SmarTS Lab
Smart Transmission Systems Laboratory

AN IEC 61850-90-5 GATEWAY FOR IEEE C37.118.2 SYNCHROPHASOR DATA TRANSFER

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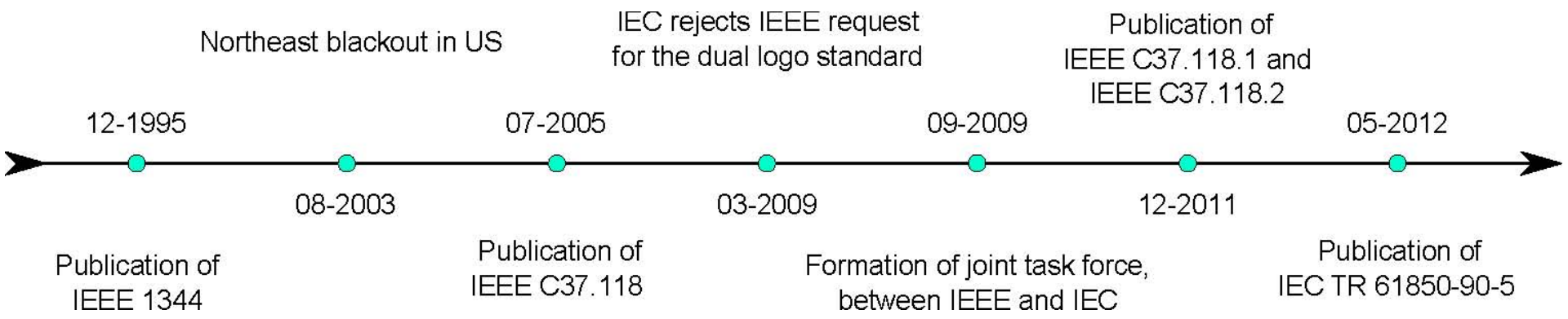
Background

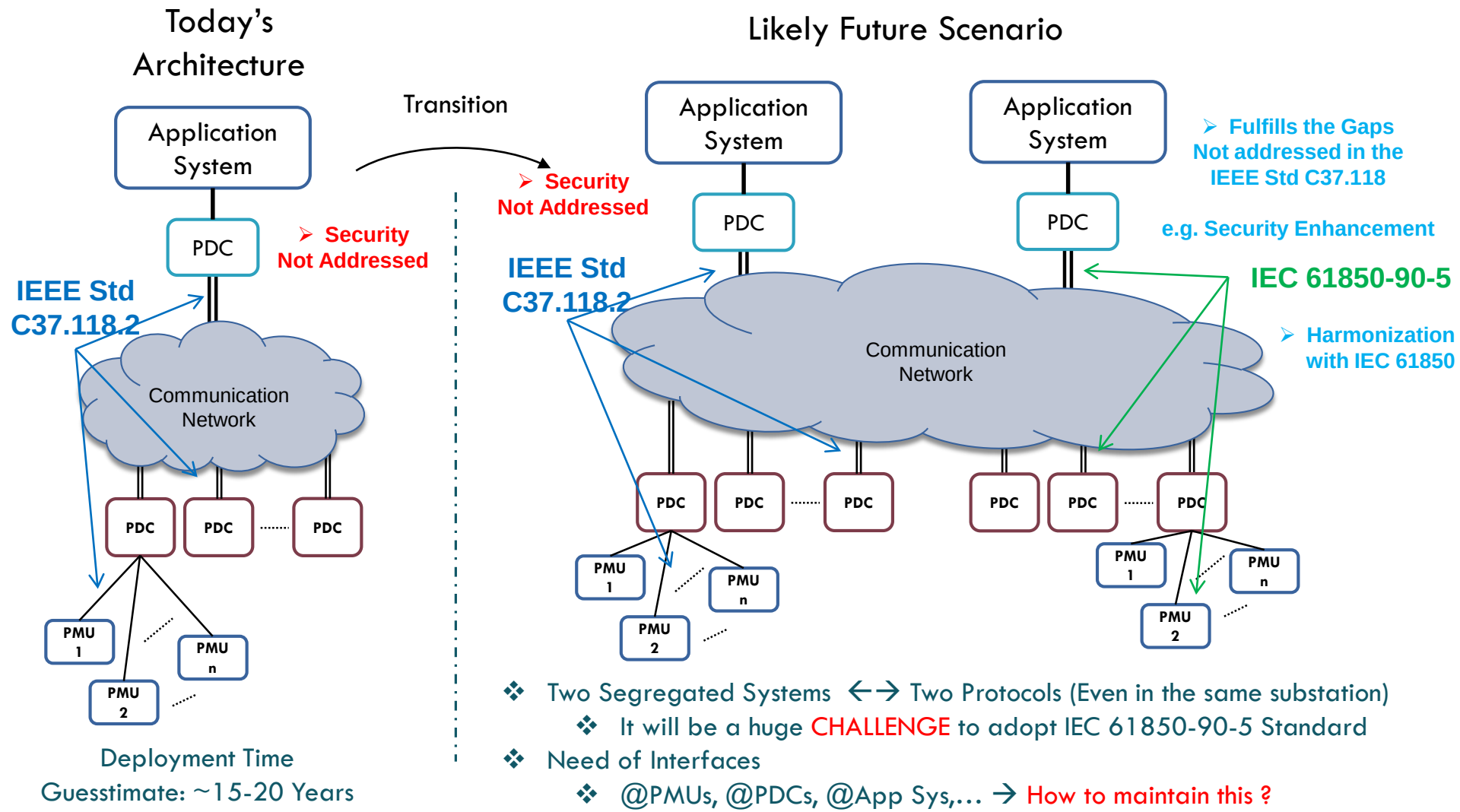
- Evolution of Synchrophasor Standards
- Likely Future Scenario Challenges
- Our Possible Contribution
- Objective and Scope of Work

Evolution of Synchrophasor Standards

- Two main international standards for synchrophasor data transfer:
  - IEEE C37.118.2-2011 (2011)
    - Defines synchrophasor measurement data transfer.
  - IEC TR 61850-90-5 (2012)
    - Provides a way of exchanging synchrophasor data between Phasor Measurement Units (PMUs), Phasor Data Concentrators (PDCs), Wide Area Monitoring, Protection, and Control (WAMPAC) , and control center applications in a way that is compliant to the concepts of IEC 61850 Substation Automation Standard.

