LTE/3G Based Wireless Communications for Remote Control and Monitoring of PLC-Controlled Mobile Vacuum Devices

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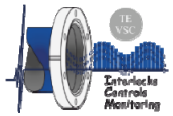

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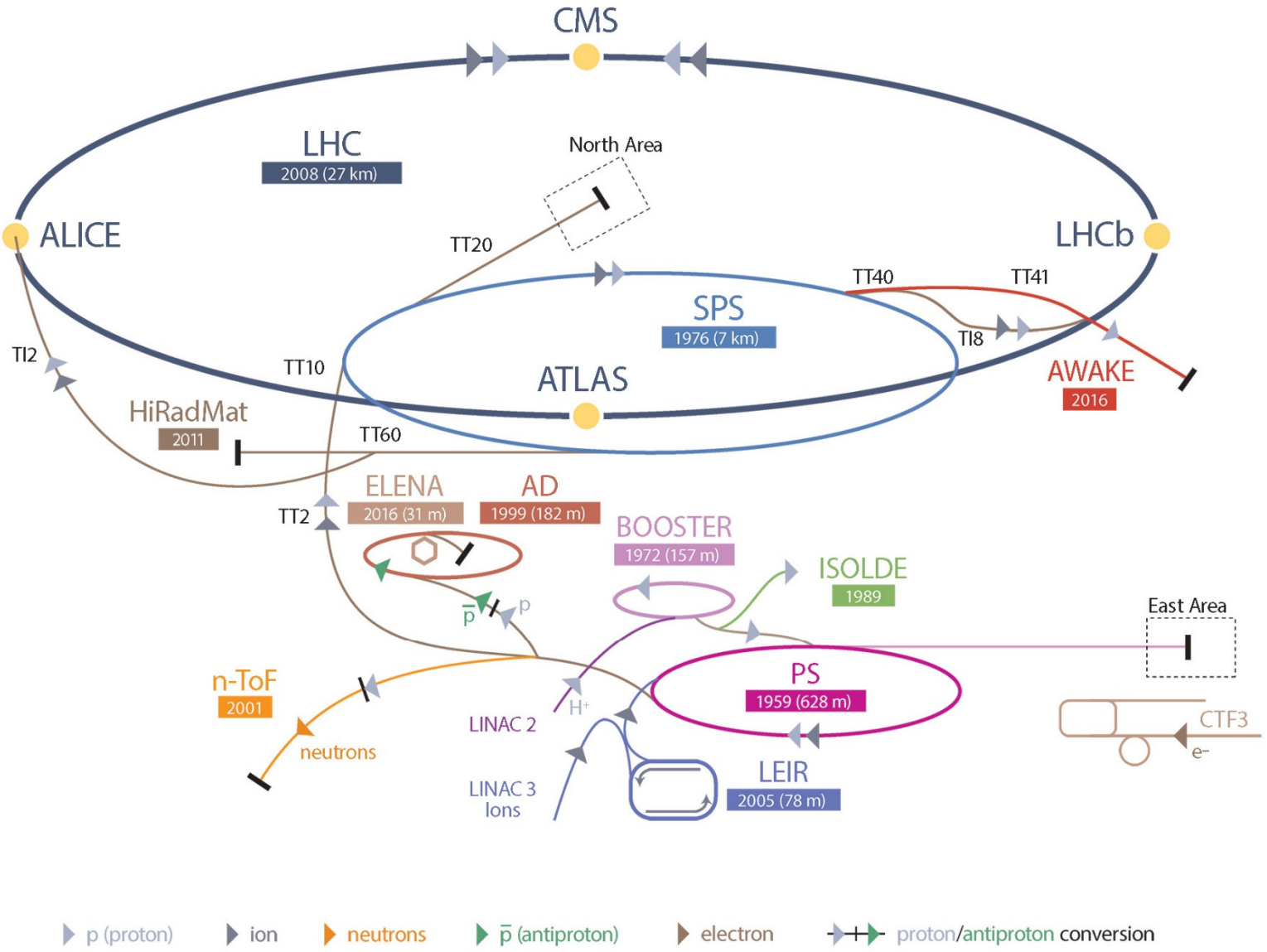
Introduction

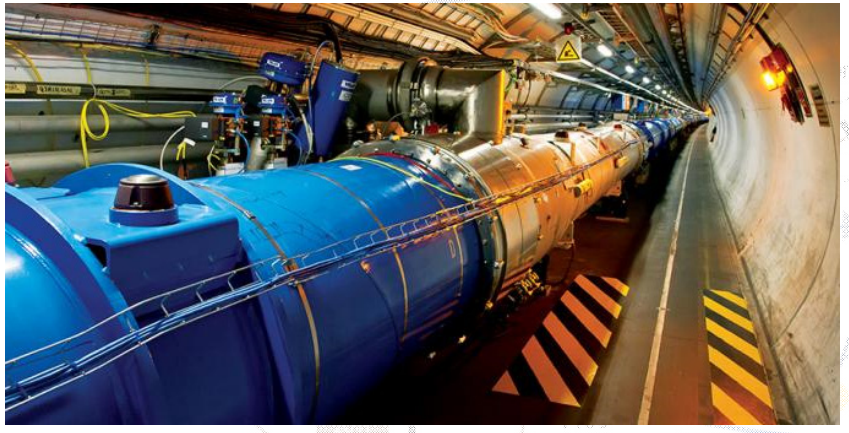
The CERN Accelerator Complex
and Vacuum System.

Mobile Vacuum Devices.


