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At the time of writing, OP MMU is doing its own tests on Proficloud; in future demonstration actions, we will include relevant extra information.

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The INCASE project

Industry 4.0 (I4.0) is the next industrial revolution. Manufacturers are focussing on client-specific production and added-value products. In Germany 84% of the companies feel the pressure to digitize and 57% will significantly change their business model due to the digital revolution. Germany is world leader in this revolution. The project main objective is to **close the gap between the 2 Seas region and Germany & other leading countries**, by developing and demonstrating the necessary key technologies towards companies, in this way facilitating the conversion towards I4.0.

INCASE develops knowledge, innovative applications and pilots on key enabling automation technologies for the future I4.0. INCASE will deliver **10 thematic demonstration trajectories** on those key enabling automation technologies for smart factories and green technologies for smart homes and factories. The demonstration actions will inspire practicing engineers towards new products and new production methodologies. The intermediary organizations will actively create awareness on the future I4.0.

The project contains **three main workpackages**. **WP1** develops pilots on key enabling automation technologies for Industry 4.0, to achieve an early market uptake by and increased awareness of the manufacturing industries. Involved technologies are Industrial Communication (PROFINET, Power Line Communication, Proficloud, Networked Control) and Integrated Design (Mobile robotics, Industrial Hardware Targets, Cosimulation). **WP2** develops pilots to reduce energy consumption in both home automation and industrial automation, and increase the awareness & knowledge for the automation and manufacturing industries. Involved technologies are Communication and HMI technologies for smart factories and smart houses (PROFIenergy, Power Line Communication for smartgrids, Control & HMI for Smart Houses, energy monitoring devices connected to the Internet of Things). **WP3** develops demonstration tools, based on the pilots, to perform numerous demonstration actions for practicing engineers in industry. In this way the knowledge on new technologies is increased and an early market uptake of Industry 4.0's new automation technologies is achieved in the 2 Seas region.

The **main objective** of INCASE is preparing the industry (automation & manufacturing industry) for the future "Industry 4.0" (I4.0) and "Industrial Internet of Things" (IIoT). This is done by:

- Creating awareness of technical management and decision makers of companies on the possibilities of the new technologies.
- Preparing practicing engineers by demonstrating new technologies for the future smart interconnected factories, smart buildings and sustainable engineering.

The project *specific objectives* are:

- Pilots on Proficloud
- Pilots on Stress-testing on PROFINET
- Feasibility study on PLC
- Pilots on Networked Control
- Pilots on Integrated Design
- Pilots for PROFIenergy
- Pilots for smartgrids using PLC
- Pilots for Control&HMI for Smart homes
- Pilots for energy monitoring devices connected to IOT, IIOT and industrial networks
- Demonstration tools & actions

This project has received funding from the Interreg 2 Seas programme 2014-2020 co-funded by the European Regional Development Fund under subsidy contract No 2S01-049.

1. Introduction

INCASE (towards INdustry 4.0 via Networked Control Applications and Sustainable Engineering) aims at designing and implementing networked control application pilots, using the new and emerging key automation technologies for the future factories and buildings, in order to increase market introduction.

As steps toward this goal, the involved partners first tested on local small demonstrators (D1.1.1), and then jointly developed an interregional Proficloud demonstrator.

This report is structured as follows. Chapter 2 describes the objective and architecture of the interregional demonstrator. Chapter 3 gives an overview of the local plants of this interregional demonstrator. The functions and operation of the interregional demonstrator connecting all local plants are explained in chapter 4. The results and the remarks are summarized in chapter 5 and appendices Appendix A: Systemcoupler unable to add in PC Worx 6.30.1914 and Appendix B: CLOUD COUPLER-PRO as IO-Device - Duplicate IP-address.

Finally, for information, there are two articles about the Proficloud implementation at the Swiss company Ricola, which are in appendices Appendix C: Using the cloud to meet certification requirements and Appendix D: Ricola leverages Proficloud to satisfy strict FDA requirements. This illustrates early market uptake. The cloud system had several issues, detected within the project and fixed by the producer, allowing more robust results.

2. INCASE interregional Demonstrator

2.1. Main objective

In order to evaluate the possibilities of Proficloud technology for remote control of industrial installations, INCASE has chosen as industrial application a drinking water distribution network. The work carried out by PPs 2, 4 and 6 implements PC technology on an interregional demonstrator.

Each partner developed a part of the system and the whole was integrated with the appropriate technological components to build the final interregional demonstrator

2.2. General architecture

The architecture of the demonstrator below highlights the most important elements of pumping and distribution network, a few tens of kilometres away and connected by the Proficloud.

The involved partners developed and implemented the three parts located on 3 remote sites: KUL, Icam and UL. The following sections describe each part of the interregional demonstrator and their integration.

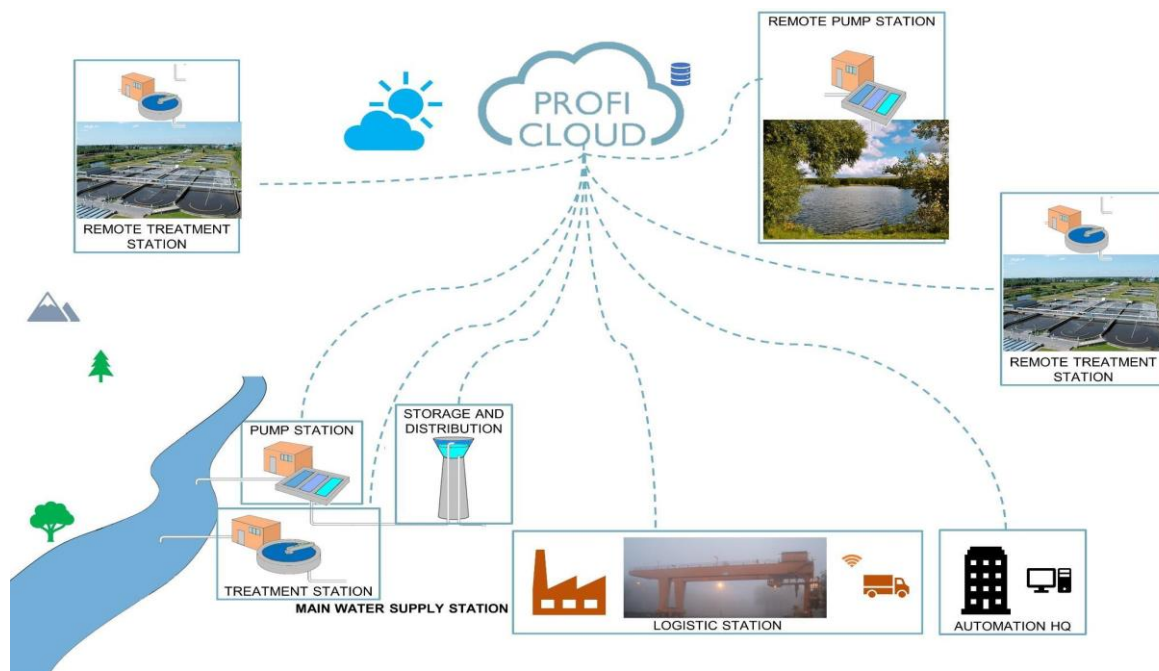


Figure 1: General architecture of the interregional demonstrator

3. Local demonstrators

3.1. Icam local demonstrator

The core of Icam demonstrator represents a local site of production (pumping), storage and distribution of drinking. The following diagram illustrates its configuration which includes a pumping source, a storage area and the distribution network to the users (Figure 2-a). In order to emulate such system, we use of three tanks setup (Figure 2-b) representing all parts of our water station system.

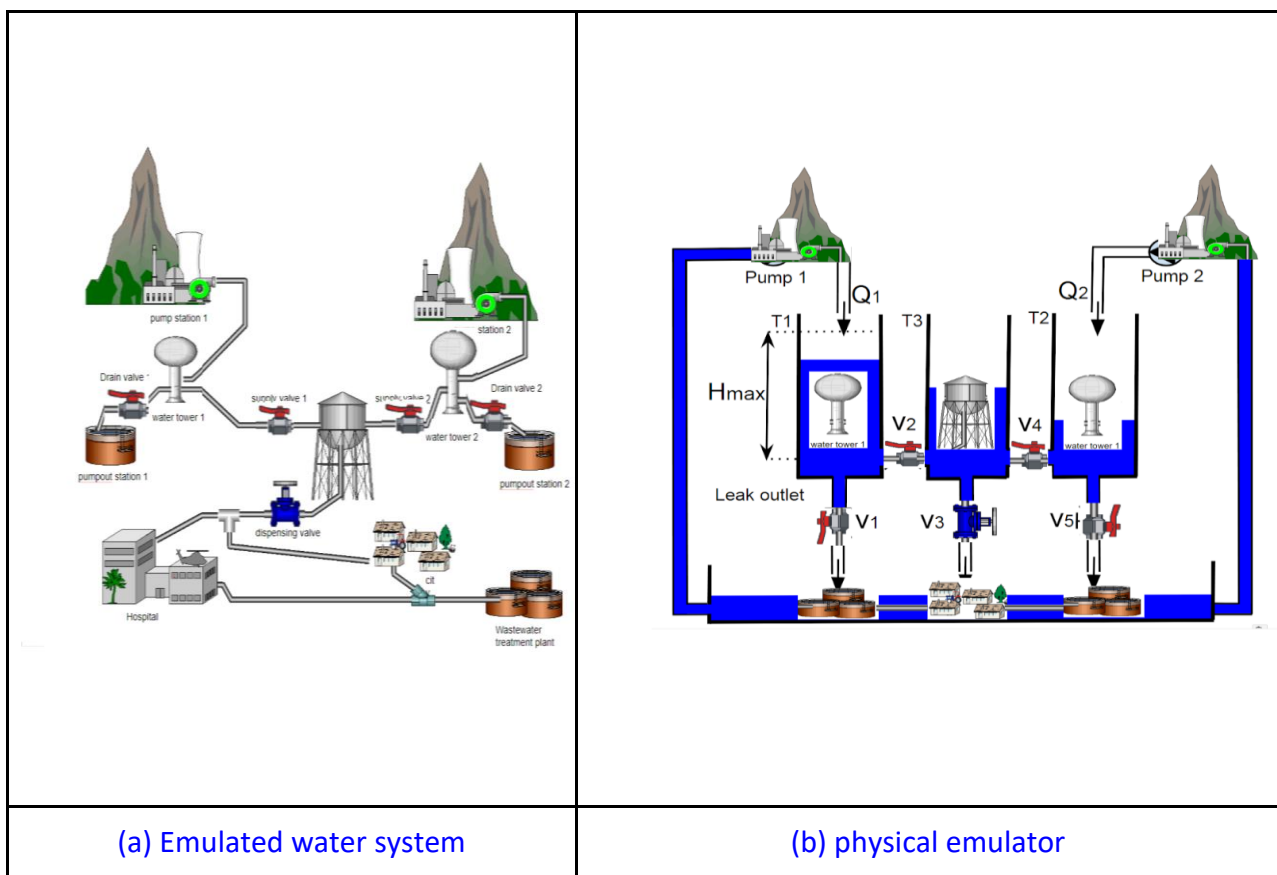


Figure 2: Proficloud application chosen by Icam

3.1.1. Description of Icam water station

Icam experimental hydraulic setup (Figure 3) is based on :

- Three tanks emulating local storages reservoir (left and right tanks) and distribution reservoir (middle tank). Each tank include level sensor.
- Lower reservoir emulating underground water and consumption/leakage;
- Two pumps feeding two tanks (left and right);
- Two valves (V_3 and V_4) supplying the distribution reservoir (middle tank);
- A proportional valve emulating consumer demands (valve V_3);
- Two valves for draining use (V_1 and V_5).

The control system is built on:

- AXC Cloud Pro (industrial PLC from Phoenix Contact).
- I/O devices from Phoenix Contact.

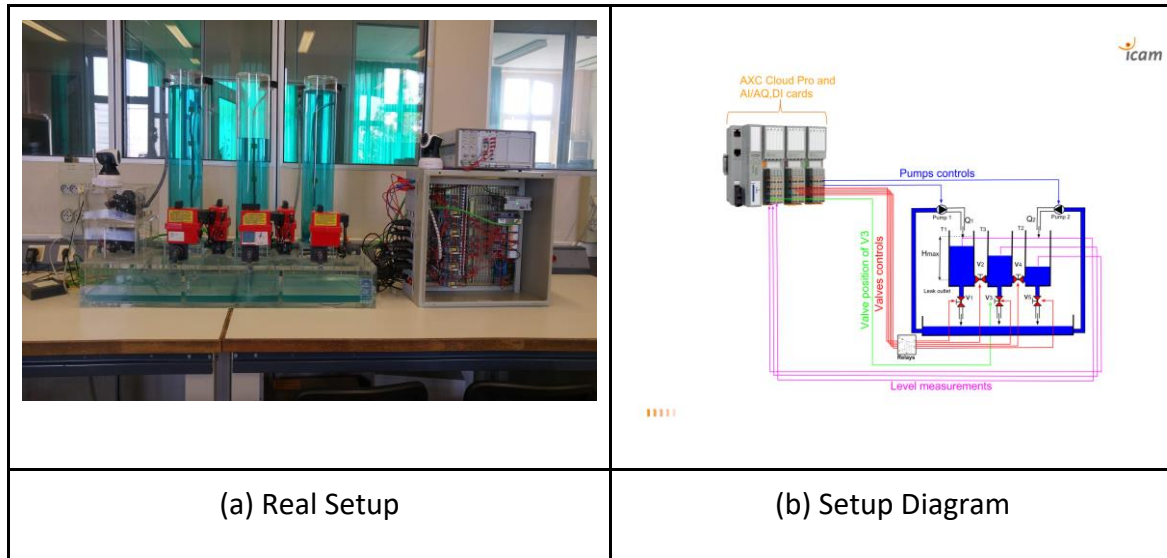


Figure 3: Experimental setup

3.1.2. Icam Proficloud demonstrator

In order to control the experimental setup via the Proficloud Technology, Icam developed a local Proficloud demonstrator (Figure 4 and Figure 5). This demonstrator is based on:

- Experimental setup described in the previous section
- Two IP camera allowing real time video streaming of the setup
- A remote control system composed of the following elements:
 - AXC 1050 (industrial PLC) containing the remote controller program;
 - A development computer for programming AX1050 using PC Worx software and design of a HMI interface using Visu+ Software ;
 - A PC for developing the HMI (Human Machine Interface) using Visu+ Software from Phoenix Contact;
 - All the previous elements are connected to the local PROFINET network thanks to a switch;
 - A Cloud Coupler device (from Phoenix Contact) enabling connection, via the Proficloud protocol, between remote controller (running on AXC 1050) and the experimental setup using AXC Cloud Pro device. The Cloud Coupler is both connected to the local PROFINET network and to Phoenix Contact server using internet in secure way.

Figure 4 and Figure 5 below represent respectively the functional diagram of the platform and an overview of the actual system developed.

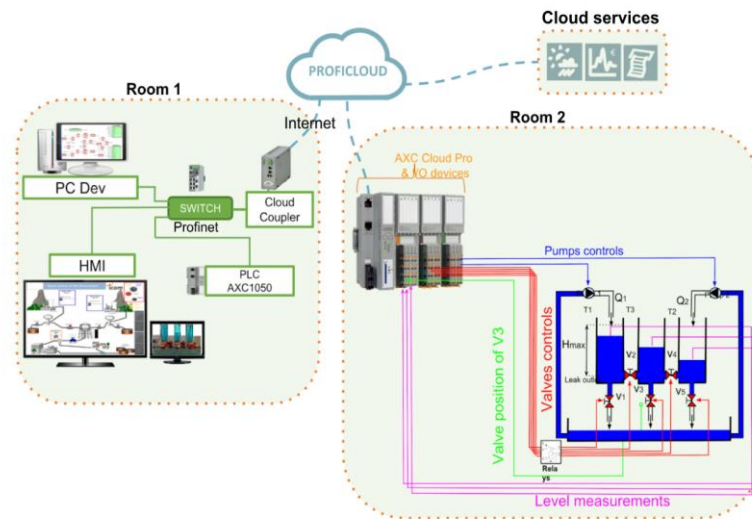


Figure 4: Diagram of local Proficloud demonstrator

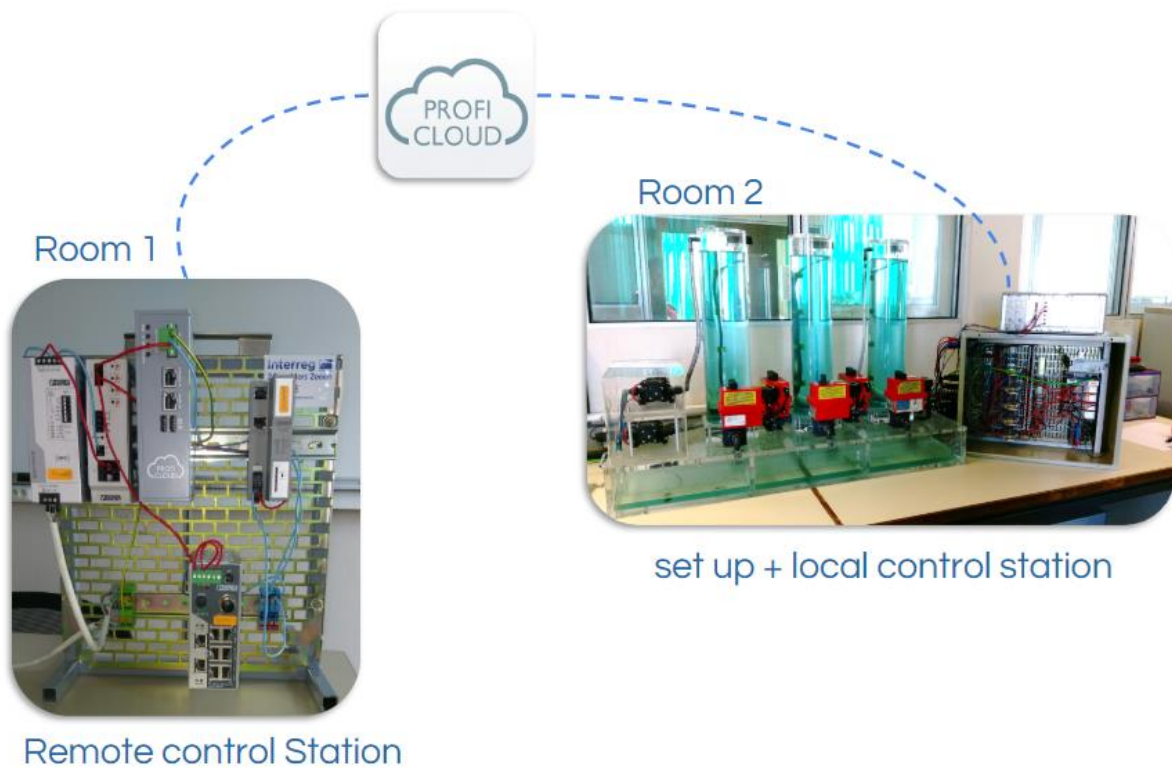


Figure 5: Physical scheme of local demonstrator

For local test and evaluation of our platform, we installed the remote control system in a room separated from the one where the experimental setup is installed (room 1 and room 2).

Proficloud technology extends the PROFINET local network into a larger network using the public Internet network. From this point of view, our Proficloud platform has Figure 6 as its

equivalent diagram.

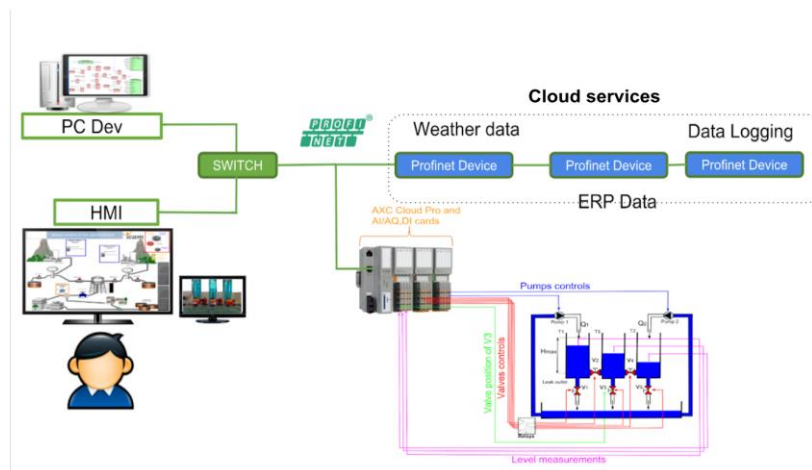


Figure 6: Equivalent diagram of Proficloud demonstrator

The HMI interface is developed for remote use of the platform. It offers two features:

- on the one hand the visualization of the process data (tank levels, water demand status, etc...)
- and on the other hand the interaction in real time with the control devices (control of valves and pumps)

This interface can be run and used in standalone mode with our Proficloud platform. Moreover, it has been integrated into the supervision and monitoring system of the interregional demonstrator hosted at the KUL site.

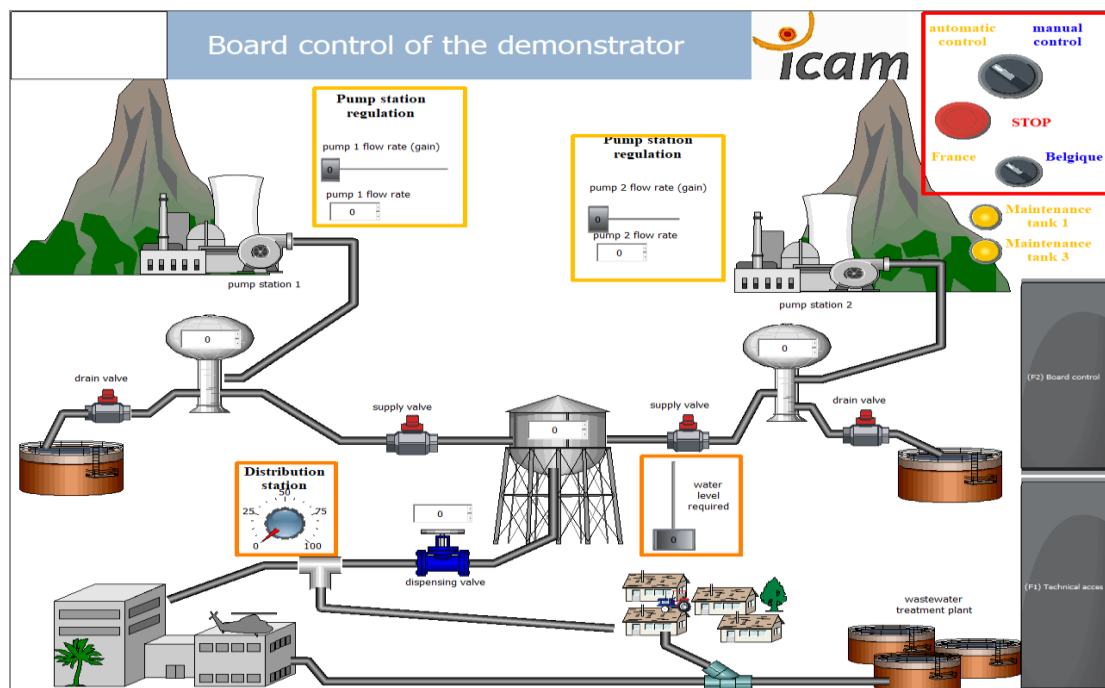


Figure 7: View of the HMI

This platform is operational and has been tested locally and remotely during technical meetings with partners , during the conference on 29/05/18 in conjunction with industry in KUL (Gent) and during the Technical Day 4 at Icam.

3.2. Univ-Lille local demonstrator

University of Lille has developed two processes for the INCASE large scale Proficloud demonstrator as shown in Figure 8. In this figure we find from left to right:

- an AXC1050 PLC with Phoenix Contact digital and analog IOs,
- a Cloud Coupler-Pro device to connect to the Proficloud,
- a virtual simulation of the physical demonstrator running on a PC and developed using the Unreal© game engine. This simulator is connected to the AXC1050 inputs and outputs using an Arduino as a gateway.
- a remote physical demonstrator controlled through an AXC CLOUD-PRO PLC with Phoenix Contact digital and analog IOs. The link between this physical demonstrator and the water production unit described above in Figure 8 is shown in Figure 9.

3.2.1. Demonstrator with Phoenix Contact PLC

Just like Icam, Univ-Lille also needs the following equipments:

- Phoenix Contact AxioControl AXC1050 (local process)
 - AXL DI 16/I
 - AXL DO 16/I
 - AXL F AI2 AO2 IH
- Phoenix Contact CLOUD COUPLER-PRO (for Profinet extension through Internet)
- Phoenix Contact AXC CLOUD-PRO (remote process)
 - AXL DI 16/I
 - AXL DO 16/I
 - AXL F AI2 AO2 IH
- the PC WORX 6 PRO software to program the PLCs,
- the VISU+ Software to design the remote process HMI,
- a PC:
 - to program the AX1050 and AXC CLOUD PRO PLCs,
 - to monitor the local virtual process through the Unreal Engine software,
 - to monitor the remote physical process using VISU+,
- an industrial Phoenix Contact FL SWITCH SMN 8TX-PN switch to connect equipments to the local PROFINET network,
- a DMZ link to connect the CLOUD COUPLER PRO and the AXC CLOUD PRO to Internet,
- IP cameras to monitor the remote physical process,
- Phoenix Contact CLOUD credits (1 per hour and per equipment connected to the PROFICLOUD).

