# NIST Presentations at the 2018 Innovative Smart Grid Technologies (ISGT) Conference

- NIST Transactive Energy (TE) Challenge–TE System Simulation Results for DER Integration on the Distribution Grid – David Holmberg
- Co-Simulation of Heterogeneous CPS Using HLA –Martin Burns
- Interoperability Testbed for Smart Sensors in Smart Grids – Eugene Song and Jerry FitzPatrick

# NIST TE Challenge Phase II Panel

## Modeling and Simulation for the Transactive Smart Grid

ISGT, February 21, 2018

David Holmberg
NIST

# Today's session

- Introduce the TE Challenge: drivers, goals and timeline
- The common TE co-simulation platform
- The TE Challenge common scenario
- The teams and their TE simulations

# NIST TE Challenge Drivers

- We need simulation tools to investigate the potential for TE approaches to integrate DER and enable customer load/DER to follow variable supply.
- We need community focus to build up knowledge of the tools and capabilities for TE, and advance the tools themselves.
- We need to provide simulation tools and results to regulators and policy makers to help make decisions on utility pilots and programs.

# NIST TE Challenge Goals

1. Perform TE simulations using collaboratively developed TE scenario that serves as a baseline for comparisons of results.
   - Challenge Scenario
2. Develop simulation-platform-agnostic common understandings and interoperable TE modeling approaches that will allow the broad community to incorporate transactive elements into their own analyses.
   - Common Platform Model (Abstract Component Model)
3. Build up the TE community and promote collaborations that can support efforts to advance TE implementations.
   - Phase I and Phase II teams
4. Enhance communication by providing visibility for different co-simulation platforms and understanding of strengths for each.
   - Meetings and publications

# TE Challenge Timeline

- September 2015: Launch of Phase I and formation of Phase I teams
- Summer 2016: Completion of Phase I team efforts, development of Co-simulation platform model
- Fall 2016: Outreach meetings in NY City and San Jose, CA.
- April 20, **2017** TE Simulation Challenge **Phase II Launch**.
- May-July Series of web meetings for **Challenge Scenario development**
- June 14, 2017 Face-to-face meeting and Scenario Workshop at the GWAC TE Systems Conference in Portland, OR.
- July 25, 2017 SEPA meeting **simulation start** announcement
- February 21, **2018** TE Challenge Capstone at ISGT to share simulation results.

# “Common Platform” for TE simulations

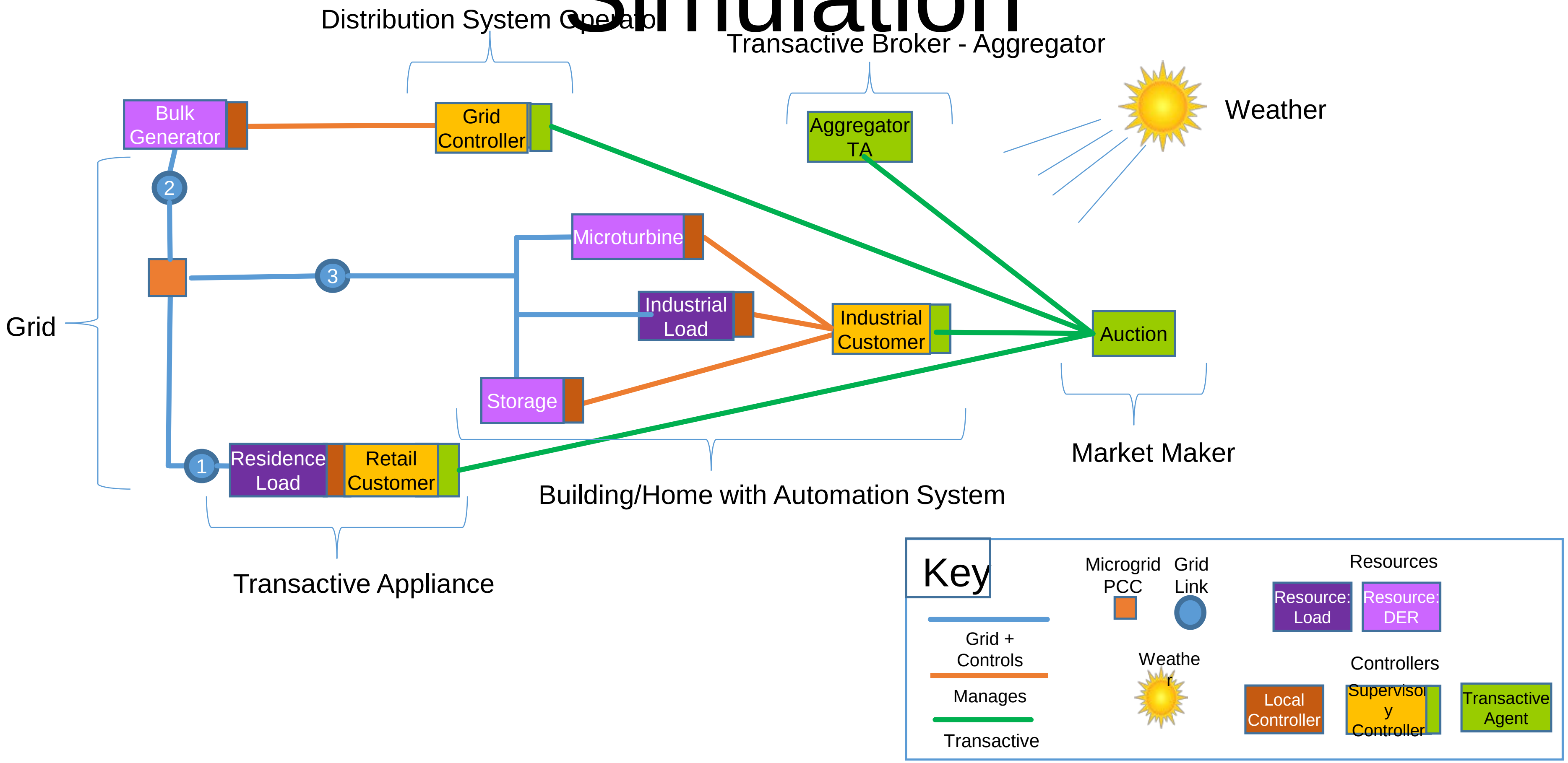
## Why do we need a “Common Platform” for TE simulations?

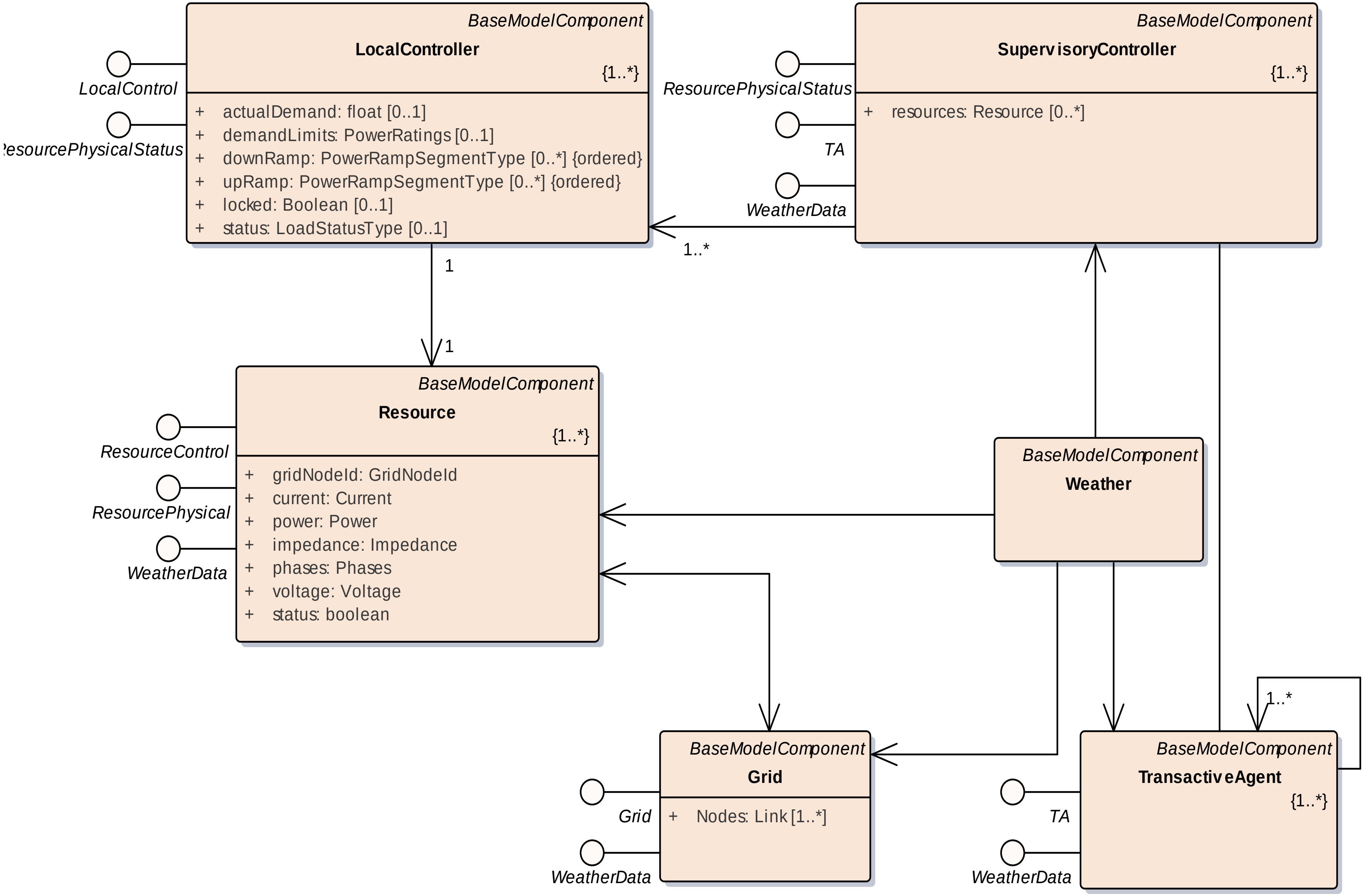
- It enables teams to **share common understanding of TE co-simulation** components and semantics
- In order to understand, evaluate, **compare and validate transactive energy approaches**, grid operations and controls.
- And to enable **potential for connecting library of tools and models** into a larger co-simulation environment for TE evaluations.

