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Special communication network topology for small process bus and distributed busbar protection deployments

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SIPROTEC 5 Application

Special communication network topology for small process bus and distributed busbar protection deployments

APN-073, Edition 2

Content

1 Special communication network topology for small process bus and distributed busbar protection deployments

1.1 Introduction

This application describes a special communication network solution for relatively small process bus and distributed busbar protection deployments. "Small" means in scope of this solution that a limited number of IEDs (process bus clients and merging units) are used, which are all connected to a single pair of specific Ethernet switches. This solution provides connectivity for up to 18 process bus clients and merging units, in any needed proportion.

The purpose of this special topology is minimizing the number of deployed communication network devices. It is done mainly for reducing investment and operation & maintenance costs.

1.2 Basic communication and synchronization concept

The IEDs are synchronized via Precision Time Protocol (PTP) [1] by help of a Global Navigation Satellite System (GNSS) or IRIG-B. Parallel Redundancy Protocol (PRP) [4] is used for avoiding single-point-of-failure in the network and for uninterrupted communication.

Figure 1 shows the functional or logical block diagram of the communication network solution for explaining the solution in principle. Please note that it differs from the actual network topology which will be discussed later.

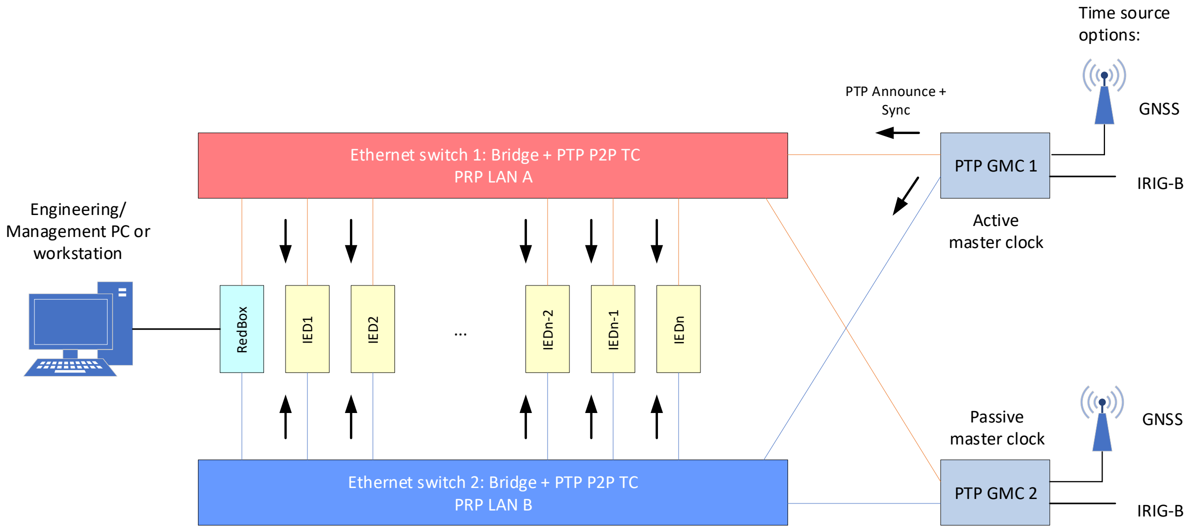

Figure 1: Functional (or logical) block diagram of the communication solution

There are two Ethernet switches in the network where all IEDs are connected to. The Ethernet switches represent PRP LAN A and LAN B [4]. The IEDs are in the role of double attached nodes for PRP (DANP). The merging units (in publisher role) generate and duplicate Sampled Measured Value (SV) frames and send the duplicates simultaneously via the two ports of the ETH-BD-2FO module to the two Ethernet switches. The latter forward the SV frames to the process bus clients (subscribers). This way the process bus clients receive duplicated SV frames from the Ethernet switches. The duplicate elimination function of the ETH-BD-2FO module forwards the first received frame of each SV frame pair for further processing and discards the later received frame of the pair. Similar, GOOSE frames are exchanged between IEDs via the two Ethernet switches. The frame duplication / duplicate elimination procedure helps to overcome single Ethernet switch outage and link failures without losing any sent frame (seamless redundancy).