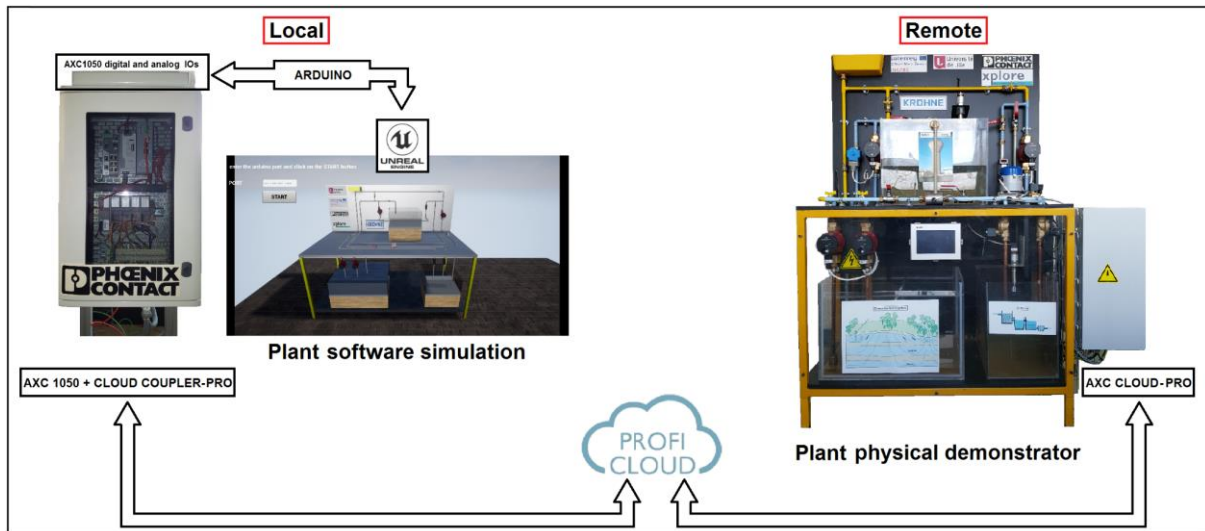


Figure 8: Processes at University of Lille (one local and one remote)

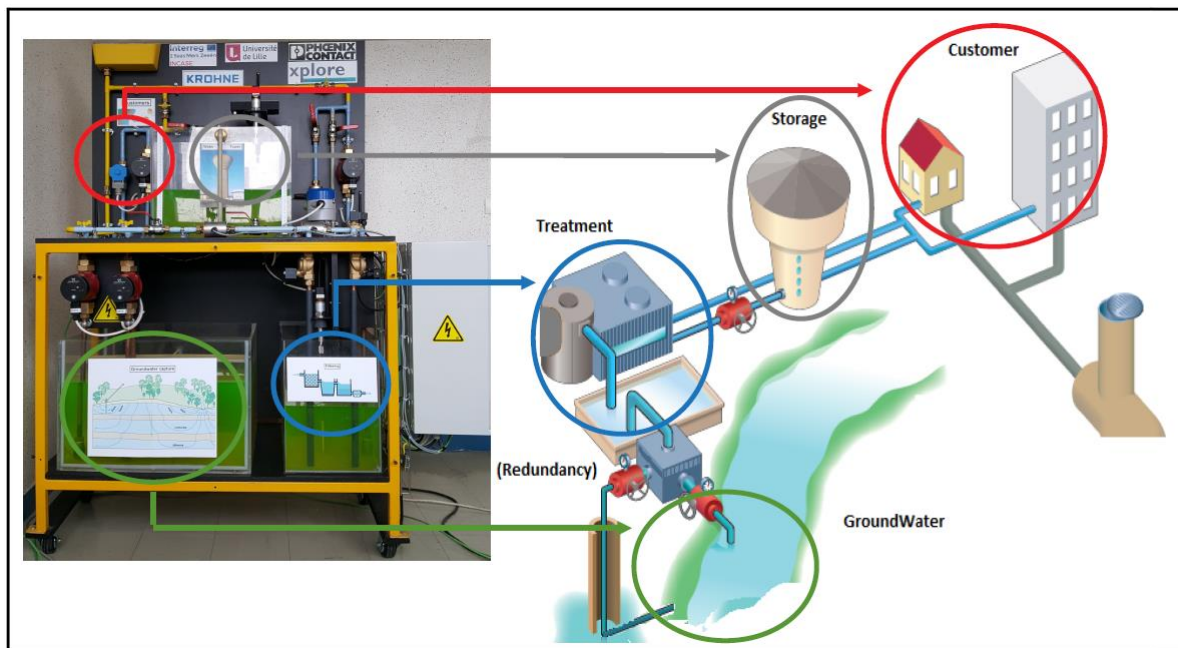


Figure 9: Relation between Univ-Lille's physical demonstrator and the water production unit diagram

3.2.2. Demonstrator description

As illustrated in Figure 10 in the case of the physical demonstrator, both the physical and virtual simulators developed at University of Lille use:

- a storage tank representing the ground water to draw,
- two drawing circuits. One of the two circuits is used for redundancy in case of the failure of the main circuit or to boost drawing to the filtration unit,
- a filtration tank,
- a water tank,
- a consumer consumption circuit which carries the water back to the ground water tank.

3.2.3. Physical process specific industrial equipment

As illustrated in Figure 10, to realize the hydraulic part of the physical simulator, we need:

- Grundfos alpha1 25-40 130 water pumps,
- ifm electronic SM700 flow meters,
- Krohne Optiflex 1100C level meters,
- Krohne Optiswitch 4000C vibrating level switches,
- Danfoss EV260B controlled valve.

Water is drawn using four Grundfos pumps. Level sensors and flow meters are used to control the height of the water stored in the main tanks and to make some measurements. This helps in particular to measure the water losses provided by the leak circuit that has been inserted after the filtration unit.

At last, manual valves are used for pumps failure simulation. They are controlled using the HMI.

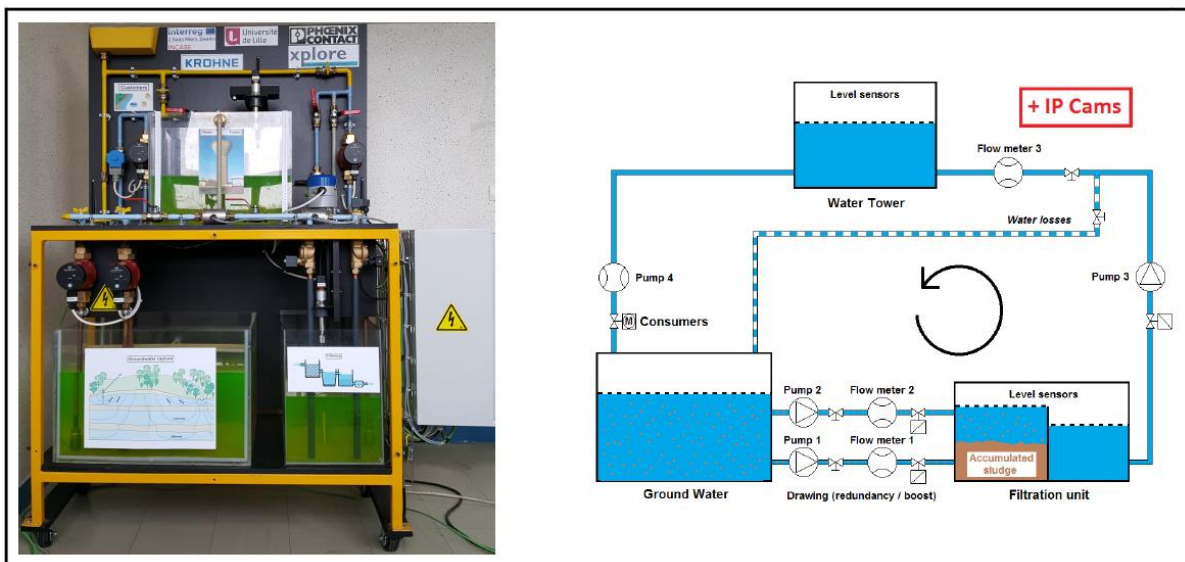


Figure 10: Relation between Univ-Lille's physical demonstrator and its hydraulic diagram

3.3. KU Leuven local demonstrators

For basic tests and measurements, KU Leuven has built two local demonstrators, one with a Phoenix Contact PLC and one with a Siemens PLC.

3.3.1. Demonstrator with Phoenix Contact PLC

This setup consists of the following parts:

- Phoenix Contact Inline Control ILC 370 PN 2TX-IB
- Phoenix Contact CLOUD COUPLER-PRO
- Phoenix Contact AXC CLOUD-PRO
 - AXL DI 16/1-ME
 - AXL F AI2 AO2 1H
- Phoenix Contact AXC CLOUD-PRO
 - AXL DI 16/1-ME
 - AXL F AI2 AO2 1H

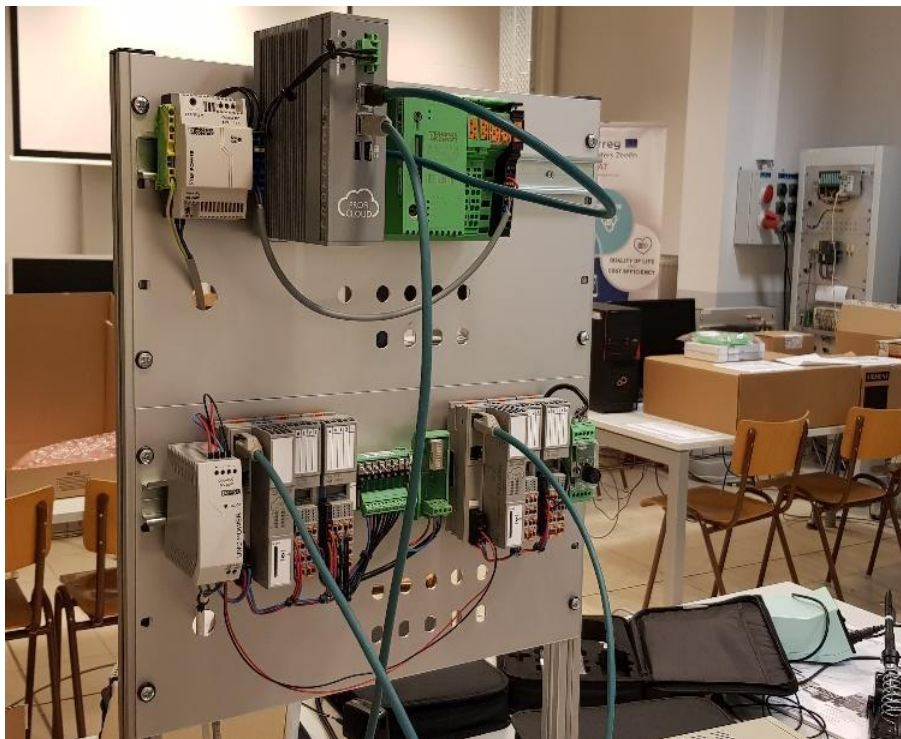


Figure 11: KUL local demonstrator with Phoenix Contact PLC

3.3.2. Demonstrator with Siemens PLC

This setup consists of the following parts:

- Siemens S7 1518-4 PN/DP
- Phoenix Contact CLOUD COUPLER-PRO
- Phoenix Contact AXC CLOUD-PRO
 - AXL DI 16/1-ME
 - AXL F AI2 AO2 1H
- Phoenix Contact AXC CLOUD-PRO
 - AXL F AI2 AO2 1H



Figure 12: KUL local demonstrator with Siemens PLC

4. Integration of Interregional pilot

4.1. Global architecture

All local demonstrators developed by the PP2, PP4 and PP6 partners were integrated to form the interregional Proficloud demonstrator as illustrated in Figure 13.

In order to achieve an operational demonstrator in line with the initial objectives, several tasks were carried out in order to overcome and resolve some technological constraints. In particular, two major problems were addressed and solved:

- Communication between the three local demonstrators and the centralized supervision system (hosted by KUL). Thanks to the work of KUL staff in collaboration with Phoenix Contact Belgium and Germany, this issue was solved by using System Couplers (Cloud Services).
- Communication between the supervision system and remote users (via internet). The solution adopted is the use of TeamViewer software (VPN connection).

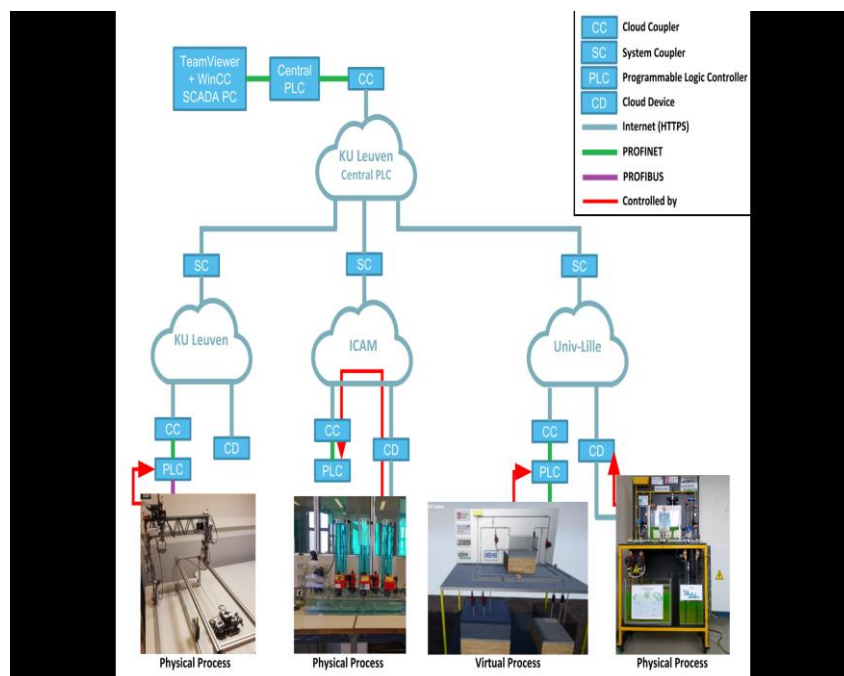


Figure 13: Architecture of the interregional Proficloud demonstrator

4.2. Supervision and monitoring

4.2.1. General purpose

Supervision means one can control the process and of course observe what happens when monitoring just consists in looking what happens.

Question is: **How to control and monitor from anywhere a process knowing that the parts of a production unit are located at different places and production units are in number?**

Solution: We make the use of Phoenix Contact's Proficloud devices as shown in Figure 14 to exchange industrial data between remote processes, PLCs and SCADA (supervision) software.



Figure 14: Industrial Data Communication through the Proficloud

4.2.2. Main features

The central control system, developed jointly by the PPs involved, is composed of:

- Central PLC located at KU Leuven that manages process data exchanges between local controllers and the central HMI;

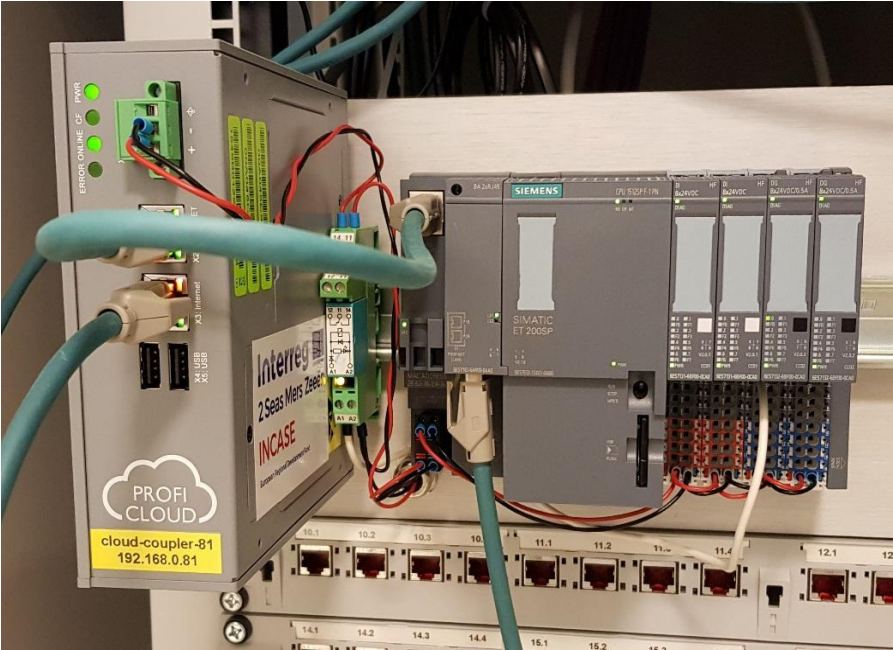


Figure 15: Cloud Coupler and Central PLC at KU Leuven

- PC SCADA (WinCC) located at KU Leuven which integrates the HMI for supervision and monitoring of the different sites. In addition, this PC includes TeamViewer

software that allows remote handling of the central PLC. If necessary, this functionality allows each partner to update the remote process control programs.

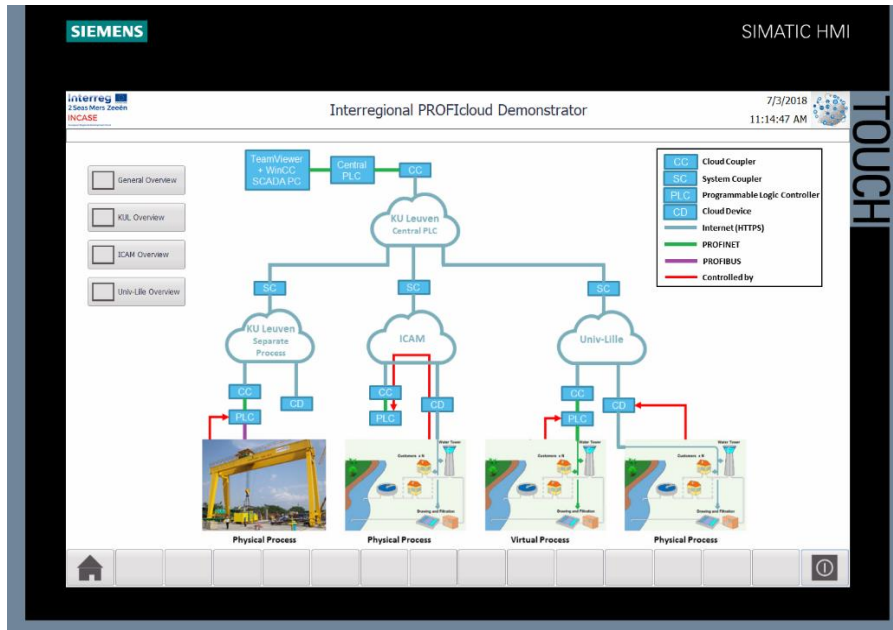


Figure 16: WinCC HMI for the central PLC – Main Screen

This centralized control system has been designed to allow two modes of operation:

- Centralised supervision from the KUL server. In this case, the local user has no longer control of his process (passive looking).
- Central monitoring of all sites from KUL server. In this case, each local user has full control of his process (supervision).

To be able to control or supervise the processes, the exchanged data needs to be defined. So for every demonstrator, a data exchange table was defined. This table includes all operational variables necessary for central PLC and local PLC data communication. This data is being sent from the local PLC through the cloud system couplers to the central PLC, and vice versa. An example of the data exchange tables is in Figure 17.

Outputs	BYTE.BIT	Variable	Type	Explanation
Byte 0	[0]	arm_position	WORD	The position of the arm
Byte 1	[1]	trolley_position	WORD	The position of the trolley
Byte 2	[2]			
Byte 3	[3]	clamp_position	WORD	The position of the clamp
Byte 4	[4]			
Byte 5	[5]			
Byte 6	[6]	crane_position_left	WORD	The position of the crane on the left rail
Byte 7	[7]			
Byte 8	[8]	crane_position_right	WORD	The position of the crane on the right rail
Byte 9	[9]			
Byte 10	[10]	arm_pos_SP	WORD	The setpoint for the position of the arm
Byte 11	[11]			
Byte 12	[12]	trolley_pos_SP	WORD	The setpoint for the position of the trolley
Byte 13	[13]			
Byte 14	[14]	clamp_pos_SP	WORD	The setpoint for the position of the clamp
Byte 15	[15]			
Byte 16	[16]			
Byte 17	[17]	crane_pos_SP	WORD	The setpoint for the position of the crane
Byte 18	[18]	auto_status	WORD	Indicates the current state of the stateflow
Byte 19	[19]			
Byte 20	[20]	arm_man_speed	BYTE	The manual speed for the arm
Byte 21	[21]	trolley_man_speed	BYTE	The manual speed for the trolley
Byte 22	[22]	clamp_man_position	BYTE	The manual position of the trolley
Byte 23	[23]	crane_man_speed	BYTE	The manual speed for the crane
Byte 24	[24]	Battery lvl nxt0	BYTE	The battery level of NXT 0
Byte 25	[25]	Battery lvl nxt1	BYTE	The battery level of NXT 1
Byte 26	[26]	Battery lvl nxt2	BYTE	The battery level of NXT 2
Byte 27	[27]	Battery lvl nxt3	BYTE	The battery level of NXT 3
Byte 28	[28].X0	homed	BOOLEAN	Indicates if the homing sequence was executed
	[28].X1	man_speed_mode	BOOLEAN	Indicates the manual speed mode
	[28].X2	man_pos_mode	BOOLEAN	Indicates the manual position mode
	[28].X3	auto_mode	BOOLEAN	Indicates if the system is in manual or auto mode
	[28].X4	truck_pos_1	BOOLEAN	Indicates if there is a truck at position 1
	[28].X5	truck_pos_2	BOOLEAN	Indicates if there is a truck at position 2
	[28].X6	crane_end_line_left	BOOLEAN	Indicates the left limit switch for the crane
Byte 29	[28].X7	crane_end_line_right	BOOLEAN	Indicates the right limit switch for the crane
	[29].X0	trolley_end_line_left	BOOLEAN	Indicates the left limit switch for the trolley
	[29].X1	trolley_end_line_right	BOOLEAN	Indicates the right limit switch for the trolley
	[29].X2	arm_end_line_top	BOOLEAN	Indicates the limit switch for the arm
	[29].X3	store_1	BOOLEAN	Indicates if there is a cup on position 1 in storage
	[29].X4	store_2	BOOLEAN	Indicates if there is a cup on position 2 in storage
	[29].X5	store_3	BOOLEAN	Indicates if there is a cup on position 3 in storage
	[29].X6	store_4	BOOLEAN	Indicates if there is a cup on position 4 in storage
Byte 30	[29].X7	store_5	BOOLEAN	Indicates if there is a cup on position 5 in storage
	[30].X0	store_6	BOOLEAN	Indicates if there is a cup on position 6 in storage
	[30].X1	store_7	BOOLEAN	Indicates if there is a cup on position 7 in storage
	[30].X2	store_8	BOOLEAN	Indicates if there is a cup on position 8 in storage

Figure 17: Example of the data exchange tables

4.2.3. Icam

In order to allow communication between the central SCADA supervisor and the local Icam demonstrator (Idem UL), the PLC-programs were adapted in order to allow remote start/stop and setpoint changes and so, including priority for the local commands (Figure 18).

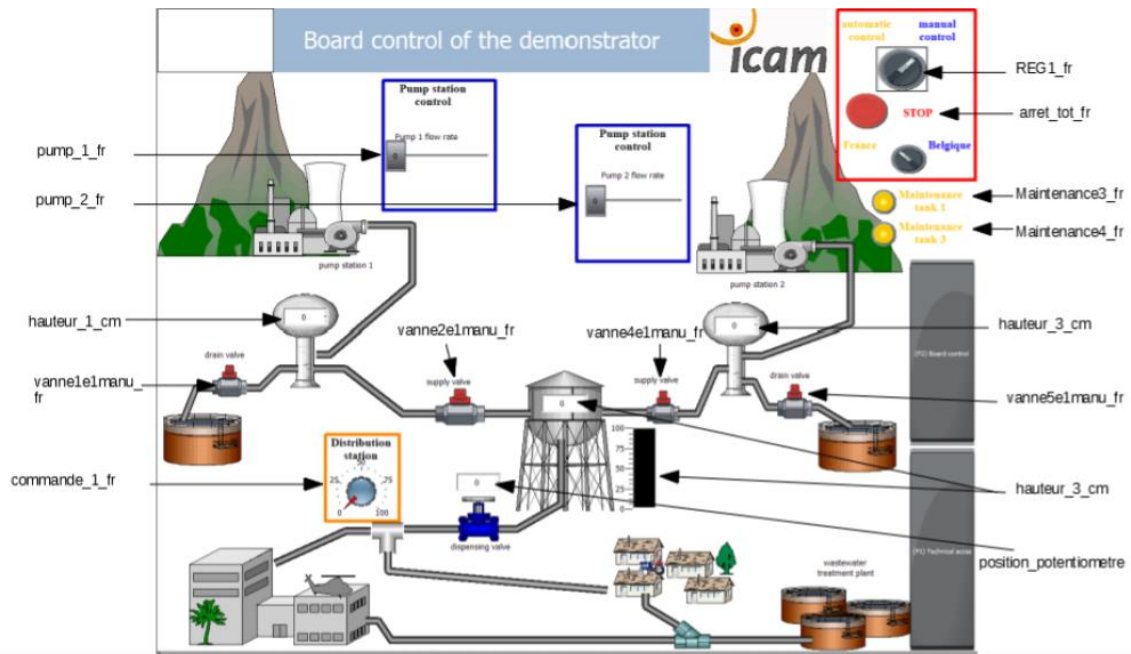


Figure 18: Icam demonstrator HMI

The HMI from Icam was recreated in WinCC for display on the central HMI.

