



Vaasan yliopisto
UNIVERSITY OF VAASA

Conventional and Lightweight IEDs Testing

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Outline

- Introduction
- Light-weight IEDs based IEC 61850
- **Case study 1:** Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach
- Results
- **Case study 2:** Light-Weight IEC 61850 GOOSE Based Loss of Mains Protection for Smart Grid
- Results
- Conclusions
- Future work
- Publication

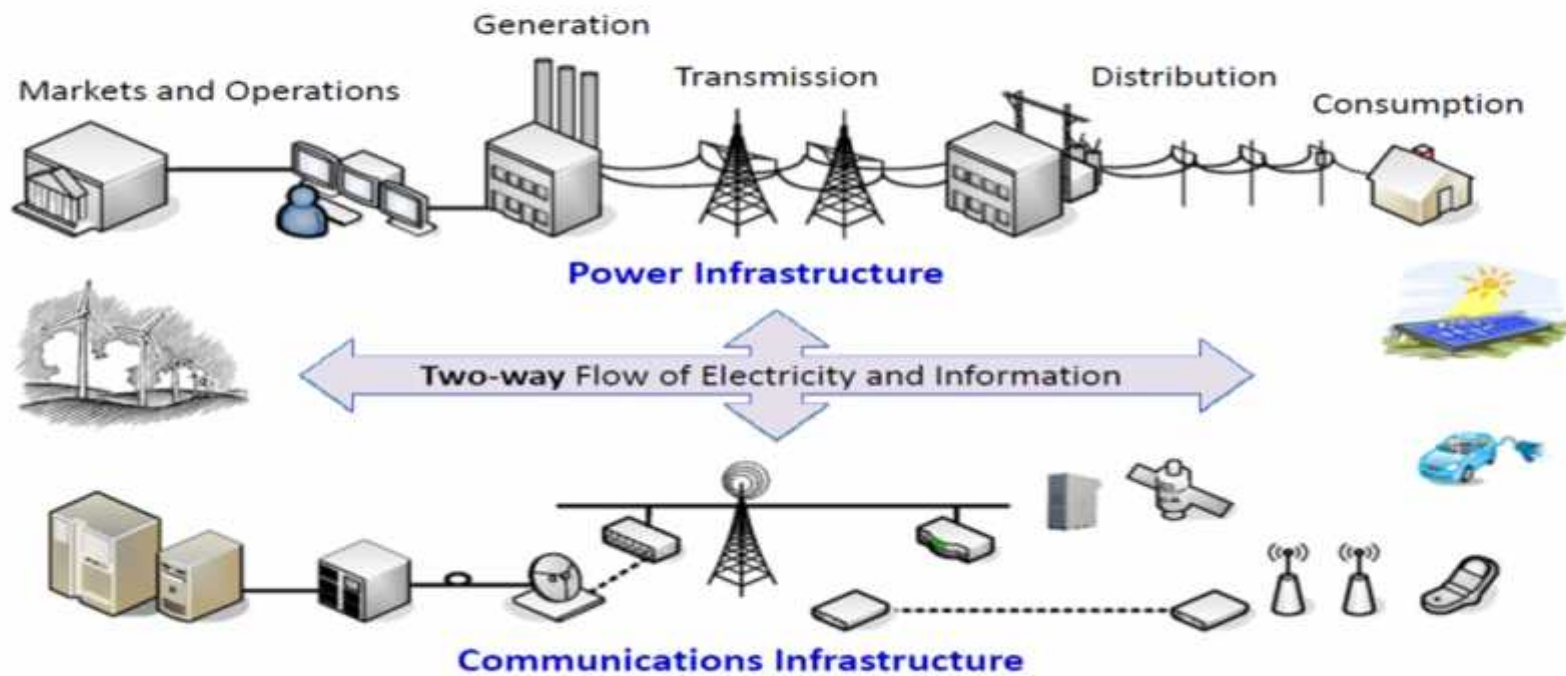


Introduction

Future power grid



Future power grid



Introduction

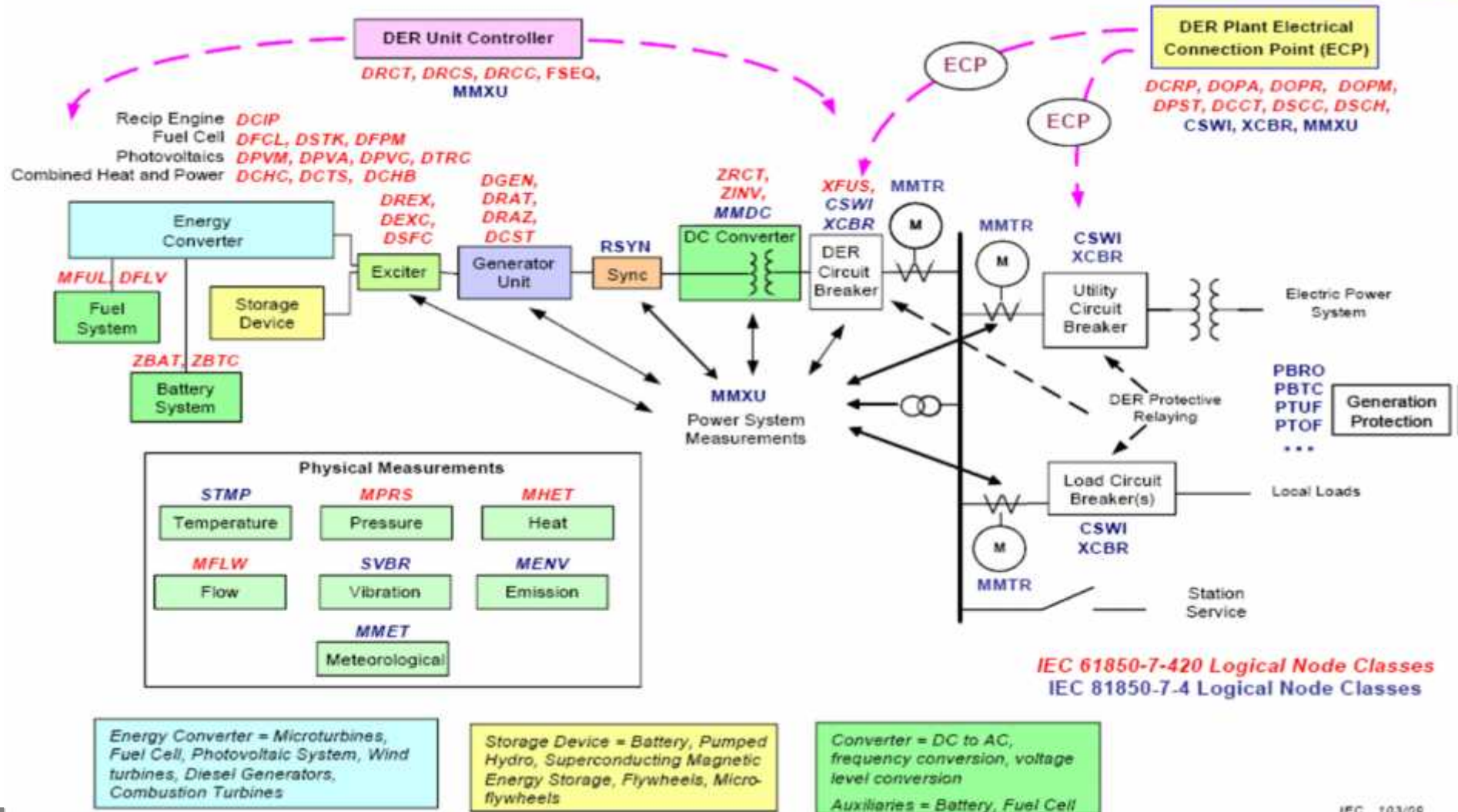
Hardware-in-the-Loop (HIL)?