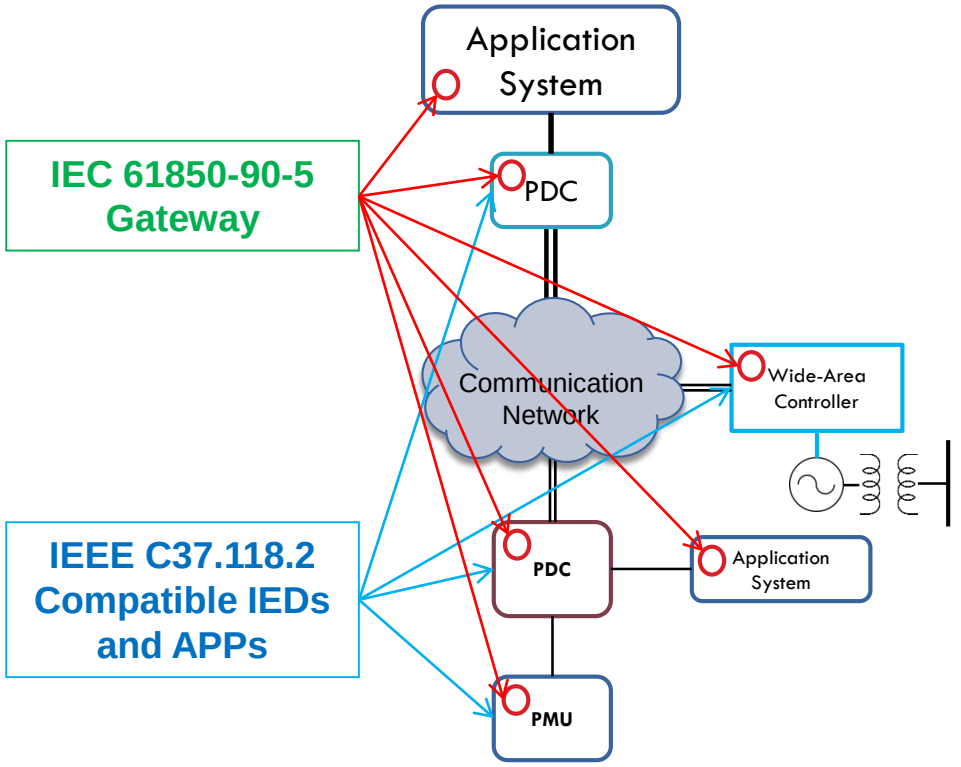


Likely Future Scenario Challenges



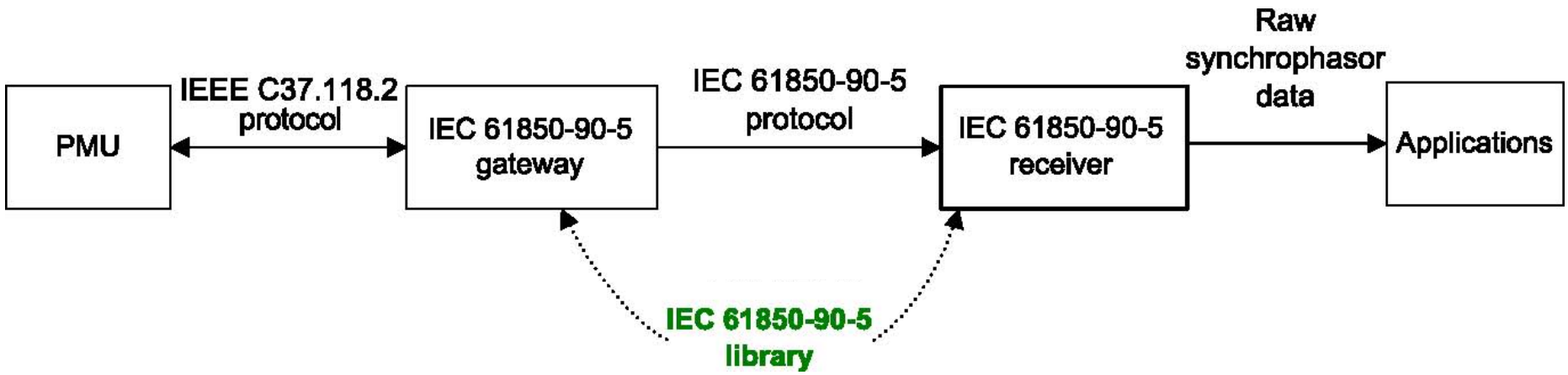
Our Possible Contribution

- Development of a Gateway:
  - To act as the IEEE C37.118.2 to IEC 61850-90-5 protocol converter.
  - Providing the future compatibility
- Capable of being used at various levels:
  - @PMU Level
  - @PDC Level
  - @Application Level
  - …



Objective and Scope of Work

- Design and Implementation of a software tool enabling integration of IEEE C37.118.2 compliant synchrophasor data in the context of the IEC 6185-90-5 standard.
- It was intended to develop a library using standard C libraries.
  - Being platform independent
  - Being able to run on embedded systems with the least HW requirements
    - Enabling fast cyclic transfer of synchrophasor streams over wide-area networks
    - Reduction of latencies in real-time applications