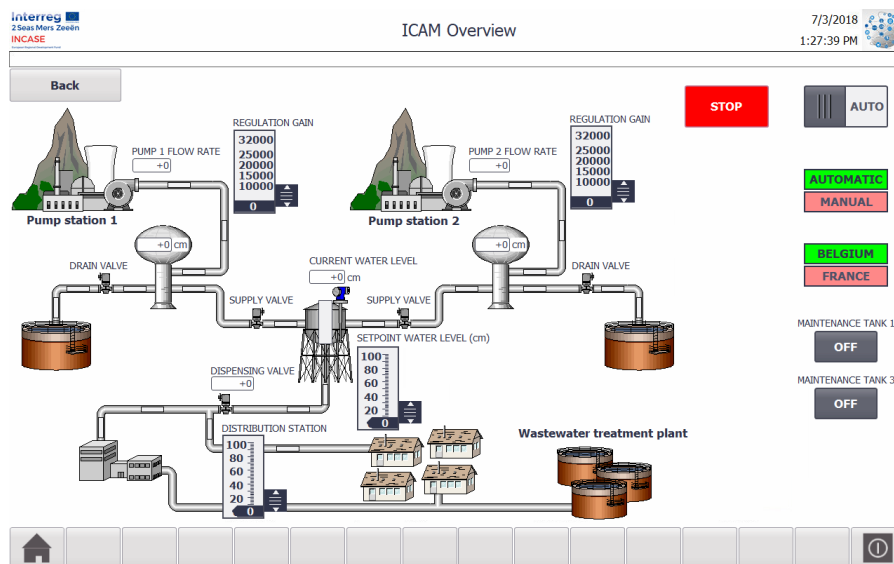


Figure 19: WinCC HMI for the central PLC – Icam HMI

4.2.4. Univ-Lille

The bloc diagram illustrated in Figure 20 shows how the water flow is controlled. The supervision / monitoring (SCADA) of the Proficloud demonstrator located at the University of Lille is inspired by this diagram.

University of Lille has developed a SCADA using Phoenix Contact's VISU+ tool when KU Leuven uses Siemens' WINCC one. The control of the processes located at University of Lille can be done by partner University of Lille as well as by partner KU Leuven but not at the

same time. For this reason it has been necessary to add a switch to the main view of Univ-Lille's supervision. Default mode gives priority to KU Leuven for control (see Figure 21) and in that case Univ-Lille can only monitor what happens but cannot act on the process to of course avoid a conflicting situation. When controlling the process Univ-Lille can then fix the set points of the tanks using the SCADA view illustrated in Figure 22.

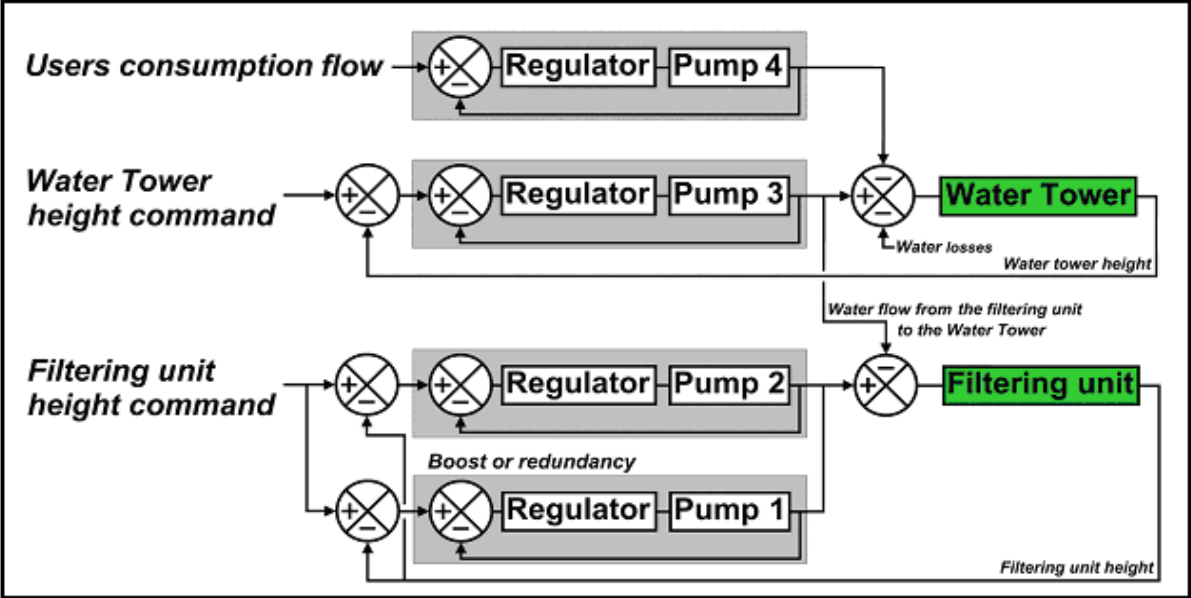


Figure 20: Univ-Lille Process block diagram

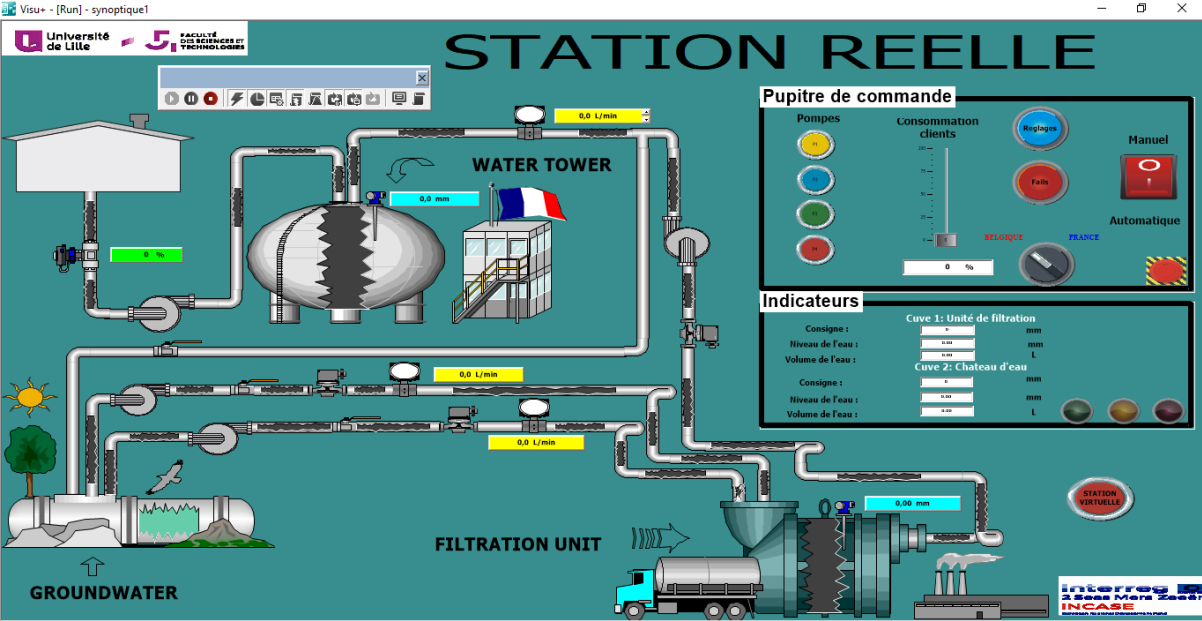


Figure 21: Univ-Lille demonstrator HMI main screen

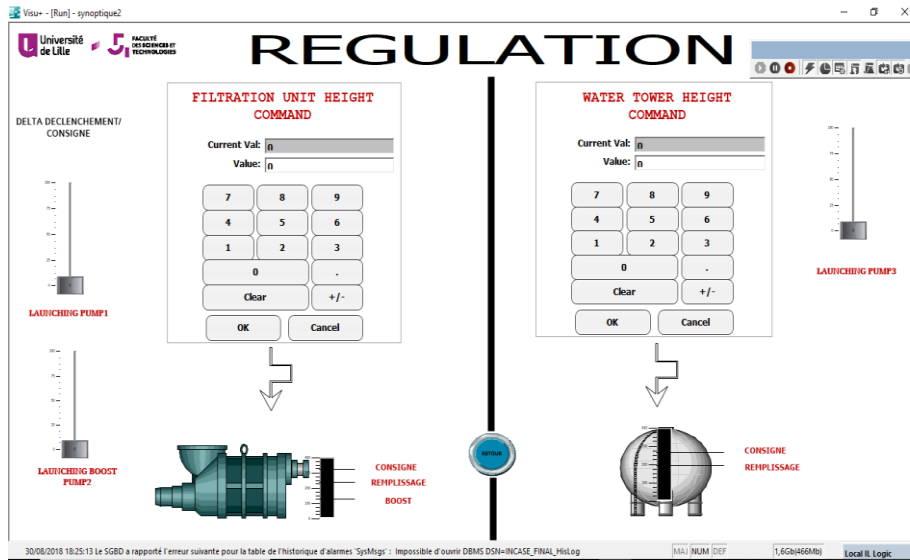


Figure 22: Univ-Lille demonstrator HMI with tank setpoints

The HMI from Univ-Lille was recreated in WinCC for display on the central HMI.

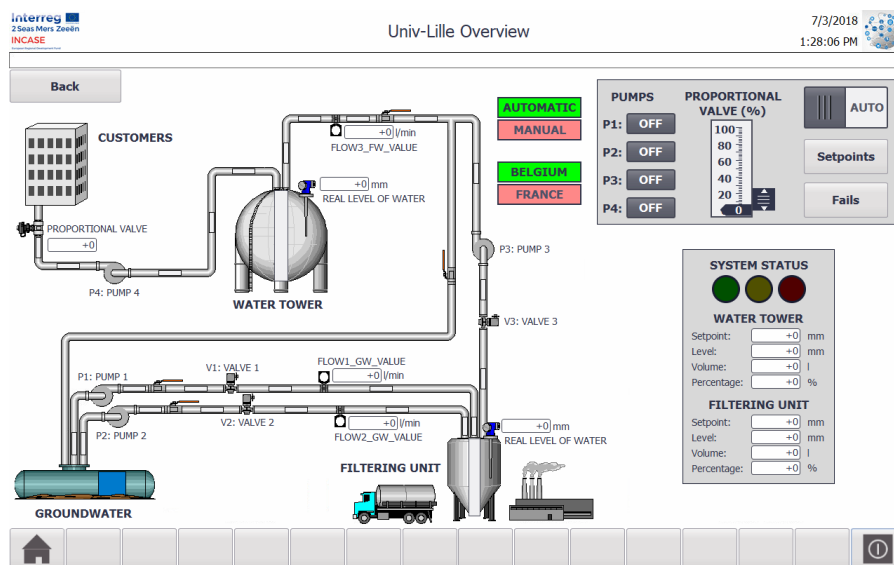


Figure 23: WinCC HMI for the central PLC – Univ-Lille HMI

4.2.5. KU Leuven

KU Leuven developed a process for the INCASE large scale Proficloud demonstrator as shown in Figure 24 and Figure 25. This process consists of following parts:

- Siemens S7 1516F-3 PN/DP
- Phoenix Contact Cloud Coupler Pro (for connection to the large demonstrator)



Figure 24: Siemens S7-1516F-3 PN/DP and Phoenix Contact Cloud Coupler Pro

- Overhead crane (LEGO)
 - 4 LEGO NXT bricks connected to the PLC via PROFIBUS
 - Various LEGO NXT sensors and actuators connected to the NXT bricks

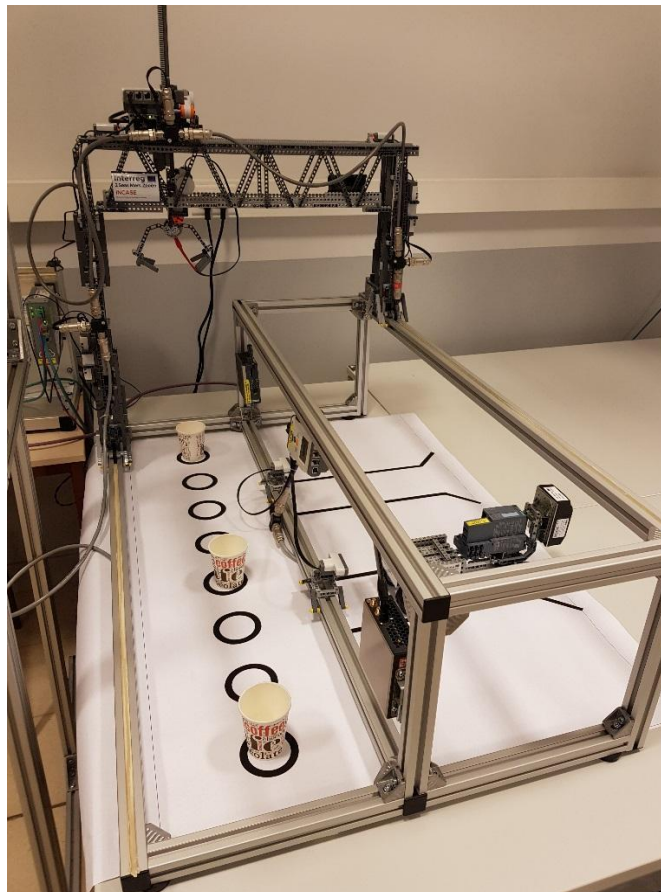


Figure 25: Overhead crane (LEGO)

The process has an automatic and a manual mode. It is controlled by switches connected to the digital inputs of the PLC.

Since the process doesn't have a local HMI, a new one had to be designed in order to control the process from the central HMI. The result is in Figure 26.

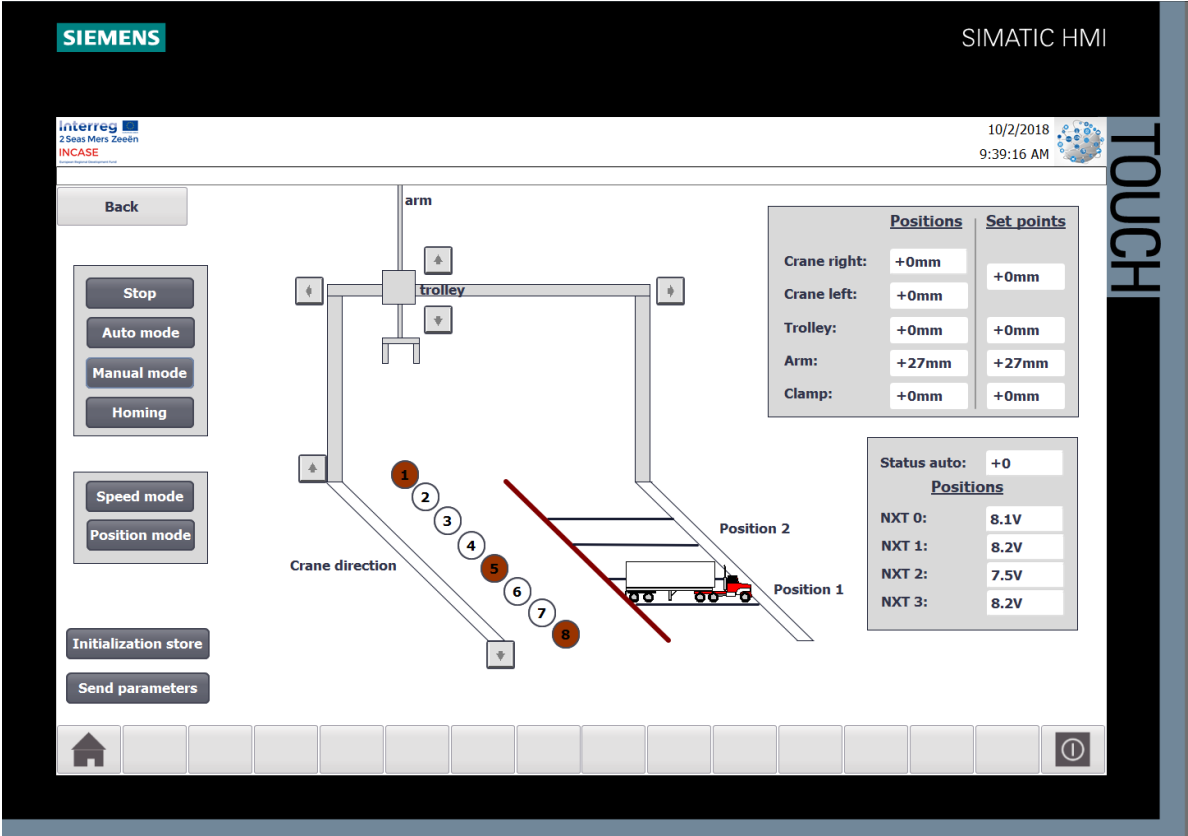


Figure 26: WinCC HMI for the central PLC - KU Leuven HMI

5. Results and remarks

5.1. Main results

An interregional demonstrator combining the remote processes (Fig. 27) into one central cloud and PLC (Fig. 28) has been developed. Paragraph 5.2 contains some elements of our early product evaluation; 5.3 contains measurements illustrating typical update times.

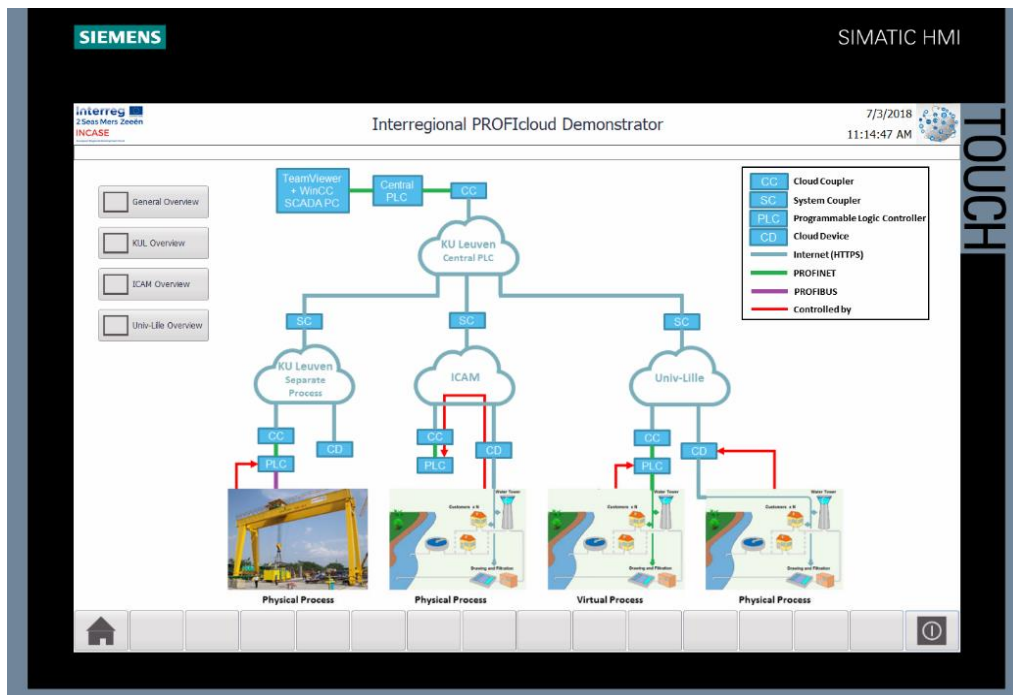


Figure 27: Overview of the interregional Proficloud demonstrator

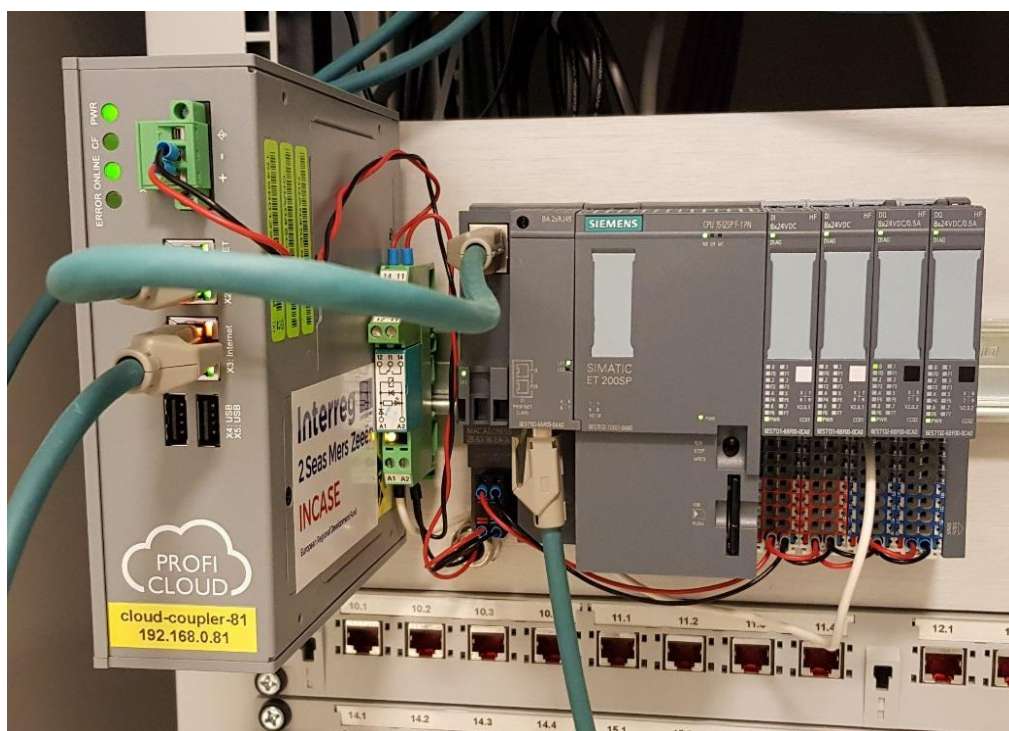


Figure 28: Cloud Coupler and Central PLC at KU Leuven

5.2. Early product evaluation

During the early development work several observations were made about the Proficloud system:

- After extended analysis by KU Leuven and OP11 Phoenix Contact Belgium, the early product evaluation showed that the Google DNS server needs to be reachable for the remote I/O stations. As this is often blocked by companies (e.g. also on KU Leuven campus Gent, Un. of Essex, UGent campus Kortrijk), this was reported to Phoenix Contact Germany and a patch was obtained.
- Initial measurements show that the update time is 500 ms for the Proficloud connection itself. On the local PROFINET backbone, this is not a real constraint, as the devices answer in time. For a connection to other remote stations via the Proficloud, this means that data exchange is logically limited to commands, results (of e.g. local fast calculations), etc. This is the expected behaviour of cloud services in general; faster connections would require what is now sometimes called the “Tactile Internet”, requiring e.g. new ethernet/internet technologies (such as TSN) and 5G wireless connections. The local communication backbone and control form the fast first layer of the control.
- Not all Proficloud diagnostics are visible in TIA Portal, nor are they well documented as far as we know now.
- The Systemcoupler isn't present in the PC Worx 6.30.1914 hardware catalog and the GSDML file couldn't be imported due to a vendor ID conflict. The import issue was fixed by changing a configuration file. See Appendix A: Systemcoupler unable to add in PC Worx 6.30.1914.
- When trying to add the CLOUD COUPLER-PRO as an IO-Device with a Siemens IO-Controller, because of a duplicate IP-address in the network. It appears that the device has two MAC addresses and thus two IP addresses on the PROFINET side. A (temporary) solution is changing the IP address set at the webpage of the CLOUD COUPLER-PRO. See Appendix B: CLOUD COUPLER-PRO as IO-Device - Duplicate IP-address.

During the development work several problems were encountered by the PP's; this delayed the progress, but all issues have been solved.

- Technologies not yet mature (bugs). For example: System Coupler, webservices JDK4J, Proficloud Coupler hardware breaks down (reported by Icam and UL) .
- The system couplers stayed offline after adding them, this was reported to Phoenix Contact Germany and the issue is fixed.
- Sometimes the data going over the system couplers was not received on one side, this was reported to Phoenix Contact Germany and the issue is fixed.

5.3. Measurements

During the development work several tests were performed at KU Leuven to determine the performance of the Proficloud system.

Some tests were performed at KU Leuven to determine the latency over the system couplers. This was tested by using a counter in a PLC that incremented every 1 ms. This value was then sent over the Proficloud using a System Coupler to another PLC, which sent the value back to the first PLC. Whenever the value coming from the Proficloud changed, the difference with the local counter was calculated to get an average for the latency. After some tests the latency averaged to about 3 seconds. In Figure 29 you can see one of the latency tests, this measurement was done over a period of almost 22 hours.

