^4 from 0.5 Mbit/s to 5 Mbit/s. In these conditions, parameters T_{SL}, T_{ID1} and T_{ID2} must be recalculated for every bit rate in the repeater-based approach and these changes are applied to all domains. In the bridge-based scenario the parameter changes only affect D^4.

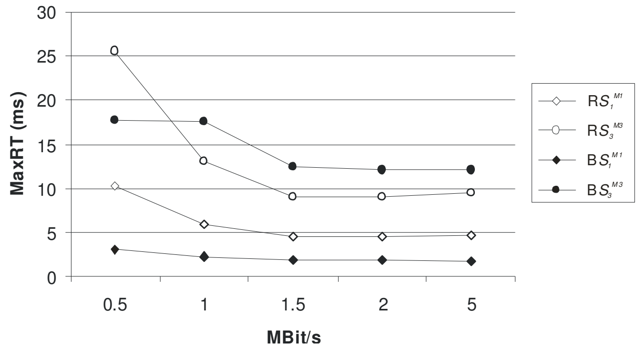

Fig. 9 – Influence of D^4 bit rate on MaxRT

From the observation of Fig. 9, we can conclude that in the repeater-based scenario the bit rate of domain D^4 has a strong influence on the MaxRT of these message streams. In this scenario, the lower MaxRT occurs when D^4 is operating at 1.5 MBit/s but it keeps increasing afterwards. The main reason for this behaviour is due to the need of inserting additional idle time to compensate the dissimilarities of the bit rates.

In the bridge-based scenario the bit rate variation in domain D^4 has a small influence on the MaxRTs of message streams $S_1^{M1}$and S_3^{M3}, since these message are not relayed by domain D^4. The decrease verified in the MaxRTs value when the bit rate increases is mainly due to a reduction of IDMP–related latencies.

4.3 Variability of the MaxRT as a Function of the ISs Delays

The ISs delay is the time required by an IS to relay a frame between its domains, either a bridge or a repeater. In the repeater-based approach it is the time required by the repeater to convert between frame formats. In the bridge-based approach it is the time required for the routing decisions, for the conversion of frame formats and for its queuing on the BM output queue.

In order to analyze the ISs internal delay influence on the network timing behaviour we performed six simulations in which the internal delay varied between 30 and 1000 µs.

In this case, there was the need to increase the message streams period to 80 ms in the repeater-based scenario, since for higher values of the internal delay (500 and 1000 µs) the network entered into saturation. The period for the other messages streams has been set using *triang*(78, 80, 82) and the offset has been set using *triang*(0, 78, 80).

Fig. 10 presents the MaxRT values for message streams S_1^{M1} and S_3^{M3}as a function of the ISs delays.

In the case of the bridge-based scenario, the internal delay of the bridge has a small influence on the MaxRT values of message stream S_1^{M1} (an IADT), since the frames exchanged in this kind of transactions are not relayed by bridges. The MaxRT value increase is mainly due to the increase of the IDMP-related latencies. The effect on message stream S_3^{M3}

(an IDT) is attenuated due to the several repetitions performed by the initiator until retrieving a response from the IDT BM_{ini}.

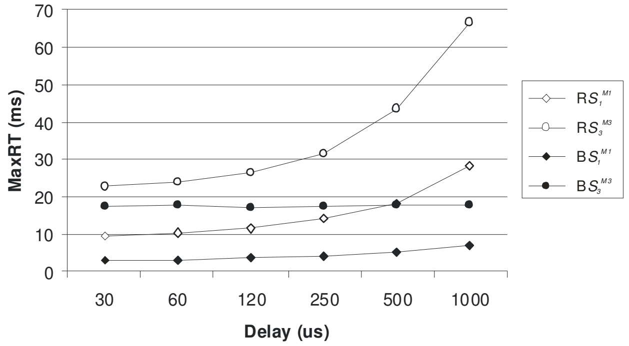

Fig. 10 – Influence of the IS delay on MaxRT

In the repeater-based scenario case, the stronger influence on MaxRT value is due the increase on the message cycle latencies. Additionally, the internal delay of the repeater affects T_{ID2} parameter of the MM, and consequently, the mobility procedure takes longer.

4.4 Variability of the MaxRT as a Function of the Maximum Frame Size

The variation of the frame size impacts the duration of message transactions not only due to the increase on the message cycle time, but also, in the case of the repeater-based approach, due to an increase in network timing parameters.

To perform this comparison we have chosen to vary the frame size of message stream S_1^{M3}. This message stream is the first message stream of master M3, a wireless mobile station and the responder is slave S4, which belongs to domain D^4. The size of the request and response frames varies between 20 and 250 bytes. Fig. 11 depicts those results.