## 6 components in the Common Platform:

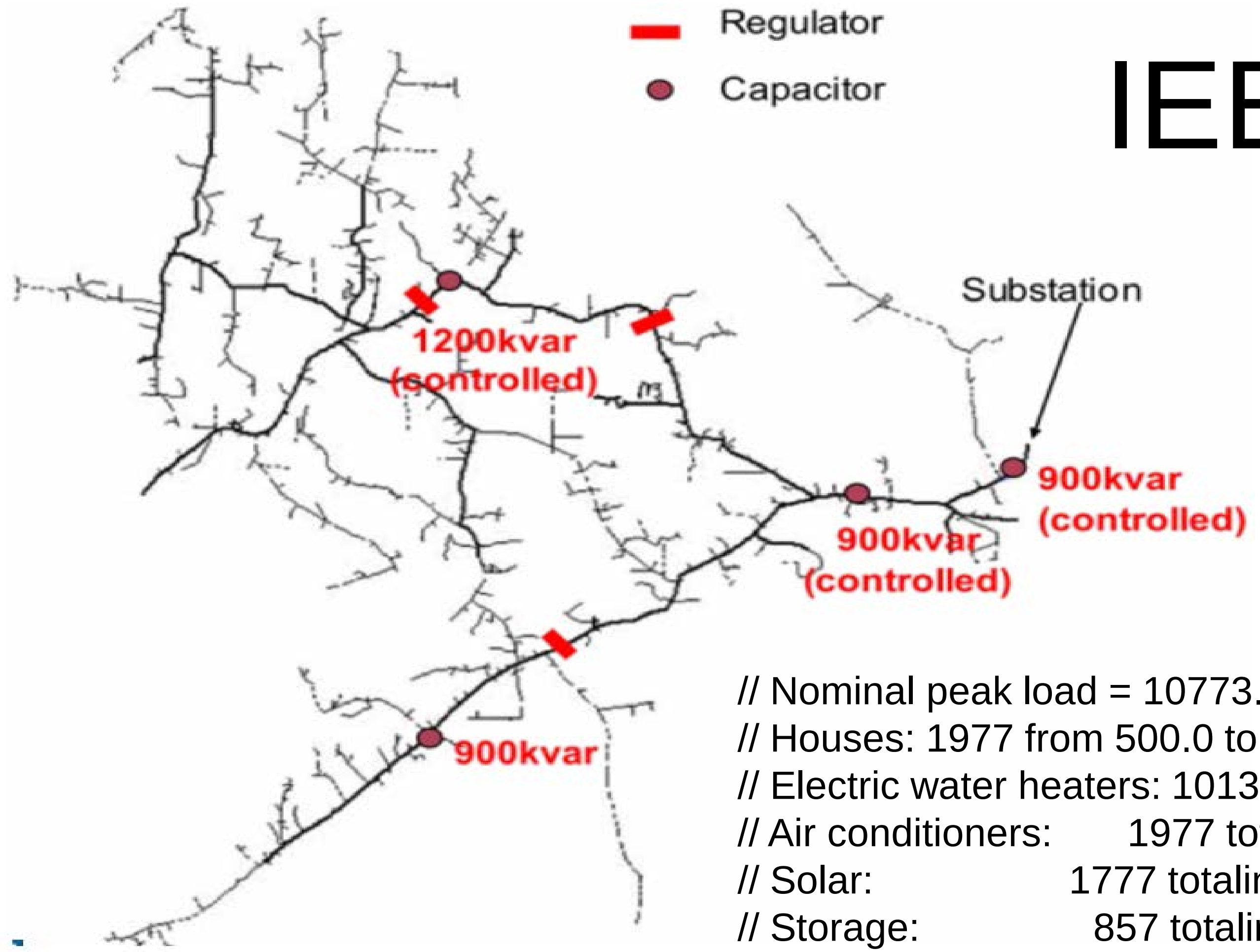
- o Grid
- o Resource (load or generator)
- o Resource controller
- o Supervisory controller
- o Transactive Agent
- o Weather

# Notional Topology of a TE Simulation



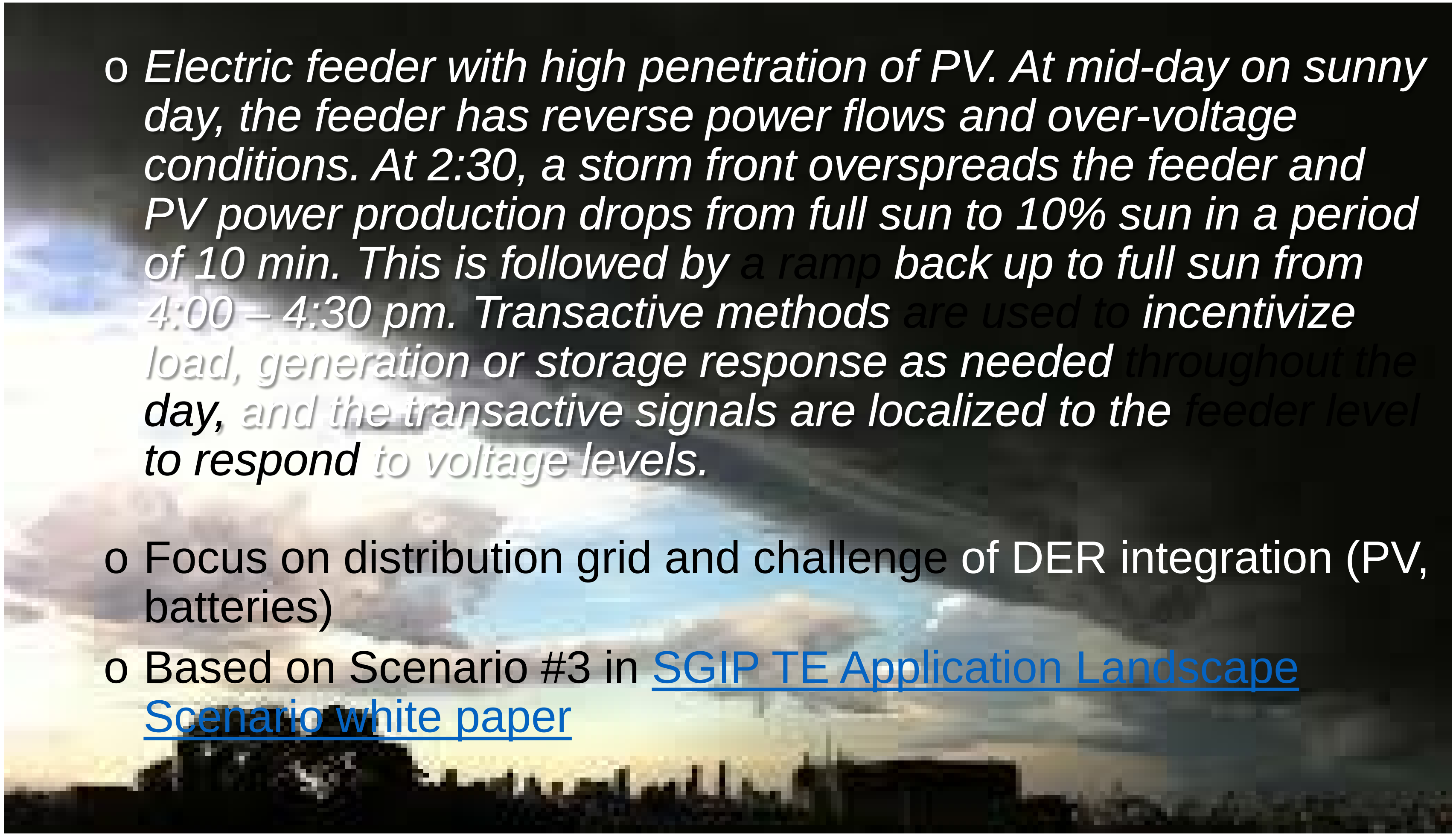

BaseModelComponent
LocalController
{1..*}
LocalControl
ResourcePhysicalStatus
+ actualDemand: float [0..1]
+ demandLimits: PowerRatings [0..1]
+ downRamp: PowerRampSegmentType [0..*] {ordered}
+ upRamp: PowerRampSegmentType [0..*] {ordered}
+ locked: Boolean [0..1]
+ status: LoadStatusType [0..1]
BaseModelComponent
SupervisoryController
{1..*}
ResourcePhysicalStatus
TA
WeatherData
+ resources: Resource [0..*]
1..*
1
1
BaseModelComponent
Resource
{1..*}
ResourceControl
ResourcePhysical
WeatherData
+ gridNodeId: GridNodeId
+ current: Current
+ power: Power
+ impedance: Impedance
+ phases: Phases
+ voltage: Voltage
+ status: boolean
BaseModelComponent
Weather
BaseModelComponent
Grid
Grid
WeatherData
+ Nodes: Link [1..*]
BaseModelComponent
TransactiveAgent
{1..*}
1..*
TA
WeatherData