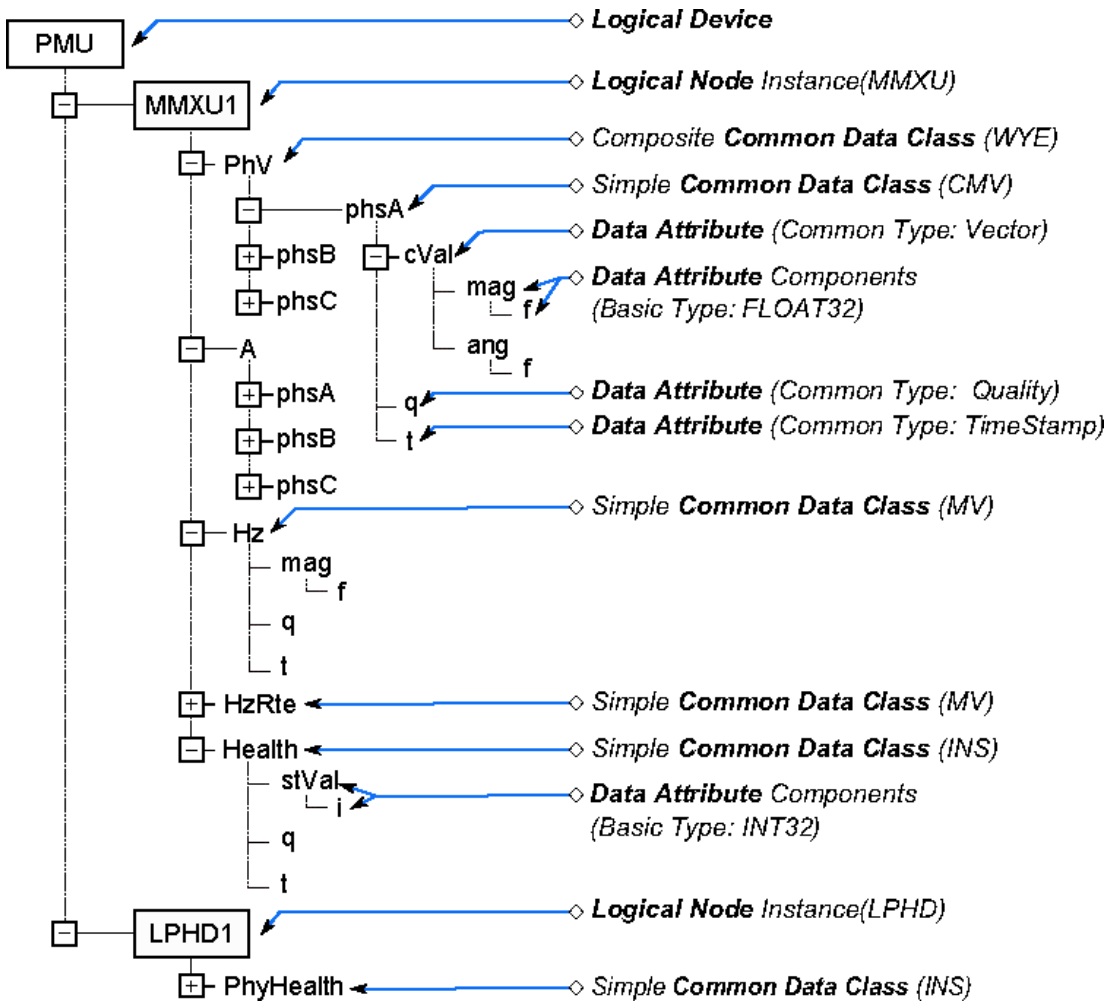


IEC 61850-90-5 Standard

- PMU Data Modeling in IEC61850
- IEC 61850-90-5 Communication Services
- IEC 61850-90-5 Session Protocol Specification

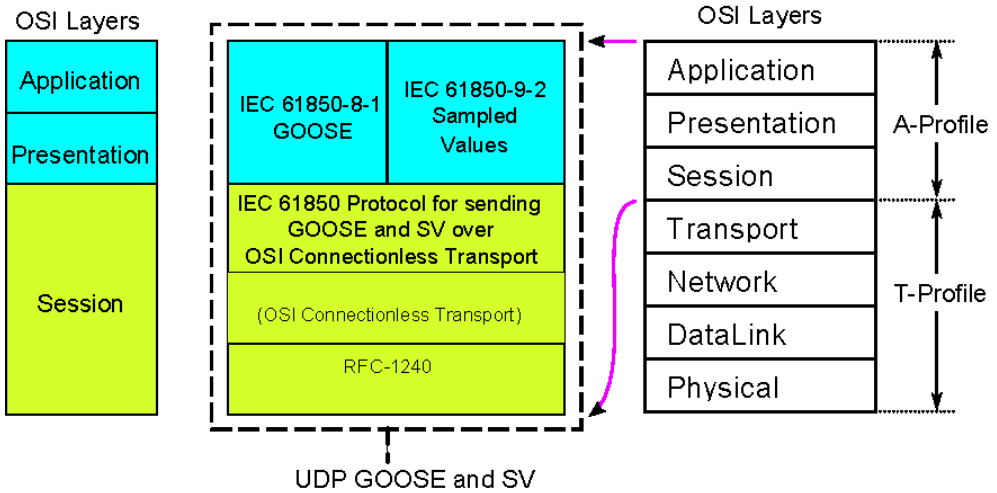
PMU Data Modeling in IEC61850

- PMU is modeled as a Logical Device within an IED
  - The Phasors and Frequency data contained in the C37.118 telegram, is mapped to the measurement Logical Node (MMXU)
  - The new data object of HzRte is added to the MMXU LN
    - To accommodate the ROCOF data.
  - The information about the status of the PMU is transmitted using the "PhyHealth" data object in an instance of the LPHD LN



IEC 61850-90-5 Communication Services

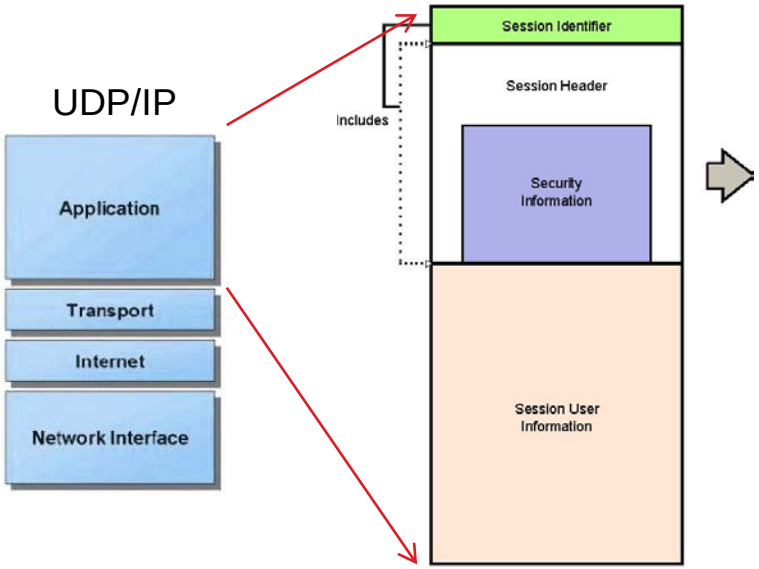
- In IEC 61850, Sampled Value (SV) & GOOSE over Ethernet inside the substation.
  - **Sampled Value (SV)** (IEC 61850-9-2)
    - Fast and cyclic transmission of raw data generated by measurement equipment inside substation.
  - **Generic Object-Oriented Substation Event (GOOSE)** (IEC 61850-8-1)
    - Considered for time-critical event-based functions such as protection functions.
- In IEC 61850-90-5, two mechanisms are introduced to transfer data outside the substation:
  - Tunneling:
    - Using high speed communication networks (e.g. SDH or SONET)
  - Internet Protocols (IP):
    - SV/GOOSE services are communicated via IP networks
  - NEW Mapping to Routable UDP
    - **Routed-Sampled Value (R-SV)**
    - **Routed-GOOSE (R-GOOSE)**