"1ms_counter"	%MD250	DEC+/-	79010078
"1a_counter_output"	%QD1026	DEC+/-	79010078
"1a_counter_input"	%ID1026	DEC+/-	79007336
"1a_counter_last_value"	%MD254	DEC+/-	79007336
"1a_counter_last_diff"	%MD258	DEC+/-	2518
"1a_counter_min_diff"	%MD262	DEC+/-	2255
"1a_counter_max_diff"	%MD266	DEC+/-	7026
"1a_counter_average_diff"	%MD270	Floating-point nu...	3096.958
"1a_counter_average_diff_count"	%MD274	DEC+/-	111353
"2a_counter_output"	%QD1282	DEC+/-	79010078
"2a_counter_input"	%ID1282	DEC+/-	79006777
"2a_counter_last_value"	%MD278	DEC+/-	79006777
"2a_counter_last_diff"	%MD282	DEC+/-	2534
"2a_counter_min_diff"	%MD286	DEC+/-	2255
"2a_counter_max_diff"	%MD290	DEC+/-	7778
"2a_counter_average_diff"	%MD294	Floating-point nu...	3100.567
"2a_counter_average_diff_count"	%MD298	DEC+/-	111779

Figure 29: One of the latency tests

Other tests were also performed at Icam (PP6) to determine the time delay over Proficloud connection between remote controlled Pumps and level sensors (controlled by AXC Pro) and the distant operator using HMI (Visu+ and AXC 1050). Their main results are as following:

- Total time delay varies from day to day between 2.4s and 3.2s
- By supposing time delay of all devices is constant, the actual time delay due to the Proficloud communication is about 1s (simple path). It is slightly varying (not deterministic, because of other traffic)
- Since we control a relatively slow dynamic system, this 1 second latency time is sufficiently fast. Hence the good results obtained during the tests. But in case of remotely controlling systems such as mobile robots or electric drives, the delay fluctuation ("jitter"), induced by the Proficloud can deteriorate the stability of the system. This is a major challenge of a long-distance remote control system.

More details on the evaluation tests and other aspects can be found out in the Appendix E (Icam demonstrator final technical report).

5.4. Proficloud devices update guide

5.4.1. CLOUD COUPLER-PRO

- Download the latest firmware from the Phoenix Contact website
- Extract the img-file from the zip-file
- Write the img-file onto a USB-stick using Win32DiskImager
- Turn off the CLOUD COUPLER-PRO
- Insert the USB-stick
- Turn on the CLOUD COUPLER-PRO
- The firmware update is started automatically, the ONLINE LED flashes quickly while the firmware update is running
- Once the update process is complete, the ONLINE LED goes out
- Turn off the CLOUD COUPLER-PRO
- Remove the USB-stick (you will need a partition manager to format the USB-stick)
- Turn on the CLOUD COUPLER-PRO

Remark: There seems to be an issue with the static IP-address setting of the coupler (FW: 1.2.0). If you use the static IP-address, the coupler won't connect to the Proficloud. Use the dynamic setting instead.

5.4.2. AXC CLOUD-PRO

- Download the latest firmware from the Phoenix Contact website
- Run the exe-file to extract the fw-file and the change notes
- Put the switch of the AXC CLOUD-PRO to "PROG"-mode
- Turn on the device and connect it to your network/computer using ethernet
- Open an FTP-connection to the AXC CLOUD-PRO using Windows explorer (ftp://yourip/), using Google Chrome doesn't work!
- Transfer the fw-file to the root directory of the device, it may take several minutes
- The FTP-connection doesn't seem very reliable, several tries may be necessary to successfully transfer the file, make sure the file is transferred completely before starting the update!
- In the "Device Details" window of PC Worx, select the "CPU Service Editor" tab
- Click the "Open Service Library" button
- The Service Library for the AXC CLOUD-PRO is the "AXC1xxx_Service_Common.slb", so choose that file
- The available services will be listed after you have opened the service library
- Select the "Firmware_Update" service with a doubleclick
- The selected service will be shown in the "CPU Request" window, all values required are set
- Start the firmware update by clicking the "Send" button
- During the firmware update the following LEDs flash alternately on the controller: "RUN" and "DBG"
- The update is complete when the LEDs stop flashing
- To check the firmware version you can open the project control dialog box in PC Worx and click the "Info" button in the project control dialog box

6. References

Univ-Lille Youtube videos:

- * "INCASE PROFICLOUD DEMONSTRATOR":
 - <https://www.youtube.com/watch?v=2nhobnMVlb07>
- * "INCASE - Lille University Proficloud demonstrator with water tank":
 - <https://www.youtube.com/watch?v=od81x-imixU>

Phoenix Contact Xplore New Automation contest 2017-2018: participation of Univ-Lille with the PROFICLOUD Demonstrator:

- * Project video presentation of the 24 finalists including Univ-Lille:
 - <https://wbc-consumer.movingimage.com/#/webcast/596da7e4340925e5f822c494>
- * Contest presentation:
 - https://www.phoenixcontact.com/online/portal/pc?1dmy&urile=wcm:path:/pcen/web/corporate/company/subcategory_pages/xplore_new_automation_award/8501d4e2-eccc-4124-9a65-3c9497b3e8cb
 - https://www.phoenixcontact.com/assets/downloads_ed/global/web_dwl_promotion/5164941_EN_HQ_xplore_New_Automation_LoRes.pdf

Appendix A: System coupler unable to add in PC Worx 6.30.1914

Problem:

It was possible to setup a communication between two Siemens CPU's over the Proficloud using the System couplers. Adding the GSDML in TIA Portal and configuring the System couplers as IO-Devices worked without any problems.

But when trying to configure the System couplers with a AXC1050 in a PCWorx 6.30.1914 project, an issue occurred regarding the GSDML/Hardware Catalog.

The GDSML file can't be added since PC Worx 6.30.1914 prevents GSDML installations with vendor ID = 0x00B0, and the System coupler isn't present in the Hardware catalog by default.

Solution:

In order to use the GSDML in Pcworx, a modification in the following configuration file is needed:

C:\ProgramData\Phoenix Contact\PC WORX\6.30\GSDMLtoFDCML.xml

(ProgramData might be a hidden folder)

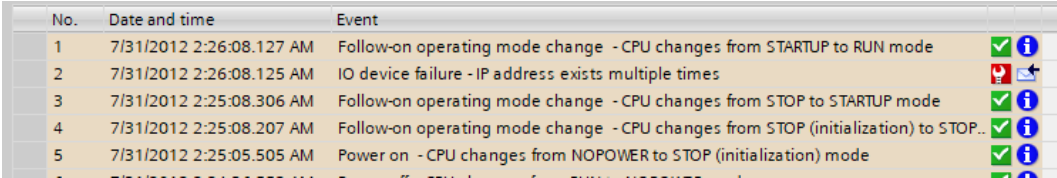
```
<configurationList>
  <config importPhoenixContactGSDML="false"/>    <<-- Here change to TRUE and
restart PCworx
</configurationList>
```

After this change it should be possible to use the GSDML file.

Appendix B: CLOUD COUPLER-PRO as IO-Device - Duplicate IP-address

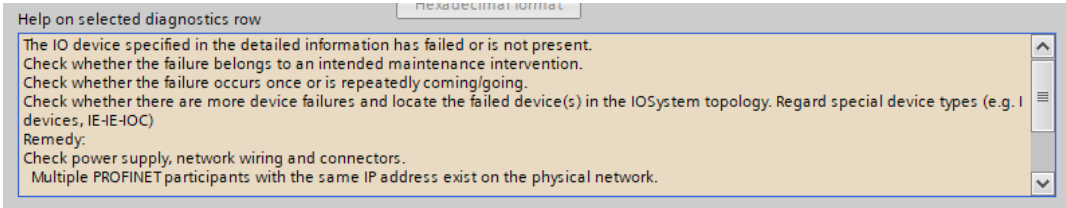
1. Problem description

When trying to add the CLOUD COUPLER-PRO as an IO-Device with a Siemens IO- Controller following error occurs:



No.	Date and time	Event	
1	7/31/2012 2:26:08.127 AM	Follow-on operating mode change - CPU changes from STARTUP to RUN mode	✓ i
2	7/31/2012 2:26:08.125 AM	IO device failure - IP address exists multiple times	✗ i
3	7/31/2012 2:25:08.306 AM	Follow-on operating mode change - CPU changes from STOP to STARTUP mode	✓ i
4	7/31/2012 2:25:08.207 AM	Follow-on operating mode change - CPU changes from STOP (initialization) to STOP..	✓ i
5	7/31/2012 2:25:05.505 AM	Power on - CPU changes from NOPOWER to STOP (initialization) mode	✓ i

Figure 1: Online Diagnostics buffer of the IO-Controller



Help on selected diagnostics row

The IO device specified in the detailed information has failed or is not present. Check whether the failure belongs to an intended maintenance intervention. Check whether the failure occurs once or is repeatedly coming/going. Check whether there are more device failures and locate the failed device(s) in the IOSystem topology. Regard special device types (e.g. I devices, IE-IE-IOC)

Remedy:
Check power supply, network wiring and connectors.
Multiple PROFINET participants with the same IP address exist on the physical network.

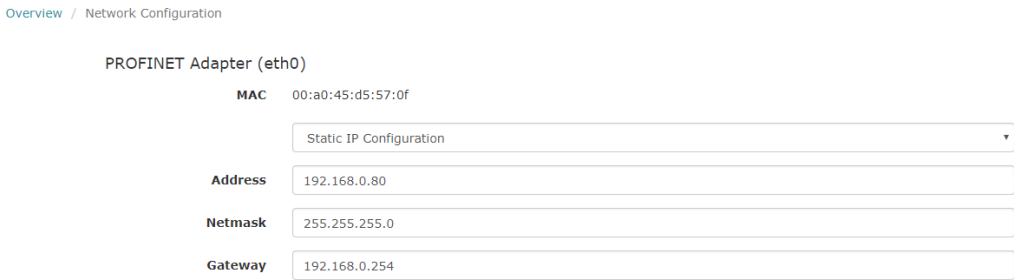
Figure 2: Online Diagnostics status of the IO-Device

Apparently there’s a duplicate IP-address in the network.

2. Measurements

2.1. Webpage

The webpage of the CLOUD COUPLER-PRO indicated the IP-address was set correctly for the PROFINET interface (Eth0) and MAC-address of the CLOUD COUPLER-PRO matches the one written on the hardware.



Overview / Network Configuration

PROFINET Adapter (eth0)

MAC 00:a0:45:d5:57:0f

Static IP Configuration

Address 192.168.0.80

Netmask 255.255.255.0

Gateway 192.168.0.254

Figure 3: Webpage settings for the PROFINET interface

2.2. PRONETA

Using PRONETA, the device name and IP-address was changed with the one used in the configuration. The MAC address didn't match the one seen earlier.

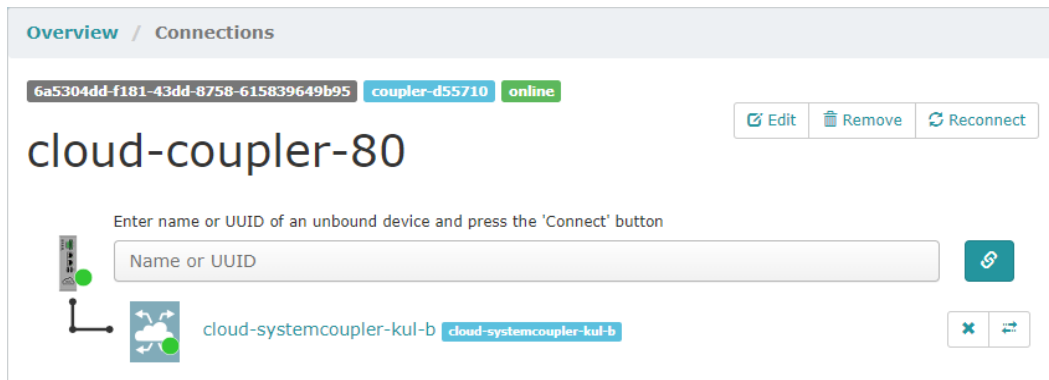


Figure 4: Initial Proficloud configuration

2	coupler-d55710	CLOUD COUPLER-PRO	0.0.0.0	00:a0:45:d5:57:10	0x00B0				
---	----------------	-------------------	---------	-------------------	--------	--	--	--	--

Figure 5: Initial IO-Device as seen by PRONETA

2	cloud-coupler-80	CLOUD COUPLER-PRO	192.168.0.80	00:a0:45:d5:57:10	0x00B0				
---	------------------	-------------------	--------------	-------------------	--------	--	--	--	--

Figure 6: Updated IO-Device as seen by PRONETA

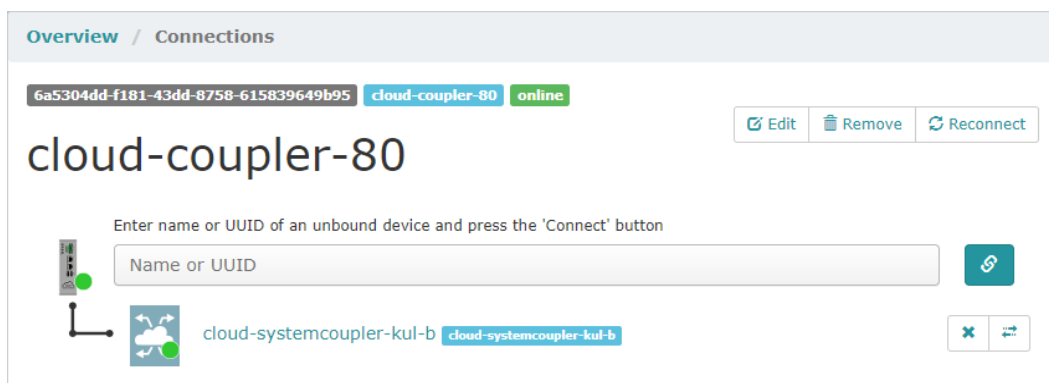


Figure 7: Updated Proficloud configuration

2.3. Wireshark

The following was measured with Wireshark:

40	26.781209	[cpu1516-132]	Broadcast	ARP	60	Who has 192.168.0.80? Tell 192.168.0.132
41	26.781209	PhoenixC_d5:57:0f	[cpu1516-132]	ARP	60	192.168.0.80 is at 00:a0:45:d5:57:0f
42	26.784287	PhoenixC_d5:57:10	[cpu1516-132]	ARP	60	192.168.0.80 is at 00:a0:45:d5:57:10

Figure 8: Wireshark measurement

Both MAC-addresses reply on the ARP request.

3. Temporary solution

By changing the IP-address set at the webpage of the CLOUD COUPLER-PRO, it is possible to make the CLOUD COUPLER-PRO accessible as an IO-Device.

Appendix C: Using the cloud to meet certification requirements



CLOUD TECHNOLOGY

USING THE CLOUD TO MEET CERTIFICATION REQUIREMENTS

Arno Martin Fast explains how Ricola has utilised cloud computing alongside its tried-and-tested automation technology to provide a cost-effective solution to meet stringent certification requirements to allow it to export its products across the globe.

A pioneer in natural herb cultivation, Ricola exports 90% of its herbal specialities to over 50 countries with its strongest sales being in the USA, Germany, France, Italy, and Switzerland. The development of new candies and opening up new markets has required the company to consider additional certification. Products heading to USA, for example, need to meet the stringent requirements set by the FDA. Storage and production processes have to be documented from end-to-end as part of such certification and this led to the company's search for a solution, which it found with cloud technology in the form of Proficloud from Phoenix Contact.

Transmitting data across sites

The PROFINET Industrial Ethernet standard can be used to realise a range of automation concepts – from machine building and production technology, through process and building automation, right through to drive technology. The real-time-capable transmission protocol uses the TCP/IP channel and IT standards, and is able to incorporate both fieldbus and cloud-based systems. Proficloud technology – Phoenix Contact's cloud-based, open IoT platform which connects hardware and software components – enables PROFINET networks, such as those operated by Ricola, to be connected to the Internet, opening up the limitless

opportunities presented by the Internet of Things (IoT) to the user.

But what does IoT have to do with making speciality herbal candy?

The Ricola herbs are grown by approximately 100 herb farmers in five regions in the Swiss mountains. A total of 1,400 tonnes of herbs are processed annually. These herbs need to be stored and processed under optimum conditions. Both the administration offices and the storage and production facilities are located in Laufen, albeit in different districts. The decentral arrangement of the individual buildings means that relevant information needs to be exchanged as cost-effectively as

possible. Furthermore, the solution must be integrated into the existing automation technology. To achieve an efficient solution, Daniel Bhend, senior director of technology/engineering at Ricola, worked with the integrator, Kundert Automation, and with Phoenix Contact. A combination of standardised communication protocols for automation technology and the Internet is used to exchange data over long distances.

Information on the condition of the storage rooms, which are located some 15km from the production facility, must be transmitted to the central distributed control system (DCS). To achieve this, the recorded measured



The AXC Cloud-Pro controller and the aligned I/O modules capture data from multiple temperature sensors that are distributed throughout the storage rooms.



The Proficloud coupler connects the local PROFINET network to the Proficloud via two Ethernet interfaces.

values are transmitted via PROFINET protocol to the process control system. The relevant PLC also assumes the function of a PROFINET controller, which is why Proficloud was an option here. This is because a standard Proficloud application is normally made up of at least one Proficloud coupler, one Proficloud device, and one PROFINET controller.

The Proficloud coupler connects the local PROFINET network to Proficloud via two Ethernet interfaces. While one interface is used to establish a connection to the local PROFINET system in the production facility, the second Ethernet interface is used to establish a connection to the Internet. The coupler then initialises a connection with Proficloud automatically and is ready for use after a short amount of time. The same applies to Proficloud devices that are simply connected to the Internet, connecting automatically to Proficloud.

At Ricola, the decentral AXC Cloud-Pro Proficloud controllers acquire the data from temperature sensors, distributed throughout the storage rooms via Axioline F I/O modules and transmit this via Internet to the Proficloud coupler. "By using Proficloud, we do not have to develop a complex network infrastructure," said Bhend. The system integrator simply had to register the Proficloud devices in Proficloud using its Universal Unique Identifiers (UUIDs) and assign them to

the central Proficloud coupler. UUIDs are used for the clear identification of information in decentral systems, ensuring secure communication via Proficloud. Upon registration, the PROFINET system records the TLS-secured data transmission via Proficloud.

Retrieving weather information

Along with the capture and transmission of measured values from the storage rooms, the latest weather information is also communicated to the DCS and this is added to the FDA inspection documents. Ricola could have installed a weather station for this, which would have had to be set and connected to the PLC. However, it was easier to use the Proficloud Weather cloud service, which allows the relevant information to be retrieved from the weather service via the Internet. This can then be used by the controller directly as PROFINET data. The Proficloud service is treated as a virtual Proficloud device in the Proficloud system. With the input process data, the user can determine which location the weather information is to be retrieved from – in this case by entering the warehouse coordinates.

As soon as a connection has been established to the Internet and therefore the cloud, the PROFINET device sends its process data to

Proficloud. Restricting communication to an outbound connection ensures that no Internet subscribers can communicate with Proficloud devices unsolicited in order to manipulate temperature data, for example. Once the connection to Proficloud has been established via the Internet, a PROFINET instance is created in the Proficloud coupler for each connected Proficloud device. The station in the warehouse and the weather device thus receive a separate IP and MAC address that is represented in the local PROFINET network. After that, each Proficloud device can be programmed as a local PROFINET device.

Protection from unauthorised access

Due to the fact that the data transmission of Proficloud couplers and devices is protected with TLS1.2 encryption and the connection can only ever be established by Proficloud devices, two fundamental aspects are taken into account with regard to data security of Proficloud. Even the web application for configuring Proficloud is securely transmitted to the user with HTTPS and is thereby protected against unauthorised access. This has been certified by independent agencies.

In conclusion, the combination of tried-and-tested automation standards and cloud technology has long been a reality. Proficloud, which has been available as a live cloud platform for over two years, is being used in ever more applications. In addition to the cloud-based PROFINET communication utilised by Ricola, time-series database solutions have also been realised and company-specific concepts have been developed that are based on Proficloud. ☺

Arno Martin Fast is product manager for Proficloud at Phoenix Contact Electronics.

Appendix D: Ricola leverages Proficloud to satisfy strict FDA requirements

Ricola leverages Proficloud to satisfy strict FDA requirements

Everyone knows the "Who invented it?" slogan from TV and radio ads that made the Swiss company Ricola famous. Now, the firm is proving that its traditional cough drops can go hand in hand with modern technology by turning to Proficloud as a solution to meet strict FDA requirements cost-effectively.

CLOUD COMPUTING IS AN INTEGRAL PART of the development of new candies at Ricola, and opening up new markets that often involves additional certifications. To be sold in the USA, for example, they must meet the stringent requirements of the FDA (Food & Drug Administration). Storage and production processes have to be documented from end to end as part of such certifications, and so Ricola is turning to cloud computing and all it has to offer. Many companies struggle to grasp what this technology is all about.

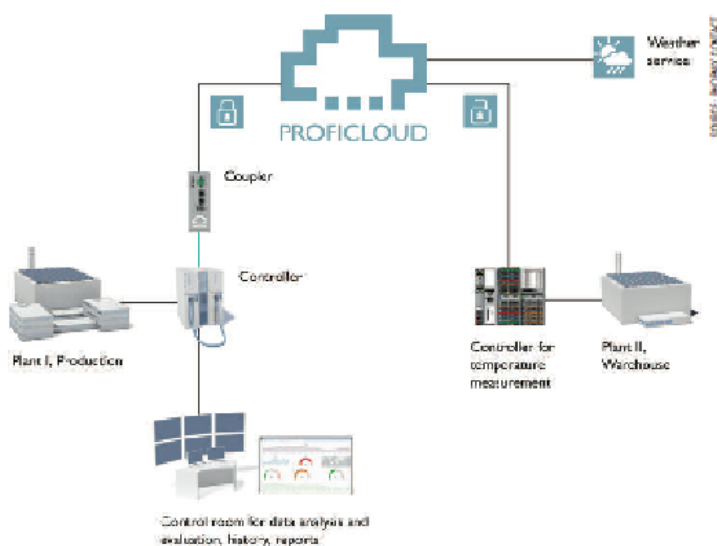
The idea is that, as intelligent devices with Internet capability are networked more and more, the data they provide will improve productivity and competitiveness; but how this will actually be realized in practice and the specific benefits are still unclear. One example of what a cost-effective solution could look like is this combination of tried-and-tested automation technology and Proficloud.

Transmit status data across sites

The PROFINET Industrial Ethernet standard can be used to realize a huge range of automation concepts from machine building and production technology, through process and building automation, right through to drive technology. The real-time-capable transmission protocol uses the TCP/IP channel and IT standards, and is able to incorporate both fieldbus and cloud-based systems. Proficloud technology now enables PROFINET automation networks to be connected to the Internet, opening up the limitless opportunities presented by the Internet of Things (IoT) to the user.

But what does IoT have to do with making speciality herbal candy? The Ricola herbs are grown by approximately 100 herb farmers in five regions in the Swiss mountains. A total of 1400 tonnes of herbs are processed annually; these herbs must be stored and processed under optimum conditions. Therefore, both the administration offices and the storage and production facilities are located in Laufen, albeit in different districts.

The decentralised arrangement of buildings means that relevant information must be exchanged as cost-effectively as possible between the various facilities. Furthermore, the solution must be integrated into the existing automation technology. Daniel Bhend,



Topology of the Proficloud application at Ricola.

Senior Director Technology/Engineering at Ricola, has therefore worked together with the integrator Kundert Automation AG and the experts from Phoenix Contact to develop an efficient solution. A combination of standardized communication protocols for automation technology and the Internet is used to exchange data over long distances.

Connecting automatically to cloud

At Ricola, information on the condition of the storage rooms, which are located some 15 kilometers from the production facility, must be transmitted to the central distributed control system (DCS). To achieve this, recorded measured values are transmitted via PROFINET protocol to the process control system. The relevant PLC also assumes the function of a PROFINET controller, which is why the Proficloud was an option. A standard Proficloud application is normally made up of at least one Proficloud coupler, one Proficloud device, and one PROFINET controller.

The Proficloud coupler connects the local PROFINET network to the Proficloud via two Ethernet interfaces. While one interface is

used to establish a connection to the local PROFINET system in the production facility, a second Ethernet interface is used to establish a connection to the Internet. The coupler then initializes a connection with the Proficloud automatically, and is ready for use after a short amount of time. The same applies to Proficloud devices that are likewise simply connected to the Internet and that connect automatically to the Proficloud.

At Ricola, the decentralised AXC Cloud-Pro Proficloud controllers acquire the data from the many temperature sensors distributed throughout the storage rooms via alignable I/O modules of the Axioline F product range, and transmit this via Internet to the Proficloud coupler. "By using the Proficloud, we do not have to develop a complex network infrastructure," Bhend said.

The system integrator commissioned by Ricola, Kundert Automation AG, simply had to register the Proficloud devices in the Proficloud using their UUIDs (Universal Unique Identifiers) and assign them to the central Proficloud coupler. UUIDs are used for the clear identification of information in decentral

systems and ensure secure communication via the Proficloud. Upon registration, the PROFINET system records the TLS-secured data transmission via the Proficloud.

Weather information from Internet

At Ricola, along with the capture and transmission of measured values from the storage rooms, the latest weather information is also communicated to the DCS in order that this can be added to the FDA inspection documents. Ricola could have installed a weather station for this, which would have had to be set and connected to the PLC. It is easier to use the Proficloud Weather cloud service, so relevant information can be retrieved from the weather service via the Internet. This can then be used by the controller directly as PROFINET data. The Proficloud service is treated as a virtual Proficloud device in the Proficloud system. With the input process data, the user determines for which location the weather information is to be retrieved, in this case by entering the warehouse coordinates.

How does the data from the Proficloud devices now find its way to the PLC and how is the process of exchanging data protected? As soon as a connection has been established to the Internet and, therefore, the cloud, the PROFINET device sends its process data to the Proficloud. Restricting communication

to an outbound connection ensures that no Internet subscribers can communicate with the Proficloud devices unsolicited in order to manipulate temperature data, for example.

Once the connection to the Proficloud has been established via the Internet, a PROFINET instance is created in the Proficloud coupler for each connected Proficloud device. The station in the warehouse and the weather device thus receive a separate IP and MAC address that is represented in the local PROFINET network. After that, each Proficloud device can be programmed as a local PROFINET device.