# IEEE 8500 grid




// Nominal peak load = 10773.2 + j2700.0 kVA
// Houses: 1977 from 500.0 to 3500.0 sf, total area 3941782 sf
// Electric water heaters: 1013 totaling 4574.7 kW
// Air conditioners: 1977 totaling 26150.6 kW
// Solar: 1777 totaling 6755.2 kW
// Storage: 857 totaling 4285.0 kW
// Water heater load is resistive
// HVAC load ZIP=0.2,0.0,0.8 with variable power factor as input
// (the fan load ZIP=0.2534,0.7332,0.0135 and pf=0.96)
// Non-responsive ZIP load is input all constant current, pf=0.95

# Challenge Scenario Narrative



- *Electric feeder with high penetration of PV. At mid-day on sunny day, the feeder has reverse power flows and over-voltage conditions. At 2:30, a storm front overspreads the feeder and PV power production drops from full sun to 10% sun in a period of 10 min. This is followed by a ramp back up to full sun from 4:00 – 4:30 pm. Transactive methods are used to incentivize load, generation or storage response as needed throughout the day, and the transactive signals are localized to the feeder level to respond to voltage levels.*

- Focus on distribution grid and challenge of DER integration (PV, batteries)
- Based on Scenario #3 in [SGIP TE Application Landscape Scenario white paper]

# Common Metrics

- Economic: wholesale price, cleared prices on feeder, bid details, revenue/bill for each resource
- Substation: real and reactive power/energy/losses
- At each feeder capacitor bank and voltage regulator: count of control actuations
- At each house meter
  - Voltage magnitude, line-to-neutral, averaged over all phases
  - Voltage magnitude, line-to-line, averaged over all phases
  - For three-phase loads only, line-to-line voltage unbalance as defined in ANSI C84.1
  - Severity index for the fluctuation in $V_{avg}$ on per-unit basis at uniform time step.
  - Violations of ANSI C84.1 voltage limits at the meter.
  - Total HVAC load (real power)
  - Total water heater load (real power)
  - Solar inverter real and reactive power
  - Battery inverter real and reactive power
  - House air temperature, and its deviation from scheduled set point
  - Water heater temperature, and its deviation from scheduled set point
  - Total bill, synchronized to the cleared market price
- Using the balanced-secondary version of the IEEE 8500-node model and net metering assumption, with DER disaggregation based on real power.

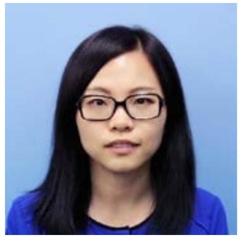
# Team Simulations

- Implementing the baseline scenario in four steps:
  1. Baseline sunny day. The event day is run with no storm front passing. Electricity price is constant with no TE market interactions.
  2. Adding storm front. Simulation repeated with storm front weather file, all else same.
  3. Adding dynamic price, but still no TE market. Teams may enable resources to be price responsive, but there are no TE exchanges (resources are price takers only).
  4. Each team may use whichever TE model they want to use with the feeder and weather event the same.

# Teams and presenters today

TE $ CHALLENGE

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Fei Ding

TATA
TATA CONSULTANCY SERVICES

Yogesh Bichpuriya

Pacific Northwest
NATIONAL LABORATORY

Yingying Tang

Massachusetts Institute of Technology

Marija Ilic, Rupa Jaddivada

VANDERBILT UNIVERSITY

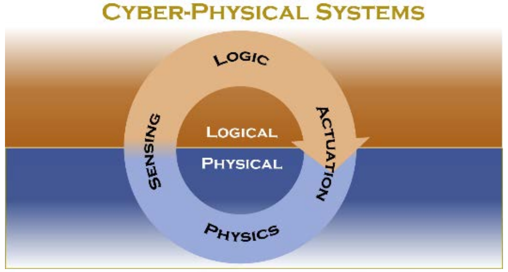
Himanshu Neema

# What the audience should learn

- Making progress on evaluating and comparing different TE approaches
- We have advanced a shared understanding of TE co-simulation
- Tools are available for TE evaluations
- Still many different approaches for TE, and simulations are needed.
- What can regulators/utilities do today?

# Thank you!

**David Holmberg**
**David.Holmberg@nist.gov**
**(301) 975-6450**




NIST

Universal CPS Environment for Federation

# Co-Simulation of Heterogeneous CPS using HLA

Dr. Martin J. Burns
Associate Director for Testbed Science
National Institute of Standards and Technology
Smart Grid and Cyber-Physical Systems Program Office

February 20th 2018

# The Session States the Challenge

Traditionally abundant reserves in the system have been eroded due to the increased penetration of variable resources, potentially impairing system reliability. To operate the power system with leaner reserve margins, distributed generation resources need to participate in maintaining—or improving—system resiliency and reliability. This requires new control and protection coordination systems, along with supporting communication networks. This is a revolution in how the power system is planned and operated, relying more heavily on hierarchical and distributed control architectures with greater dependency on a variety of communication media. Co-simulation and integrated planning of transmission, distribution, and communication systems (along with markets and other elements) allows planners to understand the bottlenecks and pitfalls of the interplay between power and communication systems to ensure safe and reliable operations; enable informed decisions on investments at multiple levels; and allow exploration of future scenarios in a wide variety of applications such as DER integration and distributed control. This panel will discuss current and future trends in this area, including utility experiences, example use cases, and ongoing development efforts.

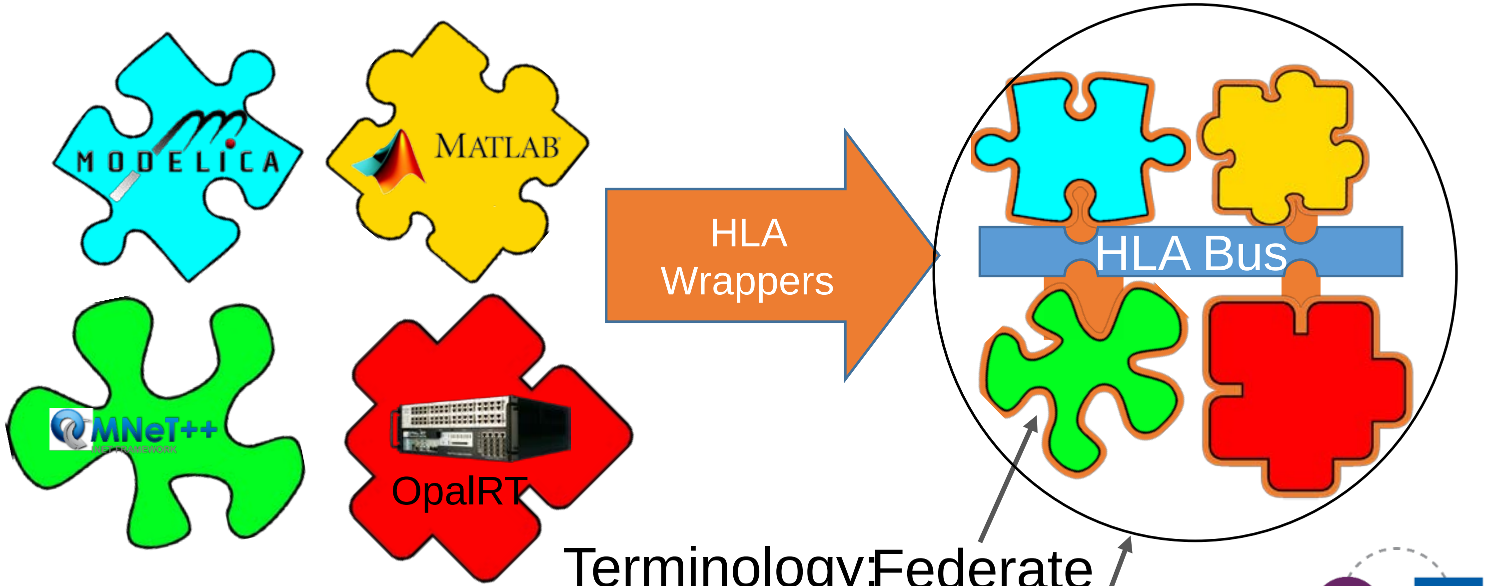
# Overview

- Federation Made Simple
- High-level Attributes of Co-Simulation Testbed
- NIST's CPS Testbed Architectural Concept
- Realization in the NIST/Vanderbilt Universal CPS Environment for Federation (UCEF)
- Transactive Energy Component Model