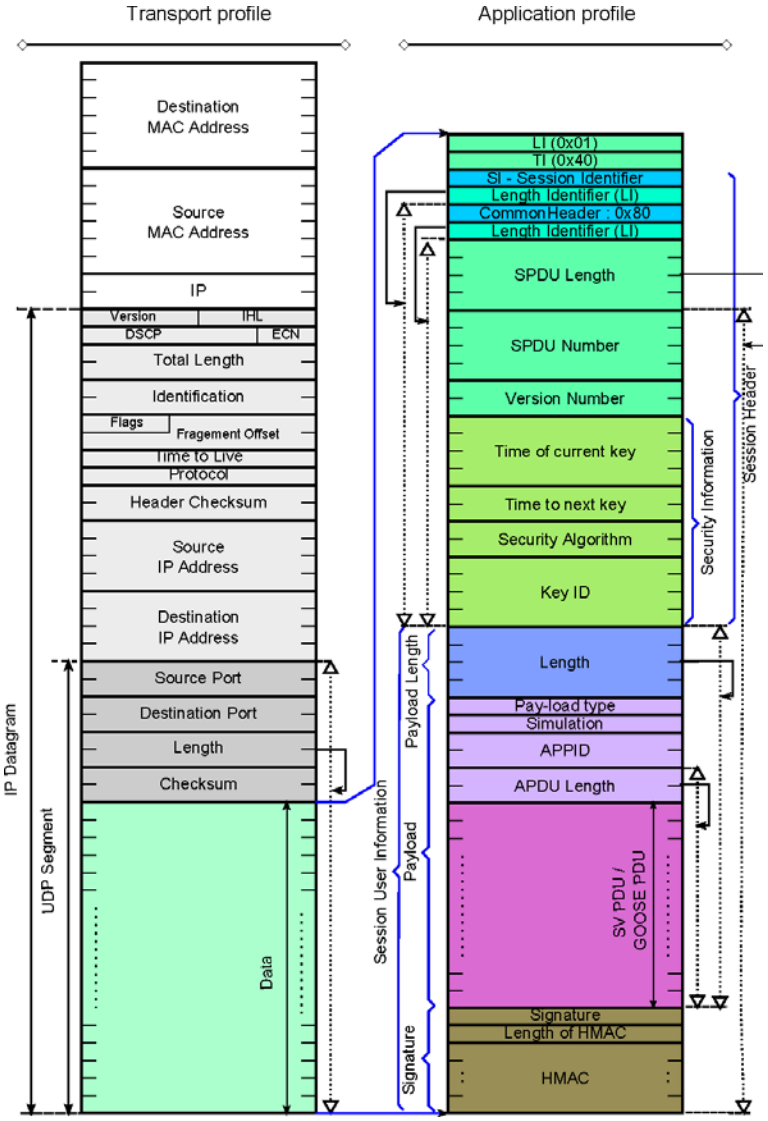


Required for Wide-Area Applications

IEC 61850-90-5 Session Protocol Specification

- In IEC 61850-90-5, the application layer specification of IEC 61850-8-1 GOOSE and IEC 61850-9-2 SV services are remained unchanged
  - A new protocol is introduced in the session layer for sending the GOOSE and SV over Open System Interconnect (OSI) connectionless transport.



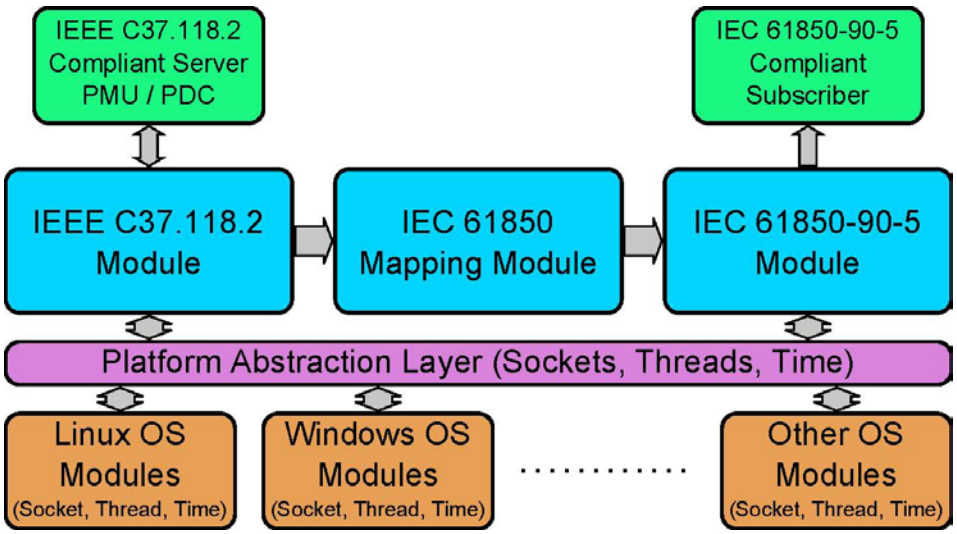


Khorjin Gateway Architecture

- Khorjin Gateway Architecture Design
- IEEE C37.118.2 Module
- Mapping Module
- IEC 61850-90-5 Module

Gateway Architecture Design

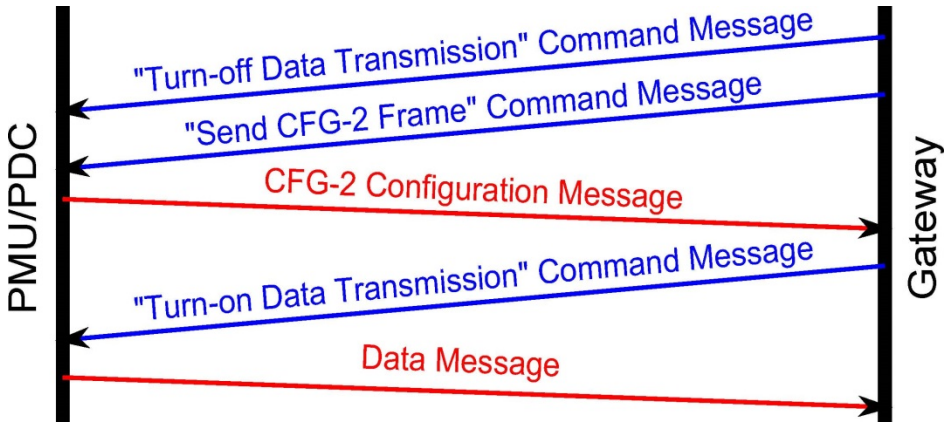
- A library, named as "Khorjin"(*), is designed and implemented with two functionalities:
  1. IEEE C37.118.2 to IEC 61850-90-5 Protocol Converter (Gateway)
  2. IEC 61850-90-5 Traffic Parser
- The Gateway part of Khorjin library is developed in three main components of:
  1. IEEE C37.118.2 Module,
  2. IEC 61850 Data Model Mapping Module, and
  3. IEC 61850-90-5 Publisher Module.
- In order to be platform-independent
  - A Platform Abstraction Layer is Implemented.
  - Depending on the platform, on which the Khorjin library is going to run → The relevant platform-dependent functions are utilized. (i.e. Socket, Thread, Time and …)



(*) In the Persian language, Khorjin, is a special bag placed on the two sides of a horse, which was used for transferring of parcels.