Hardware-in-the-loop means that there is something physically connected to the real-time simulation. This can be a piece of power hardware or intelligent electronic device (IED) ...



Light-weight IEDs based IEC 61850

IEC 61850



IEC 103/08

Light-weight IEDs based IEC 61850

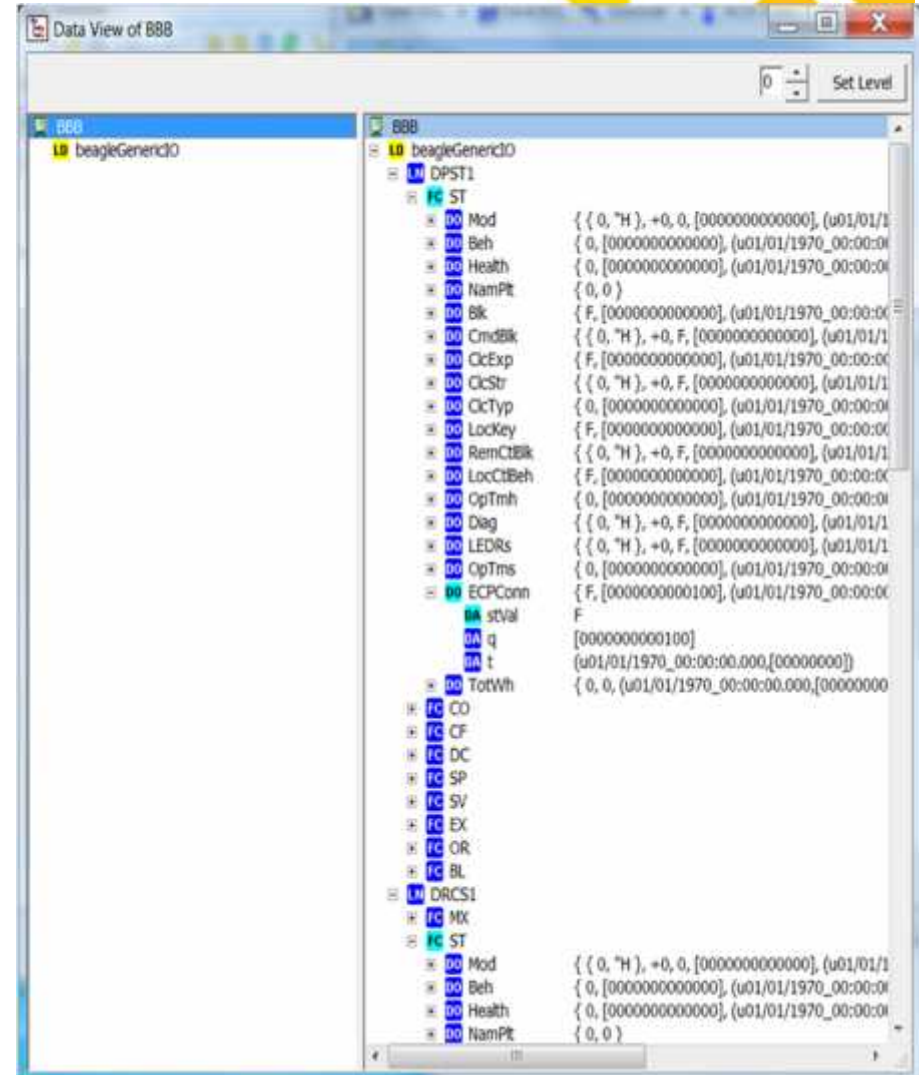
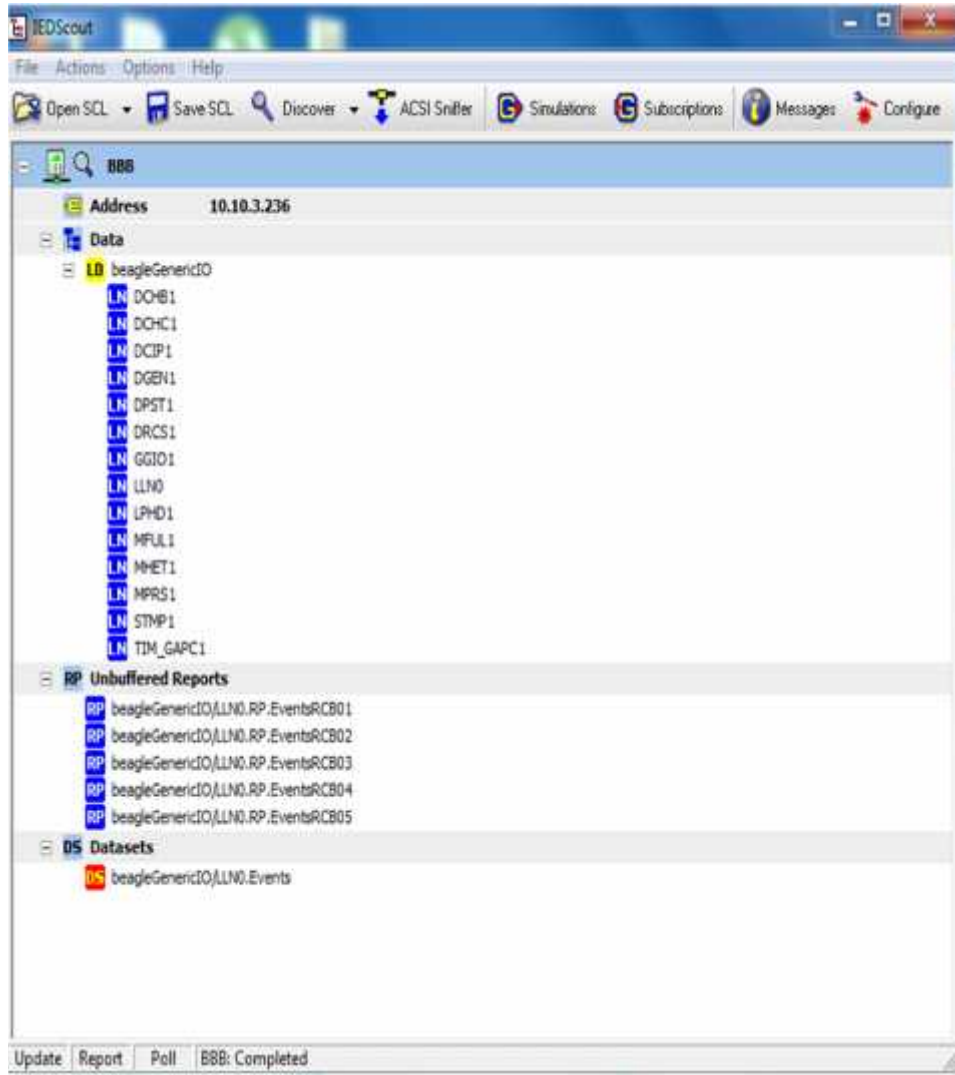
IEC 61850

- Since IEC 61850 standards are developed rapidly and there is no IED that support all different Edition 2 LNs
- Routing GOOSE (RG) and routing sample value (RSV) protocols for exchanging data (inter-substations communication) are under developments
- Therefore, monitoring, control and protection functions may be achieved by developing and implementing the light-weight IEC 61850 IED within various embedded systems, FPGA etc.