# Requirements for the CPS Testbed

| Requirement | OK | Value-add | Demo Component(s) |
|---|---|---|---|
| Integrative | ✔ | Integrates technologies, sectors, hybrid reality | Multiple platforms and models, diverse domains, integrated logical and physical time |
| Reconfigurable, Reproducible | ✔ | Rapid reconfiguration, federation manager allows reproducible experimental setup | Tear-down and setup, multiple experimental runs |
| Scalable | ✔ | Scalable platforms, distributed federation, hierarchical federation | Open Stack cloud platform, federation of federations, (remote federate) |
| Usable | ✔ | Collaborative projects, open architecture, immersive interface | Collaborative project, user deployment tools, results display |

# Basic Architectural Concept



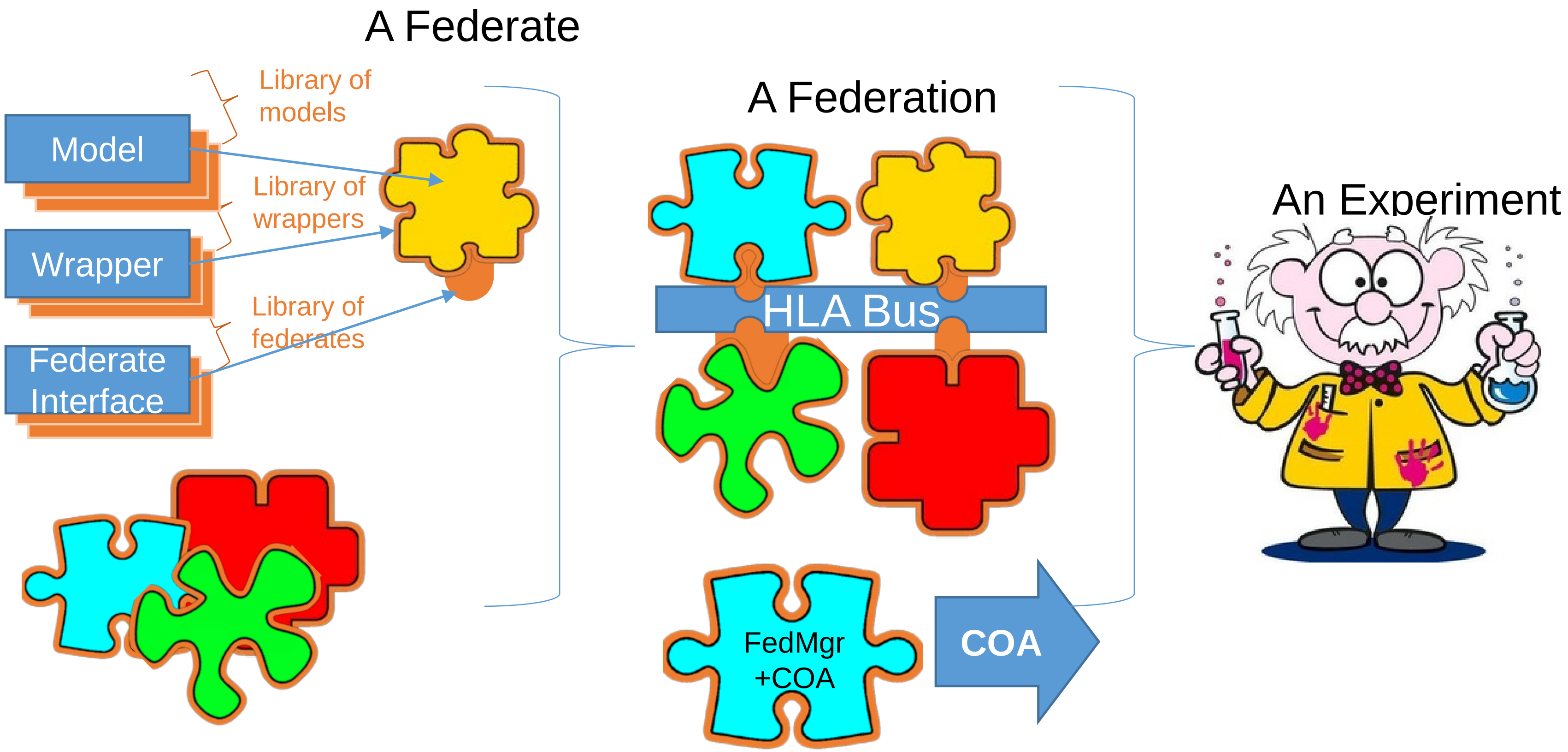

Terminology: Federate
Federation

Complete Software Platform:

Universal CPS Environment for Federation

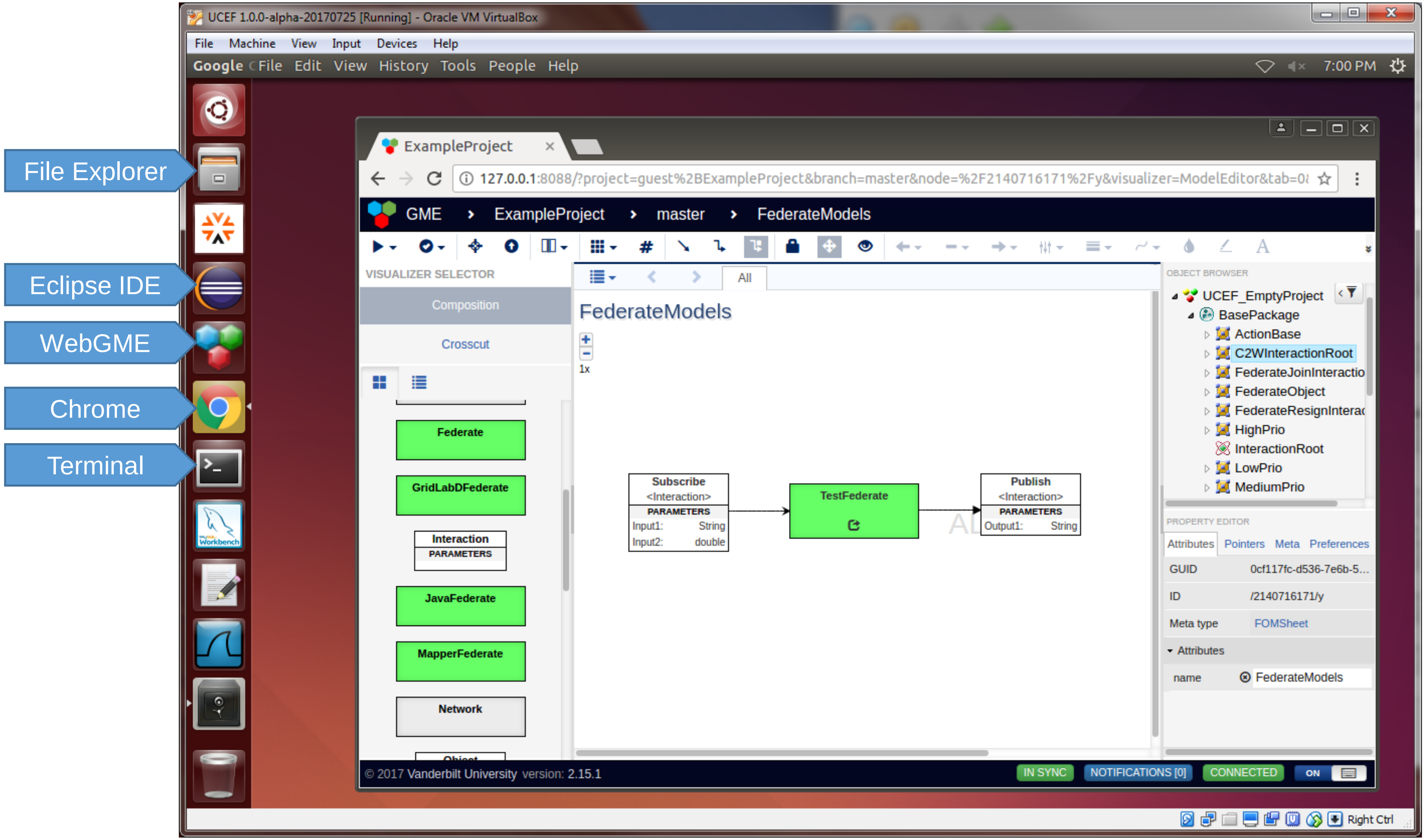
"UCEF"