The GOOSE and SV communication might be sent priority-tagged (VLAN-tag with VLAN-ID = 0) or VLAN-tagged (with VLAN-ID > 1), with one or different VLAN-IDs. The optional VLAN-tagging of frames and VLAN filtering in the switches allows isolation of GOOSE and SV streams from each other and from other communication.

There is a PC (or workstation) for engineering of the IEDs and for managing the Ethernet switches. This is done by help of IP-based protocols such as DIGSI, HTTPS and SSH. The PC is connected via a PRP Redundancy Box (RedBox) to the two Ethernet switches, since computers usually do not support PRP by their own. The engineering / management communication runs without VLAN-tag (untagged) between the PC and the switches. It can run untagged or VLAN-tagged between the IEDs and the switches. The latter is for isolation from GOOSE and SV streams.

Please note that in general PRP LAN A and LAN B (this means the switches of these LANs) are always mutually isolated from each other, for avoiding endless circulating frames and other undesired behavior. DANP do not forward frames from their LAN A port to LAN B port (and vice versa) for this purpose.

There are two PRP-capable PTP grandmaster clocks in the network. They are in the double attached master clock role [4.A] and are connected to the Ethernet switches in PRP LAN A and LAN B. These clocks execute the Best Master Clock Algorithm [1], based on periodically sent PTP Announce messages, and this way determine who is the active master of the network. The active master clock synchronizes the slave clocks located inside of the IEDs by help of periodically sent PTP Sync messages. The other grandmaster clock is in the passive master state and ready to take over if the current active master fails or loses its time source.

The time source of the grandmaster clocks can be either GNSS or IRIG-B. The synchronization to the absolute time (UTC) is not so important in the process bus and distributed busbar protection application cases but the relative time accuracy across merging units and process bus clients. A high-precision external time source must be used so that the deviation of both grandmasters local clocks is very small, and a smooth master switchover can be achieved.

The Ethernet switches combine the VLAN-related frame forwarding (VLAN bridging [5]) and PTP peer-to-peer (P2P) transparent clock role. A P2P transparent clock forwards PTP messages received at one switch port to all other ports. It determines the storage and processing delay (the so-called residence time) of specific PTP messages inside of the switch and the message propagation delay on neighboring links. These measured delay time values are populated to the correction field of forwarded PTP messages.

Figure 1 shows that the active master clock sends PTP Sync messages simultaneously over the links to the Ethernet switches of PRP LAN A and LAN B and the latter forward them to the connected process bus clients and merging units. This way the slave clocks of IEDs receive PTP Sync messages of the active master from both Ethernet switches, via separate paths. The double attached slave clocks determine the "better" path from the master clock [4.A] and use the PTP Sync messages received via this path for synchronization. If the "better" path fails (due to Ethernet switch outage or link interruption) then the slave clock changes to PTP synchronization via the other path. Furthermore, the slave clocks can recognize the failure or degradation (e.g. in case of GNSS loss) of the active master and in this case will start synchronization from the previously passive but now new active master.

Please note that in this solution PTP messages are always sent without VLAN-tag. Sending of PTP messages in VLAN-tagged frames is an optional feature [2] and currently not supported by the SIPROTEC5 ETH-BD-2FO module.

1.3 Simplified solution for small process bus and distributed busbar protection

Figure 2 shows the cost-optimized network topology of the communication solution. The IEDs and the PRP Redbox are connected to two Siemens RUGGEDCOM RSG2488 switches. In this solution, the RSG2488 switches combine the functions of VLAN bridging, PTP grandmaster and P2P transparent clock in a single device. The specific RSG2488 capability of running these functions in parallel and, additionally, some special switch configuration allows reducing the number of deployed network devices to only two: one for PRP LAN A and the other for PRP LAN B.