Unauthorized access protection

Due to the fact that the data transmission of Proficloud couplers and devices is protected with TLS 1.2 encryption and the connection can only ever be established by the Proficloud devices, two fundamental aspects are taken into account with regard to data security of the Proficloud. Even the web application for configuring the Proficloud is securely transmitted to the user with HTTPS and is thereby protected against unauthorized access; this has already been certified by independent agencies.

In conclusion, the combination of tried-and-tested automation standards and innovative cloud technology has long been a reality. The Proficloud has been available as a

live cloud platform for over two years, is being used in more and more operations applications all the time. For example, in addition to the cloud-based PROFINET communication utilized by Ricola, time-series database solutions have also been realized and company-specific concepts have been developed that are based on the Proficloud.

Flexible use of Internet

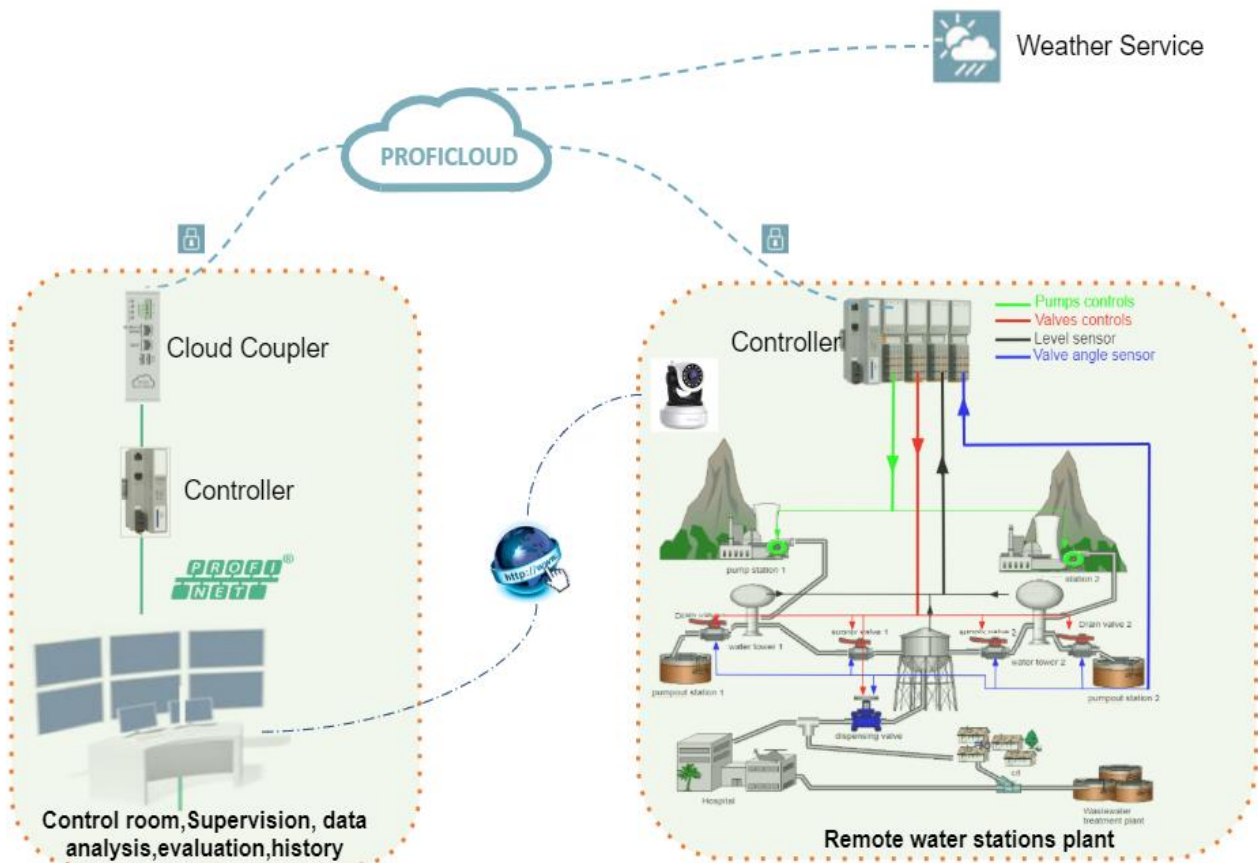
The Proficloud is a cloud-based, open IoT platform which connects hardware and software components found in an enormous variety of systems and machines. This enables automation systems to benefit from the limitless possibilities offered by the Internet. Being dependent on one single automation manufacturer is detrimental here and also contradicts the open approach of Proficloud.

The technology links real objects to the digital world in order to realize powerful industry applications and provide digital services. This improves competitiveness and opens up new business models. As an open IoT platform, the Proficloud allows innovative solutions to be developed and provided in a versatile ecosystem without having to obtain a costly developer license.

Anna Maria Faust, B.Eng., Product Manager for Proficloud, Phoenix Contact Electronics GmbH.

Appendix E: Icam Proficloud Demonstrator Technical Report

Proficloud Based Automation & Supervision of remote water stations



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ABSTRACT

New key automation technologies are needed for the transfer to the future smart factories, e.g. Long distance interconnection of smart factories and large scale industrial networks, with small extra engineering effort, such as ProfiCloud. As part of the Interreg INCASE project, realistic demonstrators of "interconnected plants" using ProfiCloud technology, have been developed. Icam, as a partner in the project, has developed a local Proficloud demonstrator that is part of the interregional demonstrator. ProfiCloud is developed as a technology to interconnect smart factories and installations over long distance. It connects directly the local high speed industrial data communication backbone (PROFINET) of the different factories and installations located at different places.

In this report, we present the Icam Proficloud démonstaror based on remote water stations. Water supply represents a vital problem for people, and this imposes the need to know the information regarding consumptions, resources and production. This implies a continuous supervision of the water supply process in order to allow any problem that could appear to be solved, and in the same time, to maintain normal functioning parameters. Proper solutions imply automation and monitoring architectures which contain: a supervision and control system for the real time installation, programmable logic controllers , communication systems, standard interfaces or dedicated ones, electrical drive elements, measuring devices, etc.

After presenting a literature review of modern remote , a methodology is presented to deploy Proficloud technology on a physical system that emulates a real situation (water stations). Then an automatic control in normal operation and in case of maintenance situations are presented. Its main features are: the use of a supervisory system for monitoring and controlling the water pumping and the water level, and the use of a communication system based on Proficloud to allow remote supervision. The good performance of the supervision algorithm is then analyzed and discussed using Proficloud technology. Then the delay times induced by the Proficloud communication are analyzed and tested for different dates to take into account the lateness of the transmission/reception of data. We concluded with some advantages and disadvantages of the Proficloud.

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1.Introduction

In this section, we focus on the state of the art in remote control of industrial processes which are geographically dispersed and scattered thousands of square kilometers. These remote industrial process can be managed by a central Control and Data Acquisition Systems (SCADA systems). They can be pipelines, water stations, electrical grid, railway transport, and different production systems. References [31], [32] describe some systems which can be of varying degree of complexity depending on the process and the specific implementation. An essential feature of remote control systems, is the reliability depends not only on the accuracy of the processing performed, but also on the time in which these results are provided.

PLC manufacturers nowadays offer solutions adapted to all types of pumping stations. The common trend is that all these systems are increasingly communicating, both with each

other and with centralized supervision. **Figure 1** shows the components and general configuration of a SCADA system. The Supervision Center houses a control server (Master Terminal Unit) and communication routers. MTU allows remote control of autonomous installations that are geographically dispersed. There is also the Human Machine Interface (HMI) which allows engineers to collect data from remote processes and generate control actions based on this information or after detected events. The field site is called an RTU (*Remote Terminal Unit*) allowing local automation, remote monitoring and local/remote control.

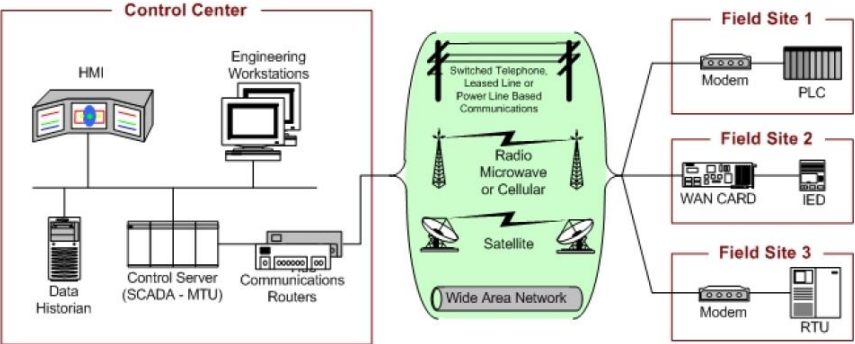


Figure 1 : SCADA System General Layout [33]

By using standard communications or proprietary protocols, information can be exchanged between the central supervisor (MTU) and the various RTUs. For example: telephone line, radio frequency, GSM, satellite..etc. Typically, the data flow in a factory has been described in the form of the so-called automation pyramid (**Figure 2**). As the figure clearly shows, at the same time as the pyramid is narrowing, the amount of information to be transmitted is increasing. At the top of the pyramid the amount of information is large, but the transmission speed is lower and the real-time needs are lower.

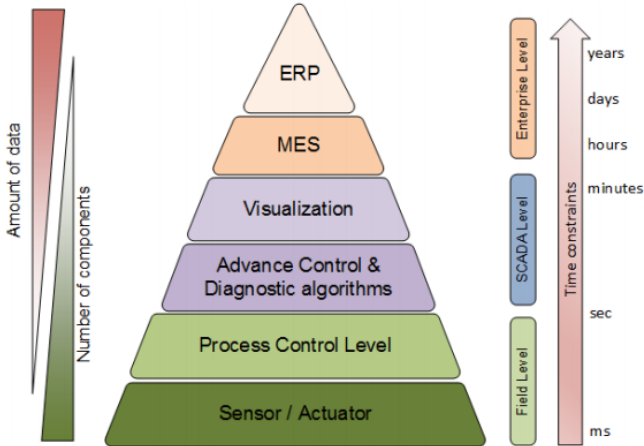


Figure 2: Automation Pyramid [34]

In the case of pumping stations, the MTU allows the operator to be alerted in case of technical problems but also it can record the operation of monitored equipment (pumps, valves...etc). It is also possible to continuously monitor the condition of a water network, analyse its behaviour and optimise its management. With the aim of: preventive maintenance, leak detection, monitoring of consumption and volumes produced and distributed. This will

result in savings in terms of energy and water resources, while limiting interventions (operator displacements) and costs.

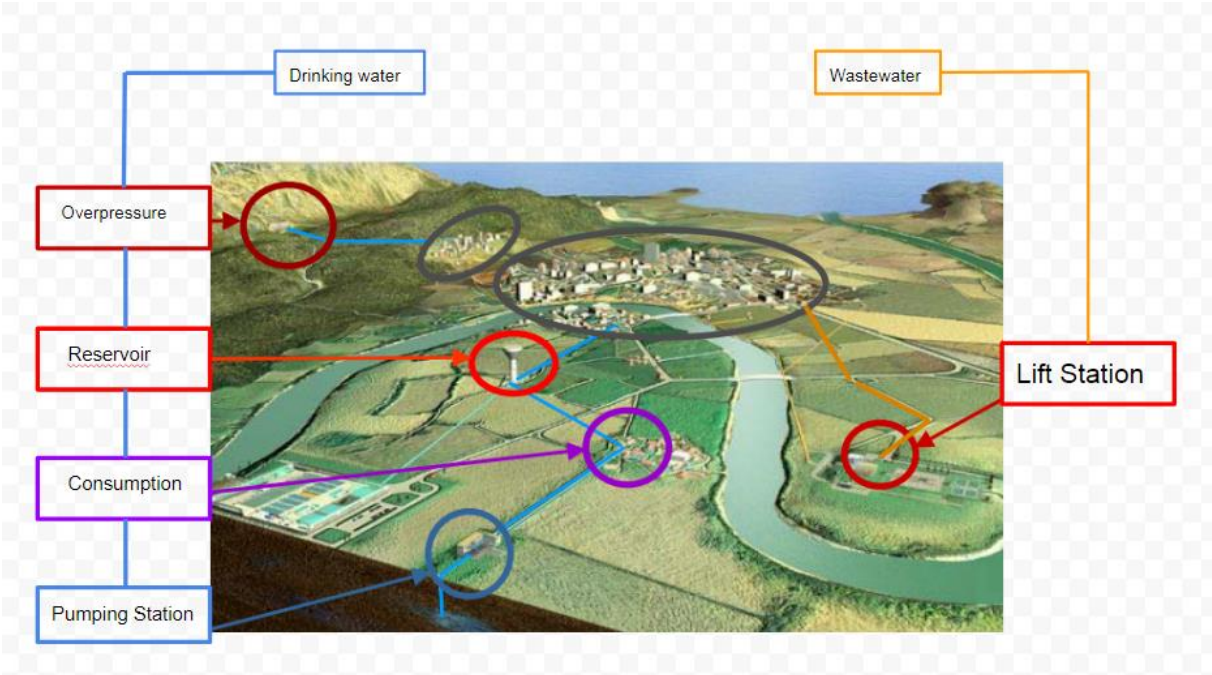


Figure 3: Water networks

As shown in **Figure 3**, the dispersion of installations throughout the territory implies specific provisions, in particular the possibility of inter-site communication. The technological choices of remote control applications are therefore regularly influenced by advances in ICT (*Information and Communication Technologies*). Today, remote access to RTUs is provided by PSTN (*Public Switched Telephone Network*), whose disadvantage is to draw a telephone line, with very high costs, in order to access to remote sites. We can also find GSM data, GPRS, radion, satellite,ADSL...etc. **Figure 4** show two examples of communication.

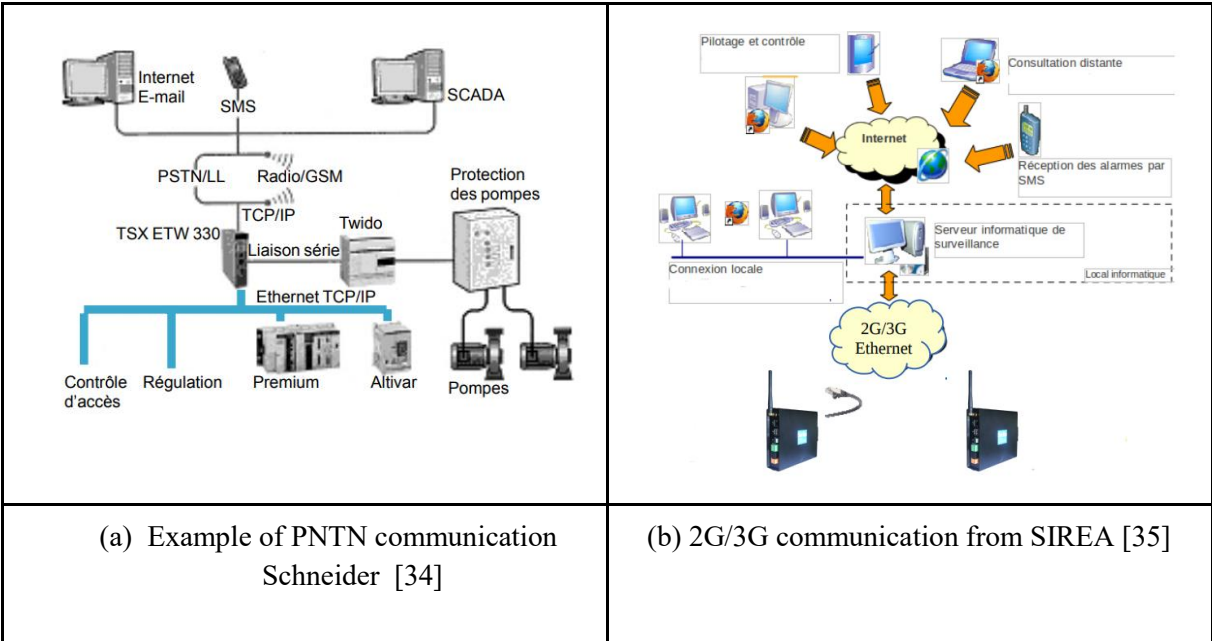













Figure 4: Examples of teleprocessing manufacturers

2. Communication Technologies

Different communications technologies supported by two main communications mean, i.e., wired and wireless, can be used for data transmission between MTU and the various RTU's. In some cases, wireless communications have some advantages over wired technologies, such as low-cost infrastructure and ease of connection to difficult or unreachable areas. However, depending on the nature of the transmission mode, the signal can be attenuated as the distance increases. On the other hand, wired solutions have few interference problems and their operation is not dependent on batteries, as wireless solutions often do [2].

Basically, two types of information infrastructure are required for the flow of information in a water system system. The first flow, for example, consists of battery-powered wireless sensors used for difficult telemetry applications, including hazardous locations. The transmission is carried out by 2.4 GHz radio waves over short distances (1 km) [3]. As suggested in [4], this data can be accomplished through powerline communication or wireless communications, such as ZigBee, 6LowPAN, Z-wave, and others. In this case, sensors communicate with the local RTU controller.

For the second information flow, between the different RTUs and the MTU, cellular or Internet technologies can be used. Nevertheless, there are key limiting factors that should be taken into account in their deployment processes, for example, operational costs, rural/urban environment, etc. An overview of communication technologies can be found in **Table 1**.

Technology	Spectrum	Data rate	Distance	Application	Example of manufacturers
GPRS	900 - 1800 MHz	14.4 Kbps??	1-10 km	Home Area Network	   [5],[10]
Bluetooth	2.4 Ghz	721 Kbps	1 – 100m	Home Area Network ,	  [6],[7]
3G Cellular	1.6-2.5 GHz	2Mbps	1-10km	Field Area Network	  [5],[8]
PLC	1.8-86.0 MHz	2-3 Mbps	1-3 km	Home Area Network	 [9]
Radio	2.4 Ghz	50 kbps-100 kbps	1 km	Home Area Network	  [5],[10]
LORA	150Mhz -1 Ghz	0.3–50 Kb/s	<30 km	Field Area Network	

	z				[11]
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Table 1: Example of communication technologies

Existing cellular networks can be a good option for communication between RTU and MTU. The existing communication infrastructure avoids operating costs and additional time to set up a dedicated communication infrastructure. In the instance that the exchanged data must be carried out at very short intervals, a huge amount of data will be generated and cellular networks can provide sufficient bandwidth for such applications. In some critical applications, it is necessary to have continuous availability of communications. However, cellular network services are shared by the customer market, which can lead to network congestion and an overall network slowdown. As a solution to this problem, a private communication network can be built. On the other hand, in the case of a critical installation, it is on optical fiber or telephone line can be used.

3. Supervision on Cloud Computing

Another way to make these systems even more communicative is to use the Cloud. Web-based software services, more commonly called cloud computing are being implemented globally by users in virtually all types of organizations to reduce cost and improve efficiency. As new systems often require new technology resources to operate and support, cloud computing provides water utilities a viable alternative for investing in additional hardware [1].

According to NIST, Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [12]. These cloud computing services have several major advantages:

- Quick to deploy;
- Very low investment;
- Experts maintain the system so that utilities can focus on their core competencies;
- Software updates automatically implemented;
- Elasticity or rapid expansion to meet changing utility needs;
- Subscription rates offer a pay-per-use option.

It is in this wake that Xylem has developed an architecture where intelligence is integrated into the pumps and connected directly to the Cloud without going through PLCs [13]. The manufacturer Crouzet develops small PLCs connected to Ethernet and which can regularly upload data logs [14]. The Siemens RTU 3030C (**Figure 4**) offers the same data transmission capabilities [15].

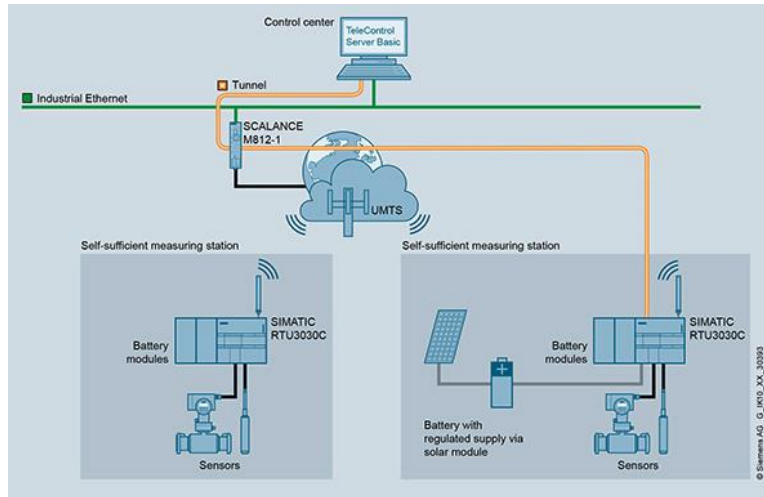





Figure 4: Data transmission from RTU [15]

One of the main elements for the supervision of water production stations is the software of the water information platform. In this section, the current solutions available on the market from different vendors for urban, industrial and agricultural water management will be summarized in the following table (**Table 2**).

Vendors	Features
 IBM Intelligent Water [20]	IBM Intelligent Water software uses advanced data management, visualization, correlation and collaboration technologies to transform the vast amounts of disparate data received from various devices (including metering systems), assets, systems and stakeholders into actionable information that can guide executive and operational decision-making.
EcoStruxure for Water and Wastewater [22] 	This software provides full visibility into the complete water supply, collection, and treatment system while delivering process control and energy efficiency from field to enterprise. It permits to control, operate, and optimize the water and wastewater infrastructure from field to enterprise level. Utilities can reach operational excellence across the full water cycle while reducing energy consumption and total cost of ownership.
 Siemens – Smart Water Platform [21]	Siemens Smart Water Platform provides a proven, reliable and cost-effective solution to help utilities and cities start solving your water challenges today and across their network over the long term. The Smart Water Platform combines EnergyIP Core Platform functionality with integration and an ever-growing portfolio of customizable apps. The


	<p>platform seamlessly integrates with new or existing metering system, providing actionable data to help address issues before they become problems, providing new ways to engage customers and strengthen relationships, and most importantly allowing utilities to generate a more predictable revenue stream.</p>
<p>TakaDu [23]</p> 	<p>TaKaDu is an early adopter of the IoT (Internet of Things) concept, aiming to create an easy-to implement cloud-based SaaS (software-as-a-service) solution, which could analyse and process the raw data measured by sensors in the water networks. TaKaDu uses big data analytics, based on sophisticated statistical algorithms, to provide in-depth visibility, real-time detection and quick insights into every, and any, type of “event”. This includes - identifying leaks before they turn into large bursts - detecting changes and trends in water pressure, anomalous usage patterns, supply interruptions, water quality issues, identifying faults in meters, valves and other assets - telemetry issues and data availability - spotting water theft, and automatic early warning of operational issues, like open valves and zone breaches. The aim of TaKaDu is to deliver tangible water and energy savings while helping utilities improve their managerial processes and customers’ satisfaction, delivering a faster response time.</p>

Table 2: Examples of Cloud water supervision vendors

So far we have seen that generally the world of PLCs and the Cloud are separated. The I4.0 industry aims to make communications between the physical world and the cloud transparent. This is called a cyber-physical system. In other words, the PLC must be deployed in the cloud by extending a variety of protocols under the generic name Fieldbus and to the cloud with uninterrupted real-time operation. This is why alliances are emerging between different PLC manufacturers and companies specializing in the Cloud. **Figure 5** illustrates the different alliances between PLC manufacturers and Cloud giants.

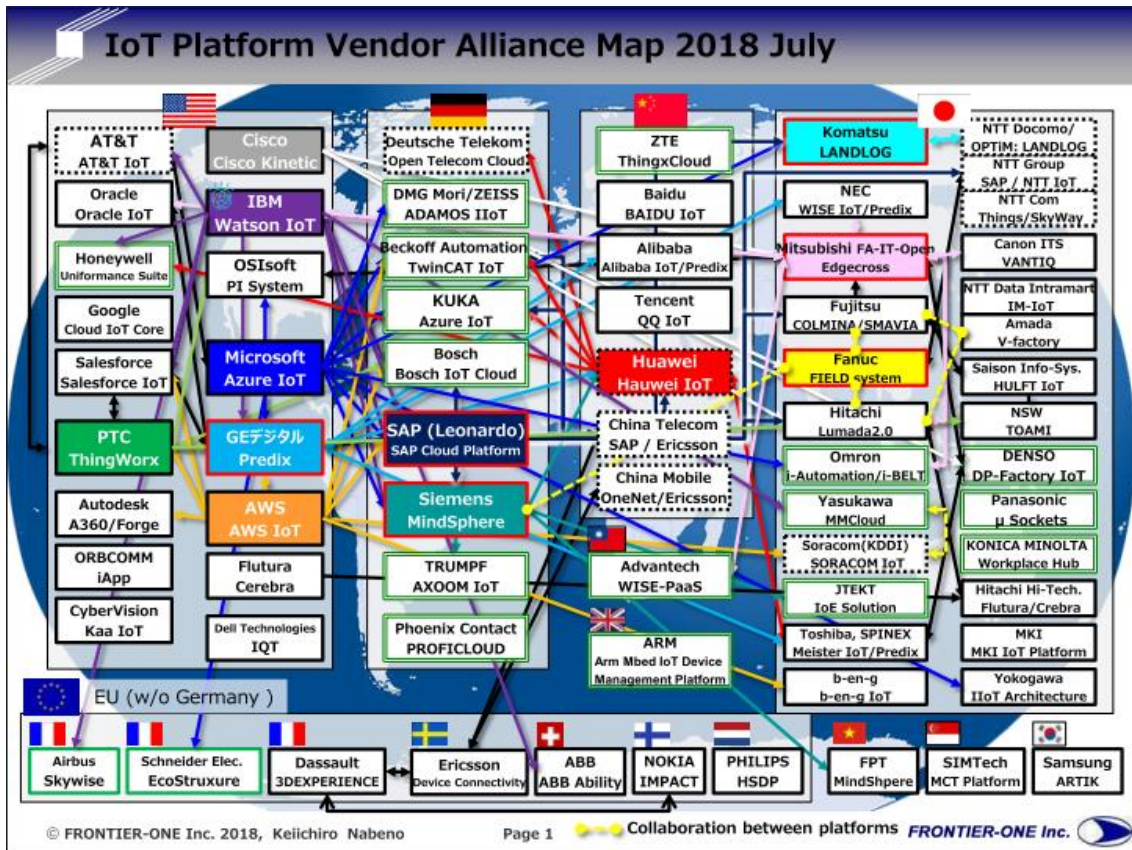



Figure 5: IoT Platform Vendor Map [24]

For example, Beckhoff employs operating systems from Microsoft for its PC-based control technology. As a Microsoft Windows Embedded Partner, Beckhoff gains early and intensive access to Microsoft technologies. This partnership-like cooperation is of great advantage to both sides: it enables optimum integration of Beckhoff automation products in the Microsoft world, while Microsoft can utilise the experiences with PC-based control technology for optimising its products for automation requirements. In this way, the technological convergence of IT and automation technology is continuously stimulated [23].