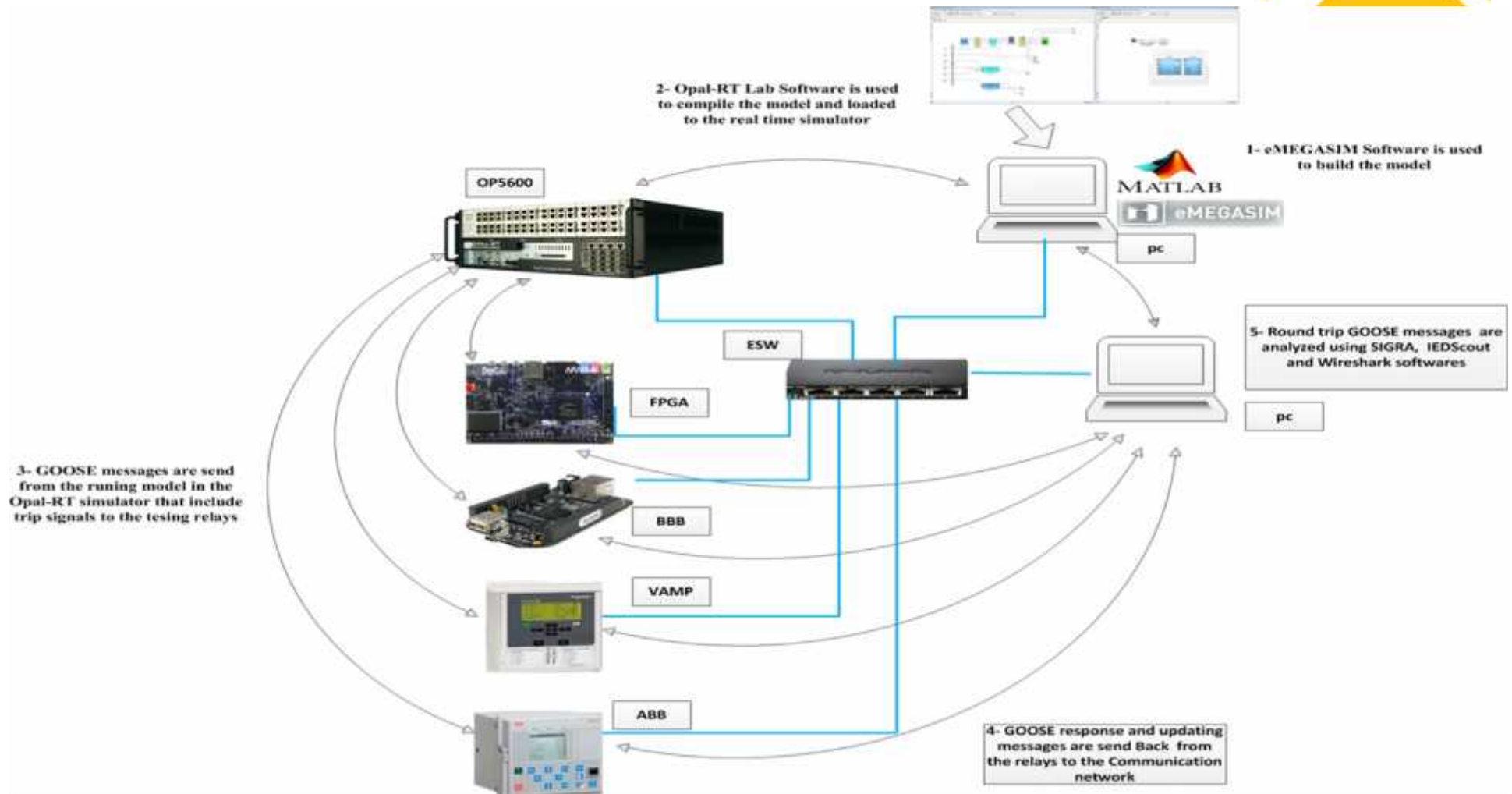
Light-weight IEDs based IEC 61850

IEC 61850



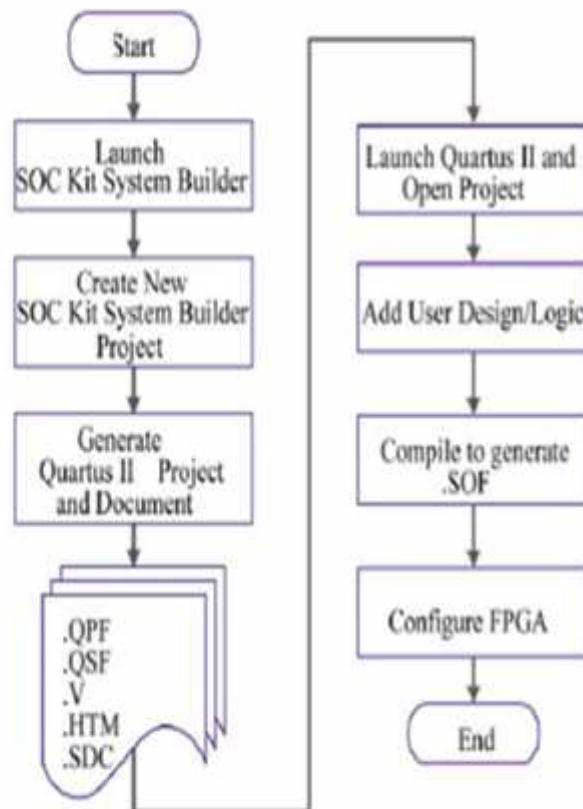
Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



