A High Performance Wireless Fieldbus in Industrial Multimedia-Related Environment*

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Abstract - This paper summarises the most important solutions that have emerged from the work carried out by our team within the framework of the EU (IST-1999-11316) project RFieldbus - High Performance Wireless Fieldbus in Industrial Multimedia-Related Environment. Within this project, Profibus was chosen as the fieldbus platform. Essentially, extensions to the current Profibus standard are being developed in order to provide Profibus with wireless, mobility and industrial-multimedia capabilities. In fact, providing these extensions means fulfilling strong requirements, namely to encompass the communication between wired (currently available) and wireless/mobile devices and to support real-time control traffic and multimedia traffic in the same network.

1. INTRODUCTION

Wireless communications will bring an enormous amount of possibilities to factory automation. However, several constrains for the use of wireless technologies in industrial environment still exist, such as insufficient performance, low level of dependability and the non existence of appropriate wireless MAC protocols to assure the real-time behaviour of the wireless network. Moreover, providing multimedia services and transparent mobility of wireless stations between radio cells turns this task even more difficult. In the scope of the RFieldbus project, a hybrid wired/wireless fieldbus system, supporting mobility and multimedia applications is being conceived [1].

Several Fieldbus standards have been assessed [2] and Profibus [3] proved to be the most appropriate infrastructure for the RFieldbus system. While this EN50170 compliant fieldbus fulfils all communication requirements initially defined for the RFieldbus system [4], it was mandatory to develop adequate mechanisms to be able to support wireless/mobile nodes, and also TCP/IP multimedia applications on top of a control network, still satisfying real-time and dependability constraints.

This paper addresses topics on RFieldbus system architecture, on the integration of TCP/IP multimedia traffic with control traffic, on the improvement of network responsiveness and on mobility management.

2. TOPICS ON SYSTEM ARCHITECTURE

2.1 The Profibus MAC mechanism

We are considering a hybrid wired/wireless fieldbus network where the medium access control (MAC) protocol is based in a token passing procedure used by master stations to grant the bus access to each other, and a master-slave procedure used by master stations to communicate with slave stations. A master station is able to perform transactions during the token holding time. A transaction consists of the request from a master (initiator) and the associated response frame (positive or negative), that is immediately issued by the responder (master or slave). The master will only process another transaction (or pass the token) upon completion of the ongoing transaction and waiting a pre-defined idle time. If an erroneous response frame is received or a timeout (before receiving any response) occurs, the master station may retry the request. A master station can also send unacknowledged requests. In this case, as there is no associated response frame, it will be able to start another transaction (or pass the token) just after a pre-defined idle time. The idle times between consecutive frames in the network should always be respected due to physical layer (PhL) requirements (namely for synchronisation).

In order to have a broadcast network (every transmitted frame is listened by every station), Intermediate Systems must act as repeaters. We assume a store-and-forward behaviour, i.e. a frame must be completely received by one port of the hopping device before being re-transmitted to the other port. Obviously, the Intermediate Systems potentially have to support functionality such as encapsulation/decapsulation, due to different PhL PDU (protocol data unit) formats, and receiving/transmitting at different bit rates.

2.2 Direct and Indirect Link Networks

A wireless fieldbus network is supposed to include at least one radio cell. Basically, a radio cell can be described as a space (in a 3 dimensional way) where all associated wireless nodes are able to communicate with each other. This common radio coverage area is here defined as Wireless Domain. A Domain is as a set of stations (of any kind) communicating via a unique medium. Therefore, a Wired Domain corresponds to the set of (wired) stations that intercommunicates via a wired segment. Correspondingly, a Wireless Domain is the set of (wireless) stations intercommunicating via the air. Since the antennas used by wireless nodes usually have an omni-directional characteristic (special applications ignored) the real

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dimension of the radio coverage area is defined by the radio coverage area of each wireless node. Taking into account that radio cells may be overlapping (sometimes it is intended), the distinction is achieved through the use of different radio channels.

The wireless communications in a radio cell may be achieved in two ways: in a direct way – *Direct Link Network* or via a B*ase Station* (BS) – *Indirect Link Network*. Both topologies are depicted next (Figs. 1 and 2, respectively).