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
p
n-ToF
2001
PS
1959 (628 m)
H+
LINAC 2
CTF3
e−
neutrons
LEIR
2005 (78 m)
LINAC 3
Ions
p (proton)
ion
neutrons
p̄ (antiproton)
electron
proton/antiproton conversion

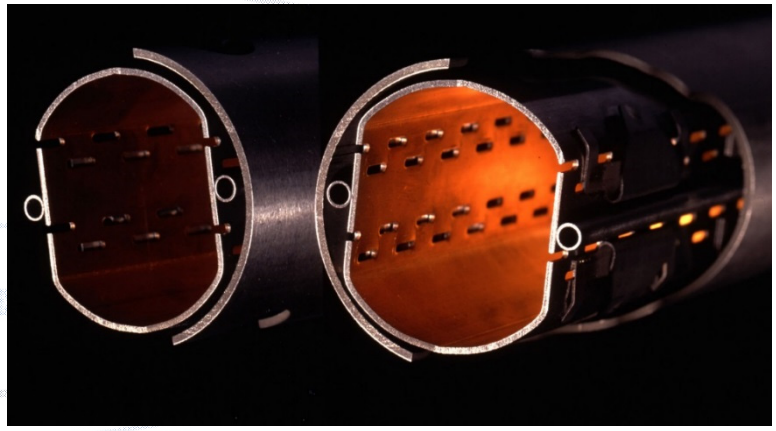
Magnets Insulation Vacuum

$Order\ of\ 10^{-8}\ mbar$



Beam Pipe Vacuum

$Order\ of\ 10^{-10}\ mbar$



Cryogenic Lines Insulation Vacuum

$Order\ of\ 10^{-6}\ mbar$

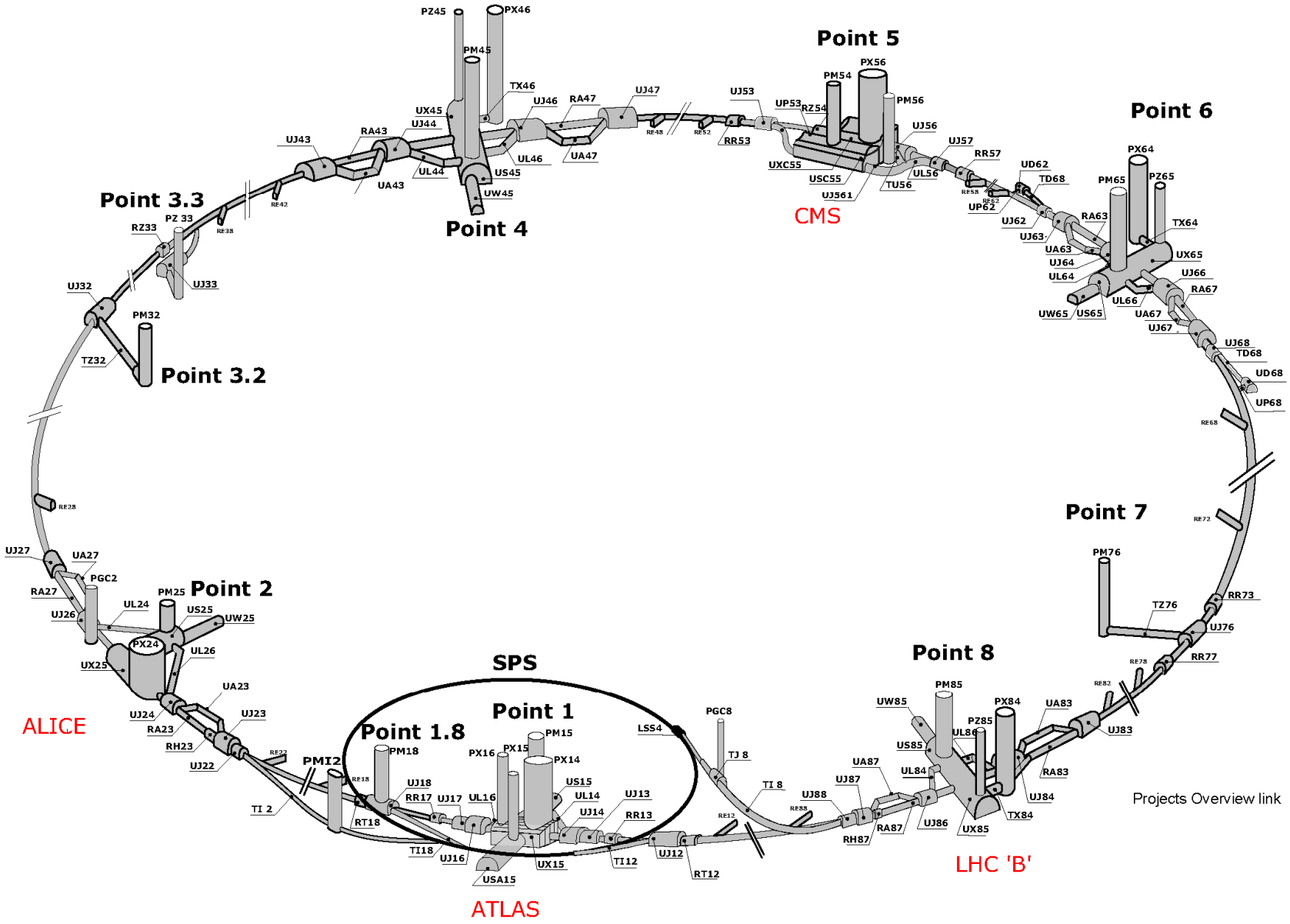
PLC-Controlled Mobile Vacuum Devices

Turbo Molecular Pumping Groups

*S7-200 controlled mobile pumping groups used in multiple locations throughout CERN. New S7-1200 control crate has been designed and renovation is under way. Around **400** units.*