IEEE C37.118.2 Module

- This module handles the real-time synchrophasor data exchange between PMU/PDC and Gateway, based on the IEEE C37.118.2 protocol.
- The data exchange is done through a TCP/IP connection between PMU/PDC (Server) and Gateway (Client).
- In order to establish connection, following data of the PMU/PDC (Server) is required as the input:
  - 1) IP address, 2) Port number and 3) IDCODE
- Messages types exchanged between the PMU/PDC and the Gateway:
  - "Turn-off data transfer" Command msg
  - "Send CFG-2 message" Command msg
  - CFG-2 Configuration msg
  - "Turn-on data transfer" Command msg
  - Data message



IEC 61850 Mapping Module – Phasor Data

- In this module, the mapping of the IEEE C37.118.2 PMU data into IEC 61850 data model is implemented for:
  1. Synchrophasor data,
  2. Time stamps and
  3. Quality data object.

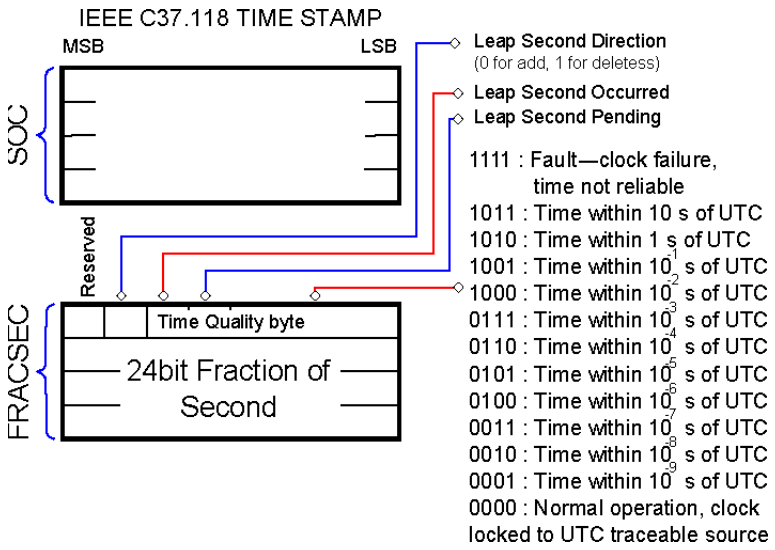
- 1) Synchrophasor Data Mapping:
  - The raw synchrophasor data contained in the IEEE C37.118.2 Data message is mapped to the IEC 61850 data model.
  - This translation is possible utilizing the data available in the Configuration message type 2 (CFG-2) received from the PMU/PDC.

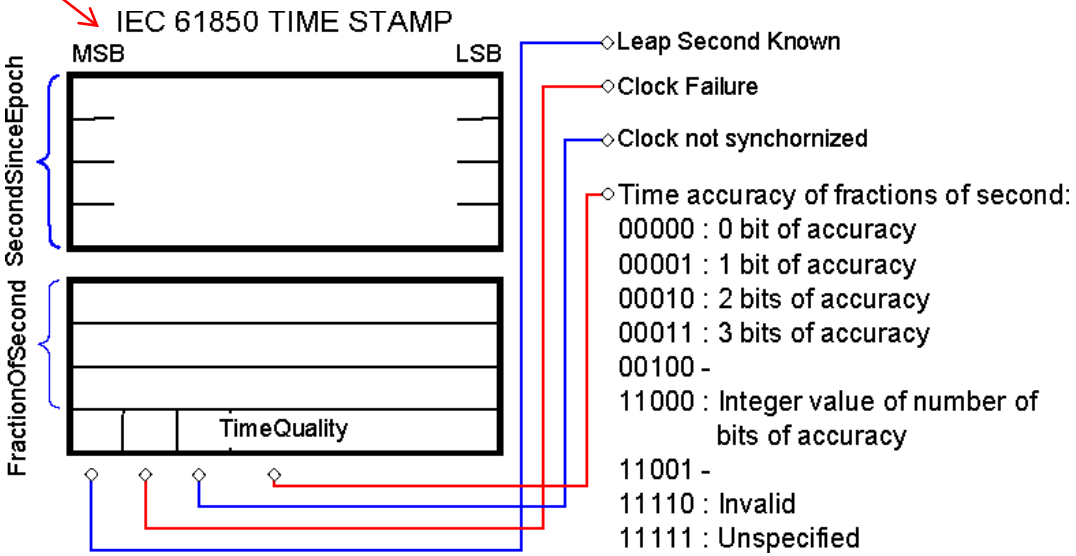
IEEE C37.118.2 Configuration Message	IEEE C37.118.2 Data Message	IEC 61850-90-5
FORMAT (Bits 0-1) PHNMR PHUNIT	PHASORS	Data attributes of "PhV" and "A" data objects in MMXU logical node. MMXU1.PhV.PhsA.cVal.mag.f MMXU1.PhV.PhsA.cVal.ang.f MMXU1.PhV.PhsB.cVal.mag.f MMXU1.PhV.PhsB.cVal.ang.f MMXU1.PhV.PhsC.cVal.mag.f MMXU1.PhV.PhsC.cVal.ang.f MMXU1.A.PhsA.cVal.mag.f MMXU1.A.PhsA.cVal.ang.f MMXU1.A.PhsB.cVal.mag.f MMXU1.A.PhsB.cVal.ang.f MMXU1.A.PhsC.cVal.mag.f MMXU1.A.PhsC.cVal.ang.f
FORMAT (Bit 3) FNOM	FREQ	Data attribute of "Hz" data objects in an instance of MMXU logical node MMXU1.Hz.mag.f
FORMAT (Bit 3)	DFREQ	Data attribute of "HzRte" data objects in an instance of MMXU logical node. MMXU1.HzRte.mag.f
FORMAT (Bit 2) ANNMR ANUNIT	ANALOG	Appropriate data objects in relevant logical node. For example: Total active or reactive power analog values are mapped to "TotW" and "TotVAr" data objects in MMXU logical node: MMXU1.TotW.mag.f MMXU1.TotVAr.mag.f
DGNMR DGUNIT	DIGITAL	Appropriate data objects in relevant logical node. For example: Circuit Breaker status flag bits are mapped to data objects in XCBR logical node: myXCBR1.Pos.stVal

IEC 61850 Mapping Module – Time Stamps

- 2) Timestamp Mapping:
  - In IEC 61850-7-2, the TimeStamp is defined as a data object including *SecondSinceEpoch*, *FractionOfSecond* and *TimeQuality* data attributes.
  - The IEEE C37.118.2 TimeStamp is mapped to the IEC 61850-8-1 mapping specification of the this data object.