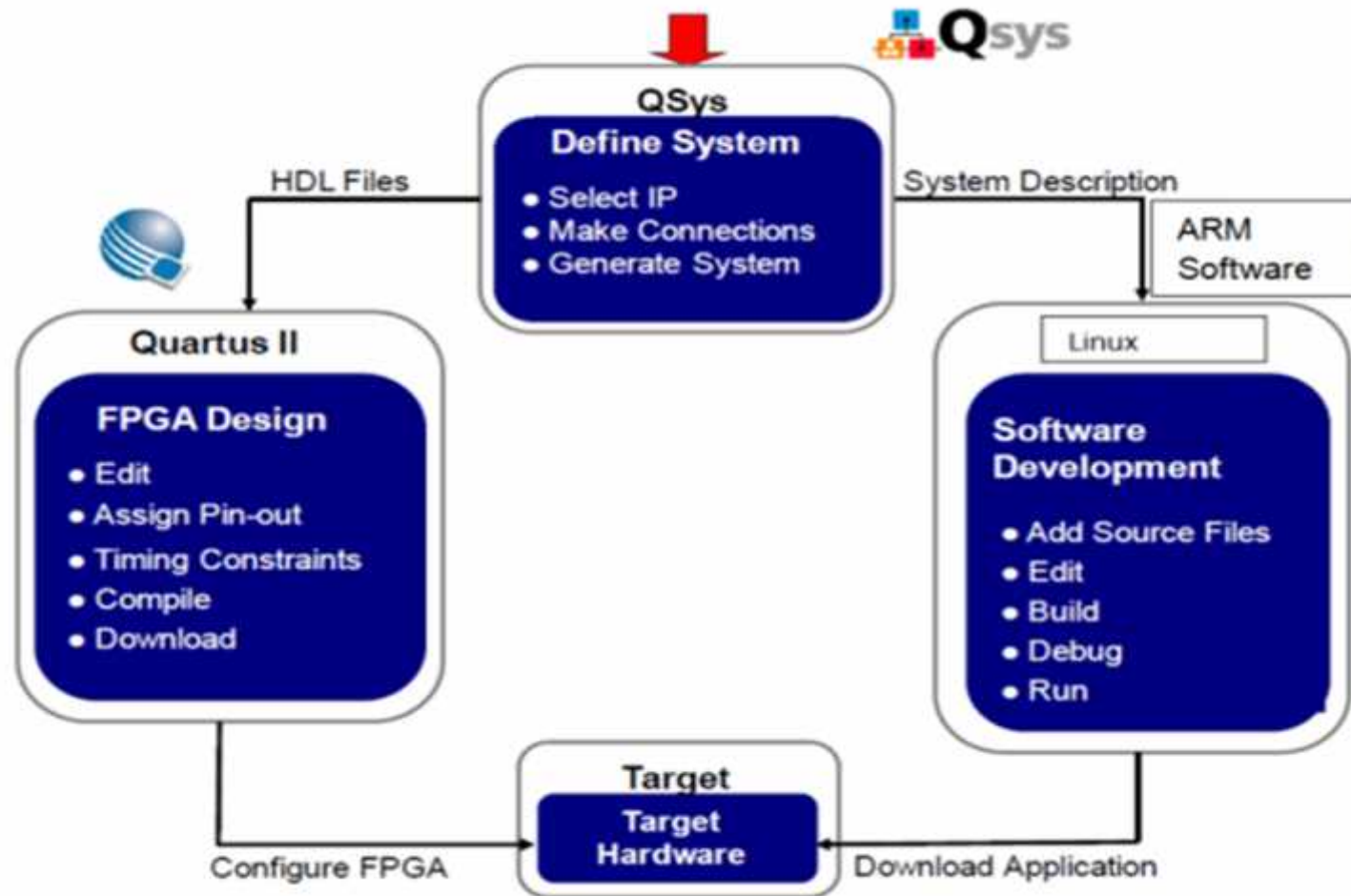
Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



The screenshot shows the Altera Programmer software interface. The title bar indicates the path: `C:/FPGA_projects/SoCkit_working_15/SoCKIT_Materials_15.0/SoCkit/SoCKit_HW_Lab_15.0/soc_system ...`. The menu bar includes File, Edit, View, Processing, Tools, Window, and Help. A search bar for `altera.com` is present. The hardware setup is configured for `CV SoCkit [USB-1]` in `JTAG` mode. The progress bar shows `100% (Successful)`. A table lists the files and devices:

File	Device	Checksum	Usercode	Program/Configure	Verify	Blank-Check	Examine
output_files/soc_system....	5CSXFC6D6F31	029E4C97	029E4C97	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<none>	SOCVHPS	00000000	<none>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Below the table is a diagram illustrating the hardware-in-the-loop (HIL) simulation approach. It shows two Altera SoC devices connected in a loop. The first device is labeled `5CSXFC6D6F31` and the second is `SOCVHPS`. An arrow labeled `TDI` (Test Data In) points to the first device, and an arrow labeled `TDO` (Test Data Out) points away from the second device, indicating a data path between the two devices.

Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach

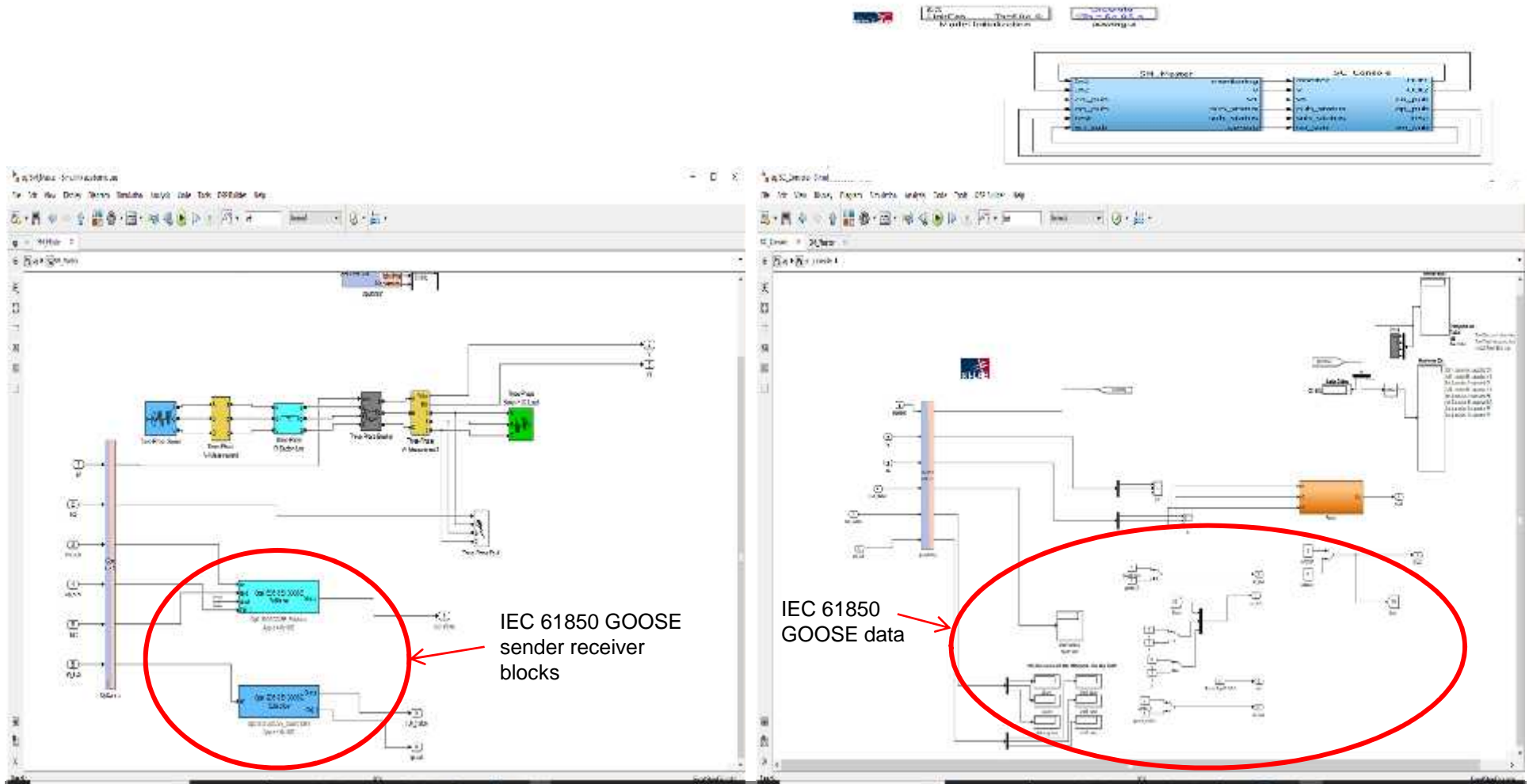


```
C:\Users\mmekka\Dropbox\SESP\test\ABB_BBB_HPS_test\hpsfpga_publisher\goose_subscriber_fuha_3_hpsfpga_pub\goose_subscriber_example.c - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window T
goose_subscriber_example.c
175  gooseCommParameters.dstAddress[2] = 0x0d;
176  gooseCommParameters.dstAddress[3] = 0x01;
177  gooseCommParameters.dstAddress[4] = 0x00;
178  gooseCommParameters.dstAddress[5] = 0x01;
179  gooseCommParameters.vlanId = 0;
180  gooseCommParameters.vlanPriority = 4;
181
182  /*
183  * Create a new GOOSE publisher instance. As the second parameter the interface
184  * name can be provided (e.g. "eth0" on a Linux system). If the second parameter
185  * is NULL the interface name as defined with CONFIG_ETHERNET_INTERFACE_ID in
186  * stack_config.h is used.
187  */
188  GoosePublisher publisher = GoosePublisher_create(&gooseCommParameters, NULL);
189
190  GoosePublisher_setGoCbRef(publisher, "AlteraIO/LLN0SG00qgnValues");
191  GoosePublisher_setConfRev(publisher, 3);
192  GoosePublisher_setDataSetRef(publisher, "AlteraIO/LLH0EValues");
193  GoosePublisher_publish(publisher, dataSetValues1);
194
195
196  uint64_t timestamp1 = Hal_getTimeInNs();
197
198  printf("    time is: %llu\n", timestamp1);
199  uint64_t diff_t1= difftime(timestamp1, timestamp);
200  printf("the difference %llu\n ", diff_t1);
201  }
202  else{
203
204      // set led
205      // off all led
206      alt_clrbits_word( ( virtual_base + ( ( uint32_t ) ( ALT_GPIO1_SWPORTA_DR_ADDR ) & ( uint32_t ) ( HW_REGS_MASK ) ) ), BIT_LED_ALL );
207      led_addr=0;
208      *(uint32_t *)led_addr=0;
209      printf("%u\n", switches);
210      printf("%u\n", leds);
211
212      // creat GOOSE publisher-----
213      // for GOOSE publisherroot
214      LinkedList dataSetValues1 = LinkedList_create();
215  }
```