Bakeout Racks

*S7-300 controlled mobile racks for in-situ bakeout of vacuum systems. They are used in all accelerators and experiments. Around **200** units.*

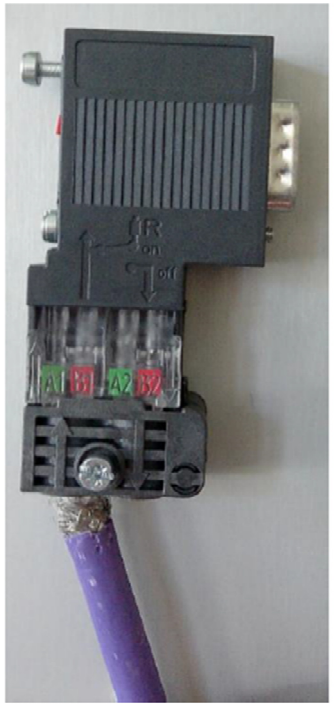


Projects Overview link

All around the LHC tunnel we have several **Profibus networks** with open connectors, managed by multiple Master PLCs.

During **Technical Stops**, mobile devices are installed and integrated in the Vacuum Control System using these Profibus networks. This solution poses some issues:

- Operators often create issues which can bring the whole network segment down, including star topologies, illegal loops, missing shunts, missing network terminations.
- The constant manipulation of the Profibus cables and connectors causes accelerated deterioration of the material .
- Adress conflicts among devices (having several mobile devices in the same network with the same DP address) are relatively frequent due to the limited amount of available Profibus Addresses.
- Only the LHC, LINAC4 and a couple of the newer installations have installed networks. Installing Profibus cable is cumbersome and expensive.



Wireless Communication

Study and implementation of a Wireless alternative for integrating Mobile Devices in the Vacuum Control System

Wireless Connectivity in the Tunnels

Wireless access points (standard 802.11bgn) are typically installed in the tunnels during the Long Shutdowns. **We cannot, however, rely on this technology for wireless connectivity due to the fact that they are removed during operation**, as they would not withstand radiation.

There is, however, a **mobile network provided by Swisscom that is permanently available in the tunnels.** This is achieved using Leaky Feeder type antenas.

Though the service is provided by Swisscom, the **APN is managed by CERN** and can be used to tap directly in our network infrastructure.

3G/LTE Connectivity for Siemens PLCs

S7-1200 | CP 1243-7

For Turbo Molecular Pumping Groups

Native LTE Communication module for S7-1200 based Control Crates.

S7-300 | SCALANCE M874-3

For Bakeout Racks

Industrial 3G wireless router that can be used with the available S7-300 Ethernet interface.

3G/LTE Connectivity for Siemens PLCs

SCALANCE M874-3

3G/LTE Connectivity for Siemens PLCs

We wish to have the same implementation for Bakeout Racks and Mobile Pumping Groups:

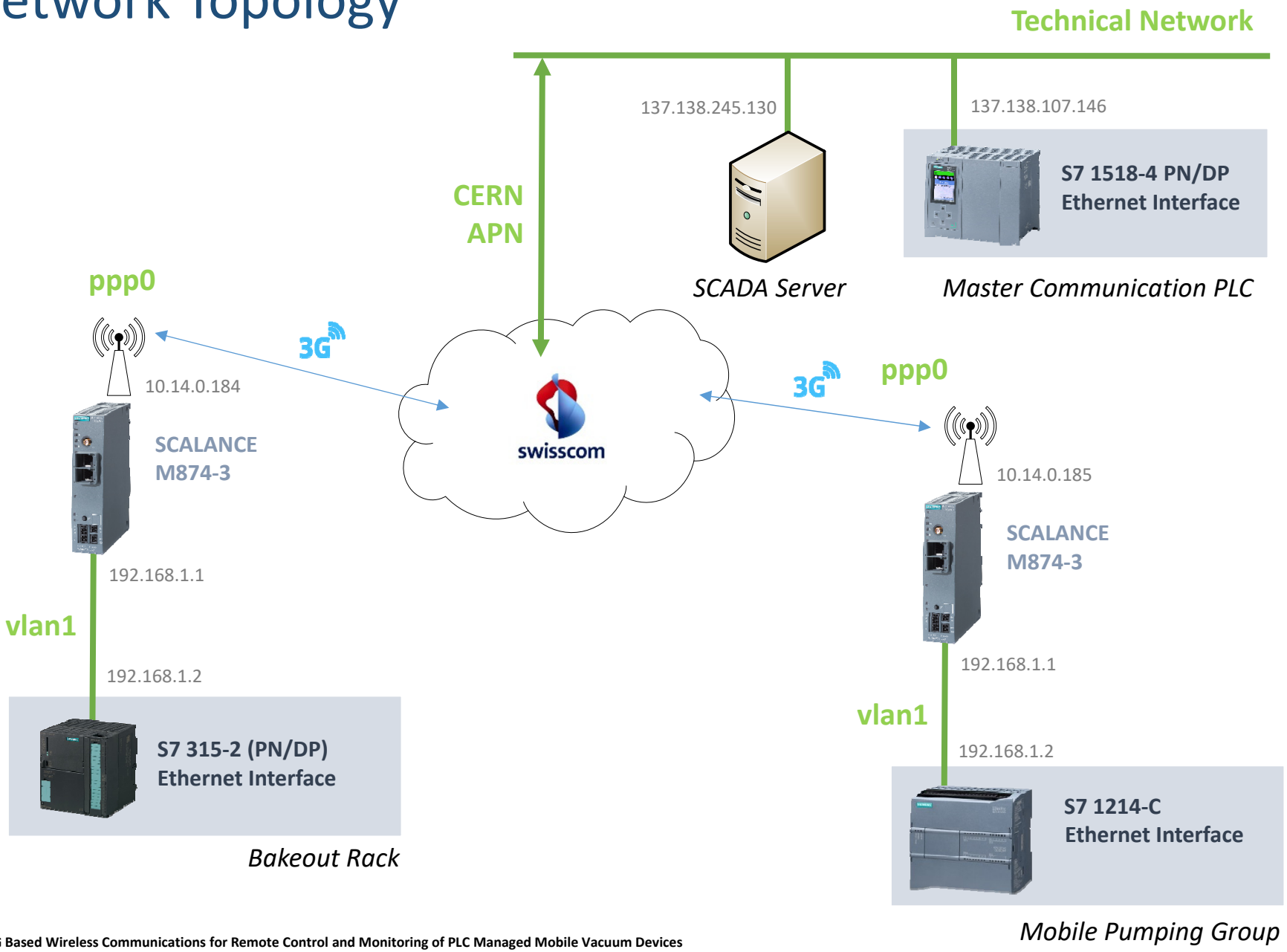
Use the SCALANCE M874-3 router for both applcations.