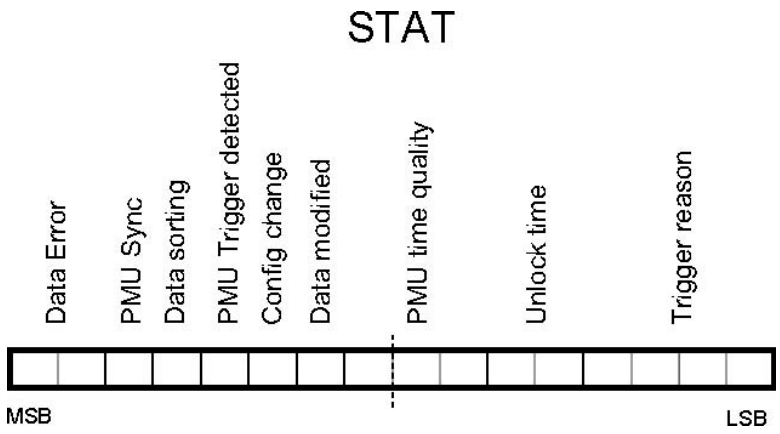
IEEE C37.118.2 Configuration Message	IEEE C37.118.2 Data Message	IEC 61850-90-5
TIME_BASE	FRACSEC (Bits 24-27)	"TimeAccuracy" attribute of "TimeQuality" data attribute in TimeStamp data object (Bits 3-7 (Time accuracy), Maximum: 11000. $1/2^{24} = 1/16,777,216 \simeq 60ns$)
	SOC	"SecondSinceEpoch" data attribute in TimeStamp data object
	FRACSEC (Bits 0-23)	"FractionOfSecond" data attribute in TimeStamp data object
	FRACSEC (Bits 24-27 =1111)	"TimeQuality" data attribute in TimeStamp data object (Bit 1 (Clock Failure))





IEC 61850 Mapping Module – C37.118.2 STAT Word

- 3) Mapping STAT Word:
  - In IEEE C37.118.2 Data message, the16-bit STAT word specify information about the status of the data stream of each PMU.
  - In IEC 61850 data model, "Quality" attribute contains information on the quality of the information.
  - In this implementation, the information provided by bits 14-15 (Data Error) of STAT word is mapped to bits 0-1 (Validity) and bit 11 (test) of Quality field.



Bits	Attribute name	Attribute value
0-1	Validity	Good(00) / Invalid(01) / Reserved(10) / Questionable(11)
2	Overflow	TRUE(1) / FALSE(0)
3	OutofRange	TRUE(1) / FALSE(0)
4	BadReference	TRUE(1) / FALSE(0)
5	Oscillatory	TRUE(1) / FALSE(0)
6	Failure	TRUE(1) / FALSE(0)
7	OldData	TRUE(1) / FALSE(0)
8	Inconsistent	TRUE(1) / FALSE(0)
9	Inaccurate	TRUE(1) / FALSE(0)
10	Source	Process(0) / Substituted (1)
11	Test	TRUE(1) / FALSE(0)
12	OperatorBlocked	TRUE(1) / FALSE(0)

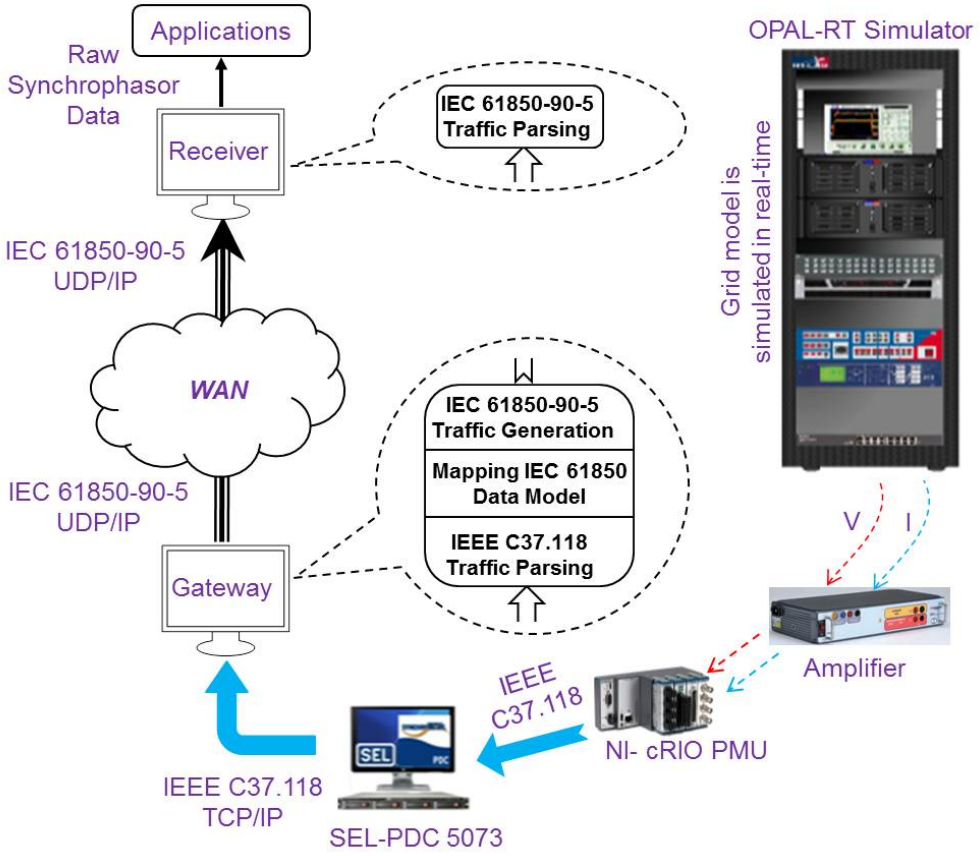
IEEE C37.118.2		IEC 61850-90-5
Configuration Message	Data Message	
	STAT (Bits 14-15 (Data Error) =01)	Quality (Bit 11(test) = FALSE, Bits 0-1(Validity)= 11(Questionable)) "PhyHealth" data object in LPHD1 ("stVal" = 3) LPHD1.PhyHealth.stVal
	STAT (Bits 14-15 (Data Error) =10)	Quality (Bit 11(test) = TRUE, Bits 0-1(Validity)=01(Invalid))
	STAT (Bits 14-15 (Data Error) =11)	Quality (Bit 11(test) = FALSE, Bits 0-1(Validity)=01(Invalid)) "PhyHealth" data object in LPHD1 ("stVal" = 3) LPHD1.PhyHealth.stVal

Performance Assessment Results

- Real-Time Hardware-in-the-Loop (RT-HIL) Validation
- Wireshark Capture Analysis