# Anatomy of a Federate: Example Gridlab-D

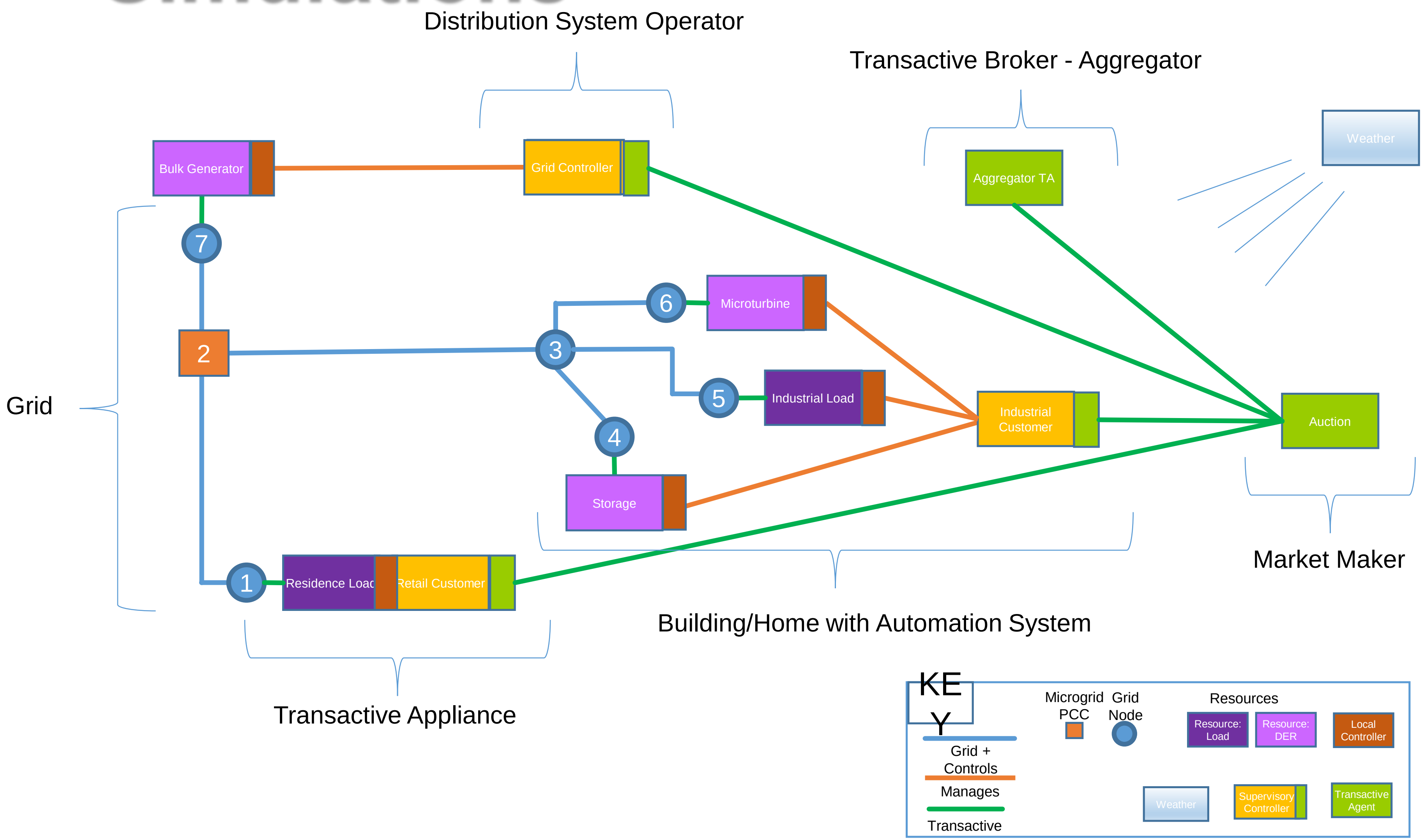


# Experiment Designer

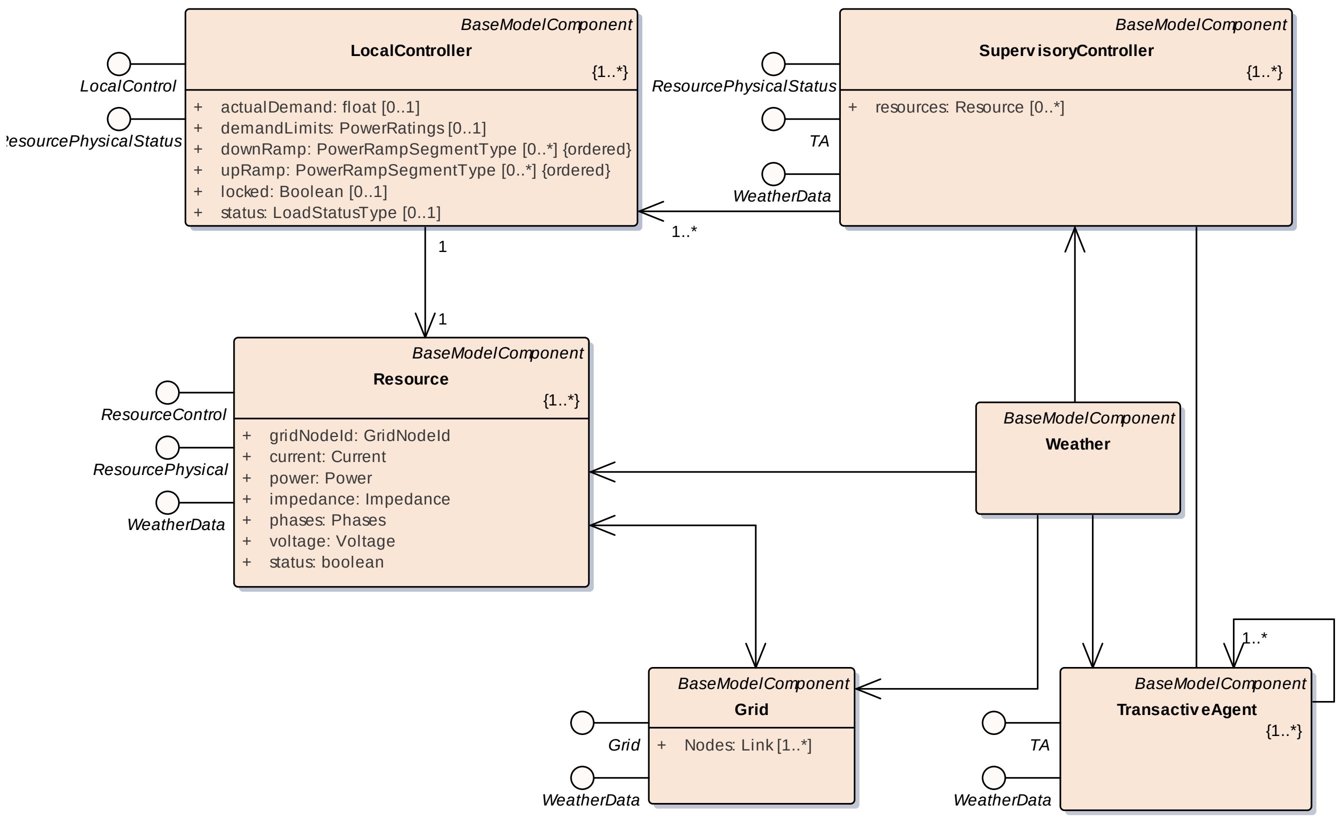
https://github.com/usnistgov/ucef



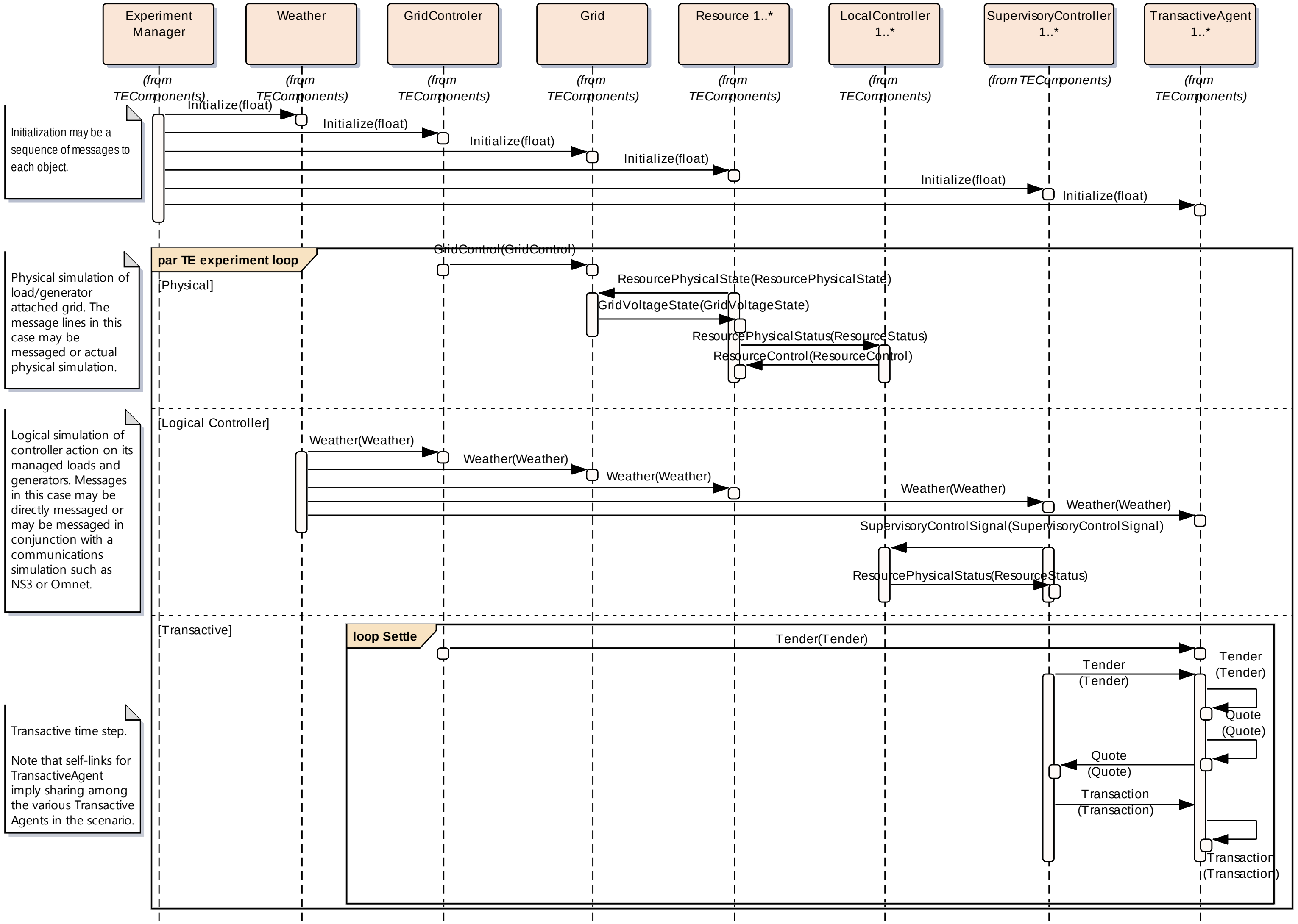
# Composability of TE Simulations



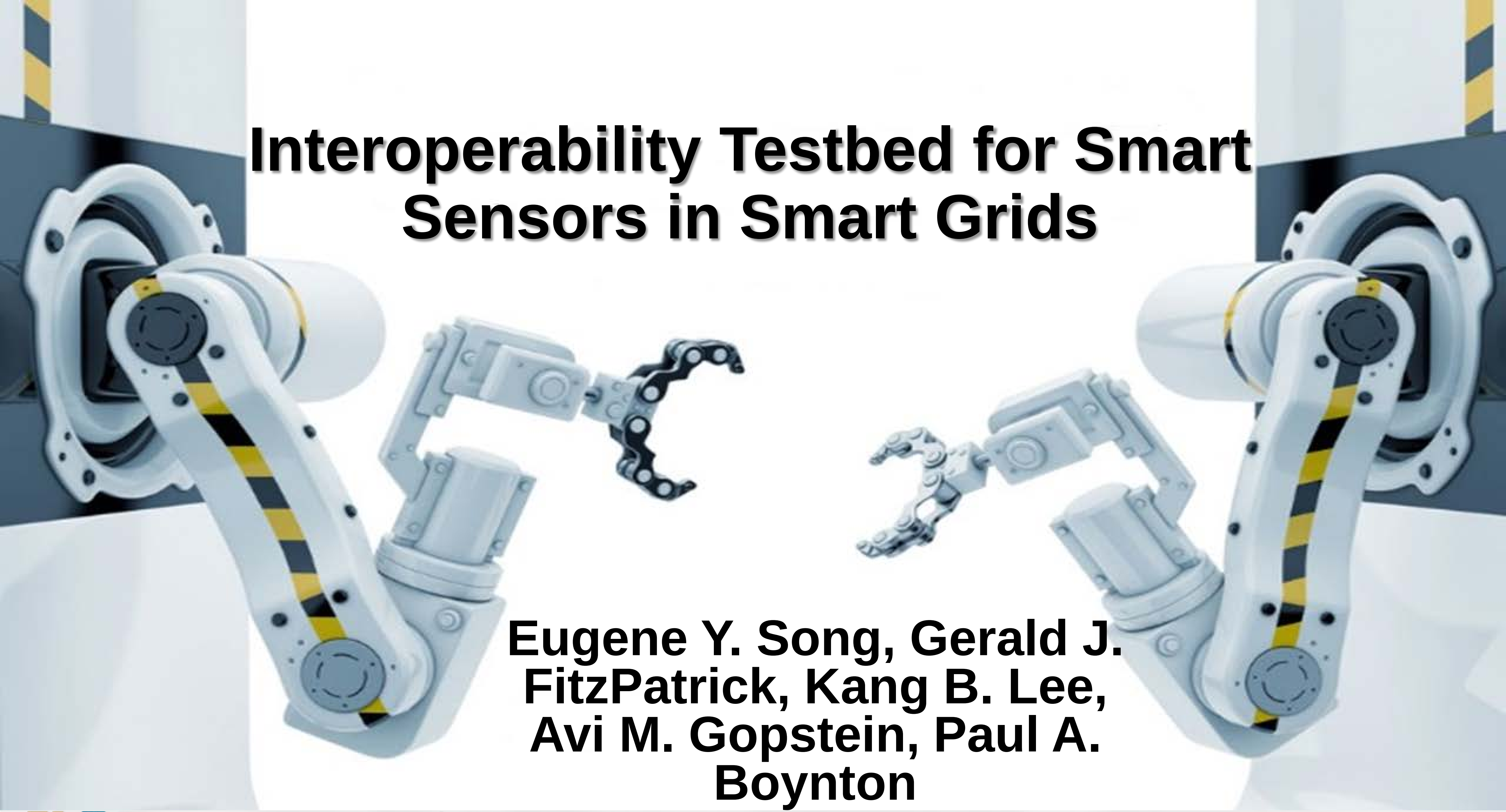
# Core Modeling Components of Common Platform



# Common Platform Canonical Simulation



# Thank YOU



# Interoperability Testbed for Smart Sensors in Smart Grids

**Eugene Y. Song, Gerald J. FitzPatrick, Kang B. Lee, Avi M. Gopstein, Paul A. Boynton**

# Agenda

1. Introduction
2. Smart Sensors in the Smart Grid
3. Interoperability Testbed for Smart Sensors
4. Test Cases for Merging Unit (MU)-based Smart Sensors
5. Summary

# 1. Introduction

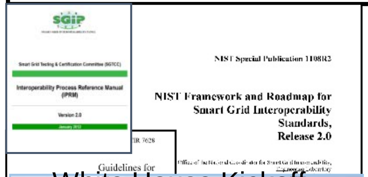