The router is used as a **Modular solution:**

- We keep a limited stock of 3G routers and respective SIM cards.
- Routers are installed in the mobile device whenever wireless connectivity is required.
- When no interventions are expected the SIM cards can be temporarily disabled and thus not billed for the month.

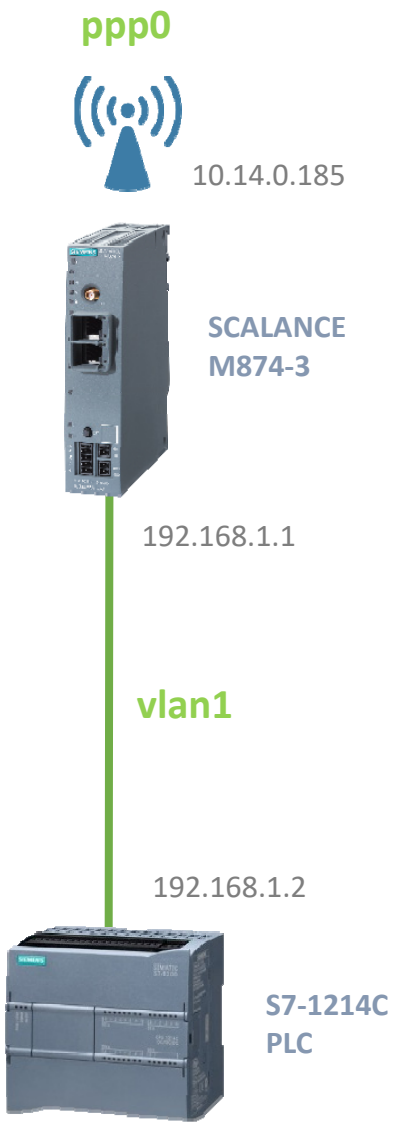
SCALANCE M874-3

Network Topology



Network Configuration

- The SIM cards are configured to connect to the data network (**ppp0**) through the CERN APN and given a fixed IP that's accessible over the Technical Network.
- The SCALANCE router is configured with a fixed IP in its Local Area Network (**vlan1**).
- The PLC is also given a fixed IP on the LAN (**vlan1**).
- Only the 3G router is visible on TN through its 3G IP, so the relevant traffic must be routed to the PLC.



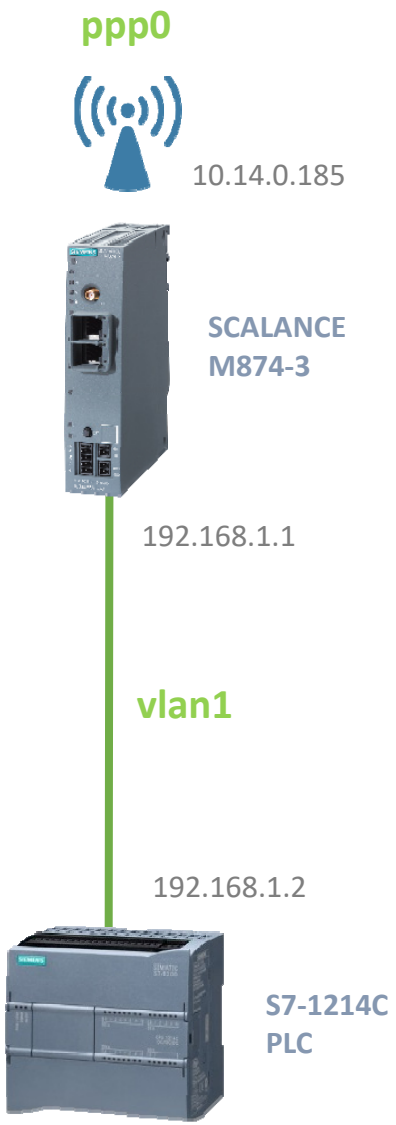
Network Configuration

Incoming Traffic

Incoming traffic arriving in the **ppp0** interface is handled using port forwarding:

- Traffic in Port **102** is routed to the PLC in **vlan1** (192.168.1.2) for the S7 communication protocol (SCADA access, debugging and reprogramming using TIA Portal or S7 Professional).
- Traffic in Port **2424** is routed to the PLC in **vlan1** (192.168.1.2) for our dedicated Mobile Device integration protocol.