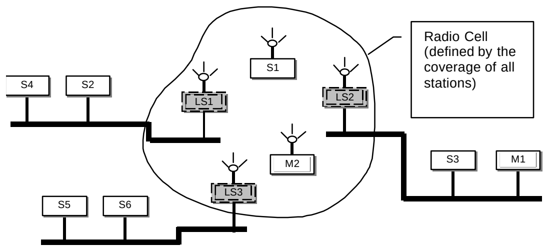

Figure 1: Example of a Direct Link Network

Moreover, in order to support the connection between wireless nodes and wired segments there is the need for *Link Stations* (LS). A link station connects wireless stations belonging to a Wireless Domain to wired stations belonging to a Wired Domain.

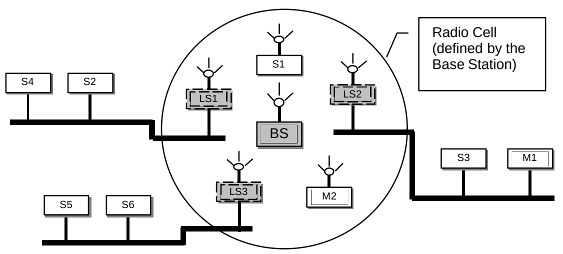

Figure 2: Example of an Indirect Link Network

It is also possible to combine the functionality of a Base Station and a Link Station in one physical device – a *Link Base Station* (LBS). Therefore, three types of Intermediate Systems are defined: Link Station, Base Station and Link Base Stations.

2.3 Network Topology and Components

RFieldbus network topology [2] is exemplified in .

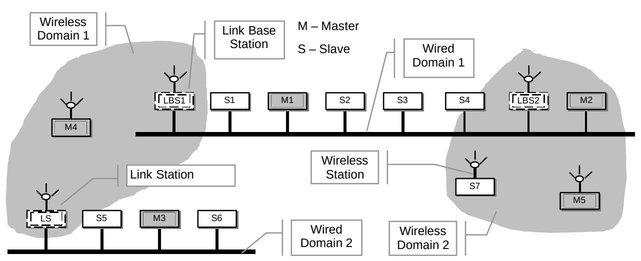

Figure 3: RFieldbus network topology and components

A domain consists of a set of stations communicating between them via a shared communication channel. No registering mechanisms are needed since we assume that wireless domains operate in different radio channels. It is also important to note that inter-domain mobility is supported if in each wireless domain messages are relayed through a base station (with up-link and down-link channels instead of direct communication between the wireless nodes) and mobile stations are able to perform channel assessment and channel switching.

3. TOPICS ON TCP/IP INTEGRATION

One of the main objectives in RFieldbus is to support a new wide class of industrial applications, usually known as industrial multimedia applications. Examples of such applications include monitoring applications interfacing to microphones and cameras, remote access to maintenance data including graphics and videos, etc. This kind of applications are usually supported by the widely used TCP/IP stack. Thus, the most effective way to integrate such applications within the PROFIBUS communication stack is to integrate the TCP/IP stack into the PROFIBUS stack.

3.1 Why this is a non-trivial matter…

The integration of the TCP/IP protocol suite in the PROFIBUS communication stack rises some challenging problems, namely:

- PROFIBUS is a master/slave network, where slaves do not have communication initiative, while TCP/IP is symmetric;
- PROFIBUS frames are very limited in length. The requirement for efficient fragmentation of IP packets is one of the problems to be solved, but also all the issues raised by the implementation of the upper-level communication relationships;
- PROFIBUS uses a simplified timed token protocol as MAC mechanism. There is a crucial requirement to preserve the real-time characteristics concerning the control-related traffic, while at the same time providing some QoS guarantees to the multimedia-related traffic. This puts enormous challenges into the specification of the RFieldbus.

3.2 Integrating TCP/IP applications with Profibus

Such integration must be correctly specified, in order to provide the adequate Quality of Service to the supported TCP/IP applications, while guaranteeing that the timing requirements of the control-related traffic are always satisfied. A transparent solution for such integration was proposed in [5], based in an adequate interface structured in three sub-layers: *IP-Mapper*; *Admission Control and Scheduler (ACS)* and *Dispatcher* (Fig. 4).

