Media Redundancy for PROFINET IO

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Abstract

The use of Ethernet based solutions in automation applications opens new possibilities for the integration of new functionalities. But one of the critical point is the availability of the communication system. This paper gives an overview of the Media Redundancy Protocol (MRP) as defined in IEC 62439 and some adaptations needed to support the Profinet IO Real-Time (RT) protocol.

1. Introduction

More and more, Ethernet based fieldbuses are used in practical applications [1], [2]. There is the promise that Ethernet based solutions will be more flexible and permit the end user a smooth integration of his field equipment in the IT world.

1.1. Requirements of the application

One of the important requirements of the automation world is the availability of the control system. So the availability of the communication network is part of the control system and influences directly the availability of control system of the plant. The important characteristic of a plant is how long it can run without a working control system. This time is called the grace time and depends on the type of the application. These requirements are described in [7] and [8].

Table 1. Application dependant grace times.

Applications	Typical grace time
Uncritical Automation Enterprise systems	20 s
Automation management Manufacturing, Discrete automation	2s
General Automation Continuous, Power plants	200 ms
Time-Critical Automation Synchronized drives	20 ms

Different classes of applications and their typical grace times are summarized in table 1.

In this paper we are interested mainly in the "General Automation" applications. The grace time is typically 200 ms. This means, that the typical cycle time of the control application is in the order of 10 to 20 ms, what is the classic application domain of Programmable Logic Controllers (PLC). One of the most promising industrial Ethernet solutions is Profinet IO [3], [4], [5]. A typical application for a Profinet IO-system is to allow a PLC to control decentralized field devices. The typical requirement for an application cycle is therefore also in the range of 10 to 20 ms.

1.2. Methods to increase the availability

With the use of such a communication network, the availability of the network influences directly the availability of the control system. There are different possibilities to increase the availability of a communication network. One classical approach is to increase the availability by introducing redundancy. Different possible structures of redundancy with communication systems are outlines in [8].

In IEC 62439 FDIS [11] four different solutions for redundancy are proposed: MRP - Media Redundancy Protocol based on a ring topology, PRP - Parallel Redundancy Protocol, CRP - Cross-network Redundancy Protocol and the BRP – Beacon Redundancy Protocol.

We focus here on media redundancy as defined in clause 5 of IEC 62439, as this version is planned to be used also in Profinet IO systems.

In a first section of this paper we will show how Profinet IO systems are setup. We give s short introduction to the media redundancy as defined in the IEC standard and show practical example of measurements made with a Profinet IO system in our laboratory with media redundancy in a fourth section and give some propositions how to improve the system. Also the solution adopted by Profinet IO in its own standard is presented.

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2. The Profinet IO system

In this section we give a short overview and introduction to the structure Profinet IO systems, as far it is important for the application we considered in the introduction.

Profinet is an automation network, based on and compatible to Ethernet (IEEE 802.3) and specified in IEC 61158-5-10 [12] and IEC 61158-6-10 [13] and IEC 61784-2 [10]. A Profinet IO-system consists of an IO-controller, one or more IO-devices and possible IO-supervisors. The IO-supervisors are typically engineering tools. Reference [5] provides a good overview about the functions of Profinet.

2.1. IO-system classes

The specification provides three conformance classes of Profinet IO-systems. These classes differ in the supported application-, communication- and redundancy-classes and specify the required features. Higher classes are compatible to the lower ones.

Class A specifies certified IO-controllers and IO-devices with standard Ethernet interfaces and standard Ethernet network infrastructure. Class B requires in addition to Class A that the network infrastructure conforms to the Profinet specification. Media Redundancy Protocol (MRP) is required to support Class B and thus basic redundancy network structures are possible. Additional redundancy protocols are optional. In class C Profinet IO-systems, additionally to the MRP also the Media Redundancy Real-Time (MRRT) protocol and the Isochronous Realtime (IRT) protocols are mandatory.

2.2. Structure of an IO-system

In a typical Profinet IO-system an IO-controller does control one or more IO-devices. During the initialization sequence, an Application Relation (AR) between the IO-controller and the IO-device is set up. Inside this AR different Communication Relations (CR) are defined. One CR is dedicated for the cyclic exchange of process data. We focus our study on this cyclic process data.

The cycle time of the data exchange may be different for every CR. Data is sent from the producer to the consumer over the CR. The IO-device is the producer and the IO-controller is the consumer for the input data and vice versa for the output data.