C source file length: 10 099 lines: 349 Ln: 34 Col: 1 Sel: 0 | 0 Unix (LF) UTF-8 OVR

Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



The screenshot displays the RT-LAB 2017 simulation environment. At the top, there are two waveform windows. The left window, titled '3V', shows three signal traces with a time offset of 600. The right window, titled '31', shows three signal traces with a time offset of 600. Below these is a 'use' window with a menu bar (Simulation, Analysis, Code, Tools, Help) and a toolbar. The main area shows a circuit diagram with various components and connections. A terminal window titled '193.166.118.252 - PuTTY' is open, displaying log output with timestamps and system messages. A status bar at the bottom indicates '2_sc_console' while the simulation is running.

Case study 1

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



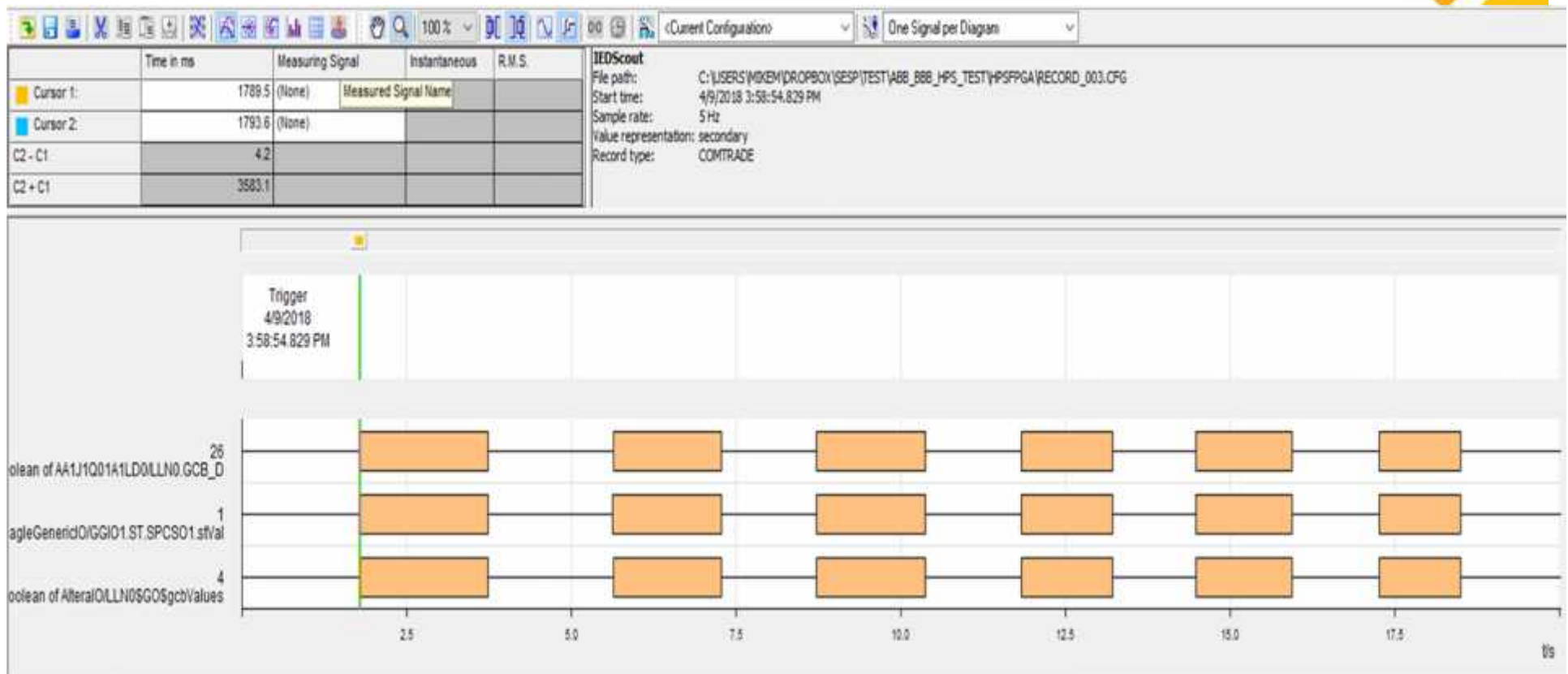
The screenshot shows the 'GOOSE Subscriptions' application window. It features a tree view on the left and a detailed view on the right. The detailed view shows the configuration for three different GOOSE subscriptions. The middle subscription is highlighted in blue.

Subscription	GoCBRef	DstMac	GoID	AppID	DatSet	StNum	SqNum	Data	ObjRef unknown
1	SERVER-GOOSEDevice 1/LLN0\$GO\$CB_Goose_TRIP 1	01:0c:cd:01:00:01	Goose_TRIP 1	0x1000	SERVER-GOOSEDevice 1/LLN0\$Goose_TRIP 1	144	41		{True,False,False}
2 (highlighted)	simpleIOGenericIO/LLN0\$GO\$gcbAnalogValues	01:0c:cd:01:00:01	simpleIOGenericIO/LLN0\$GO\$gcbAnalogValues	0x03e8	simpleIOGenericIO/LLN0\$AnalogValues	1	0		{1234,?? (Tag=140(0x8c) Size=4(0x4) Data(0x): 00 00 00 00),162e,True}
3	AA 1J0 1Q0 1A 1Relay/LLN0\$GO\$gcb 1	01:0c:cd:01:00:00	GOOSEID	0x1000	AA 1J0 1Q0 1A 1Relay/LLN0\$DSG 1	122	15		{False,False,True}

At the bottom of the window, there are four buttons: 'Subscribe', 'Unsubscribe', 'Sniffer', and 'Recording'.