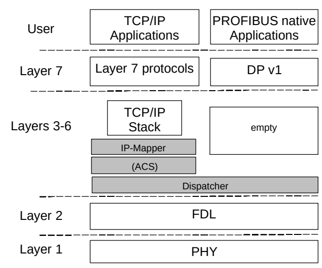

Figure 4: RFieldbus multimedia-related sublayers

[1] This demands the decoding of the DLL PDU, in order for the master station to know if it received a token frame.

The IP-Mapper sub-layer (Fig. 5) resides directly below the TCP/IP Protocol Stack. This layer is responsible for the conversion of IP packets into/from PROFIBUS FDL frames. Therefore, it maps the TCP/IP services into the PROFIBUS FDL services and performs the identification, fragmentation and re-assembly of the IP packets to/from PROFIBUS FDL frames. The IP-Mapper layer is also responsible for the transparent support of the peer-to-peer relationship inherent to the IP protocol, mapping it to the PROFIBUS FDL master/slave paradigm.

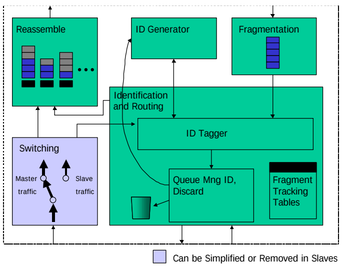

Figure 5: IP-Mapper sub-layer

The Admission Control and Scheduling (ACS) sub-layer (Fig. 6) resides directly under the IP-Mapper sub-layer. The ACS sub-layer is responsible for the control/limitation of the network resources usage by the TCP/IP applications. Moreover, this sub-layer must implement appropriate scheduling policies able to provide the desired Quality of Service for the multimedia applications.

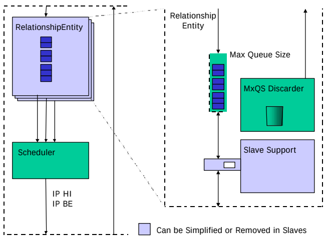

Figure 6: Admission Control and Scheduling sub-layer

The Dispatcher sub-layer resides above the PROFIBUS FDL and is depicted in Fig. 7. Both PROFIBUS native traffic and IP traffic (fragmented in PROFIBUS frames) pass through this sub-layer. The dispatcher is responsible for maintaining proper timing constraints for the different types of traffic that are conveyed through the network, thus providing the desired Quality of Service for multimedia applications, while guaranteeing that the timing requirements of the control-related traffic are always satisfied.

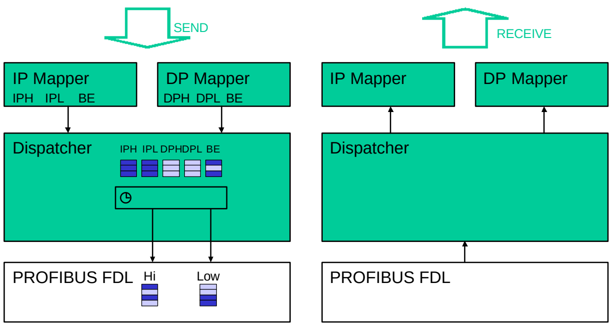

Figure 7: Dispatcher sub-layer

4. IMPROVING NETWORK RESPONSIVENESS

Broadcast networks that are characterised by having different physical layers (PhL) demand some kind of traffic adaptation between segments, in order to avoid traffic congestion in Intermediate Systems. In many LANs, this problem is solved by the actual Intermediate Systems, either behaving like gateways or "intelligent bridges" that use some kind of congestion control/avoidance mechanism. RFieldbus fits into the case of token-passing fieldbus networks operating in a broadcast fashion and involving message transactions over heterogeneous (wired/wireless) physical layers. In this case, real-time (bounded message response times) and reliability (loss of frames not allowed) requirements demand a new solution to the traffic adaptation problem. Our approach relies on the insertion of an appropriate idle time before a station issuing a request frame [6]. In this way, we guarantee that the Intermediate Systems' queues do not increase in a way that the timeliness properties of the overall system turn out to be unsuitable for the targeted applications.