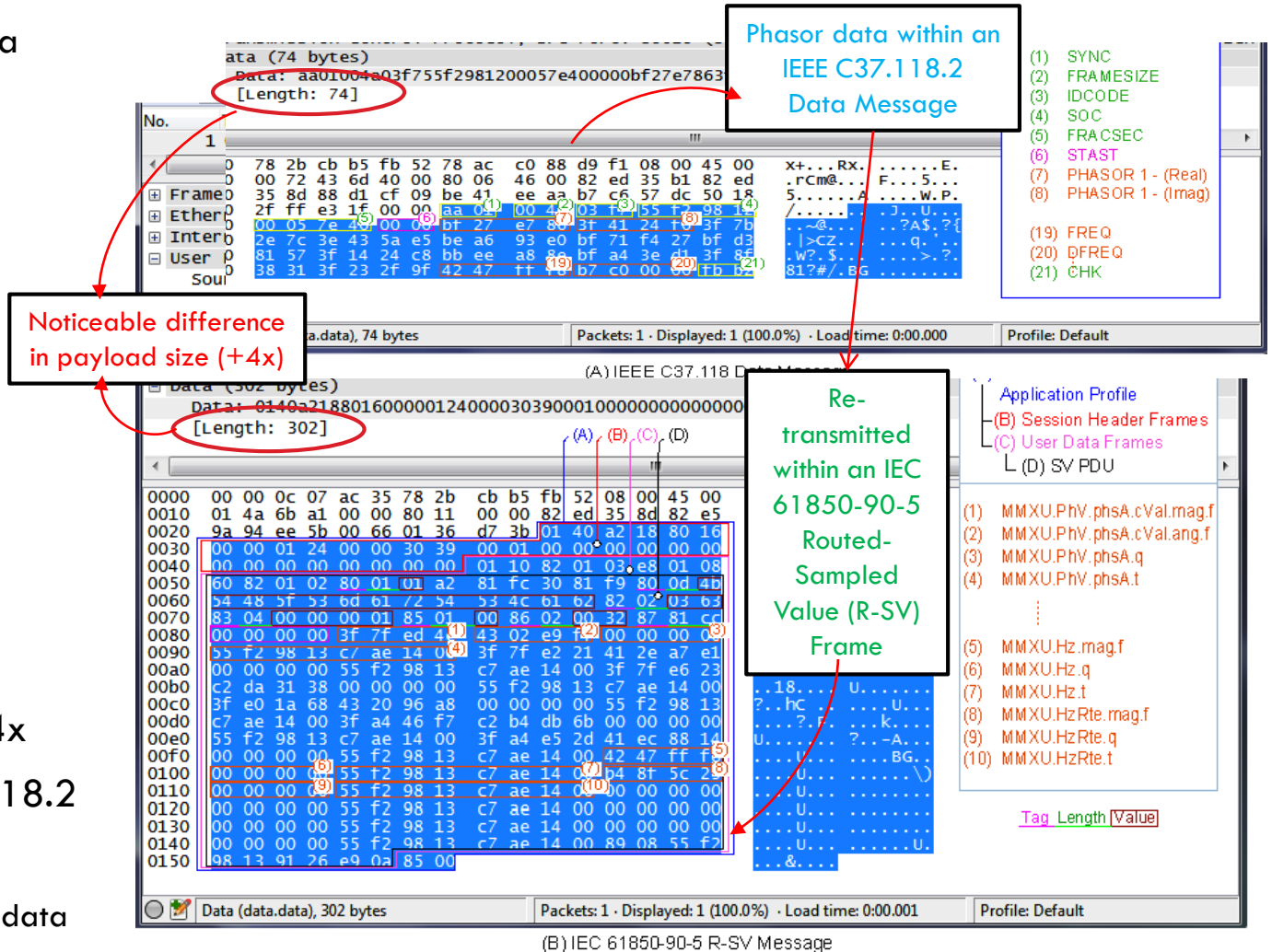
Real-Time Hardware-in-the-Loop (RT-HIL) Validation

- The Khorjin Gateway is interacting with real-time data
  - Its functionality validated in a Real-Time Hardware-in-the-Loop (RT-HIL) simulation environment.
- IEEE C37.118 Conformance:
  - Verified by successful connection and communication with the SEL-5073 synchroWAVe PDC software (SEL-PDC 5073), compliant with IEEE C37.118.
- IEC 61850-90-5 Conformance:
  - Verified by analyzing the UDP/IP frames captured by Wireshark network protocol analyzer software



Wireshark Capture Analysis – Routed-Sampled Value

- Routed-Sampled Value (R-SV) Traffic Generation Test
  - A. IEEE C37.118.2 Data Message (TCP/IP)
  - B. IEC 61850-90-5 R-SV Message (UDP/IP)
    - Exchanged Data
      - 1 PMU data stream:
        - 3 Voltage Phasor
        - 3 Current Phasor
        - No Analog
        - No Digital
        - Frequency
        - ROCOF
    - R-SV payload is +4x larger than IEEE C37.118.2 Data Message
      - The same raw PMU data



Wireshark Capture Analysis – Routed-GOOSE

- Routed-GOOSE (R-GOOSE)