Results

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach



Results

Conventional and Lightweight IEDs Testing based Real-Time Hardware-in-the-Loop (HIL) Simulation Approach

$$\bar{t}_{RT} = \bar{t}_{out.TS} + \bar{t}_{net} + \bar{t}_{in.DUT} + \bar{t}_{App} + \bar{t}_{out.DUT} + \bar{t}_{net} + \bar{t}_{in.TS}$$

GOOSE round trip				
	BBB	Vamp52	ABB	FPGA
Mean val. ms	11.2	18.8	3.6	4.2

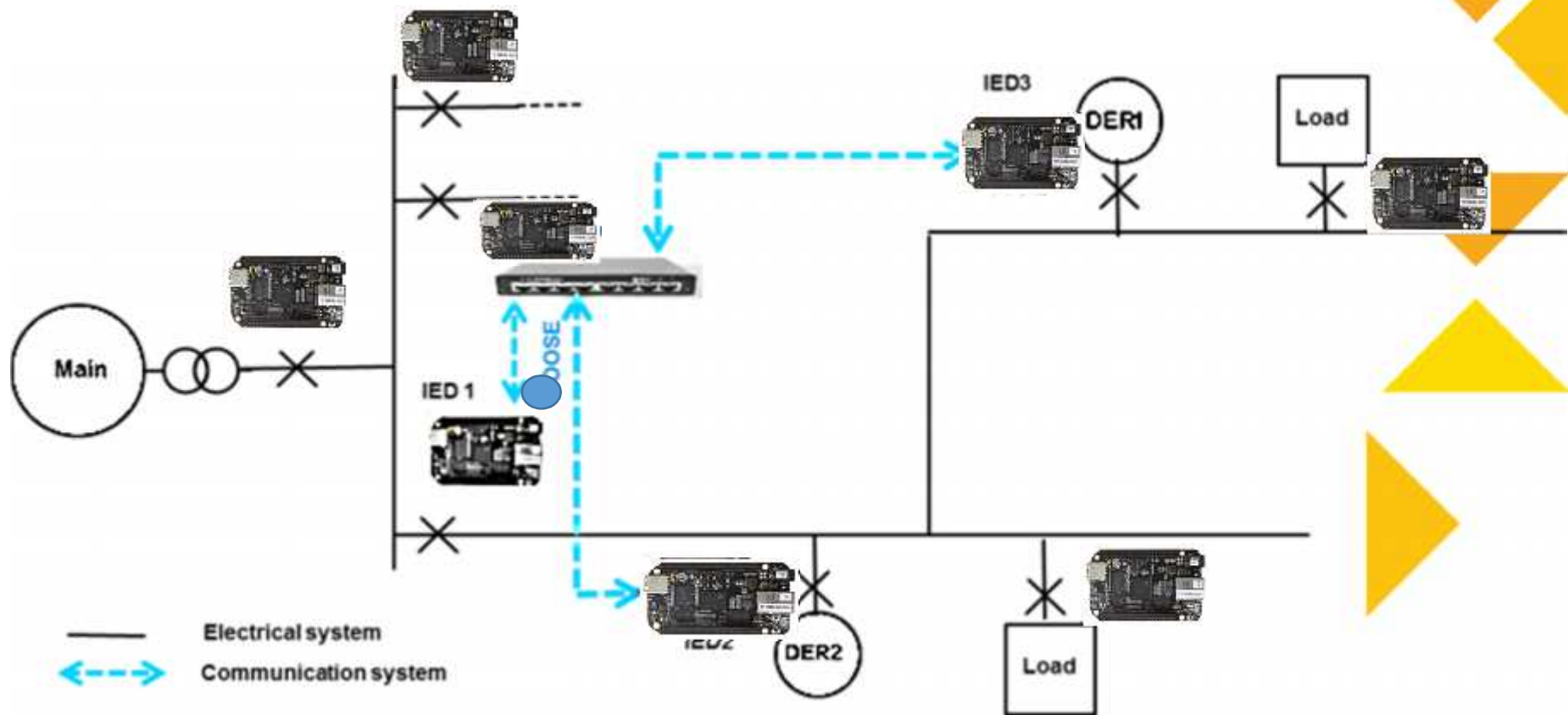


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Light-Weight IEC 61850 GOOSE Based Loss of Mains Protection for Smart Grid