4.1 Traffic congestion in Intermediate Systems

When interconnecting domains with different PhL frame formats and data rates, the queuing delay in the Intermediate System may increase, from one transaction to the next. The timing diagram depicted in Fig. 8 illustrates a sequence of transactions between an initiator and a responder both in the same domain (D_a), and the resulting frames in the other domain (D_b). One Intermediate System interconnects the two domains and it is assumed that the frame duration in D_b is twice the frame duration in D_a.

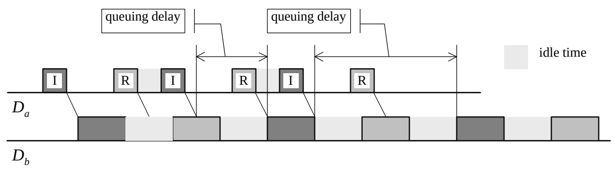

Figure 8: Increasing queuing delay in an Intermediate System

Note that since the idle time is usually defined as the duration of a predefined number of (idle) bits separating consecutive frames in the network, its duration may be different for the two domains.

Clearly, if a request from an initiator in D_a and a responder in D_b appears after the last response shown in Fig X, this transaction will be affected by the cumulative queuing delay in the Intermediate System. The queuing delay in such Intermediate System depends on the number and duration of consecutive transactions where initiator and responder belong to D_a. Even a sequence of short frames may lead to very long message response times. For instance, a sequence of token passing between master stations that have nothing to transmit may also cause traffic congestion.

A way to avoid traffic congestion in Intermediate Systems (and long message response times) is through the insertion of an additional idle time before initiating a transaction (exemplified in Fig. 9; inserted idle time in black).

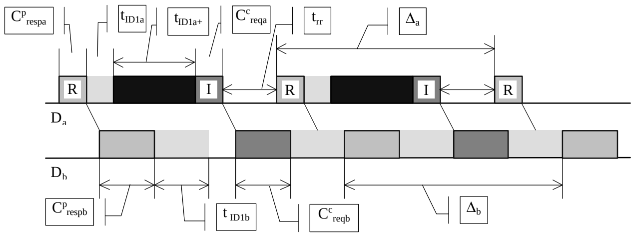

Figure 9: Eliminating queuing delay by inserting idle time

Obviously, the insertion of this additional idle time reduces the number of transactions per time unit when the responder is not in the same domain as the initiator. Nevertheless, the advantage of avoiding traffic congestion is enormous. It leads to a better responsiveness to failure (when an error occurs, retransmissions are undertaken sooner) and to smaller worst-case message response times [7].

5. TOPICS ON MOBILITY MANAGEMENT

Emerging standards such as IEEE802.11 [8] or Bluetooth [9] are generally inadequate for fieldbus networks. This problem is even more acute in the RFieldbus case where the network must have a broadcast behaviour. Nevertheless, since the underlying communication platform of RFieldbus is Profibus, only one node is able to communicate at a given instant of time. This permits a different approach concerning the handoff mechanism. More specifically, it is not mandatory to have node location information in each Base Station if all messages are broadcast throughout the overall network. Thus, and since there is no need to undertake registration mechanisms in the Base Stations, the handoff mechanism may be reduced to channel assessment and switching. Thus, a simpler handoff mechanism was proposed [10], bypassing the usually complex handoff mechanisms that are based on registration and location awareness information in all Base Stations.

5.1 *The mobility master*

Taking into account the mobility requirements in the RFieldbus system, a transparent solution for all kinds of mobile stations supporting a seamless (mobile master/slave/LS) handoff with no loss of data frames is outlined next.

One specific station - the *mobility master (MobM)* - must support some additional functionality, since it is responsible for triggering the mobility management procedure (Fig. 10). Within a certain period – *beacon period*, all mobile stations are expected to assess the quality of the three different radio channels (existing in the Rfieldbus system), finally switching to the one considered as having the best quality.