The send cycle is defined by two parameters: the SendClockFactor and the ReductionRatio as described in formula (1).

$$T_{sendcycle} = \text{SendClockFactor} \times \text{ReductionRatio} \times 31.25\ \mu s \quad (1)$$

Every producer is responsible to keep the cycle time within a prescribed jitter. With class A and class B Profinet IO-devices, the cycles are running independent. Only with the more advanced class C, the cycles in all producers are synchronized. To avoid problems with not synchronized cycles, only full duplex communication and switched Ethernet at 100 MBit/s is allowed for Profinet IO systems.

Every cyclic CR is supervised with a WatchdogTime. The WatchdogTime is calculated by multiplying the send cycle time with the WatchdogFactor. If the WatchdogTime expires in the consumer without the reception of a cyclic data frame, the AR is considered as failed and an abort followed by a new initialization sequence is executed.

2.3. Media Redundancy Classes

Profinet IO defines three different classes of media redundancy. In media redundancy class 1 the Media Redundancy Protocol (MRP) solution is mandatory. The target is to fulfil the requirements of applications with typical grace times of more than 200 ms. In redundancy class 2 additionally to the MRP also MRRT is required to reach a bump less switchover. With an additional planning of the communication with the IRT protocol an additional media redundancy class 3 is defined.

3. Media Redundancy Protocol (MRP)

In this section we outline the basic functionality of the Media Redundancy Protocol (MRP).

3.1. History

The Spanning Tree Protocol (STP) and the Rapid Spanning Tree Protocol (RSTP) [9] do not full fill the requirements of the automation applications [6].

Hirschmann and Siemens presented already in 1999 a first media redundancy protocol based on a ring topology for Ethernet based networks. This protocol was called HiPER-Ring and allowed the compensation of one single point of failure in the ring structure with a maximal switch over time of 500 ms. The Ring Manager (RM) supervises the topology with special watchdog frames and opens the ring, if the ring topology is complete.

IEC started in 2005 in the scope of SC65C in MT9 a new work for the standardisation of “high availability automation networks” and published the first CDV in April 2007. The standard is planned to be finished in 2008. The requirements are clear: a media redundancy protocol is needed, which allows a switch over time less than 200 ms which is free of property rights and may be used as far as possible for most of the different Real-Time Ethernet (RTE) solutions outlined in IEC 61784-2 [1],[10].

Such a solution is now proposed in clause 5 of IEC 62439 under the name of Media Redundancy Protocol (MRP) for ring topologies. First switching devices which are supposed to have this version implemented are already available on the market.

3.2. Basic Functions of MRP

The MRP Protocol is structured very similar as the Spanning Tree Protocol (STP) or the Rapid Spanning Tree Protocol (RSTP) explained also in [6]. It is based on the layer 2 of the Open System Interface (OSI) reference model as outlined in figure 1. The basic mechanisms also are the same: blocking or forwarding of frames on ports and clearing of the Filtering Data Base (FDB) in the switches.

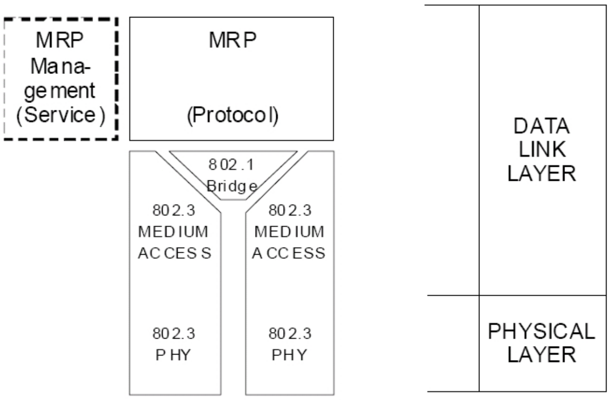

Figure 1. Layer structure of MRP

In a MRP ring one switch is the Media Redundancy Master (MRM) and all others are the Media Redundancy Clients (MRC). The MRM sends a test frame (MRP_Test) in both directions throughout the ring. These test frames are marked with a special MAC address and forwarded by the MRCs only in the ring. They are send in a delay of TSTDefaultT which is proposed to be 20 ms. If the MRP_Test frames arrive on both ends back to the MRM, the ring is detected as closed and the MRM opens the ring. This is done by changing the state to BLOCKED at one of the ring ports in the MRM and the other as FORWARDING as shown in figure 2. On this BLOCKED port only test frames to supervise the ring (MRP_Test) and other management frames like LLDP (Link Layer Discovery Protocol) are sent. Data frames are sent by the MRM only on the port in the FORWARDING state.