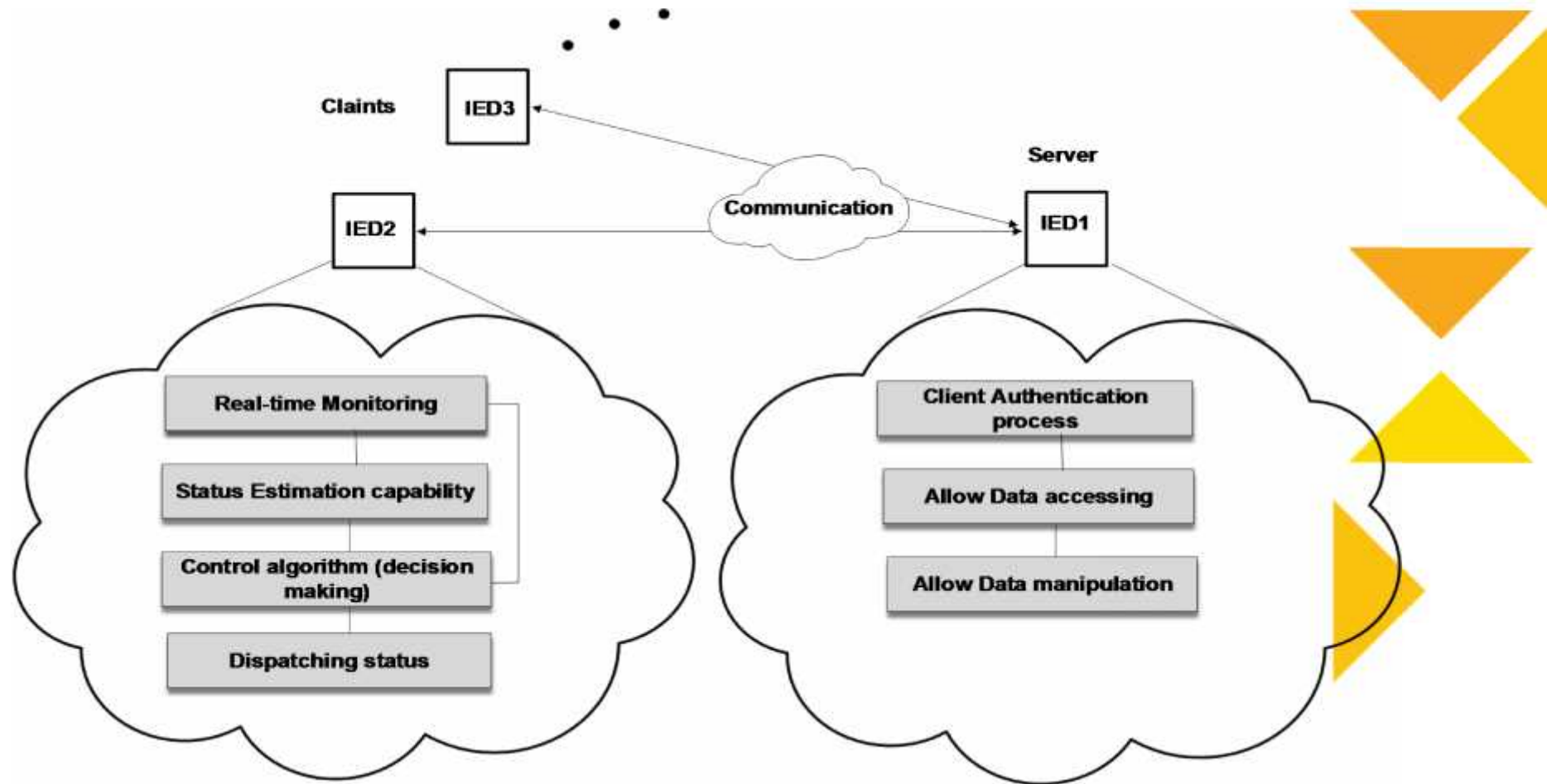
Case study 2

Light-Weight IEC 61850 GOOSE Based Loss of Mains Protection for Smart Grid



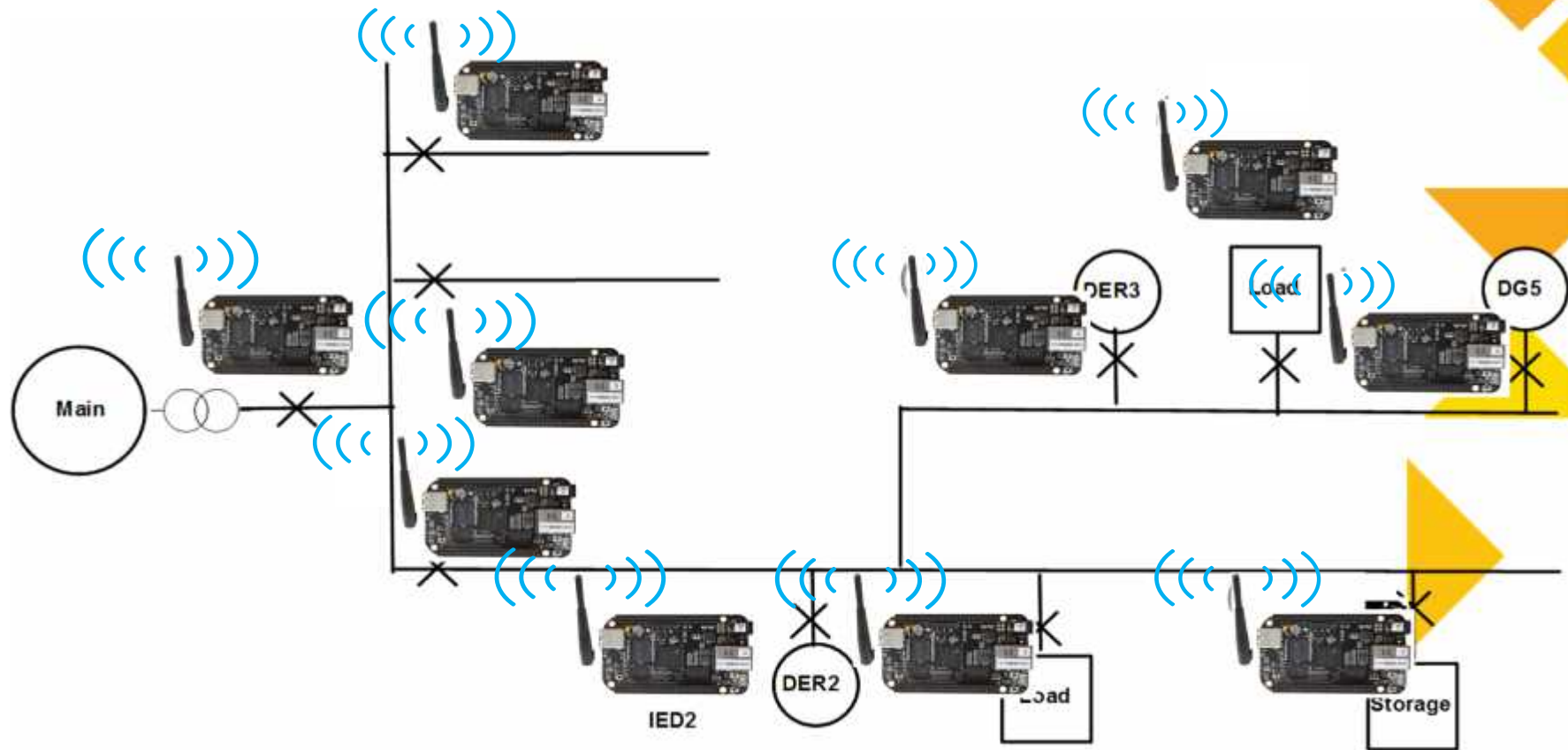
Case study 2

Light-Weight IEC 61850 MMS Based Loss of Mains Protection for Smart Grid



Case study 2

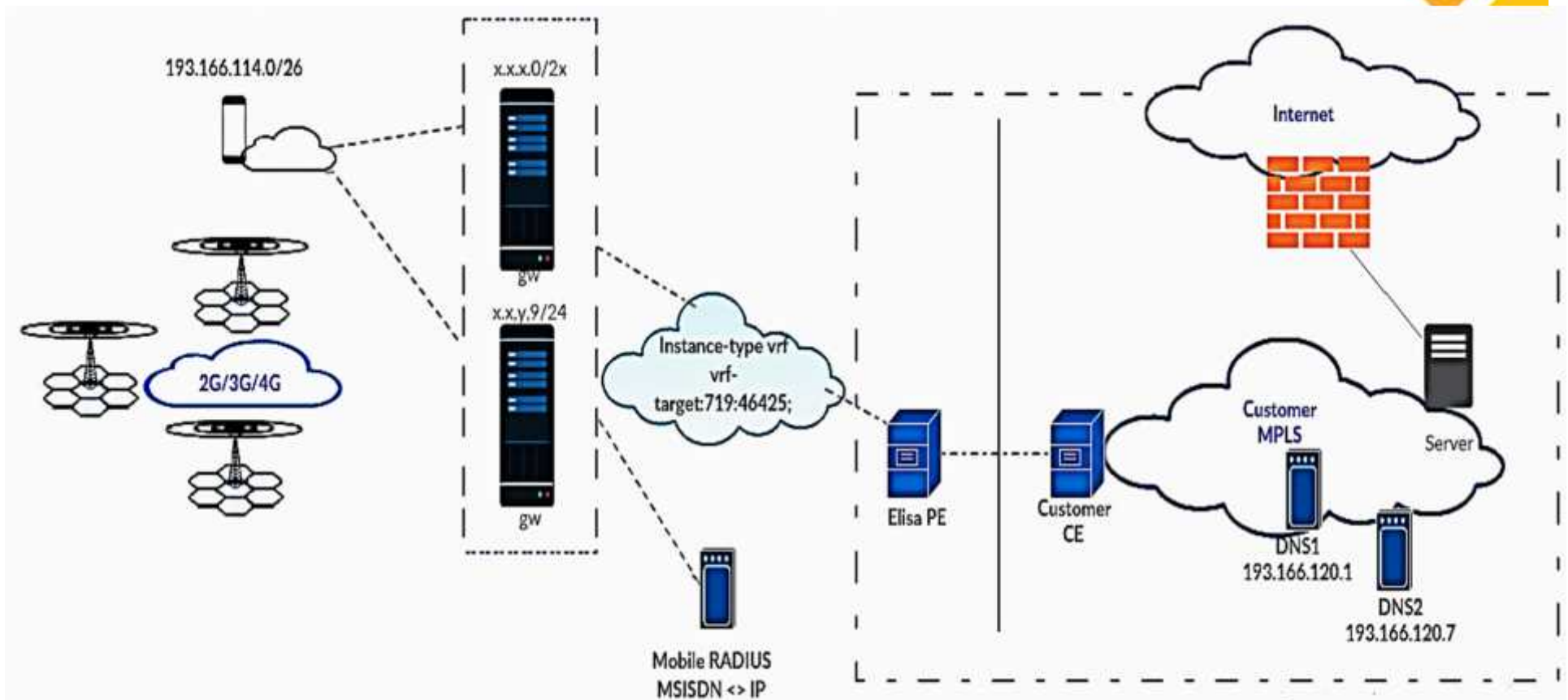
Light-Weight IEC 61850 MMS Based Loss of Mains Protection for Smart Grid