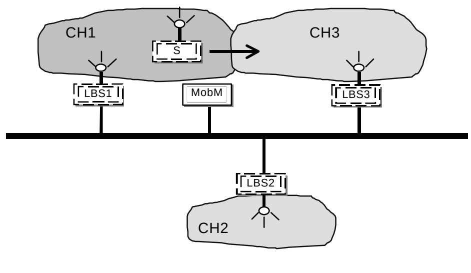

Figure 10: The mobility master (MobM)

5.2 *The beacon trigger*

The mobility master (i.e., the master that has the responsibility of triggering the handoff procedure) sends a special (unacknowledged, with a special address or SAP) frame – the *beacon trigger*, with a periodicity that is dependent on the maximum speed of the mobile stations.

This beacon trigger is broadcast to the entire Rfieldbus network. The reception of the beacon trigger frame causes each base station to send a number of beacons in its radio channel. Mobile stations listen to these PDUs, assess the signal quality of all radio channels and switch to the best channel. This is roughly depicted in Fig. 11:

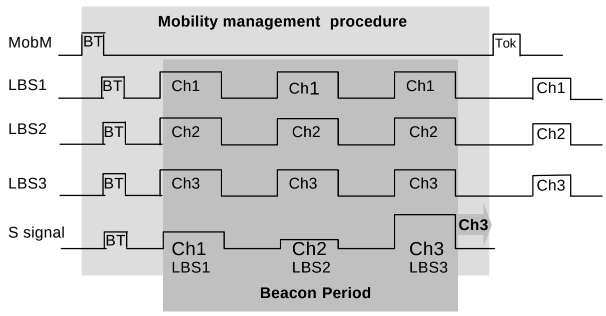

Figure 11: Mobility management procedure timing diagram

The beacon trigger (sent by the mobility master) is received (and relayed) by the (Link) Base Stations, which then start to send beacons (special frames) in their own frequency, in order for the mobile stations to be able to undertake the channel assessment and handoff. Taking into account the scenario presented in Fig. 10, where the mobile station is moving towards the range of LBS3, it must perform channel assessment and switch to CH3 (Fig. 11). After this period for the mobility management procedure, the mobility master is able to pass the token to another master.

Obviously, mobile stations must assess all radio channels existent in the network. The minimum frequency for undertaking the handoff procedure is a function of the maximum allowed speed of a mobile node and of the characteristics of the overlapping area between two adjacent cells.

6. CONCLUSION

In this paper, we present an overview of the major developments of our research team, in the scope of the RFieldbus project (IST-1999-11316). We have started by outlining a hybrid wired/wireless fieldbus network architecture. It is a broadcast network with a unique logical ring, where wired and wireless domains are interconnected by Intermediate Systems acting as store-and-forward repeaters. Both direct and indirect (via Base Station) communication between wireless stations is supported in RFieldbus. In the latter, it is possible to support unconstrained inter-cell mobility with a very simple and real-time compliant mobility management mechanism. This mechanism relies on a master to issue periodic beacon trigger frames (standard Profibus MAC functionality) that make Base Stations to send beacon frames during a certain time (beacon period). During this period, all wireless/mobile stations are supposed to assess the quality of the (3) radio channels, finally switching to the best (handoff).

We had also to tackle the problem of traffic congestion in Intermediate Systems, a problem inherent to broadcast networks with heterogeneous physical layers (bit rate, frame format). This would lead to high and unpredictable message response times, which is unacceptable in a real-time system. Our proposal to overcome this problem relies on the insertion of appropriate idle times before master stations issuing request frames.

Maybe the most difficult task in the project was make TCP/IP multimedia applications and control applications to coexist in the same fieldbus network. While some level of QoS was required for the multimedia traffic, real-time control messages should not be disturbed. Moreover, to support TCP/IP multimedia applications on top of Profibus, we had to overcome some Profibus-inherent limitations, such as frame length and the slave initiative problems.

Currently, the implementation phase is going on, and there will be two field trials (discrete-part manufacturing and process industry) where these technological breakthroughs will be tested, validated and demonstrated in real industrial environments.

7. REFERENCES

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