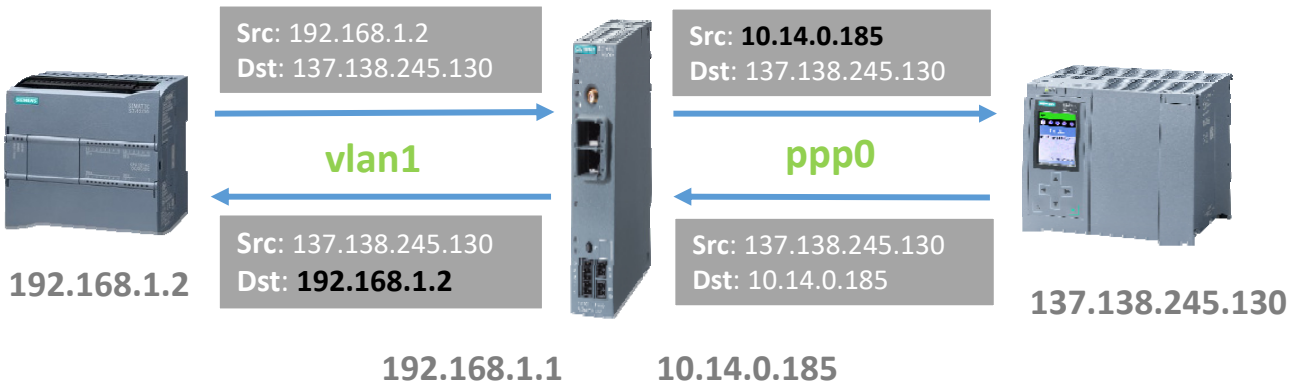
On Ports 102 and 2424 the PLC is transparently accessible on the TN through the IP of the SIM card.



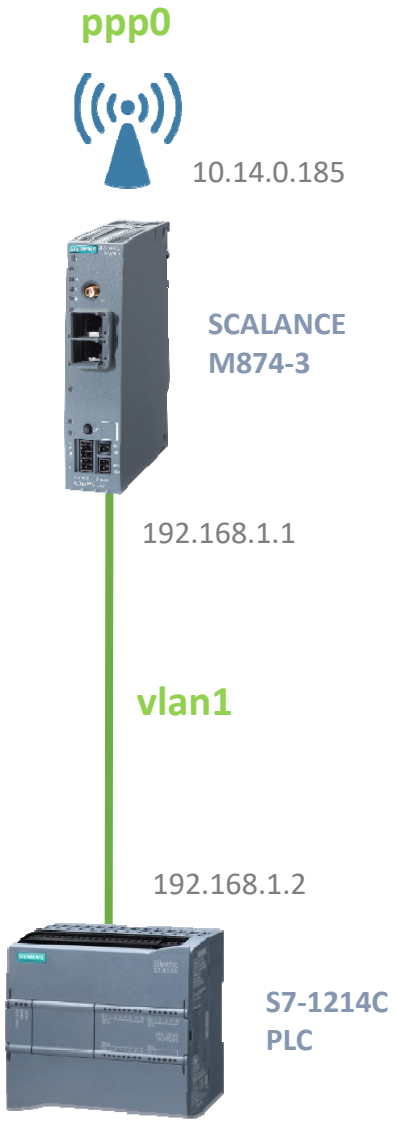
Network Configuration

Outgoing Traffic

Outgoing traffic from **vlan1** to outsider networks is routed using Network Address Translation (**NAT**):



The PLC can access IP outside of its LAN, regardless of port.