The following table (Table 3) shows some Cloud technologies, which may be the result of an alliance between PLC manufacturers and cloud specialists such as the Proficloud developed by Phoenix Contact and IBM.

Manufacturer	Technology
Rockwell Automation [16]	<i>FactoryTalk</i> Cloud
Siemens [17]	
General Electric	PREDIX


[18]	
Phoenix Contact [19]	

Table 3 : Management via the Cloud

One of the objectives of the Interreg INCASE project (Industry 4.0 via Networked Control Applications and Sustainable Engineering) [26] is to develop a demonstrator for interconnected factories. The ProfiCloud technology was chosen. It's is developed as a technology to interconnect smart factories and facilities over long distance. It connects directly the local high speed industrial data communication backbone (PROFINET) of the different factories and installations located at different locations.

It is in this context that the Icam of Lille, an engineering school, has developed a demonstrator for the supervision of a pumping station using Proficloud technology. It will be presented and detailed in the following sections.

4.ProfiCloud Technology

4.1 Architecture and working principle

The local Fieldbus Profinet can support cloud functions via a technology called Proficloud. The cloud functions can also be added to existing installations. Proficloud, as illustrated in **Figure 6**, allows Profinet users to utilize modern cloud services and telecontrol applications with ease to control remote locations centrally. With Proficloud users can import valuable data from Profinet systems to cloud servers such as usage and network statistics. Proficloud implementation has always at least one cloud coupler and one cloud device. In **Figure 13** we see how Profinet devices are connected to Proficloud. The cloud coupler has two Ethernet ports, one for the local network connection and one for connecting to the Internet. The coupler automatically sets up a connection to the Proficloud so that it is operational after a short period of time. This is accomplished by preconfiguring the cloud devices before setting them up at the preferred location. With preconfigured devices Proficloud tries to reduce complexity of setting up a VPN connection. Network data is obtained via DHCP [26].

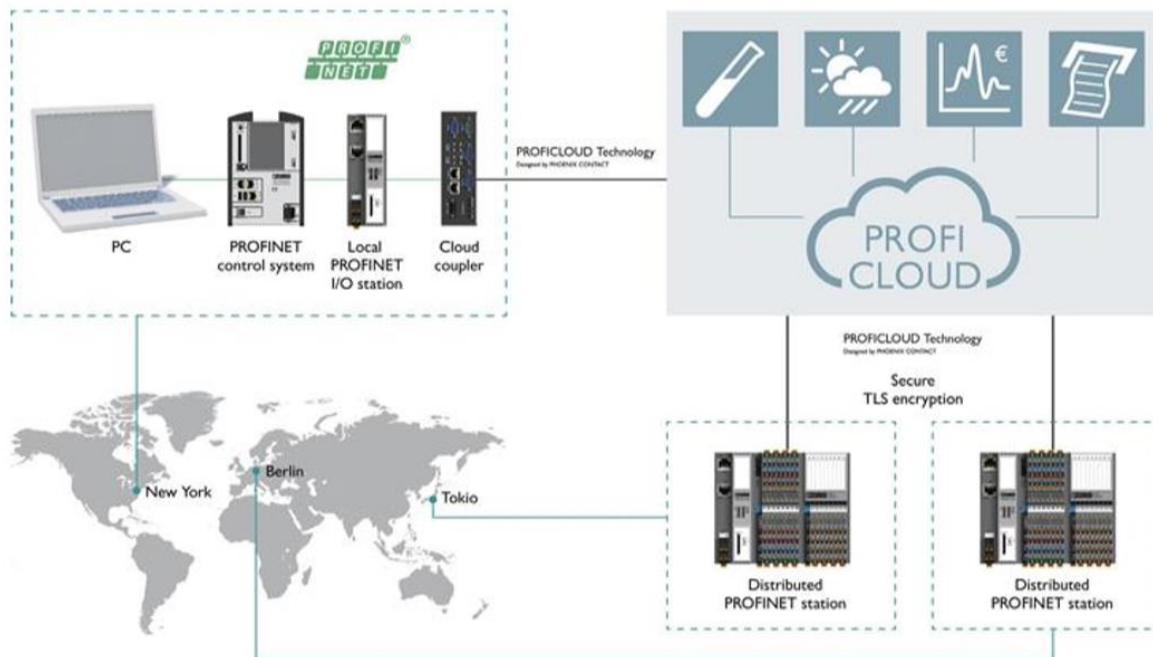


Figure 6: Overview of the Proficloud technology [26]

Data transmission is encrypted with TLS encryption which is also used, for example, in banking solutions. With the use of WebSockets as data transfer points, Proficloud aims to be firewall friendly. This is because WebSocket is a standardized web mechanism which uses ports 80 and 443. Connecting devices to the Internet presents a risk for unauthorized access. Proficloud takes this into account by only allowing outbound traffic. Connections from the Internet are denied. In addition Proficloud devices do not have any open ports. Connecting production networks straight to the Internet is not considered to be a good method. The cloud coupler contains two separate network cards for local network and the Internet, these network cards are not linked via TCP/IP. The communication between the network cards is handled solely on the application layer and is limited to Profinet-relevant data [26].

4.1.1 ProfiCLOUD coupler

This is a PROFINET device of the PROFNET master system which is a coupler device. On one side it needs to be connected to the local PROFINET network of the PROFINET master. On the other side it needs to be connected to an open internet connection. The PROFINET coupler will receive an IP address by means of DHCP. Identification of the coupler is done over the UUID in the web service environment. This device contains a webserver for configuring the major settings.



Figure 7: Cloud coupler-pro [27]

4.1.2 ProfiCLOUD device

This is a PROFINET device of the PROFINET master system which is a cloud device. It can be connected to an open internet connection and will receive an IP address by means of DHCP. Identification of the coupler is done over the UUID in the web service environment. The master will monitor and control these devices. No specific flash cards are needed as the device AXC CLOUD-PRO contains all the necessary functionality. The device has no webserver, the local bus devices are read in automatically.



Figure 8: Cloud coupler-pro [28]

4.1.3 ProfiCLOUD web service

The web service environment is the place where all the PROFICLOUD devices are registered. The devices can be inserted here based on their UUID. The web service can be reached through the following link: <https://www.proficloud.net/>

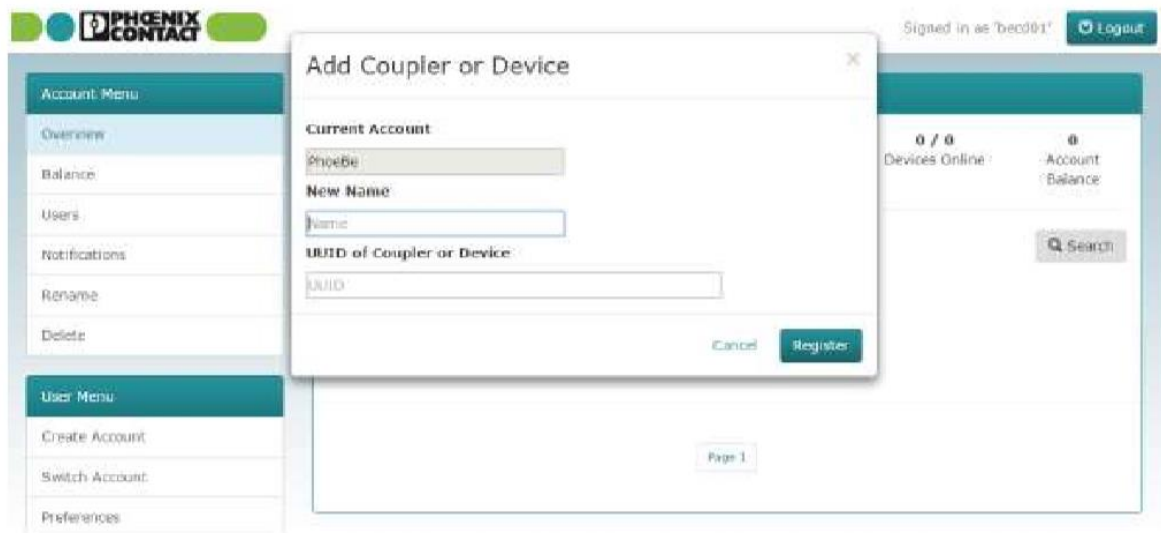


Figure 9: Adding a device (real or virtual) under proficloud.net

Each device: real or virtual (like weather services) consumes credits. For each device which is online one credit per hour will be removed from the account balance. The voucher for one year will be valid for 8760 credits (24x365).

3. Materials and Methods

3.1 Brief Description of the system

The following **Figure 10** shows the principal structure of the plant. The used abbreviations are described in the following. The system consists of three plexiglass cylinders T1, T2 and T3 with the cross-sectional area A which are interconnected in series by two connecting pipes (cylindrical pipes with the cross section S_n). The liquid leaving T2 is collected in a reservoir from which pumps 1 and 2 supply the tanks T1 and T2. The pumps are driven by DC motors [28].

All three tanks are equipped with piezo-resistive pressure transducer for measuring the level of the liquid. A digital controller controls the flow rate Q_1 and Q_2 such that the levels in the tanks T1 and T2 can be preassigned independently. The level in tank T3 is always a response which is uncontrollable. The connecting pipes and the tanks are additionally equipped with manually/automatically adjustable valves and outlets for the purpose of simulating clogs as well as leaks. H_{max} denotes the highest possible liquid level. In case the liquid level of T1 or T2 exceeds this value the corresponding pump will be switched off automatically. Q_1 and Q_2 are the flow rates of the pumps 1 and 2. Below are some of the technical features of the plant :

- ❖ $A=0.0154 \text{ m}^2$
- ❖ $S_n=5 \cdot 10^{-5} \text{ m}^2$
- ❖ $H_{max}=62 \text{ cm}$
- ❖ $Q_{1max}=Q_{2max}=6 \text{ l/min}$

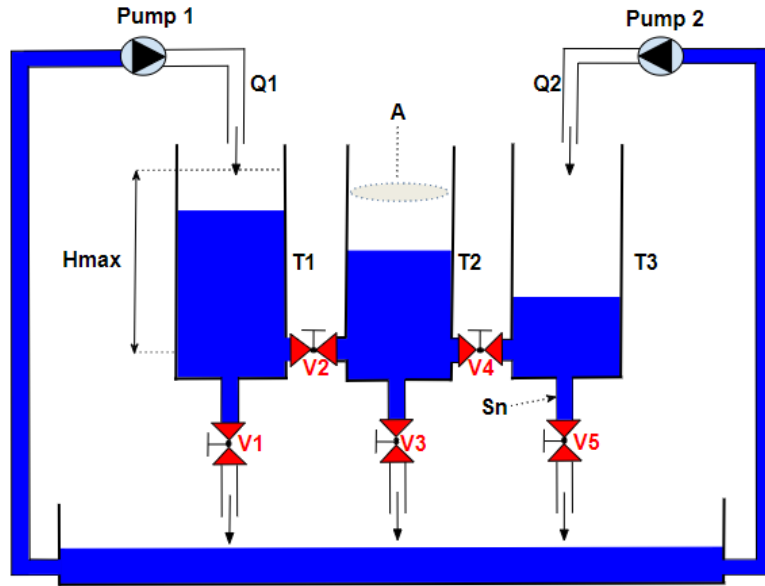


Figure 10: Structure of the plant

For the purpose of simulating clogs or operating errors, the connecting pipes and the nominal outflow are equipped with manually/automatically adjustable ball valves, which allow to close the corresponding pipe. For the purpose of simulating leaks each tank additionally has a circular opening with the cross section S_l and a manually adjustable ball valve in series. The following pipe ends in the reservoir. The pump flow rates Q_1 and Q_2 denote the input signals, the liquid levels of T_1 and T_2 denote the output signals. The necessary level measurements are carried out by piezo-resistive differential pressure sensors. At each of it a pressure line measures the pressure of the atmosphere.

3.2 Architecture of the controller

Here a controller is implemented on AXC 1050 PLC. The PLC is programmed to send commands via the analog card (output device in **Figure 11**) to both pumps from 0 to 10 V DC. The servo-amplifier powered by 230 V AC thus send the supply voltage (between 0 and 24 V DC) to DC motors which drives the pumps. The relay system has been added and wired in the control cabinet in order to be able to control the electrovalves of the three tank system in both directions of rotation. This allow to simulate leaks, clogs, increased or decreased water consumption.

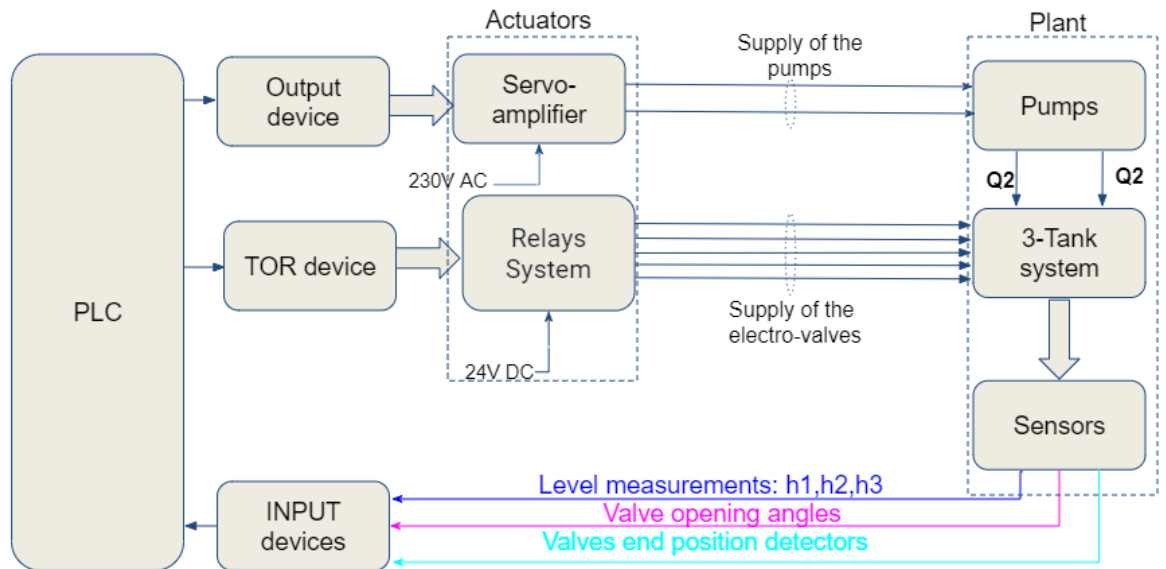


Figure 11 : Control Loop Structure

The relay commands are carried out with a 24V DC digital card (TOR device). The bench is also instrumented in order to have all the relevant information of the system to optimize control structure. There are 3 types of measurements:

- ❖ Tank level measurements: h_1, h_2 and h_3 ,
- ❖ Measurement of valve opening angles,
- ❖ Detection of limit stops when valves reach saturation.

Figure 11 shows the principal structure of the complete control loop.

3.3 Architecture of the Emulated System

The core of Icam demonstrator represents a local site of production (pumping), storage and distribution of drinking. The following diagram illustrates its configuration which includes a pumping source, a storage area and the distribution network to the users (**Figure 12 (a)**). In order to emulate such system, we use of three tanks setup (**Figure 12 (b)**) representing all parts of our water station system.

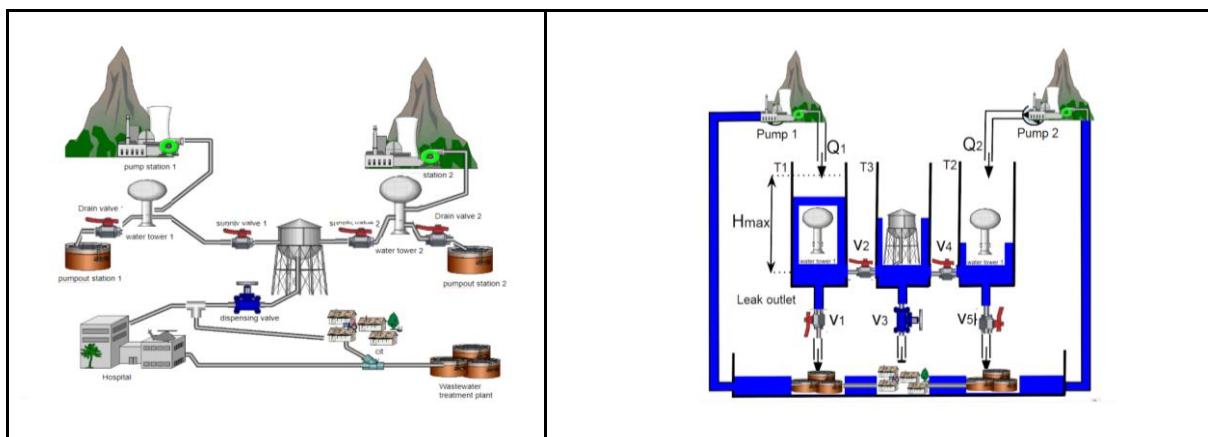




Figure 12 : Proficloud application chosen by icam

Icam experimental hydraulic setup is based on :

- The three tanks emulating local storages reservoir (left and right tanks) and distribution reservoir (middle tank). Each tank include level sensor.
- Lower reservoir emulating underground water and consumption/leakage;
- Two pumps feeding two tanks (left and right);
- Two valves (V2 and V4) supplying the distribution reservoir (middle tank);
- A proportional valve emulating consumer demands (valve V3);
- Two valves for draining use (V1 and V5).
- The control system is built on:
 - AXC Cloud Pro (industrial PLC from Phoenix Contact).
 - I/O devices from Phoenix Contact.

3.4 Proficloud network and features

The ProfiCloud devices all support DHCP, this is the mechanism for them to receive IP address. Once connected to the “internet” the device can be registered in the Web-Services environment based upon their UUID. For this matter the following ports need to be opened on the provider side: 443 and 80. After connecting the Internet (X3) port of the Cloud coupler-pro to an open internet connection we applied 24 VDC to the module. The Cloud coupler-pro by default has the IP address 192.168.0.10.

After that, we use Web Based Management (WMB) opened in a browser (eg. Internet Explorer, Mozilla Firefox) in order to configure the Cloud coupler-pro. Then Cloud coupler-pro and AXC Cloud Pro are registered in our ProfiCloud account (www.proficloud.net). After that we coupled the AXC CLOUD-PRO device to the Cloud coupler-pro. **Figure 13** illustrates the connection of the elements to deploy proficloud technology

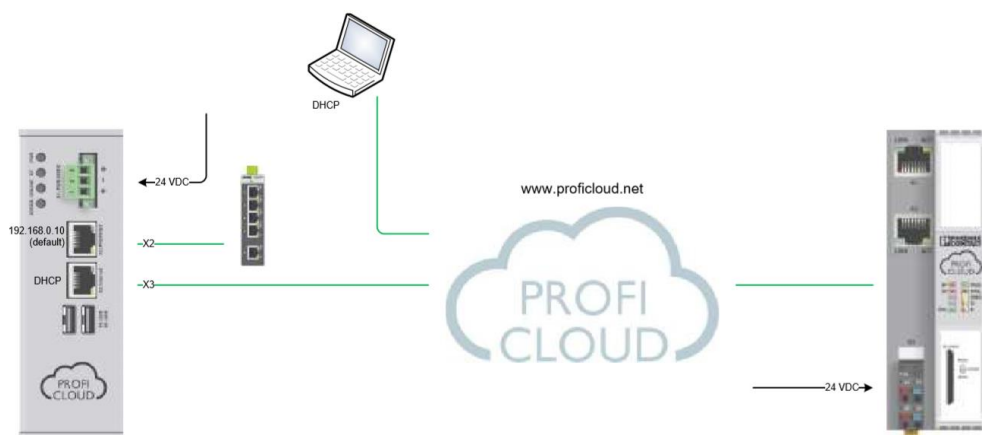


Figure 13: ProfiCloud system description

The main characteristics of proficloud as illustrated in **Figure 14** are

- Smart, reliable and secure data exchange between machines;
- World wide networking of manufacturing systems;
- Integration of 3rd parties in the whole solution;
- Integration of 3rd party applications;
- Design and running of web-based services and applications.

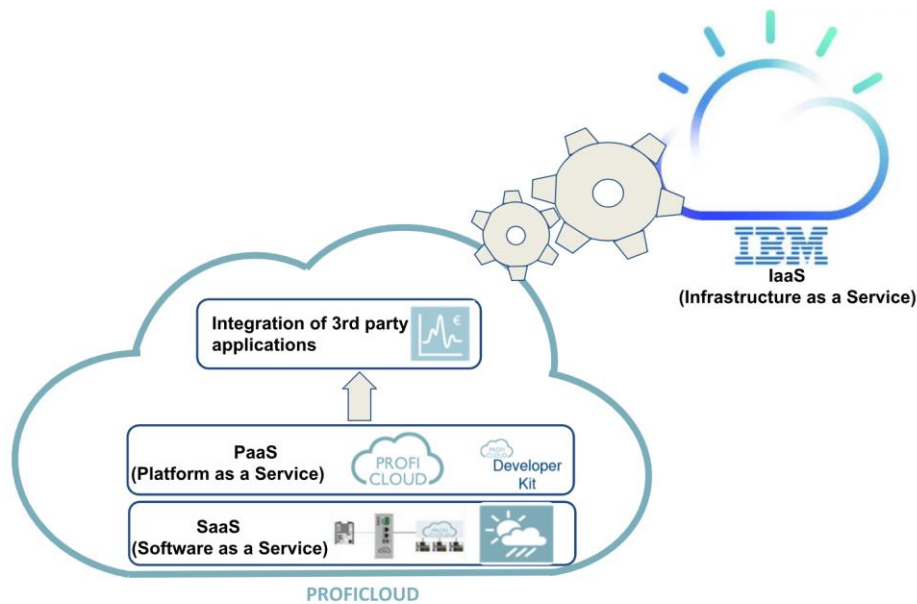


Figure 14: Proficloud – the Internet of Things (IoT) platform

3.5 Icam proficloud demonstrator

Water is a critical natural resource today. Projections made by the 2030 Water Resources Group [29] show that world demand for water will exceed accessible supplies significantly, threatening to impede global economic growth and result in large-scale food insecurity. Water efficiency is reduction of water wastage by measuring the amount of water required for a particular purpose and the amount of water used or delivered. ICT (Information Communications Technologies) has emerged as a strong way to understand water security challenges. They are increasingly being adopted as key decision support mechanisms for water use. The proper use of ICT applied to water use efficiency allows gathering data to know in real time about supply, demand and use of water among its users.

The major difficulties are the situation of the water tanks, access difficulty, electric power supply and difficulty of communication between some stations and those responsible for the water supply. Some remote stations (one or more water tanks) can be in isolated places, with difficult access, and often do not have power supply. On the other hand, the distance between the station and the responsible entity can be huge. So that the responsible

entity has reliable and up-to-date information about each water tank, as well as the amount and quality of the water, it is necessary to implement a system that answers to these questions.

The work presented in this report was guided by the design and implementation of an information system to supervise remote water stations using Proficloud Technology.

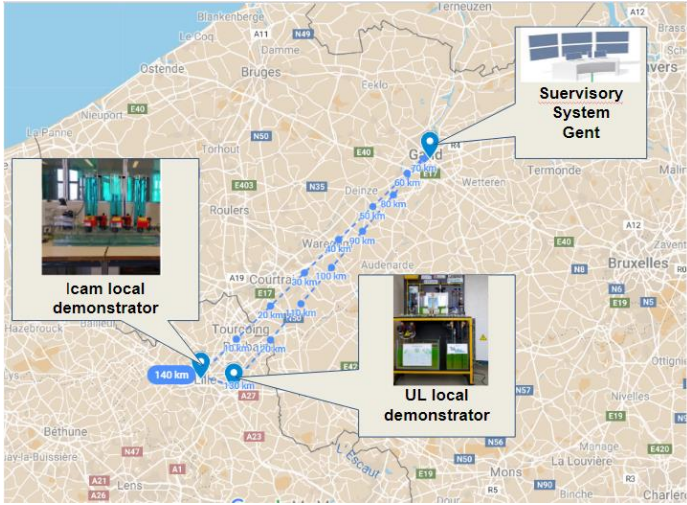


Figure 15: Interregional Proficloud Demonstrator

This work was developed as part of a European research project Interreg INCASE. The Local Proficloud demonstrator developed at Icam is part of an interregional demonstrator that covers an area of 700 km² as shown in **Figure 15**.