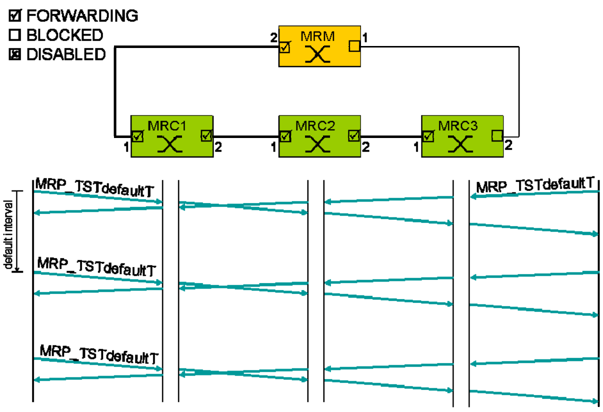

Figure 2. Normal exchange of test frames

Every switch in the ring, the MRM and all MRCs, start now with normal data transfer and set up their normal Filtering Data Base (FDB) to reflect the actual line topology of the usable Ethernet links.

3.3. Failure detection with MRP

If TSTNRmax test frames in sequence are not received anymore by the MRM the ring topology is considered as interrupted. This counter TSTNRmax is set typically to three, so that the time to detect a failure in the ring $T_{detection}$ takes according to formula (2) typically 60 ms.

$$T_{detection} = TSTdefaultT \text{ x } TSTNRmax \quad (2)$$

Now we have to change the topology in the whole ring. For this all MRCs and the MRM have to clear their FDBs in the same time as the redundant port is changing state form BLOCKED to FORWARDING to keep the network consistent. The MRM sends several MRP_TopologyChange messages into the ring with the indication, that the topology has changed and this will take effect in a certain delay. The number of MRP_TopologyChange messages needed and the delay between these messages can be configured. Typical values is a delay (TOPchgT) of 20 ms and retries (TOPNRmax) of three. This leads to a Trecovery according of formula (3) of at least another 30 ms.

$$T_{recovery} = T_{setupFDB} + (TOPchgT \text{ x } TOPNRmax) \quad (3)$$

The blocked, redundant port on the MRM is changing state to FORWARDING. Every MRC receiving these MRP_TopologyChange indications of topology changes is supposed to clear its Filtering Data Base (FDB) at the specified time. Afterwards it has to build up again the FDB based on the new topology. This time is difficult to specify and depends also on the resources available in the switch and the number of switches in the ring. There fore the maximal number of switches in the ring is limited to 50.

To speed up this error detection optionally every MRC may supervise also its ring ports. As soon as the MRC detects one of its ring ports going down, it sends a link down frame (MRP_LinkChange) indicating the expected down time on the other ring port. The MRM receiving the link down frame reduces the interval of the test frames to TSTshortT which is typically set to 10 ms: so the detection of the ring interruption $T_{detetion}$ will be possible in less than 30 ms time!

The complete reconfiguration time $T_{reconfiguration}$ includes the $T_{detection}$ and the $T_{recovery}$.

$$T_{recovery} = T_{detection} + T_{recovery} \quad (4)$$

According to [11] the reconfiguration time of such an MRP ring is limited to 200 ms. This value includes pessimistic software delay time estimations. In practical implementation better performance should be reachable.

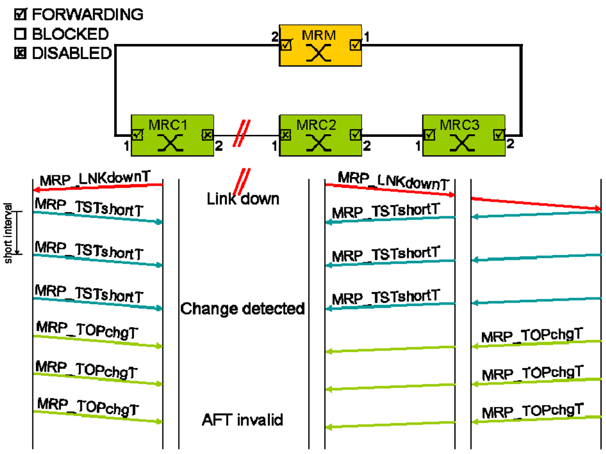

Figure 3. Failure detection

4. Setup of a Profinet IO-system

If the specified MRP is independent of the RTE solution selected it should be possible to use it also in a Profinet IO-system setup.

4.1. Example IO-system setup

We used in our laboratory an IO-controller and two IO-devices with simple build in two port switches from two different manufactures, two industrial Ethernet switches from two different manufacturers supposed to support also the MRP protocol, one working as an MRM and the other as an MRC. Both switches act also as IO-devices.