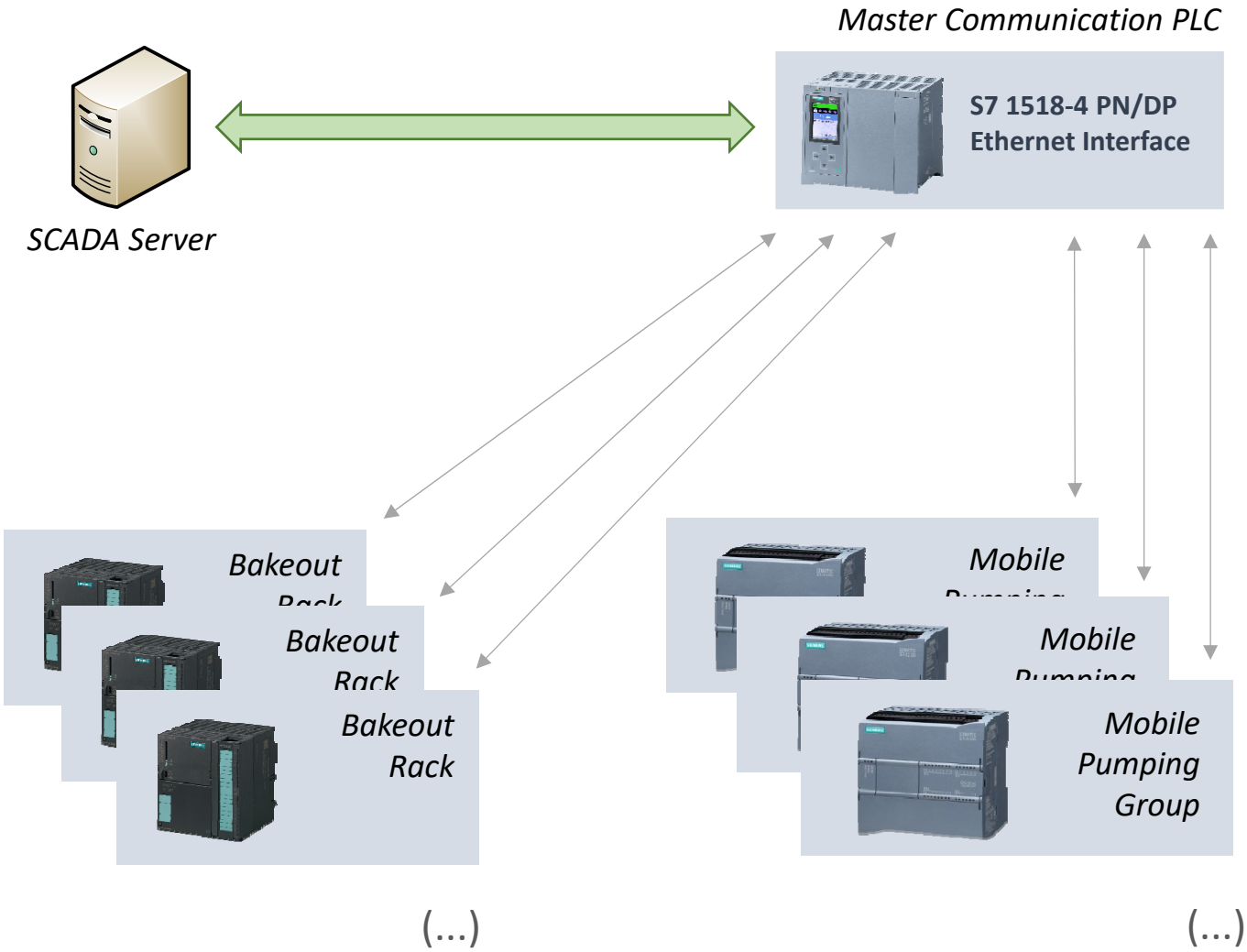
Mobile Protocol

Implementation of a dedicated communication protocol that allows mobile devices to automatically identify themselves.

Automatic data exchange between Master PLC and Mobile Devices.

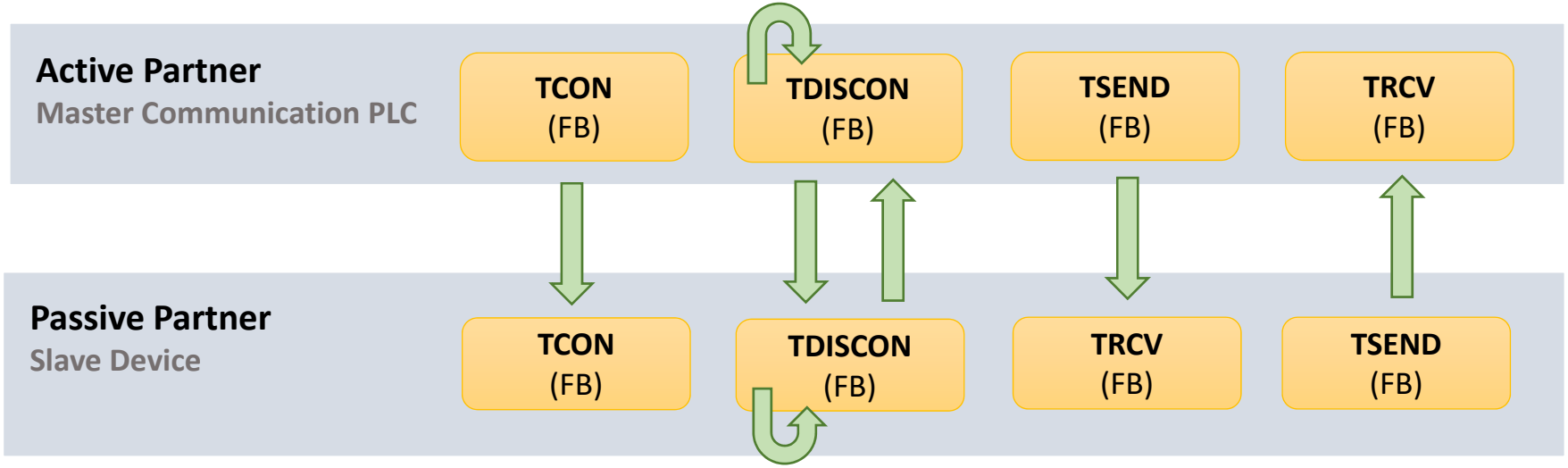
Integration in the SCADA.

Communication Scheme



OUC - Open User Communication

OUC is a set of function blocks provided by Siemens that allows the **establishment of IP connections** between a PLC and any Ethernet enabled partner.



Connection-oriented (TCP, ISO) and connectionless (UDP) protocols are possible.

Connections are **fully created and managed in code and during runtime**, so there is no need for prior hardware configuration (as in the case of S7 connections).

After the connection is established, packet-based data exchange with TRCV and TSEND occurs as normally.

PDU – Protocol Data Unit

The PLCs trade data packets of a fixed structure in a **Request/Response** pattern, with the Master taking initiative.

The protocol uses a 138 byte long Protocol Data Unit (**PDU**), with a 10 byte header for control data and a 128 byte data payload.

Offset	Master to Slave	Slave to Master
0.0	Type ID	Type ID
2.0	Connection State	Connection State
4.0	Connection ID	Connection ID
6.0	Request Code	Response Code
8.0	Page Number	Page Number
10.0 … 137.0	Request Data	Response Data

TypeID – Identifies the partner in the exchange (255 for Master, 1 to 254 for Mobile Devices).

Connection State – Current state of the connection, calculated by the Master (Disconnected, Connected, Recognized, Ready).

Connection ID – TCP/IP connection identifier. Chosen by Master, used as Handshake value.

Request and Response Codes

Request and Response codes identify the purpose of each packet.

Code No.	Request (Master to Slave)	Response (Slave to Master)
1	Send Handshake and Request Type ID	Return Handshake and Type ID
2	Request Device Name	Return Device Name
3	Request Device Position	Return Device Position
4	Request Occurrence Number	Return Occurrence Number
5	Request Device State	Return Device State
6	Send Device Commands	Confirm Device Commands

Data (Device Name, Position, Occurrence and State) is returned by the Mobile Device in the "Response Data" area of the PDU.