Regardless of the size of the water installation, the trend is to transfer operating data and events, via GSM, 3G or Ethernet, to centralized management. This will make it possible :

- to supervise the operation of the installations;
- to set up a predictive maintenance policy;
- to optimize the exploitation;
- to monitor energy consumption;
- to monitor pump wear and tear;

3.6 From Profinet Fieldbus to Proficloud

Historically the factory production lines have been separated from the rest of the enterprise. The only method to get information about the production progression is to be present at the production line, the same goes for updating machines and handle oversights. The industry aspired to have the factory activity connected with the

enterprise, using some type of standard solution which all automated devices can communicate within, allowing someone to have oversight of the process in the factory without being present. The solution became to introduce industrial Ethernet protocols. The goal of an industrial Ethernet protocol is to enable communication between automation devices, and also be able to communicate to the office landscape using Ethernet cables. One of the most commonly used industrial Ethernet protocols today is Profinet. The PROFINET Industrial Ethernet standard can be used to realize a huge range of automation concepts from machine building and production technology, through process and building automation, right through to drive technology. The real-time-capable transmission protocol uses the TCP/IP channel and IT standards, and is able to incorporate both fieldbus and cloud-based systems. Proficloud technology enables PROFINET automation networks to be connected to the Internet, opening up the limitless opportunities presented by the Internet of Things (IoT) to the user [30].

The decentralised arrangement of water stations means that relevant information must be exchanged as cost-effectively as possible between the various facilities. Furthermore, the solution must be integrated into the existing automation technology. Thanks to Proficloud and the corresponding components, you can create a secure connection for efficient remote control in a very short time. Integrate a Proficloud coupler into the local network of your control center. The coupler displays all devices which are located across the world and networked via the cloud as local network devices. The distributed controller connects to the Proficloud via the internet. It now appears as a local device in the network and can be used without further configuration or programming. The I/O components connected to the distributed controller are started up automatically. A combination of standardised communication protocols for automation technology and the Internet is used to exchange data over long distances.

Figure 16 shows the topology of the proficloud topology and **Figure 17** the real Setup. This demonstrator is based on:

- Experimental setup described in the previous section,
- two IP camera allowing real time video streaming of the setup;
- A remote control system composed of the following elements:
 - AXC 1050 (industrial PLC) containing the remote controller program;
 - A development computer for programming AX1050 using PCworx software and design of a HMI interface using Visu+ Software ;
- All the previous elements are connected to the local profinet network thanks to a switch;
- A Cloud Coupler device (from Phoenix Contact) enabling connection, via the Proficloud protocol, between remote controller (running on AXC 1050) and the experimental setup using AXC Cloud Pro device. The Cloud Coupler is both connected to the local profinet network and to Phoenix Contact server using internet in secure way.

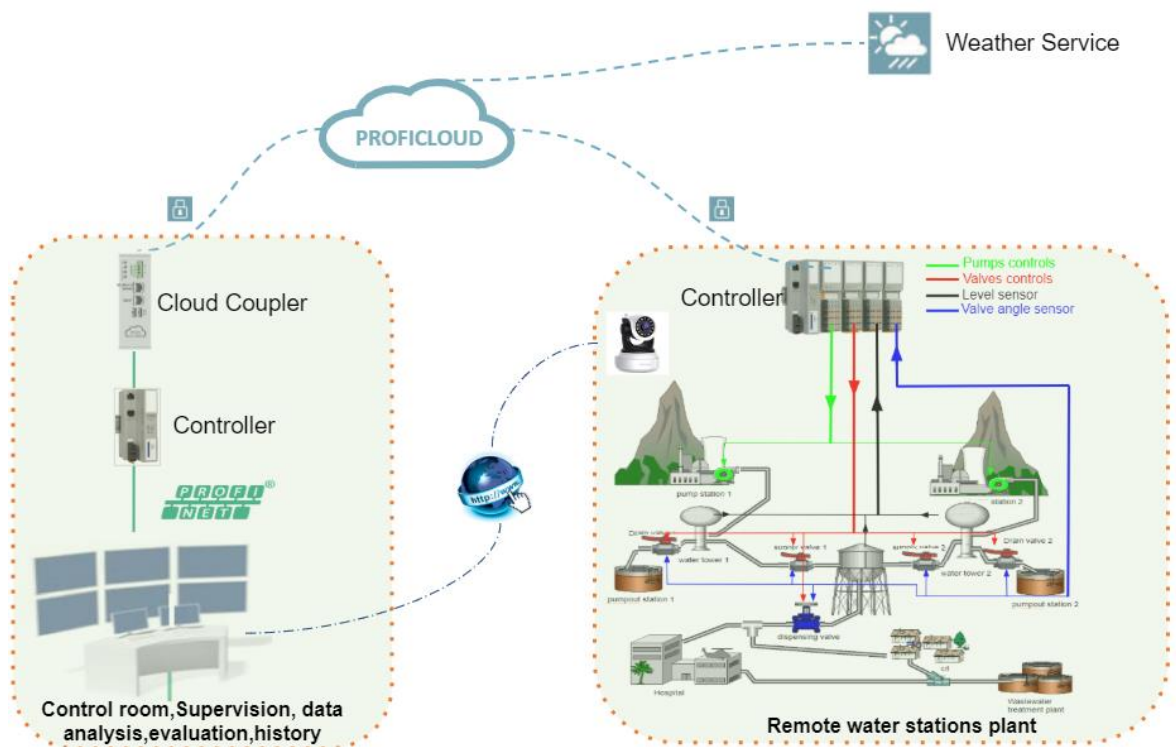


Figure 16 :Topology of the Proficloud application at Icam.

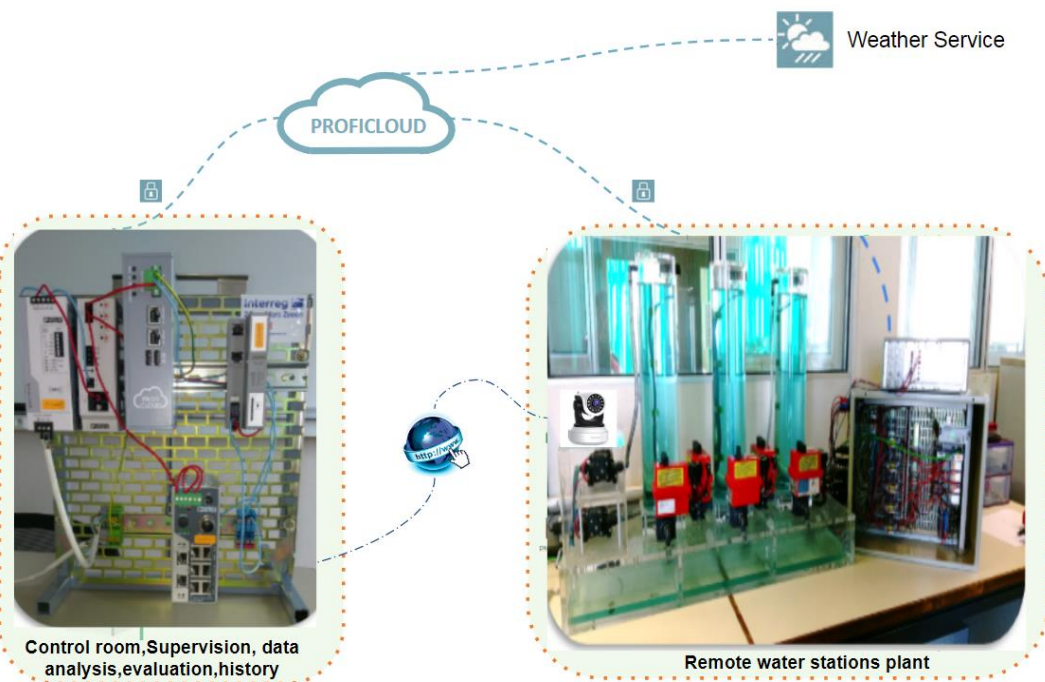


Figure 17 :Icam Real Proficloud demonstrator .

For local test and evaluation of our platform, we installed the remote control system in a room separated from the one where the experimental setup is installed (room 1 and room 2,

both connected on different network). Proficloud technology extends the profinet local network into a larger network using the public Internet network. Once the connection to Proficloud has been established via the Internet, a PROFINET instance is created in the Proficloud coupler for each connected Proficloud device. The remote station and the weather device thus receive a separate IP and MAC address that is represented in the local PROFINET network. After that, each Proficloud device can be programmed as a local PROFINET device. From this point of view, our Proficloud platform has an equivalent diagram as shown in **Figure 18**.

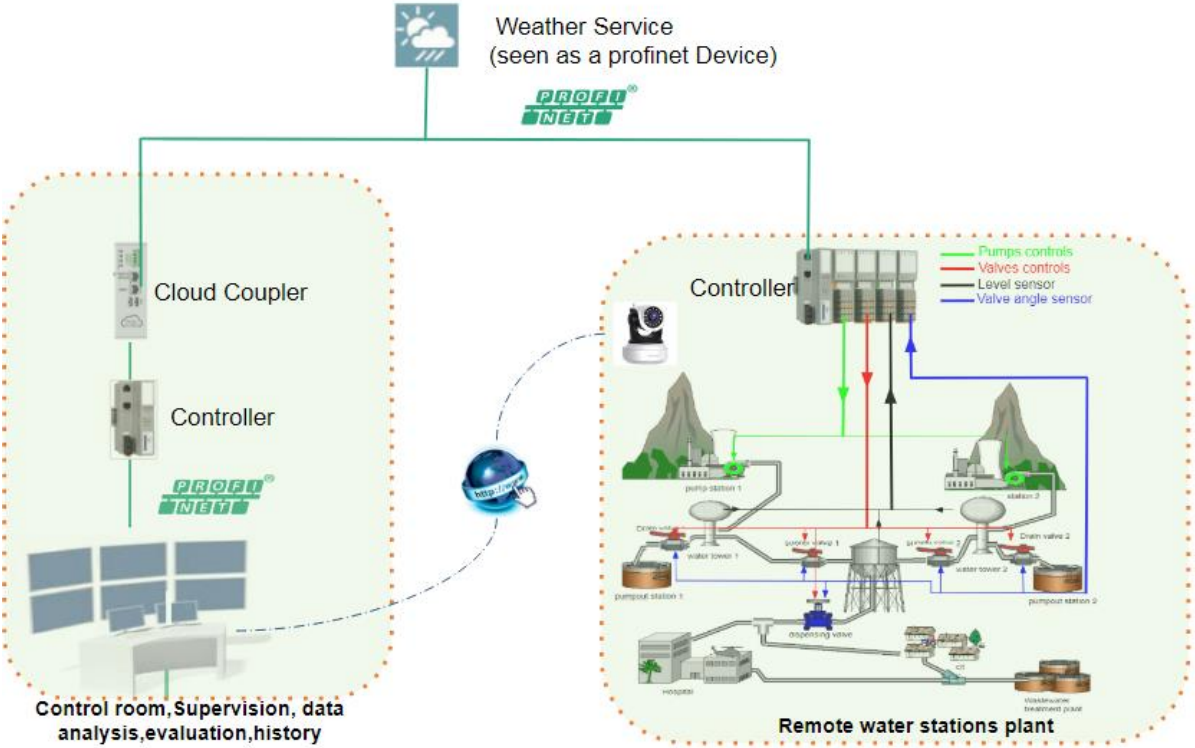


Figure 18: Equivalent diagram of Proficloud demonstrator

The PLC program must be designed to work with supervision system. It must be possible to communicate by the Proficloud between the PLC and the supervision station. This is possible by creating an exchange table between the AXC Cloud Pro PLC and the AXC 1050 PLC. The table created, under PC work, in the remote PLC and local PLC are illustrated in **Figure 19** and **Figure 20**.

<pre>(*Carte entree DI TOR butées vannes*) I_2_IN.B0—PC_OUTPUTS[0] I_2_IN.B1—PC_OUTPUTS[1]</pre>	<pre>(*Carte sortie DO TOR contrôle vanne*) PC_INPUTS[0]—Q_1_OUT.B0 PC_INPUTS[1]—Q_1_OUT.B1</pre>	<pre>(*Carte Analogique1 Pompe et niveaux*) I_3_IN.B0—PC_OUTPUTS[8] I_3_IN.B1—PC_OUTPUTS[9] I_3_IN.B2—PC_OUTPUTS[10] I_3_IN.B3—PC_OUTPUTS[11] PC_INPUTS[8]—Q_3_OUT.B0 PC_INPUTS[9]—Q_3_OUT.B1 PC_INPUTS[10]—Q_3_OUT.B2 PC_INPUTS[11]—Q_3_OUT.B3</pre>	<pre>(*Carte Analogique2 potentiomètre et niveau*) I_4_IN.B0—PC_OUTPUTS[12] I_4_IN.B1—PC_OUTPUTS[13] I_4_IN.B2—PC_OUTPUTS[14] I_4_IN.B3—PC_OUTPUTS[15] PC_INPUTS[12]—Q_4_OUT.B0 PC_INPUTS[13]—Q_4_OUT.B1 PC_INPUTS[14]—Q_4_OUT.B2 PC_INPUTS[15]—Q_4_OUT.B3</pre>
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Figure 19:Exchange table implemented on AXC Cloud Pro

The data exchange between the AXC Cloud Pro and AXC 1050 and is done by reading and/or writing the internal %M bits.

<pre>(*récupération variables carte sortie TOR*) vanne1E3—var_sort[1].X0 vanne1e1—var_sort[1].X1 vanne2E3—var_sort[1].X2 vanne2e1—var_sort[1].X3 vanne4E3—var_sort[1].X6 vanne4e1—var_sort[1].X7 vanne5E3—var_sort[0].X0 vanne5e1—var_sort[0].X1</pre>	<pre>(*récupération variables carte entrée TOR*) var_ent[1].X0—butee1_1 var_ent[1].X1—butee1_2 var_ent[1].X2—butee2_1 var_ent[1].X3—butee2_2 var_ent[1].X4—butee3_1 var_ent[1].X5—butee3_2 var_ent[1].X6—butee4_1 var_ent[1].X7—butee4_2 var_ent[0].X0—butee5_1 var_ent[0].X1—butee5_2</pre>	<pre>(*Affectation des variables de sortie*) var_sortie_ana2.B0—var_sort[8] var_sortie_ana2.B1—var_sort[9] var_sortie_ana1.B0—var_sort[10] var_sortie_ana1.B1—var_sort[11] (*Carte analogique2 AI2 AO2 Bac3 / Pot3 Pot3 alim /vide*) var_sortie_ana4.B0—var_sort[12] var_sortie_ana4.B1—var_sort[13] var_sortie_ana3.B0—var_sort[14] var_sortie_ana3.B1—var_sort[15] var_ent[12]—var_entree_ana4.B0 var_ent[13]—var_entree_ana4.B1 var_ent[14]—var_entree_ana3.B0 var_ent[15]—var_entree_ana3.B1</pre>	<pre>(*Affectation des variables d'entrée*) var_ent[10]—var_entree_ana1.B0 var_ent[11]—var_entree_ana1.B1 var_ent[8]—var_entree_ana2.B0 var_ent[9]—var_entree_ana2.B1</pre>
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Figure 20: Exchange table implemented on AXC1050

3.7. Automation and Supervision System

In order to set up the supervision program, it is necessary to proceed as follows

- Define the supervision functions.
- Define the number and type of variables to be exchanged between the PLC and the supervision.
- Have Ethernet communication with the PLC.
- Know the IP address of the PLC communication module.

a- Inventory of equipment

- Experimental setup described in the previous section,
- two IP camera allowing real time video streaming of the setup;
- A remote control system composed of the following elements:
- AXC 1050 (industrial PLC) containing the remote controller program;
- A development computer for programming AX1050 using PCworx software and design of a HMI interface using Visu+ Software ;

- All the previous elements are connected to the local profinet network thanks to a switch;
- A Cloud Coupler device (from Phoenix Contact) enabling connection, via the Proficloud protocol, between remote controller (running on AXC 1050) and the experimental setup using AXC Cloud Pro device. The Cloud Coupler is both connected to the local profinet network and to Phoenix Contact server using internet in secure way.

b- Supervision functions

The purpose of modelling the operation of a water distribution system with the three tank system bench. For this purpose, we consider TANK 2 as the distribution to the customer. Valve 3 (Valve3) thus represents customer demand. It is possible to vary this request from 0 to 100% . Depending on the difference between the measured level and the desired level, the flow rate of the pumps (pump1, pump2) will be more or less important. Note that it is possible to optimize the system's response time by adjusting the gain. Valves 2 and 4 are distribution valves, they will open automatically when the desired level is higher than the actual level and close again when the set value is reached. Valves 1 and 5 are not affected by the regulation. These are drain valves that can be operated manually. They are used for maintenance operations. In the event of a malfunction, the system must be switched to manual mode and the faulty components isolated.

c- List of variables

Below is the list of variables used for

- **actreg1** allows you to set the regulation mode.
If actreg1 = 0 <=> auto mode
actreg1 = 1 <=> manual mode
- **niveaouvoulu1** represents the setpoint value.
- **gain1** represents the value of the gain. This variable is only visible when the auto mode is active.
- **Pump1auto, pump2auto** are read variables that are visible in auto mode. They indicate the flow rate of the pumps.
- **Pump1, pump2** are the pump control variables when we are in manual mode.
Valve2e1, valve4e1 control the operation of distribution valves 2 and 4. Their values are controlled by the controller, so in auto mode.
**If desired height1 > height2_cm
then valve2e1 = valve4e1 = 1 (closing the valves)**
- **Valve1e1, Valve2e1manu, Valve3e1, Valve4e1manu and Valve5e1** control the operation of the system valves.
For X = 1...5
if ValveXe1 = 0 => valve open

otherwise Valve closed

- **Height2_cm** indicates the height of the distribution tank (tank 2).

d- Grafcet diagram

Figure 21 and **Figure 22** show the supervision diagram in automatic mode and the supervision diagram in case of maintenance of one of the tanks.

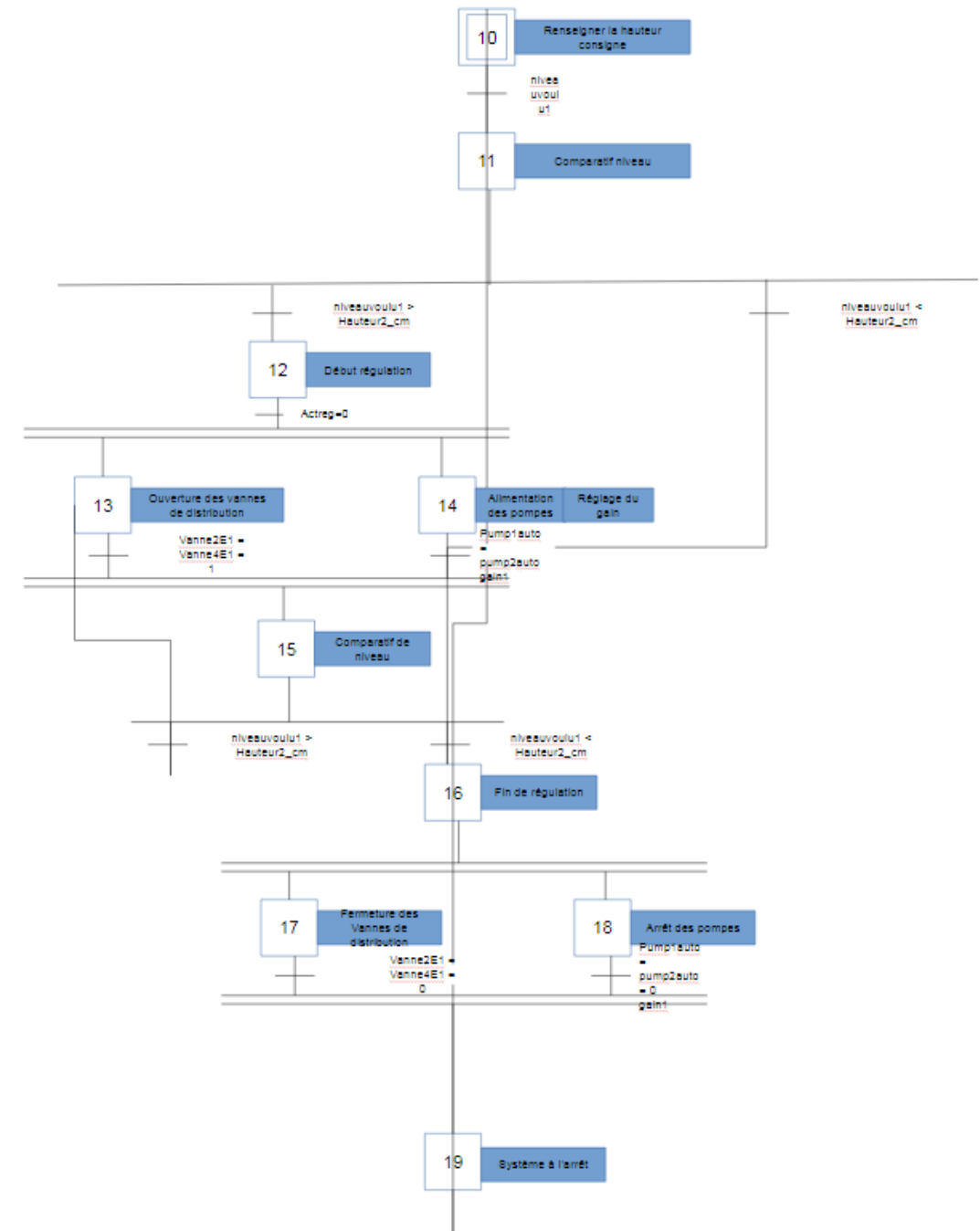


Figure 21: Automatic control of the water station

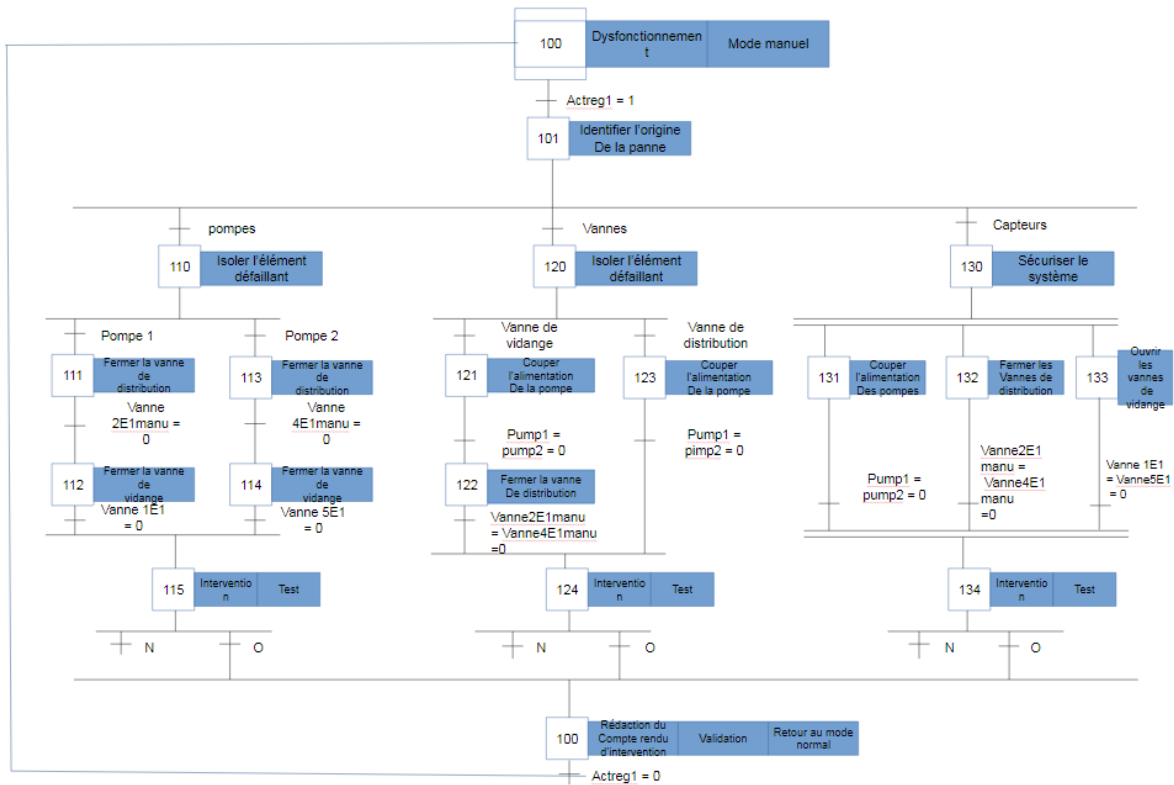


Figure 22: Automatic control in case of fault

Figure 23 shows the level control loop based on a proportional corrector.