Case study 2

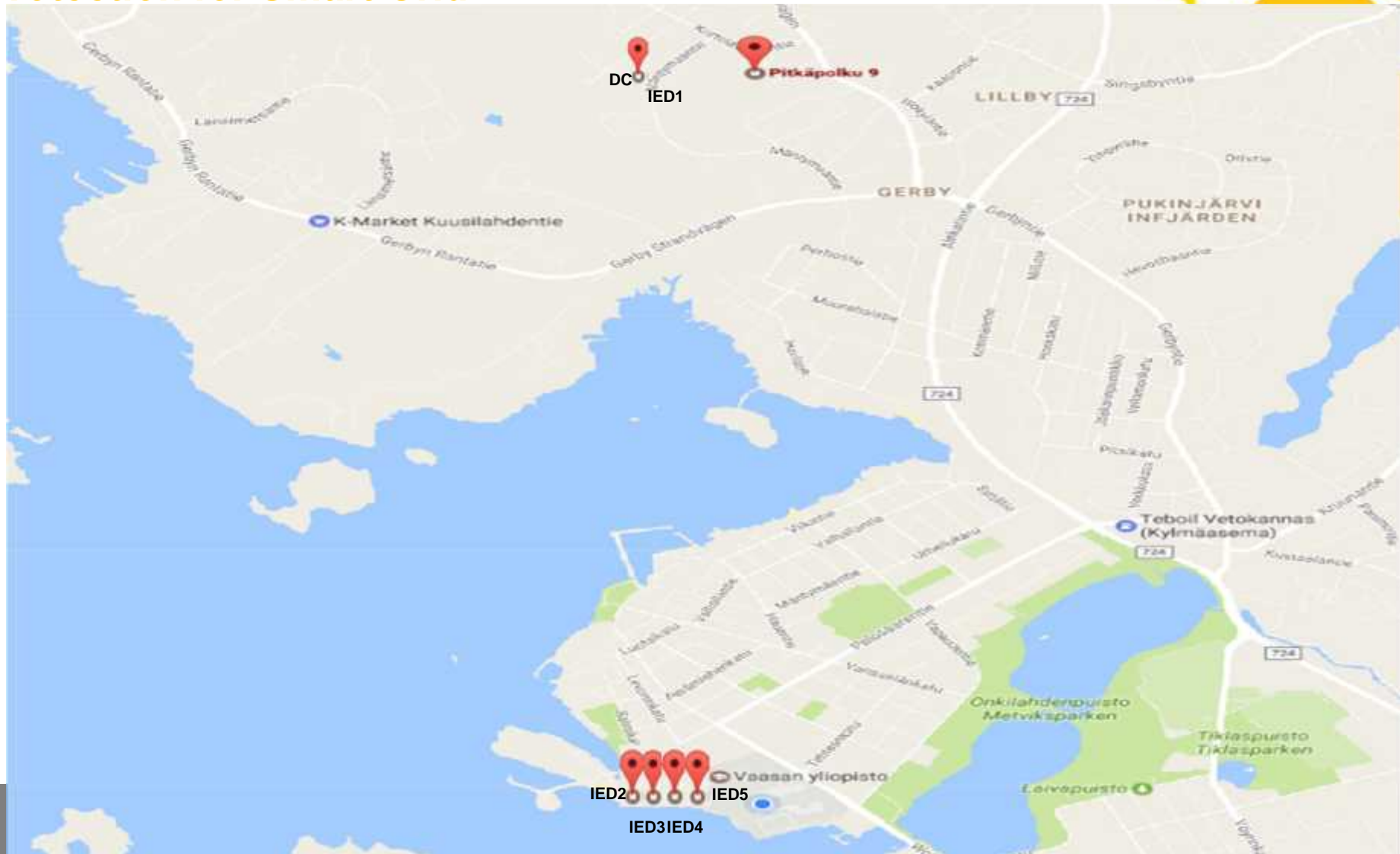
Light-Weight IEC 61850 MMS Based Loss of Mains Protection for Smart Grid

APN mob.uwasa communication system network configuration



Case study 2

Light-Weight IEC 61850 MMS Based Loss of Mains Protection for Smart Grid



Results

Light-Weight IEC 61850 GOOSE Based Loss of Mains Protection for Smart Grid

$$\bar{t}_{RT} = \bar{t}_{out.TS} + \bar{t}_{net} + \bar{t}_{in.DUT} + \bar{t}_{App} + \bar{t}_{out.DUT} + \bar{t}_{net} + \bar{t}_{in.TS}$$

$$\dagger^2_{RT} = \dagger^2_{out.TS} + \dagger^2_{net} + \dagger^2_{in.DUT} + \dagger^2_{App} + \dagger^2_{out.DUT} + \dagger^2_{net} + \dagger^2_{in.TS}$$

LoM Based GOOSE

	DPST.ECPCConn		DRCS.ModOnConn	
	IED1-IED2	IED1-IED3	IED1-IED2	IED1-IED3
Mean val. ms	18.006	15.180	24.505	18.871
Std. dev.	5.083	3.209	6.627	3.332

LoM based Clients-Server communication MMS

	DPST.ECPCConn			
	IED1-IED2	IED1-IED3	IED1-IED4	IED1-IED5
Mean value ms	645.434	648.222	1548.406	636.714
Std. dev.	377.384	316.597	486.493	370.383

Conclusion

- **Designing and implementing light-weight IEC 61850 IEDs that support new LNs for different DERs**
- **Using the GOOSE and MMS IEC 61850 protocols based LoMs protection**
- **Exchanging real time data between different DERs based on IEC 61850**
- **Remotely monitoring and controlling DERs and within the acceptable range of latency**



Future work

- **To be used for the WAMPAC functions for example fault detecting and locating, interlocking etc.**
- **Classification of other Electrical Systems events (Supervisory Situation Awareness)**
- **Upgrade and refurbish legacy relays (to support IEC 61850 or even wireless IEC 61850 IED)**
- **To be used in Power Management in smart grid**
- **Distribute the client IEDs over wide geographical area for example over different cities in Finland to get a better view about the communication jitter for the WAMPAC applications**



Publication

- *“Wireless Light-Weight IEC 61850 Based Loss of Mains Protection for Smart Grid”* published in **The National Biannual Automation Conference Automaatiopäivät22, held in Vaasa 23-24 March 2017 Vaasa energy week.**
- The extended version of the paper *“Wireless Light-Weight IEC 61850 Based Loss of Mains Protection for Smart Grid”* has been requested and submitted in to the **Open Engineering – Special Issue Automation in Finland Journal**
- *“Light-Weight IEC 61850 GOOSE Based Loss of Mains Protection for Smart Grid”* has been published in **WORKSHOP 2018 ON MICROGRIDS AND LOCAL ENERGY COMMUNITIES CIRED2018 7-8 JUNE 2018 Ljubljana, Slovenia**

Thank you

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