Traffic Generation Test

A. IEEE C37.118.2 Data Message (TCP/IP)

B. IEC 61850-90-5 R-GOOSE Message (UDP/IP)

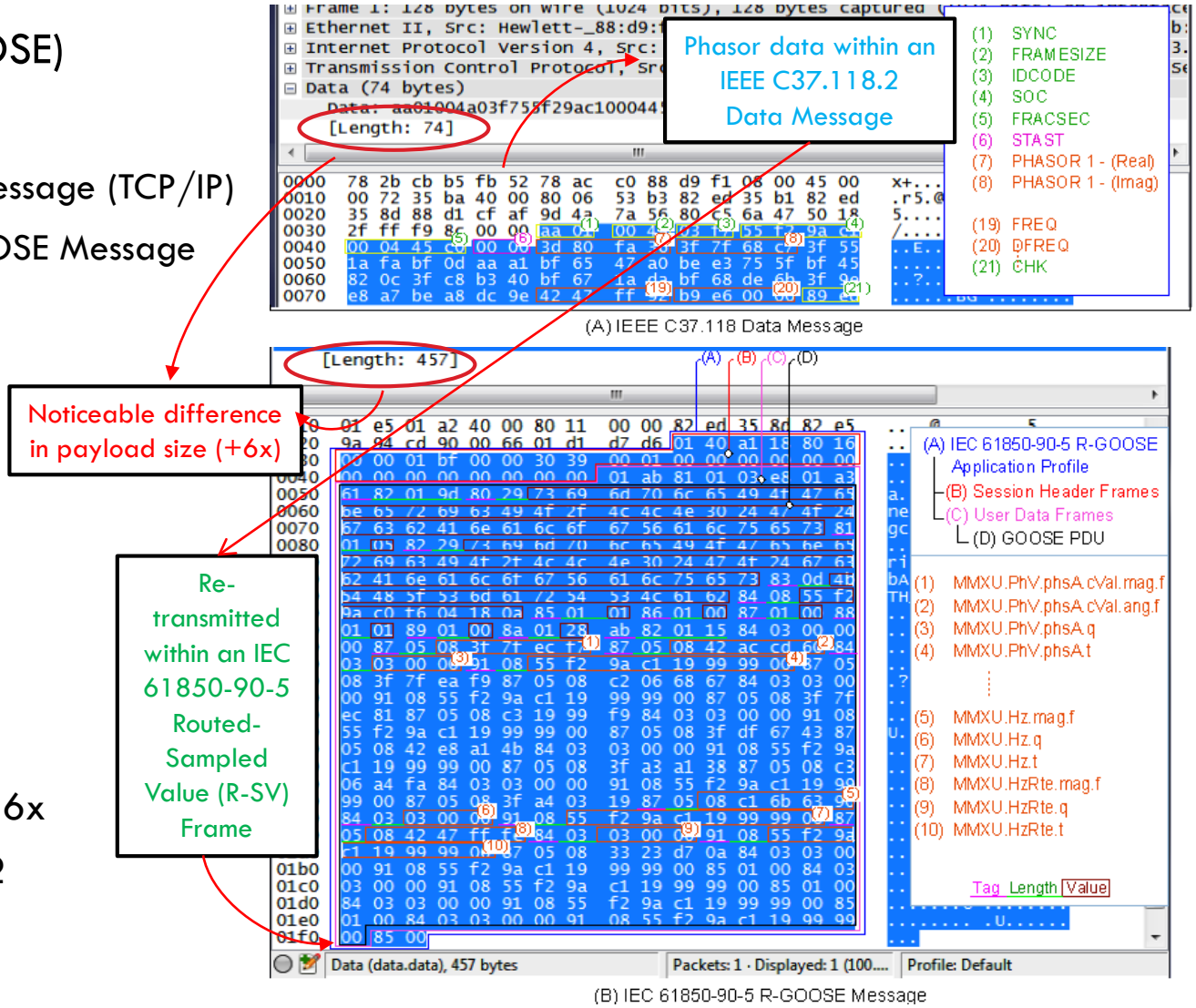
  - Exchanged Data

    1 PMU data stream:

    - 3 Voltage Phasor
    - 3 Current Phasor
    - No Analog
    - No Digital
    - Frequency
    - ROCOF

  - R-GOOSE payload is +6x larger than IEEE C37.118.2 Data Message

    - The same raw PMU data



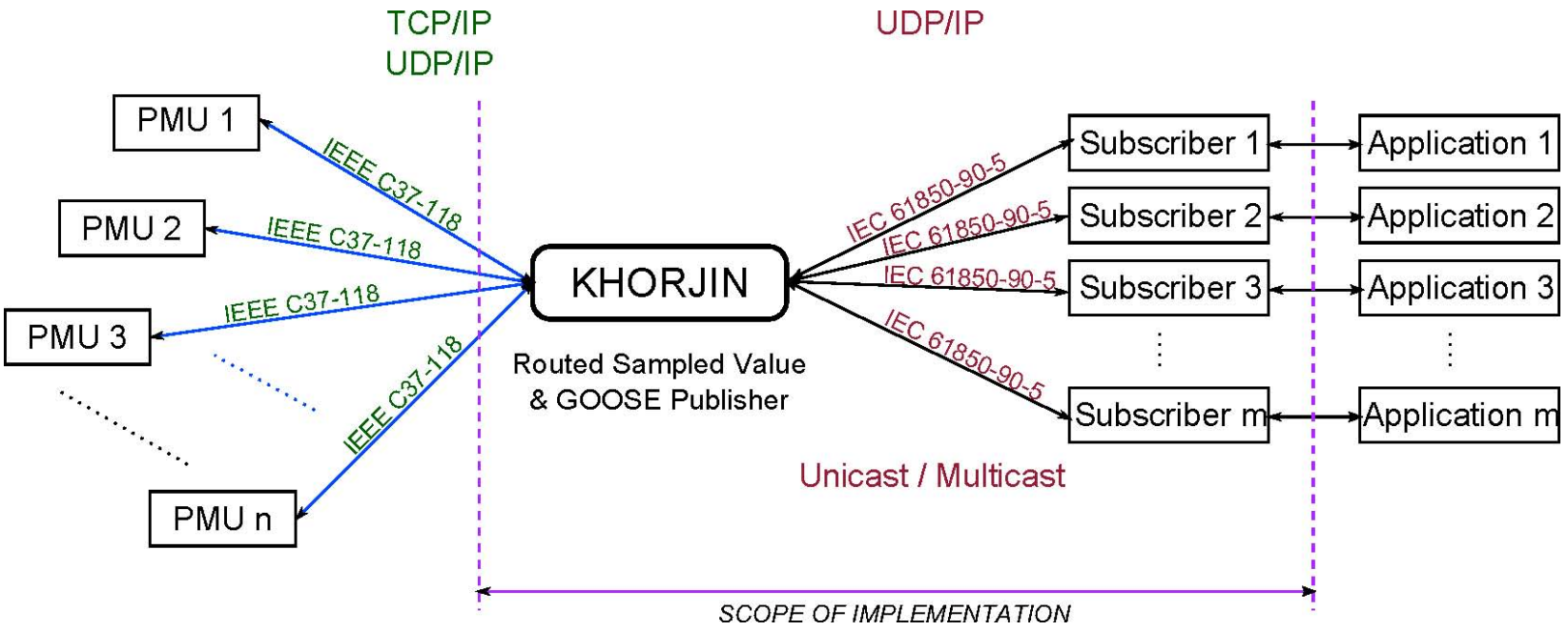
Conclusion and Future Works

Conclusion

- IEC 61850-90-5 (2012) and IEEE C37.118.2 (2011) are the two major standards for synchrophasor data transfer.
- A library, named as "Khorjin", is developed providing two functionalities of:
  1. IEEE C37.118.2 to IEC 61850-90-5 Protocol Converter (Gateway)
  2. IEC 61850-90-5 Traffic Parser
- The modular architecture of Khorjin Gateway library is introduced.
- The mapping specification of data contained in IEEE C37.118.2 Data and Configuration type-2 (CFG-2) messages to the IEC 61850 data model is presented.
- The functionality of the Khorjin library is validated in the Real-Time Hardware-in-the-Loop (RT-HIL) simulation environment available at the KTH SmarTS Lab.
- Wireshark captures of the IEEE C37.118.2 and IEC 61850-90-5 frames are analyzed.
- One of the noticeable issues in comparison to IEEE C37.118.2, was the multiple fold difference in the frame payload size. (R-SV +4x, R-GOOSE +6x)

Future Works

- Implementation of security algorithms presented in the IEC 61850-90-5
- Implementation of the PDC Functionality of Khorjin Gateway
  - Communicating with multiple PMUs/PDCs using IEEE C37.118.2 and transferring multiple PMU/PDC Data Streams within an IEC 61850-90-5 Routed-Sampled Value /Routed-GOOSE message.



Questions?

Thank you!

Reference

[1] S.R. Firouzi, L. Vanfretti, A. Ruiz-Alvarez, F. Mahmood, H. Hooshyar and I. Cairo, *"An IEC 61850-90-5 Gateway for IEEE C37.118.2 Synchrophasor Data Transfer"*, Accepted to be published in the proceedings of the IEEE Power Engineering Society (PES) General Meeting, Boston, USA, July 2016.