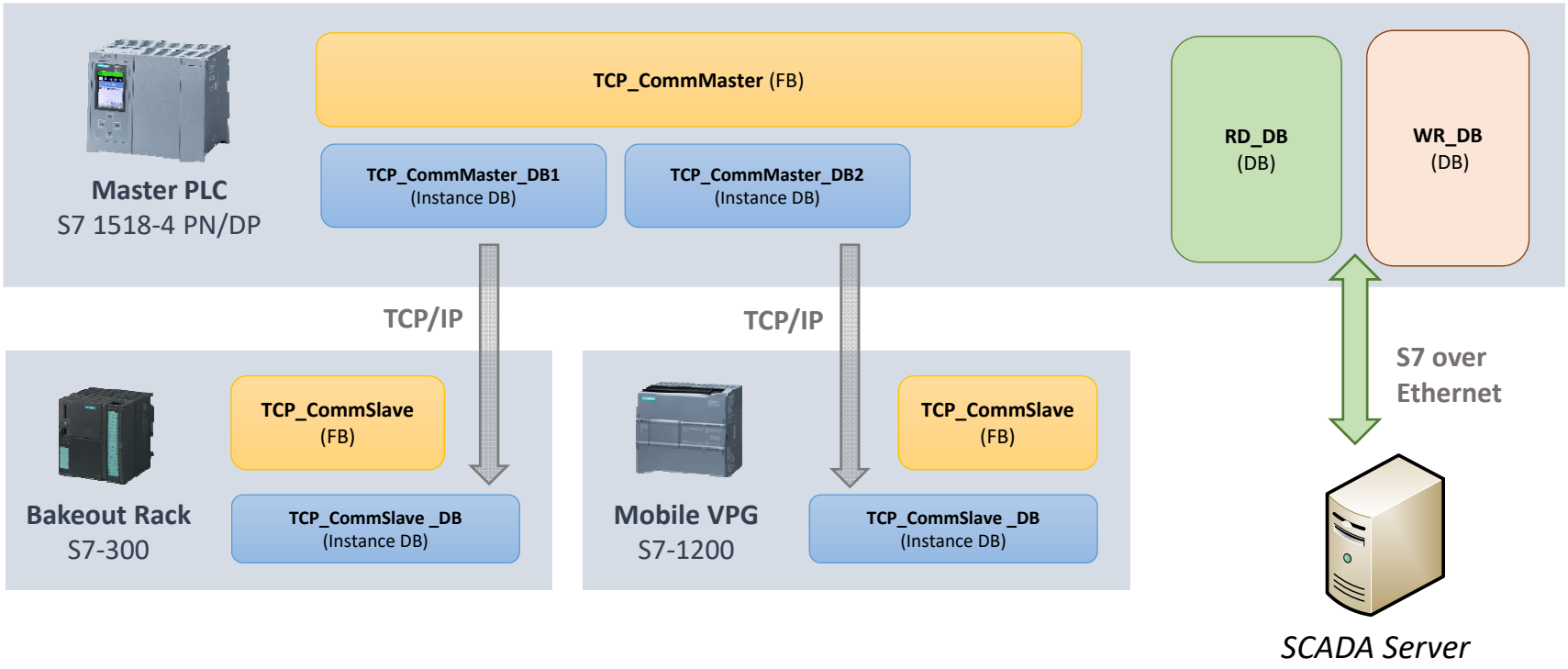
Commands are sent by the Master in the "Request Data" area of the PDU.

Device State and Commands are exchanged in binary format, using predefined registers.

Software Architecture

On the Master side the protocol is implemented in Function Block ***TCP_CommMaster***, which acts as the active part of the system. One instance of the FB is created per SIM card.

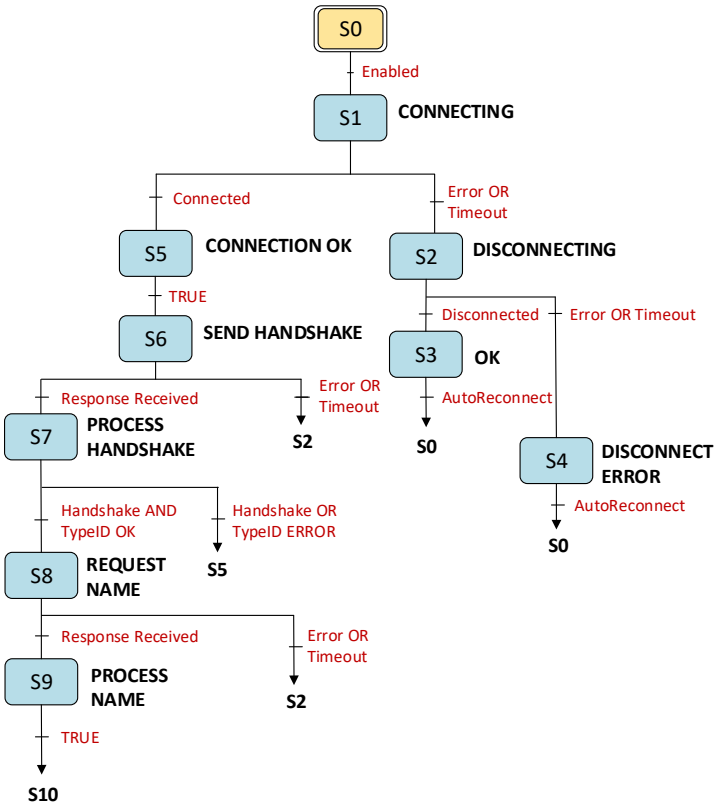
On the Mobile Device end, the system is managed by FB ***TCP_CommSlave***. This block behaves as a server, responding to requests from the Master. One instance exists per PLC.