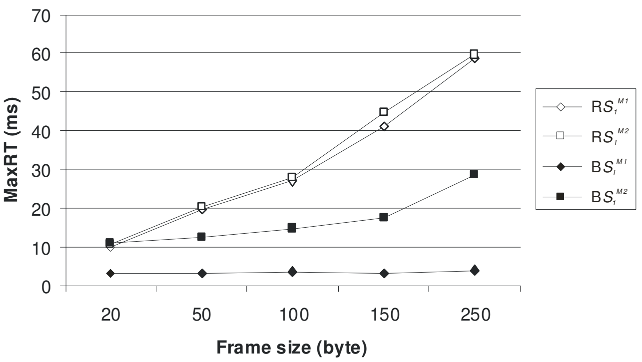

Fig. 11 – Influence of the maximum frame size on MaxRT

Once again, there was the need to increase the period to 160 ms and to adjust the T_{SL} in the repeater-based scenario, T_{ID1} and T_{ID2} parameters for every frame size. The period for the others messages streams was set using *triang*(140, 160, 180) and the offset was set using *triang*(0, 140, 160).

All message streams are affected by the increase of the maximum frame size. In the bridge-based scenario, this influence is stronger for message streams which are routed through the same domains as S_1^{M3}, which is the case of message stream S_1^{M2}. But for S_1^{M1} that influence is neglectable, contrarily, in the repeater-based scenario all message streams are severely affected.

5. Responsiveness to Errors

One of the major problems with the repeater-based scenario is that the setting of the T_{SL} parameter must be made with larger values than in the bridge-based scenario. Larger values for the T_{SL} parameter imply a lower responsiveness of the network to token errors and to transmission errors, since the time required to detect an error is increased and consequently the time required by the PROFIBUS DLL before making another retry also increases. Additionally, it is expected that the occurrence of errors becomes higher in a wireless domain than in a wired domain, which makes this problem more acute for the type of network being considered. Another consequence of setting a high T_{SL} parameter value is related to the time required to recover from a lost token situation, which is detected when a master does not detect any network activity for a time defined by the setting of its `Time Out Timer` (T_{TO}), which is equal to $T_{TO}=6*T_{SL}+2*n*T_{SL}$, where n is the master address.

Fig. 12 shows the variability of the T_{SL} in both scenarios as a function of the bit rate in domain D^4. Note that in the bridge-based approach only domain D^4 has a different T_{SL}.

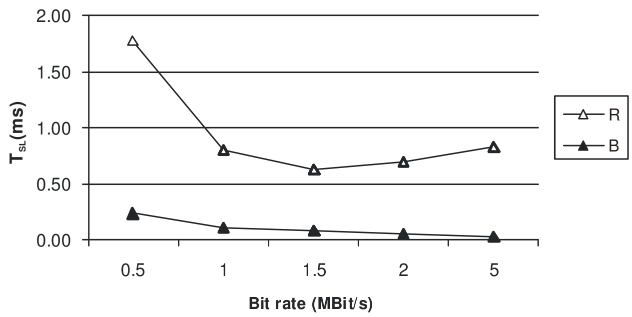

Fig. 12 – T_{SL} as a function of the bit rate in domain D^4

The T_{SL} in the repeater-based scenario is much higher than in the bridge-based scenario. A consequence of this setting in the repeater-based scenario is that the time required to detect a lost token (T_{TO}) is also much higher, as illustrated by the results depicted in Table 3, which shows the T_{TO} parameter in every master in the network for both scenarios.

Table 3 – T_{To} values (ms)

	M1	M2	M3	M4	M5	M6	M7	M8	M9
R	14.2	17.8	21.4	24.9	-	-	-	-	-
B	0.6	2.3	0.8	1.1	1.0	1.4	1.2	5.1	1.4

6. Discussion and Conclusion

In this paper, we have performed a performance comparison between the repeater and the bridge-based architectures based on simulations results. We have carried out experiments which showed the influence of varying certain network parameters in message response times.

From these experiments, we noted that in the bridge-based approach the variability of the response time histograms is smaller than in the repeater-based approach. Although, in some cases, the maximum response time for IDT can be superior.

The bridge-based approach benefits from the multiple logical ring segmentation, which isolates the traffic between domains permitting lower response time for IADT in relation to the repeater-based approach. Additionally, the network segmentation permits the independent setting of the network parameters (e.g. T_{ID} and T_{SL}) in every domain. Contrarily, in the repeater-based approach, the parameter setting depends on the network parameters and configuration, resulting on higher duration for the message cycles. The segmentation also permits a better responsiveness to errors (transmission and token loss) in the bridge-based approach since T_{SL} can be set to smaller values.

Finally, the segmentation operated by the bridges permits a higher throughput of the overall network, which can be confirmed in our experiments, since in the bridge-based case the number of message transaction performed was not reduced.

It is also noticeable that the messages queuing order has practically no influence in the maximum response time of a message stream in the bridge-based approach, contrarily to the repeater-based approach.

From the experiments in which the network parameters have been varied, it can be concluded that the repeater-based in more influenced by these changes specially when the maximum frame size in the network is increased.

Nevertheless, the use of repeaters leads to a simpler solution since the repeater devices only operate at the PhL level, contrarily to the bridge-based approach which requires a more complex set of protocols – the IDP and the IDMP – implemented at the DLL level. Additionally, the mobility procedure used in the bridge-based approach leads to higher inaccessibility times for the wireless mobile stations, since these stations must deregister from the original domain and register in the destination domain.

Ongoing work focuses on the improvement of the IDMP mechanism in order to tolerate a higher level of faults during the evolution of its phases.

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