- Under the **Energy Independence and Security Act (EISA) of 2007,** the **National Institute of Standards and Technology (NIST)** was assigned the "***primary*** ***responsibility to coordinate development of a framework that includes protocols and model standards*** *for information management* ***to achieve interoperability of Smart Grid devices and systems****…*" (EISA Title XIII, Section 1305) *.

* https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/EISA_Title_XIII_Smart_Grid.pdf

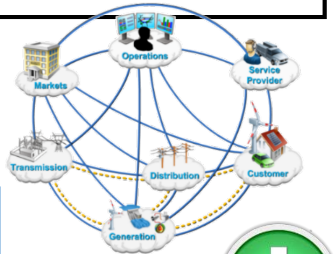
# 1. Introduction (Cont'd)

## NIST Outcomes

**NIST SG Framework (Release 1.0, 2.0 & 3.0)**




White House Kickoff




**Priority Action Plans (PAPs)**

NISTIR 7628 Guidelines for Cyber Security

**Smart Grid Interoperability Panel**

SGIP

SGIP SMART GRID INTEROPERABILITY PANEL

Smart Electric Power Alliance **(SEPA)**

Catalog of Standards, Governing Board, Completed PAPs, Committees/Pubs, …

New/revised smart grid standards, guidance, implementations

IEEE SAE NAESB IEC NEMA Underwriters Laboratories Inc. …more!