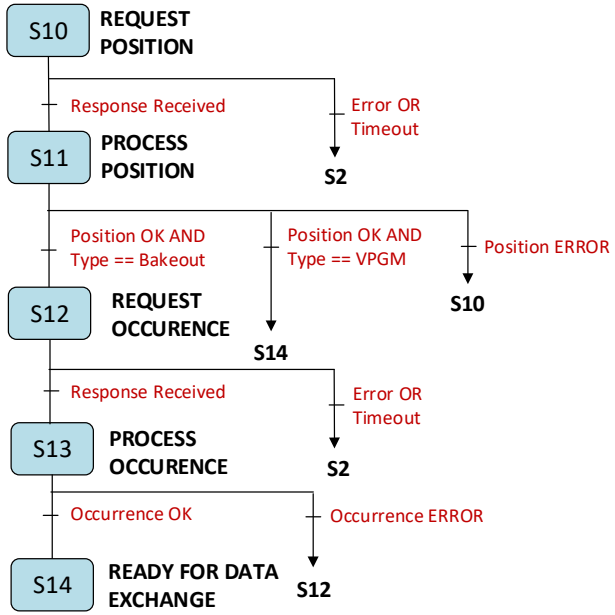


State Machines

The communication protocol and registration procedure are implemented by two State Machines (Master in *TCP_CommMaster* and Slave in *TCP_CommSlave*).

The following image shows the simplified flow of the registration procedure, from the point of view of the Master. The Slave is essentially responding to requests.





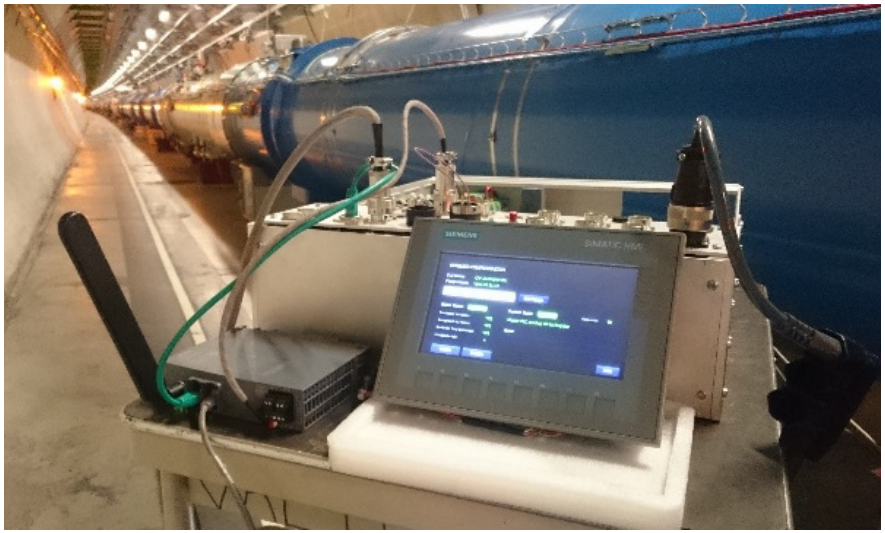
Conclusion

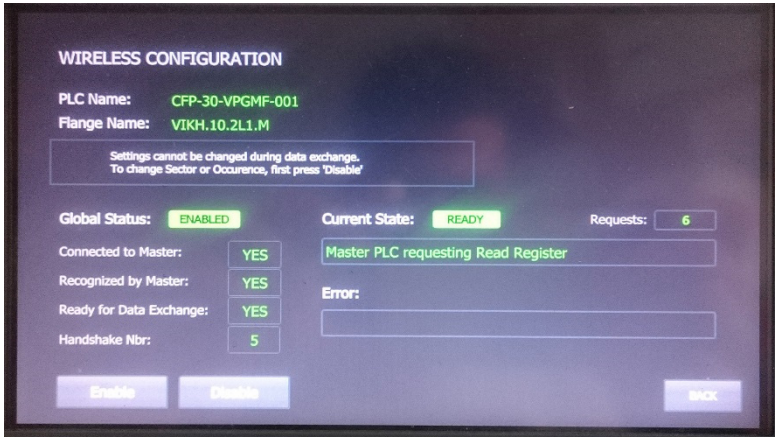
Tests, Validation and Final Remarks.

Tests and Validation

Tests have been performed in a production environment. A controller crate for a Mobile VPG was mounted on a trolley on the LHC tunnel and the 3G router was connected to it. The Master PLC was installed on the surface, on a Technical Network outlet in the Lab.

The device registered itself on the Master without any issues. Cyclic data exchange occured uninterrupted for about one hour, while the trolley was moved for about 1 Km, connecting to several mobile cells. No connection drops were experienced.





Final Remarks

We have successfully implemented a 3G/LTE based PLC to PLC communication system and developed the required software in order to support our Mobile Device operation and integration in the Vacuum Control System. **The main shortcomings of our current Profibus based system have been addressed:**

- SCADA Integration of Mobile Devices is now possible in every accelerator without installing new infrastructure.
- No cable manipulation required, easier for the operators. No chance for topology errors or missing elements to bring the network down. No more accelerated degradation of cables and connectors.
- Adress space increased from 124 addresses to the full range of the IP addresses on the particular subnet used.
- IPs are automatically attributed, so no more address conflicts.

The necessary **SCADA developments are ongoing** and the system will be fully deployed in the near future.

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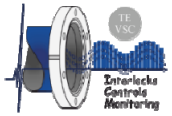

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