The IO-controller was configured to control all four devices. Also the Switches are Profinet IO devices, to allow the monitoring of the network state by the IO-controller. Possible setups are shown in figure 4.

The cycle time of the different CR to the end IO-devices (e.g. Io-devices 2 3 and 5 in figure 4) are set therefore with a SendClockFactor = 32 and a ReductionRatio = 1 according to formula (1) to 1 ms. Whereas the ReductionRatio of the switches (Io-device 1 and 4) are set to 128, which results in a much slower cycle time of 128ms. This is sufficient if the goal of this connection is just to monitor the state of the network.

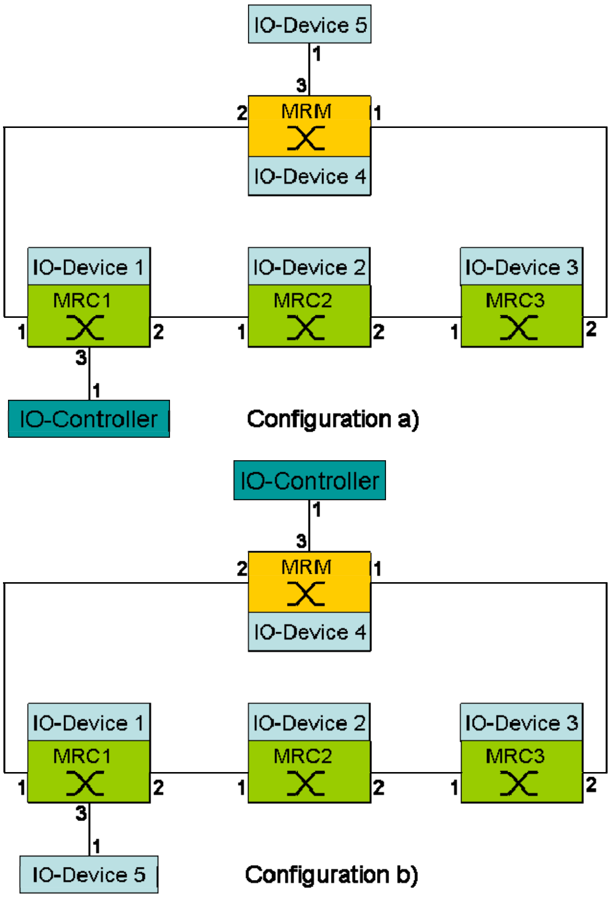

Figure 4. PROFINET IO system test setup

4.2. First results

It was possible to close the ring. The test frames are forwarded from the MRM and even if the intermediate switches in a ring are not MRCs – e.g. MRC2 and MRC3 in figure 4 – the ring is detected as closed by the MRM. As soon as we remove an active connection in the ring, the topology is changed as expected.

But the required timings are completely missed: the Profinet Application Relations (AR) between the IO-Controller and some of the IO-Devices are reset, what can take up to 30 seconds to be build up again.

The main point is the watchdog time of the cyclic Profinet IO-CR. The AR is supervised with this watchdog time, specified as a factor of send cycle times. In this setup the WatchdogFactor was set to 3. If a consumer of an AR does not receive the cyclic data frame for more than 3 ms, the AR is released and build up again. This setup of the AR takes more than the grace time of the application.

To be usable, the reconfiguration time of the MRP ring network must be smaller than the WatchdogTime of all used Profinet IO ARs. If the reconfiguration time of the MRP ring is at most 200 ms, the WatchdogFactor and the send cycle is 1 ms, the WatchdogFactor has to be set to be at least 200. In our setup this was the case for the low-speed connections to the switches, but not to the user data connections!

To increase the WatchdogTime to the maximal grace time of the application is not really a good solution. The most critical point of the redundancy is not the availability of the links: the MRM is able to detect the interruption of the ring topology in latest $T_{detection}$ which is typically less than 60 ms. The problem is with the FDBs of the different MRCs in the ring and the $T_{recovery}$. As long as the FDBs are not reset or corrected according to the new topology the Real-Time (RT) Profinet IO frames will not reach the consumer in time.

We propose here different possibilities for improvements of this MRP for fast Profinet IO.

4.3. Fix the position of the MRM

The correction mechanism for the FDB in the MRCs does work also with the reception of the cyclic data: as soon as a switch receives the cyclic data frame over a new port, the FDB is changed accordingly and so automatically adapted to the new topology.