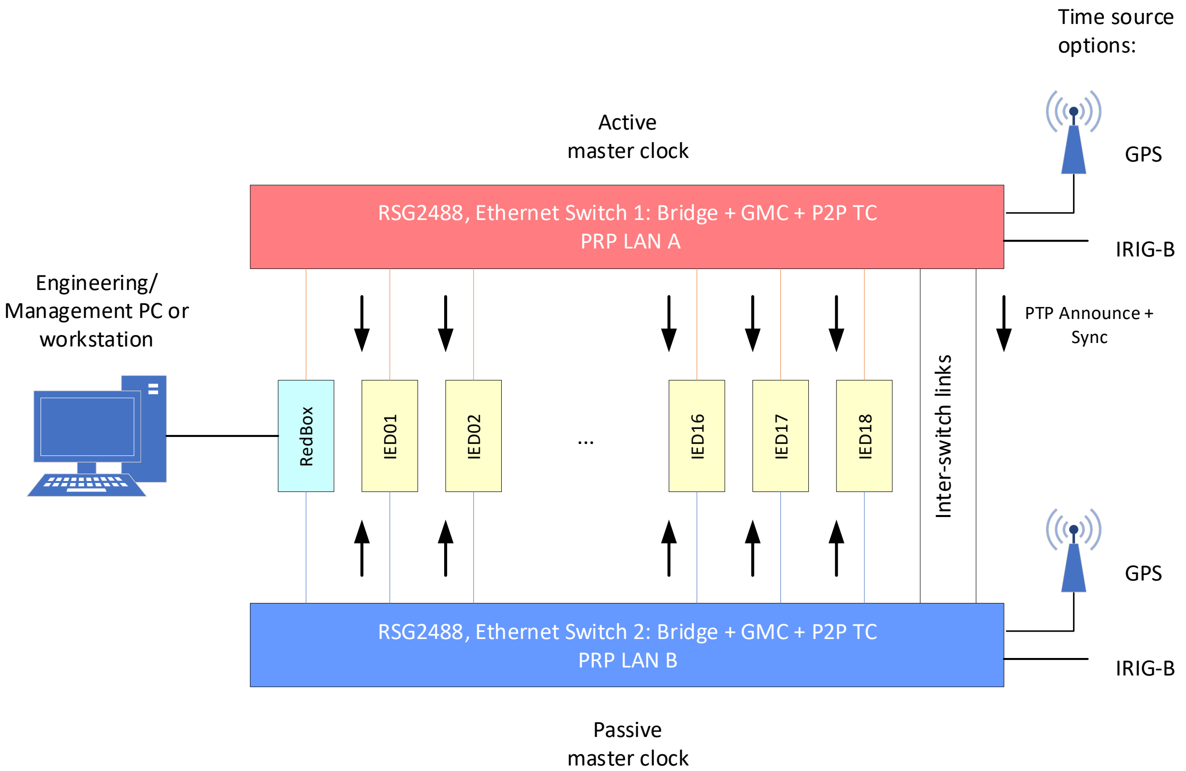

Figure 2: Network topology of the communication solution

All communication runs via these two switches. Forwarding of GOOSE, SV frames and of the engineering/management communication is done as describe above.

The RSG2488 switches are directly connected by two links, named inter-switch links. There are two such links for redundancy purposes: one is forwarding and the other blocking, the latter ready to take over if the first one fails. This redundancy procedure is executed by the Rapid Spanning Tree Protocol (RSTP) [5] which is activated on the inter-switch link ports.

PTP messages of both grandmasters are sent over the active inter-switch link. This way the grandmasters "see each other" and determine who is currently the active and who the passive master clock. The active and master clock role during faultless operation can be pre-determined by configuration, e.g. the Priority2 parameter. The passive master can recognize the active master's failure or degradation and will become the active master clock in this case.

Figure 2 shows that the RSG2488 switch with active master clock sends PTP Sync messages via its switch ports to the connected ETH-BD-2FO module port of the process bus clients and merging units. Additionally, this RSG2488 sends PTP Sync messages over the inter-switch link to the other switch where they are forwarded via the build-in PTP transparent clock and the switch ports to the other ETH-BD-2FO module port of the IEDs. By help of this procedure, the double attached slave clocks of the devices receive the PTP Sync messages from the active master via two paths: via the direct link to the RSG2488 switch running the active master on one hand and via the inter-switch link, the other switch and the link to that switch on the other hand. The slave clocks determine the "better" path for PTP synchronization and handle link interruption and switch failures as described above.