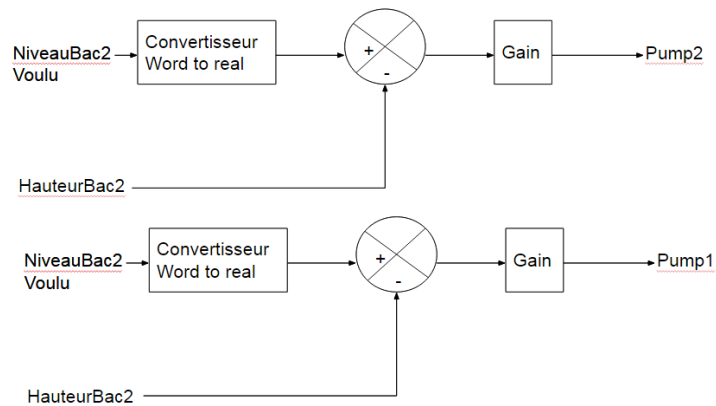


Figure 23: Proportional controller

e- Human Interface machine

The HMI interface is developed for remote use of the platform. It offers two features: on the one hand the visualization of the process data (tank levels, water demand

status, etc...) and on the other hand the interaction in real time with the control devices (control of valves and pumps)

This interface can be run and used in standalone mode with our Proficloud platform. Moreover, it has been integrated into the supervision and monitoring system of the interregional demonstrator hosted at the KUL site.

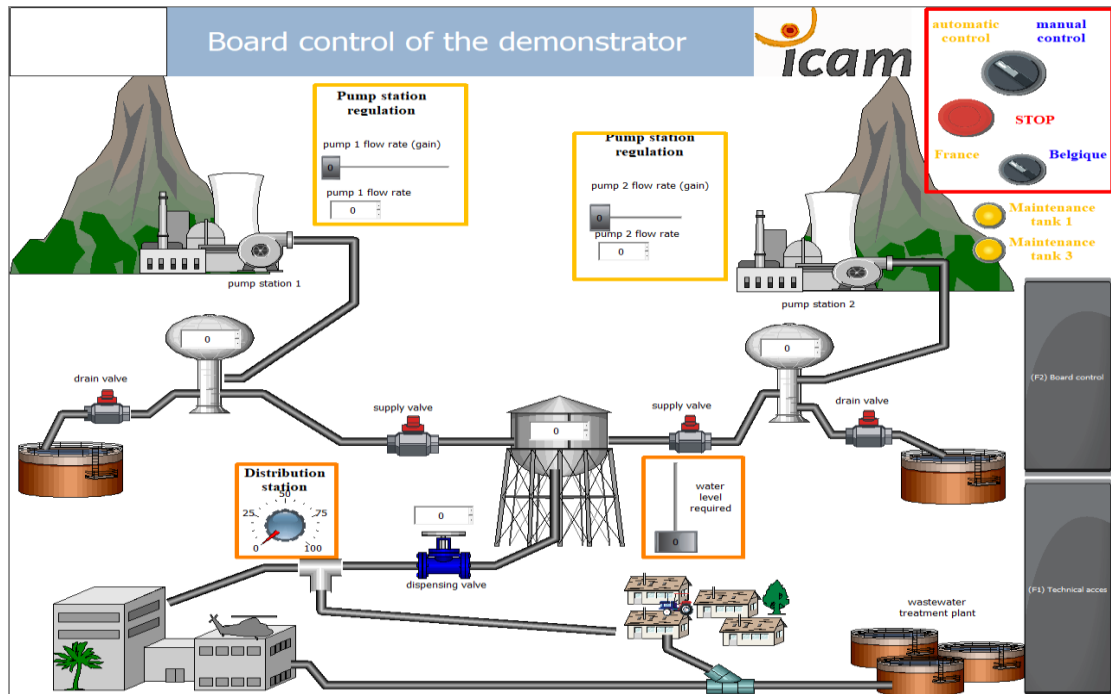


Figure 24: View of the HMI

4. Early product evaluation and main results

4.1 Validation of the supervision system using the Proficloud

In order to test and validate the implementation of the proficloud for the remote management of a water station, we placed the remote control in a room, the coupler being connected to a public internet address and the process in another room where the cloud prod is also connected to another public address. The connection via the Proficloud was successful.

The experimentation tests are being carried from the main screen of SCADA application (**Figure 25**) it is possible to access, by clicking on the equipment icon, the following features:

- Monitoring: status (on / off) and status of each valve, water level of each tank, valve opening angle.
- Supervision: controller set points (reference values of water level, water consumption), Valves commands, maintenance mode, supervision mode by KUL or by Icam.

Figure 25 (a) shows the level setpoint for the distributed tank (red line). The blue line indicate the measured level. as can be seen, the set point is well respected between 0 and 12 minutes approximately. During this time, the consumption valve is 10% open (**Figure 25** (b)). At t=12 minutes the consumption valve is 75% open. In order to reduce the gap between the set point and the measurements a proportional controller has been implemented. Thus the system reacts to keep the deviation to a minimum by starting the pump.

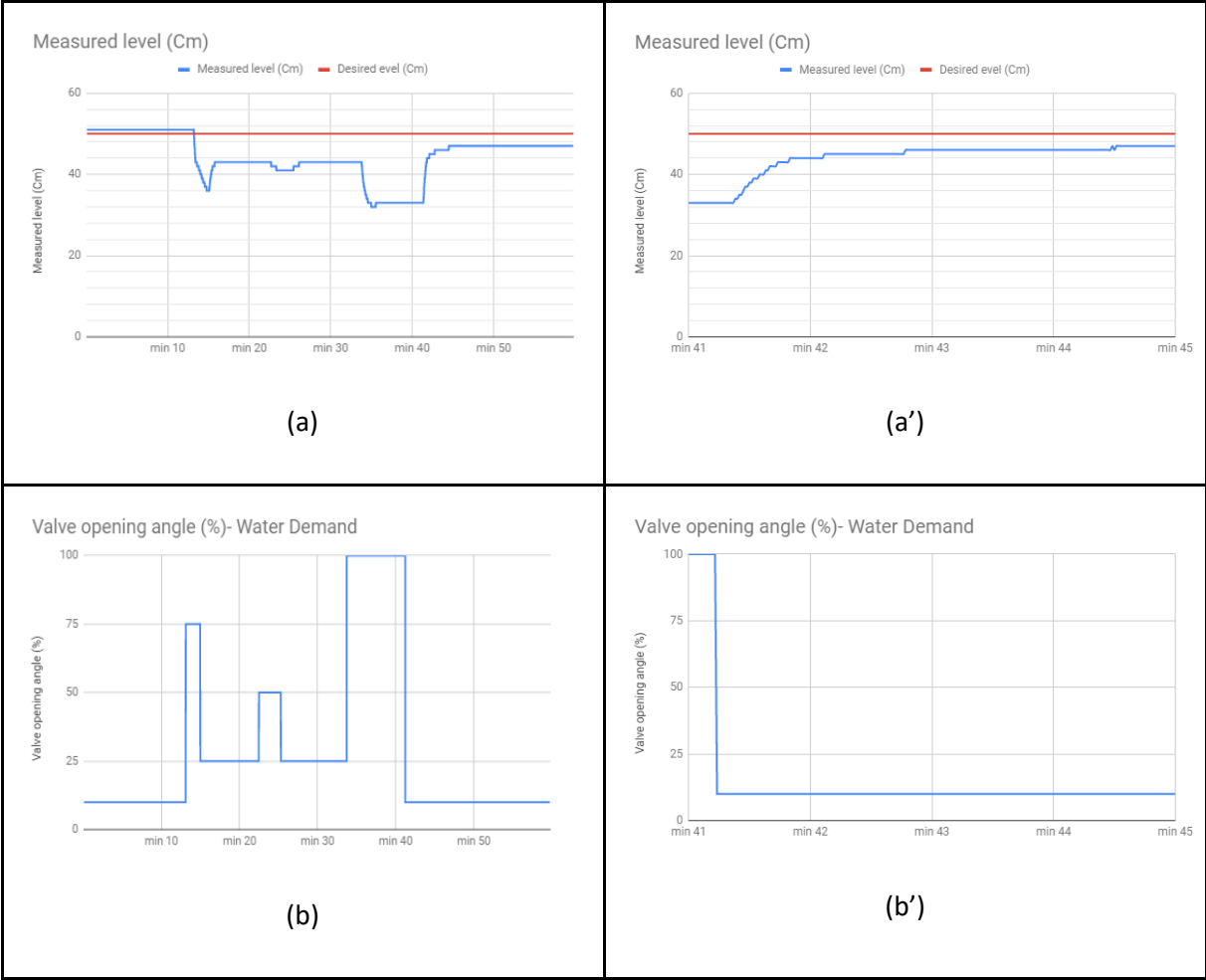


Figure 25: Remote control analysis: proof of concept

At t= 42 min, the opening of the consumption valve is reduced from 100% to 10% (**Figure 25** (b')). It can be seen that the gap between the set point and the measurement is narrowing because the opening of the valve can be considered as a disturbance in relation to the control system in place (**Figure 25** (a')).



Figure 26: Pump power

4.2 Time delay evaluation and analysis

In order to evaluate the delay times induced by the network, we performed several tests by controlling pump 1. For better comparisons, we have developed two tests:

1. Local control (**Figure 27**): the 3-tank system is controlled locally with the AXC cloud Pro PLC. Via the visu+ software, you can send commands and receive measurements.

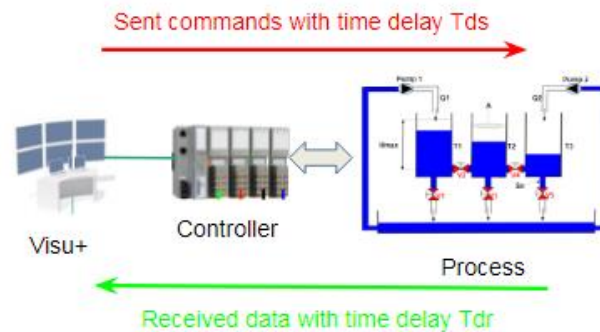


Figure 27: Local control of the three tank system

2. Remote control via Proficloud as shown in **Figure 28**. The visu+ software is used to send the remote controls via the Proficloud and to collect the measurements.

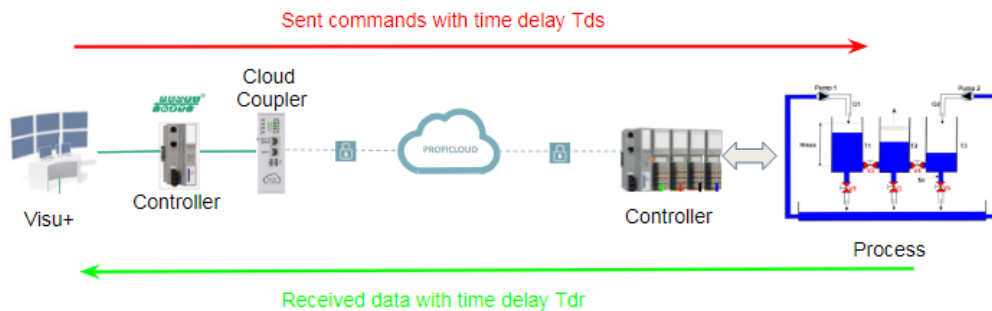


Figure 28: Remote control of the three tank system using the Proficloud

We applied maximum controls on pump 1 (100% of its rated power) and observed the water level in the tank. as soon as the water level is stabilized, a new control to the pump is sent. **Figure 29** shows the results of the tests during the local control.

With Visu+ we obtained 2 csv files with a resolution around 15 ms that gives us values of the two variables over time. One when we are using proficloud and the other when we connect directly to the AXC cloud Pro. The tests are limited to one hour because the Visu+ software (evaluation version) does not allow us to go any further.

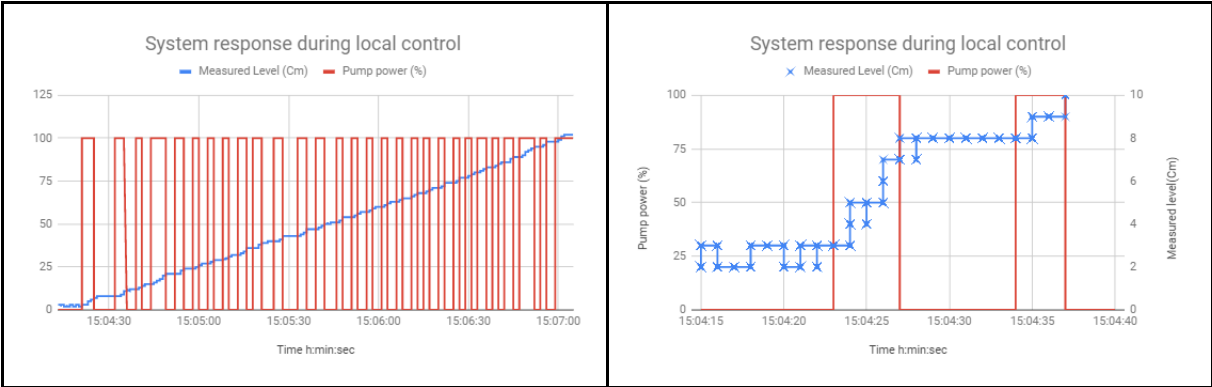


Figure 29: System response during local control

In **Figure 29** (left) The red line shows the control of pump 1. It increases from 0% to 100% of its nominal power as soon as the level measurement is constant. The purpose is to determine the delay between the moment when the pump control is applied and the response of the system (variation of the water level). The blue line represent the level measurements. The right figure (**Figure 29**) shows a zoom between the moments: 15h:04min:15sec and 15h:04min:42s.

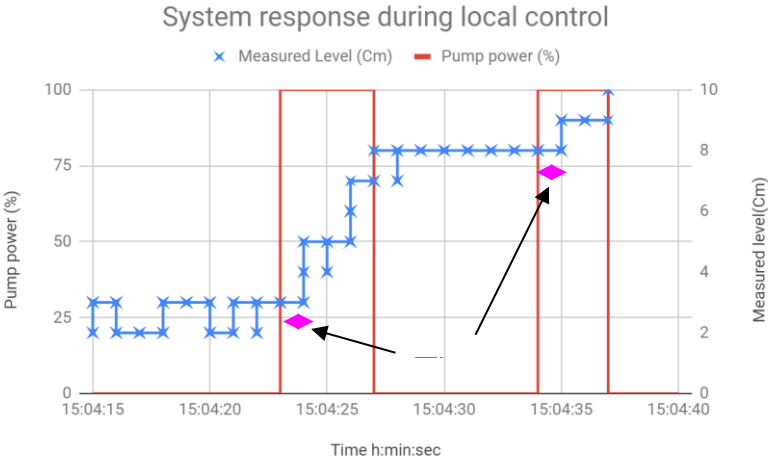


Figure 30: Time delay during local control

Figure 30 show the the time delay between action and reaction. Here, the delay duration is between 1 second. We did it many times to obtain a mean value. We did it with a program in Perl to extract all delay times. We also performed these tests for two different days. Once all the delays have been extracted, we have grouped them together in the histograms in **Figure 31**.

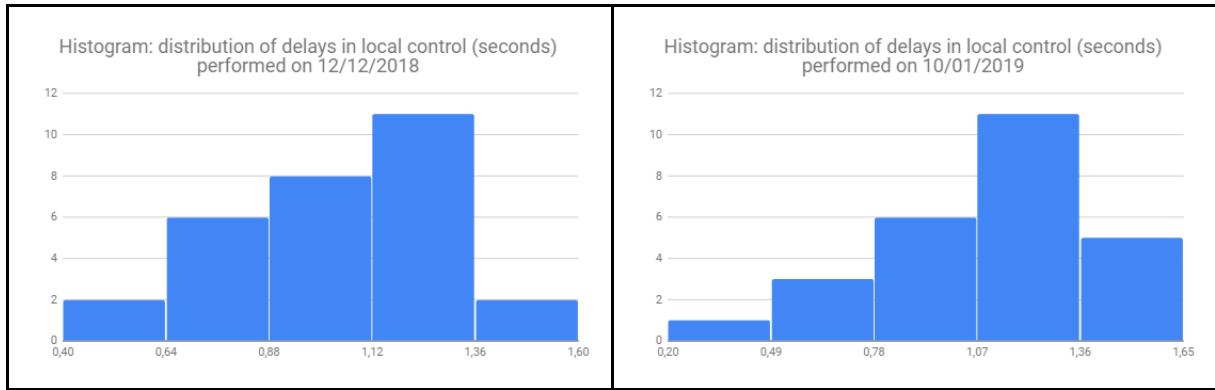


Figure 31: evaluation of time delays during local control: test from two different dates

As shown in the histograms, the majority of delays are between 1s and 1.36s. **Table 4** summarizes the analysis of delays during local control.

	Maximum	minimum	Mean value	Standard deviation
Time delays Tds+Tdr (test on 12-12-2018)	1,582002 s	0,438575 s	1,206081 s	0,2668861915
Time delays Tds+Tdr (test on 10-01-2019)	1,613329s	0,219287 s	1,077159269 s	0,3193276316

Table 4: Analysis of time delays (local control)

The average delay value is in the order of a second. If we assume that the transmission and reception times are equal, we can conclude that $T_{ds}=T_{dr}=0.5$ s. This time includes, the sampling time of the PLC, the acquisition times of the I/o devices and the acquisition time of the Visu+ software. Then we have similar tests using proficloud technology. The tests on the pump and the water level acquisition are shown in **Figure 31**. The blue line represent the level measurements. The right figure (**Figure 31**) shows a zoom between the moments: 16h:41 min:37 s and 16h: 42min:02s.

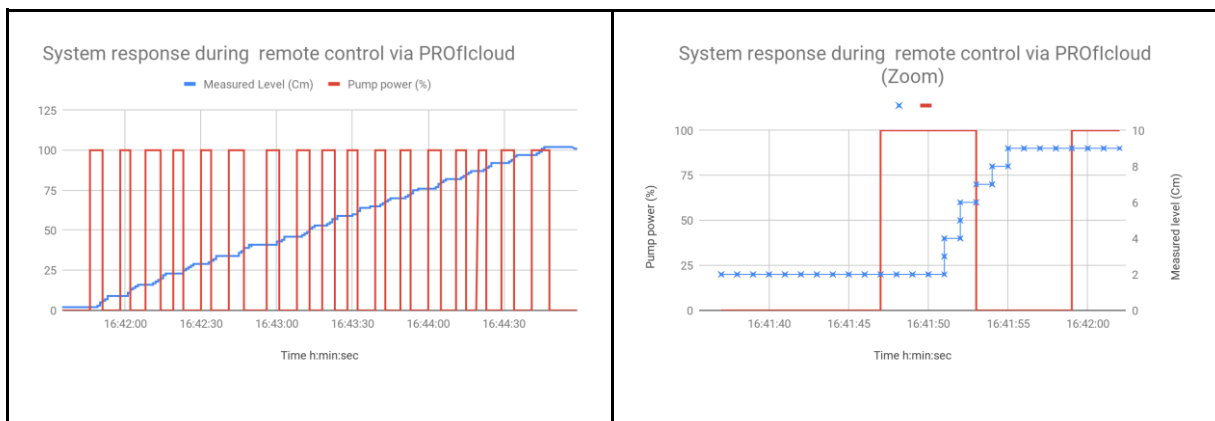


Figure 31: System response during remote control via Proficloud

The next figure show the time delay duration (between 16h:41 min:47 and 16h:41 min:51). The time required to send the order and receive the measurement is about 4 seconds. It's the time delay induced par Proficloud technology.

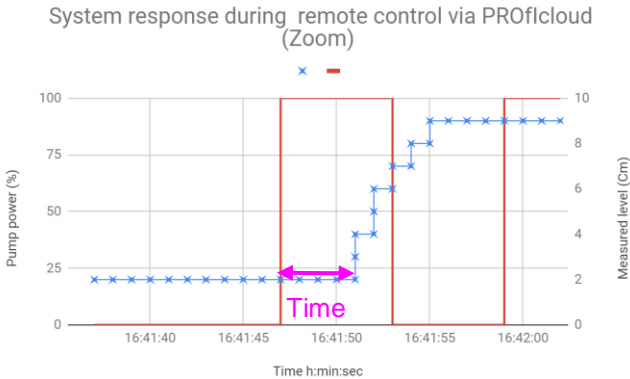


Figure 32: Time delay during remote control via the proficloud

As with previous tests, we have grouped and analyzed the delays induced by the proficloud technology. As shown in the histograms, the majority of delays are between 2.4s and 3.2s. During remote control tests for two different dates, we notice that the histograms are very different because Proficloud a time delay fluctuation because of cross-traffic.

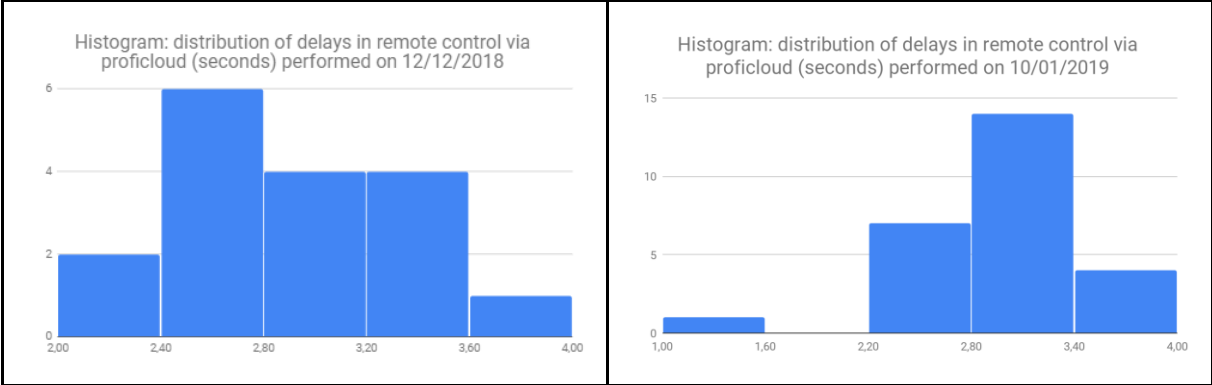


Figure 33: evaluation of delays during remote control via Proficloud: test from two different dates

The following table summarizes the analysis of delays during local control. The table shows that latency is quite different for both tests in two different days . Based on the measurements Proficloud induced, in worst case, a delay time of 3.7 seconds.

	Maximum	minimum	Mean value	standard deviation
Time delays Tds+Tdr (test on 12-12-2018)	3,680897 s	2,443489	2,891277706 s	0,4558577937
Time delays Tds+Tdr (test on 10-01-2019)	3,69656s	1,049447 s	2,820570556	0,5522231981

Table 5: analysis of time delays (remote control)

Since the deviation is low, we can consider that the average of 2.8 s is representative. It is the time induced by the proficloud, visu+ and PLCs as well as their I/o device to send the pump command and receive the level measurement data.

So we can conclude that to send command from AXC 1050 to the local AXC Cloud Pro proficloud induce a time delay :

$$\begin{aligned}
 & \frac{(\text{max} + \text{min})}{2} - \text{mean} \\
 & = \frac{(3,680897 + 2,443489)}{2} - 2,891277706 \\
 & \approx 0,1150995
 \end{aligned}$$

$$\text{Time delay} \approx 0,1150995 \text{ s}$$

Since we control a relatively slow dynamic system, this 1 second latency time is more than enough. Hence the good results obtained during the tests. But in case of remotely controlling systems such as mobile robots, the delay fluctuation, induced bay the Proficloud can deteriorates the stability of the system. it is a major challenge of a long-distance remote control system.

5. Conclusion

In order to manage water more efficiently, the concept of water managements are investigated and the available technologies and methodologies analysed and

discussed. Water Management combines existing water management techniques with cutting-edge ICT to enable more efficient water management. One main component of the Smart Water Management is the implementation of novel technologies where data is collected 24/7 and transmitted in real-time to a centralized control system. This requires a range of technologies from network communications to microelectronics to big data management and analytics. Analysis of current trends in remote system management has shown that Cloud Computing technology is a major challenge for intelligent remote factories.

In this study, we managed to interconnect PLC with a CLOUD platform. First of all, we emulated pumping stations by a physical system of three tanks. The choice of pumping stations is motivated by the fact that water plants are generally dispersed over large areas. It is an ideal candidate for remote control and for sending data back to a centralized system.

After presenting the physical system we used Phoenix Contact's Proficloud technology to remotely control it and retrieve the data. The Proficloud coupler connects the local PROFINET network to Proficloud via two Ethernet interfaces. While one interface is used to establish a connection to the local PROFINET system in the production facility, the second Ethernet interface is used to establish a connection to the Internet. As soon as a connection has been established to the Internet and therefore the cloud, the PROFINET device sends its process data to Proficloud. After that, each Proficloud device can be programmed as a local PROFINET device.

Then an automatic control in normal operation and in case of maintenance are presented in this report. Its main features are: the use of a supervisory system for monitoring and controlling the water pumping and the water level, and the use of a communication system based on Proficloud to allow remote supervision.

The result is a solution that can be used for remote control of water stations. The Proficloud is very suitable for our slow dynamic system (open loop response time is 1305 s) . Through dozens of measurements, was observed an interval with a small range of values. The value of the average delay induced by the Proficloud is 1 s and the maximum value observed is 1.35 s

Hence the good results obtained during the tests. But in case of remotely controlling systems such as mobile robots, the delay fluctuation, induced by the Proficloud can deteriorates the stability of the system. it is a major challenge of a long-distance remote control system. 5G should multiply by ten times the transmission capacity while reducing latency times to less than one millisecond. 5G applications will thus be practically able to provide real time.

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