**NEMA SG-AMI 1, IEC 61850/CIM, IEEE 1547 & C37.118, UL1741, OASIS Energy Interop, ASHRAE 201 FSGIM, NAESB Green Button (ESPI)…more!**

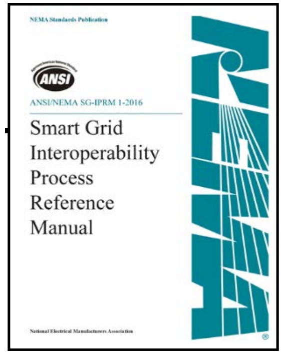
**NIST Smart Grid Research Portfolio: R&D, standards, testing/certification, publications, …**

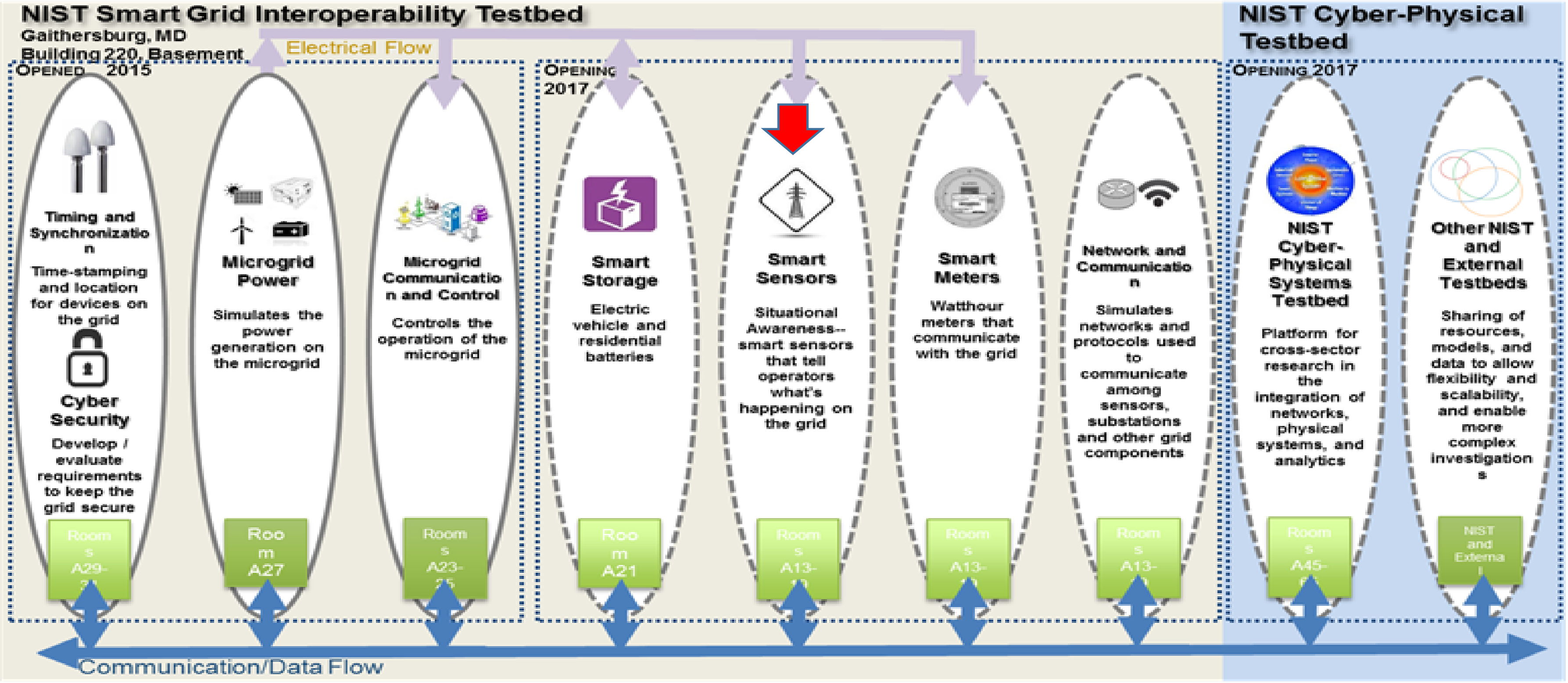
Source: David Wollman's presentation of NIST

# 1. Introduction (Cont'd)

**Testing and Certification**:

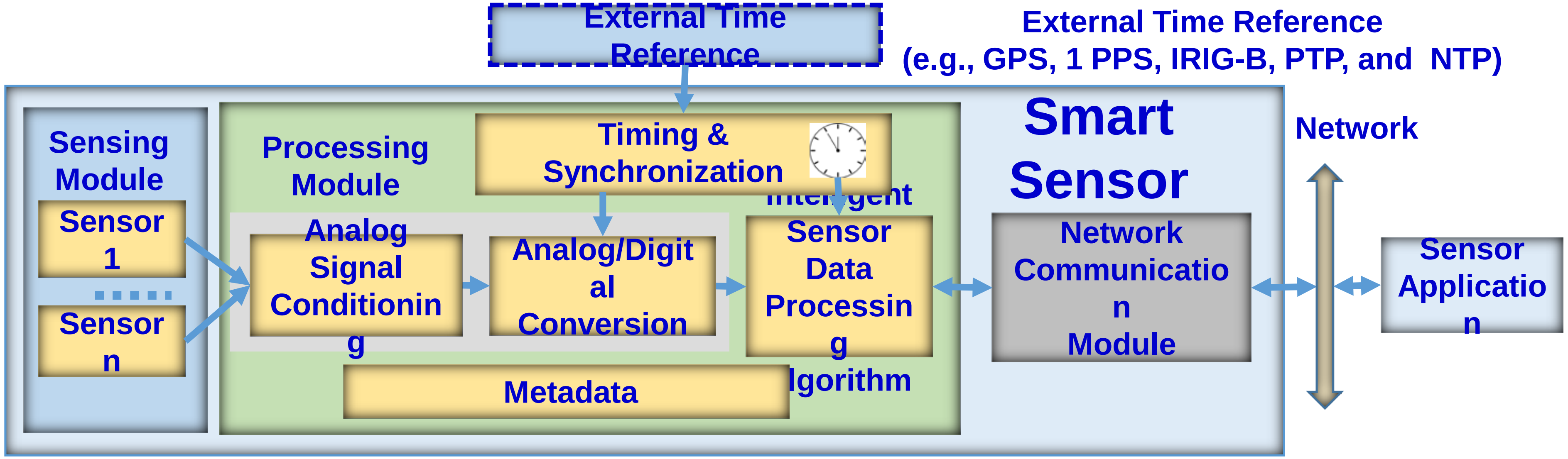
- **SG Interoperability Process Reference Manual (IPRM) - Guideline for T&C**
- **NIST SG Interoperability Testbed Facility - A platform for SG standards development**



# 2. Smart Sensors in Smart Grids

## A Generic Smart Sensor Model



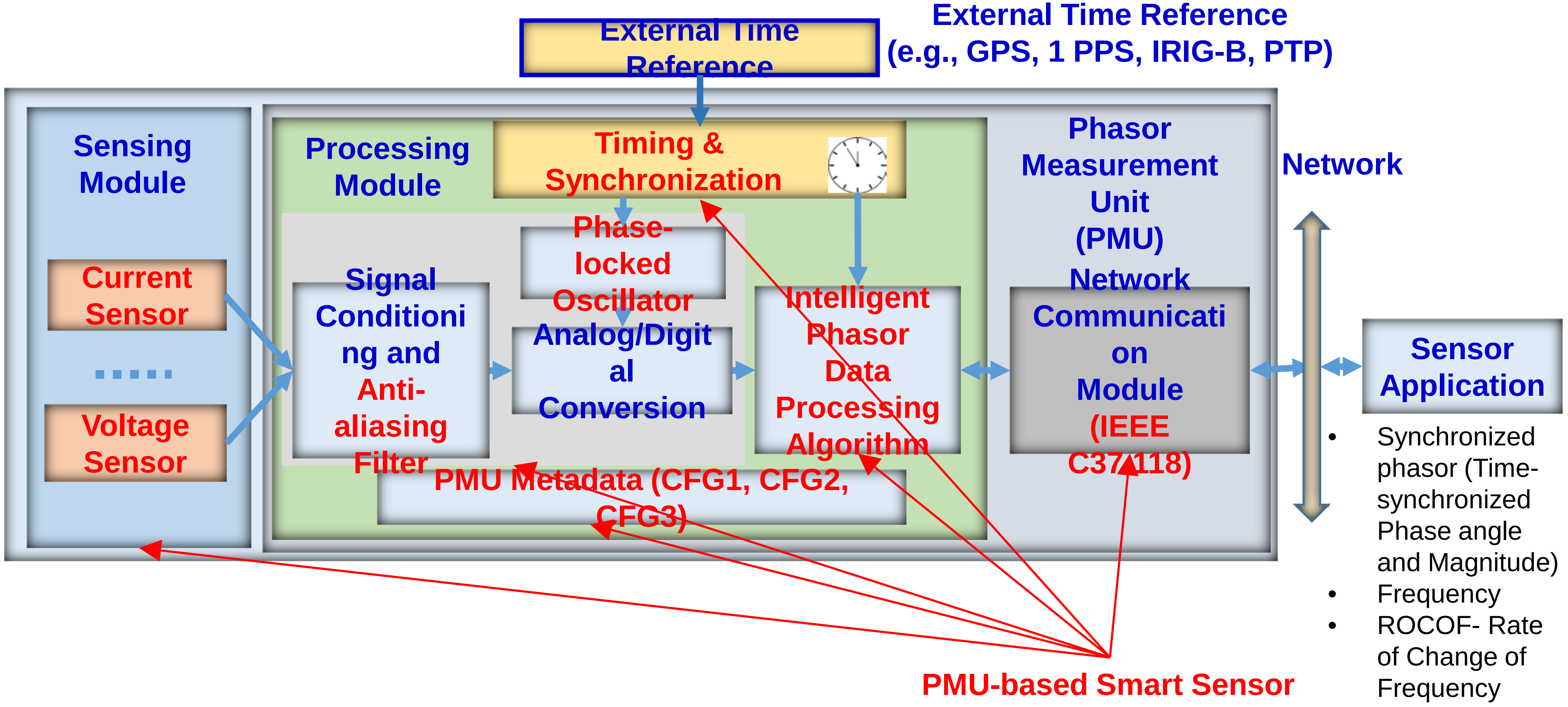

**Three Modules:**
- Sensing module
- Processing module (timing, signal processing, data processing and metadata)
- Communication Module