Special communication network topology for small process bus and distributed busbar protection deployments

It was described in the previous chapter that Ethernet switches in PRP LAN A and LAN B are always isolated from each other. They cannot directly be connected. But exactly this is the case due to the inter-switch links used in this specific network topology. For avoiding misbehavior, special care is taken by switch configuration so that only PTP, but no other communication runs over the inter-switch links. The technical details are contained in the comments of the switch configuration example below.

1.4 Rules and restrictions of this special communication solution

Please consider the following rules and restrictions of this special communication solution:

- The RSG2488 switch ports 2/4, 4/4, 6/4 and 7/2 cannot be used for PTP if the master clock and P2P transparent clock functions run in parallel (Figure 3). This information is from the RUGGEDCOM ROS manual. It means that in this solution these four switch ports cannot be used for connecting devices requiring PTP synchronization, such as the process bus clients and merging units. But these ports can be used for connecting the PRP Redbox, since the engineering / management PC does not need PTP synchronization. This results in the maximum number of 18 IEDs which can be connected to the RSG2488 switches (since the switch provides maximum 24 ports and two PTP-capable ports are used for the inter-switch links).
- RSG2488 does not support PTP in combination with PRP redundancy. Nevertheless, it works, but only with this specific network topology and switch configuration and with the following restriction: PRP supervision frames are not sent and not processed. This limits network diagnostic capabilities but other problems resulting from this restriction have not been found.
- RSG2488 switches with Hardware ID RSG2488 (instead of RSG2488v2) do not support the combined master and P2P transparent clock function and cannot be used for this solution. The Hardware ID is shown in *Diagnostics >> View Product Information* of the RSG2488 user interface (Figure 4).
- This solution is sensitive regarding wrong device configuration and wrong device connection to ports. A not or wrong configured or wrong connected device can confuse the whole network. It is recommended that unused switch ports are administratively disabled.
- GOOSE and SV frames can be sent priority-tagged by IEDs (default setting). Alternatively, sending VLAN-tagged frames with VLAN-ID > 1, in combination with VLAN filtering in the switches can be advantageous for isolation of GOOSE and SV streams from each other and from engineering / management communication.
- This solution has been tested and it works with RUGGEDCOM ROS 5.4.1 and 5.4.2. Its operation with other ROS versions cannot be guaranteed and requires new testing.
- This solution uses specific feature capabilities of RSG2488 switches and is tailored to the communication needs of small process bus and busbar protection deployments (as described in this application note). It has been carefully evaluated and tested by Siemens. Any changes or enhancements or use for other purposes will require additional evaluation and new testing.

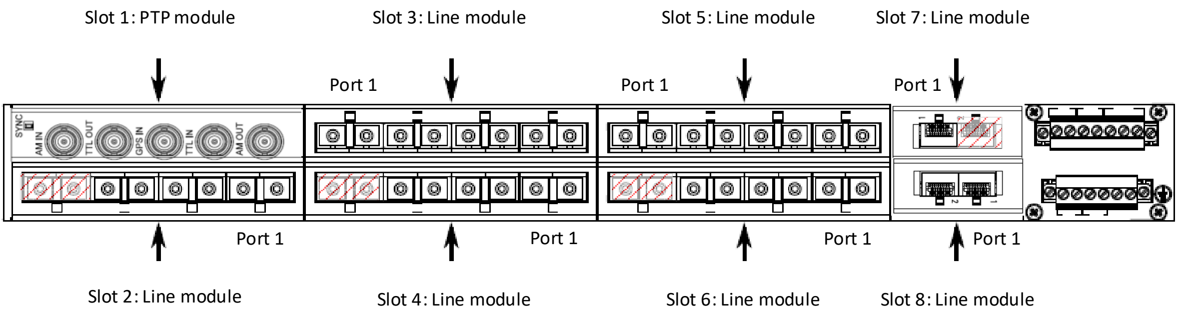

Figure 3: RSG2488 rear view and ports not usable for PTP synchronization (in scope of this solution)