In configuration a) in figure 4 the cyclic frames are sent from the IO-controller to the IO-devices 4 and 5 over port 1 of MRC1 and for the IO-devices 2 and 3 over port 2, if the MRM set his port 1 as blocked. As soon as we get an interruption of the link between MRC1 and MRC2, this is detected by MRC1 and all frames are send automatically over port 1. This will force MRC3 and MRC2 to adapt their FDB also.

If in the same configuration the link between MRC2 and MRC3 is interrupted, this will not be detected by MRC1. MRC1 will still send the frames for IO-device 3 to port 2 and the frames will not reach the IO-device 3, until the FDB is cleared.

A first solution could be, to fix the position of the MRM to be always connected to the IO-controller as shown in figure 4 configuration b). In this case all cyclic frames are always sent to the correct port, as soon as the MRM detects an open ring. This leads to a faster reconfiguration of the MRP ring. In the worst case 60 ms are needed by the MRM to detect the interrupted ring and another send cycle to send a RT Frame to all devices and correct the FDBs in all switches. But this method is strongly depended of the topology and therefore not generally usable.

4.4. Shorter life time of the FDB

The second proposition is to reduce the FDB life time. Every entry in an FDB in switch has a life time. After this life time the entry is cleared. This leads to an automatic redetection of the topology. Typical values of such life times are several seconds for automation applications up to several minutes for office applications.

This life time must be at least as big as the send cycle time for Profinet IO systems. This could be very short, in the range of ms. To improve now the automatic reconfiguration it could be use full, to fix this life time to a reasonable factor of three time the send cycle time.

In our experimental setup this would mean, that if the send cycle is 1 ms, the life time is fixed to 3 ms and the ring is reconfigured in latest 4 ms after the closing of the new topology.

This solution needs a modification in all MRCs and loads with this short life time supervision a heavy processing burden to the switches.

4.5. Ignore the FDB for Real-Time

Here we consider a third solution: Ignore the FDB and keep the ring closed for the Profinet RT frames.

The problem is not caused by the normal UDP/IP frames. The applications using this type of protocol have a grace time much higher than the cyclic process data. So it is natural to focus on a special solution for only the cyclic Real-Time (RT) data frames.

The idea is, that the RT-frames are always sent over both ring ports. This means in a simple IO-device with an included MRC as IO-device 2 and 3 in figure 4 that the FDB for RT frames is ignored for outgoing frames. If an RT frame is received on one of the ring ports, it has only to be checked against the MAC of the device.

Due to the ring topology every IO-device will now receive the RT frames twice in normal operation. This is not really a problem, as every cyclic RT frame includes a time-stamp. A received RT frame with the same or an older time stamp will be discarded automatically by the receiver. So the redundant RT frames are removed. This only works, if the ignorance of the FDB is only effective for the RT frames including the timestamp. All other frames are passed as before. This improved version allows a bump less switchover, or there will be no interruption at all.

The ring ports have to be in a special state, to register that the ring is closed. As soon as the ring is opened, this has to be detected and additional repair measures have to be started.

This third solution is included in the IEC 61158 under the name Media Redundancy Real Time (MRRT) in the clause specific for Profinet.

This MRRT solution is very similar to the Parallel Redundancy Protocol (PRP) as also defined in [11] and described in [14].

5. Conclusions

We showed in this paper, that the Media Redundancy Protocol (MRP) as defined in the new IEC 62439 clause 5 is not suited to the Real-Time (RT) protocol used by Profinet IO according to IEC 61784-2 CPF3/5. Therefore in IEC 61158-5-10 an additional Medium Redundancy Real Time (MRRT) is defined, which allows the redundant routing of RT frames in both directions over an Ethernet ring topology. This new MRRT protocol may be combined without problems with the standard MRP protocol for standard frames.

The problem with this solution is only, that in the conformance classes of Profinet IO this MRRT protocol is only mandatory for class C installations. This will make it difficult to install a class b installation with MRP redundancy but no MRRT supported. It is not clear how the set reasonable parameters for cycle time, watchdog and redundancy which could work together in a reasonable manner.

Our experiences in the lab showed also, that the setup time for Profinet IO ARs are far too long. This is also one of the reason, that a "fast-setup" procedure is now defined in the new issue of the standard [12],[13]. This setup procedure must be shorter than the expected grace time of the application.

Also important for the availability of a system is the mean time to repair. The detection of a failure in the ring topology and a quick localisation of the failed link in the ring is a major issue. So as a next step we will include the ring topology in the maintenance approach with the automatic topology detection mechanism and extend the studies of [15].

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