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Main Version    v5.4.1 (Dec 18 2019 13:49)
Hardware ID     RSG2488v2
Descr           RSG2488
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Figure 4: Hardware ID of RSG2488

1.5 RSG2488 Configuration Examples

Configuration examples are provided for RSG2488 Switch 1 and Switch 2 and for GPS and IRIG-B time sources (files rsg2488_gps_switch1.csv, rsg2488_gps_switch2.csv, rsg2488_irig-b_switch1.csv, rsg2488_irig-b_switch2.csv). These files contain only the solution-related configuration (so-called partial configuration). The files can be downloaded to the switches e.g. via the serial interface, by help of a terminal program (like TeraTerm) and using XMODEM. Please see the RSG2488 User Guide, Section 4.5.1. The downloaded partial configuration is merged automatically with the previous RSG2488 switch configuration.

The example RSG2488 switches are fully equipped with the PTP module and seven line modules (in summary 24 ports). Ports 2/1-2/3,3/1-4/3,5/1-6/3 are used for connecting IEDs, port 4/4 is for connecting the PRP Redbox and ports 8/1, 8/2 are for the inter-switch links.

1.6 Glossary

Grandmaster clock: Within a domain, a clock that is the ultimate source of time for clock synchronization using the protocol. [1]

Master clock: In the context of a single Precision Time Protocol (PTP) communication path, a clock that is the source of time to which all other clocks on that path synchronize. [1]

Slave clock: A clock that synchronizes to another clock.

Transparent clock: A device that measures the time taken for a Precision Time Protocol (PTP) event message to transit the device and provides this information to clocks receiving this PTP event message. [1]

Peer-to-peer transparent clock: A transparent clock that, in addition to providing Precision Time Protocol (PTP) event transit time information, also provides corrections for the propagation delay of the link connected to the port receiving the PTP event message. In the presence of peer-to-peer transparent clocks, delay measurements between slave clocks and the master clock are performed using the peer-to-peer delay measurement mechanism. [1]

Doubly attached node: Node that has two ports for the purpose of redundant operation. [3]

Singly attached node: Node that has only one port to a LAN. [3]

RedBox: Device attaching singly attached nodes to a redundant network. [4]

1.7 Abbreviations

BMCA	Best Master Clock Algorithm
DANP	Double Attached Node PRP
GMC	Grandmaster Clock
GNSS	Global Navigation Satellite System
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol

HTTPS	HTTP Secure
ID	Identifier
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
L2	Layer 2
LAN	Local Area Network
MU	Merging Unit
P2P	Peer-to-Peer
PC	Personal Computer
PRP	Parallel Redundancy Protocol
PTP	Precision Time Protocol
PVID	Port VLAN Identifier
RSTP	Rapid Spanning Tree Protocol
SSH	Secure Shell (Protocol)
SV	Sampled Measured Values
TC	Transparent Clock
VLAN	Virtual LAN

1.8 Reference to standards

[1] IEEE 1588:2008
Precision Clock Synchronization Protocol

[2] IEC 61850-9-3:2016
PTP profile for power utility automation

[3] IEC 62439-1:2010
Industrial communication networks – High availability automation networks –
Part 1: General concepts and calculation methods

[4] IEC 62439-3:2016
Industrial communication networks – High availability automation networks –
Part 3: Parallel Redundancy Protocol (PRP) and
High-availability Seamless Redundancy (HSR)

[4.A] IEC 62439-3:2016, Annex A
Clocks synchronization over redundant paths in IEC 62439-3

[5] IEEE 802.1Q-2014
Bridges and Bridged Networks

1.9 Conclusion

Taking advantage of specific capabilities in the RSG2488 switches, it is possible to reduce the number of deployed network devices in a process bus solution to only two. This network configuration demands a very special switch configuration and it is suitable only for small process bus stations and for the busbar differential protection. Keep in mind that this solution provides connectivity for a maximum of 18 process bus clients and merging units, in any needed proportion.

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