**Five Basic Capabilities:**
- Sensing
- Signal and data processing (intelligence)
- Network communication
- Timing & synchronization
- Metadata

**Standardized network Interfaces:**
- IEEE C37.118 PMU-based Smart Sensors (SSs)
- IEC 61850-9-2 MU-based SSs
- IEEE 1815 (DNP3)-based SSs
- IEEE 1451-based smart transducers (sensors and actuators)
- ……

# 2. Smart Sensors in Smart Grids (Cont'd)

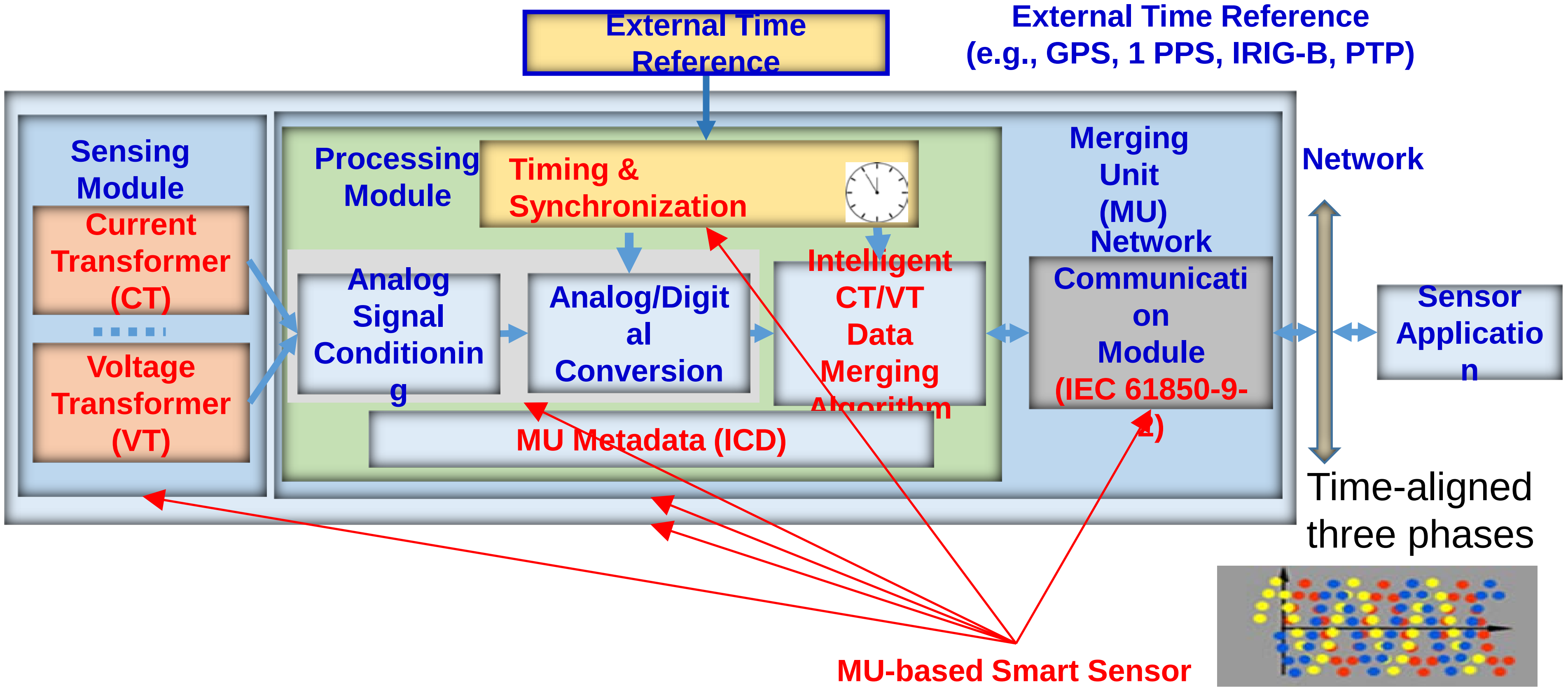
## IEEE C37.118 PMU-based Smart Sensor




- Synchronized phasor (Time-synchronized Phase angle and Magnitude)
- Frequency
- ROCOF- Rate of Change of Frequency

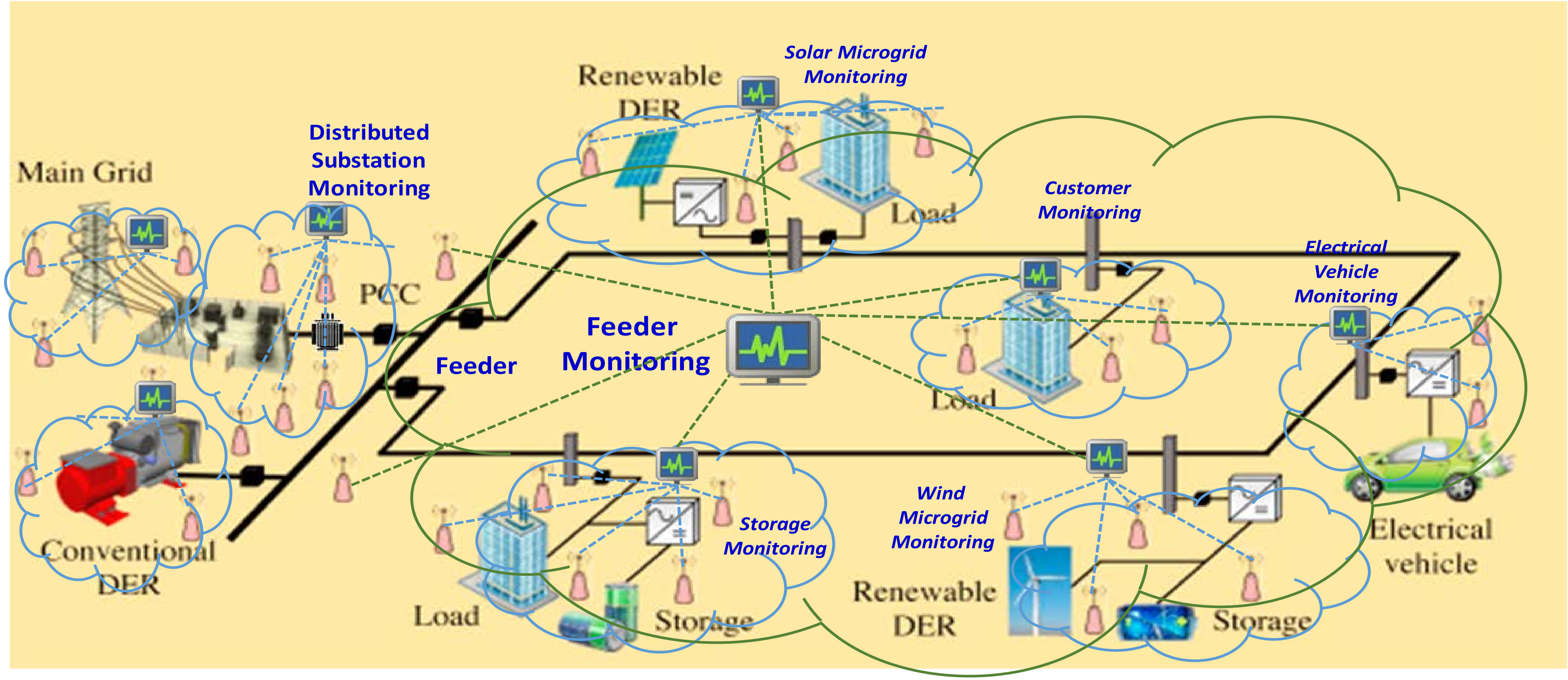
# 2. Smart Sensors in Smart Grids (Cont'd)

## IEC 61850-9-2 MU-based Smart Sensor



# 2. Smart Sensors in Smart Grids (Cont'd)

## Example of Monitoring, Protection, and Control for DERs




http://ars.els-cdn.com/content/image/1-s2.0-S1040619017300702-gr1.jpg

# 2. Smart Sensors in Smart Grids (Cont'd)

## Example of Substation Automation System (SAS)

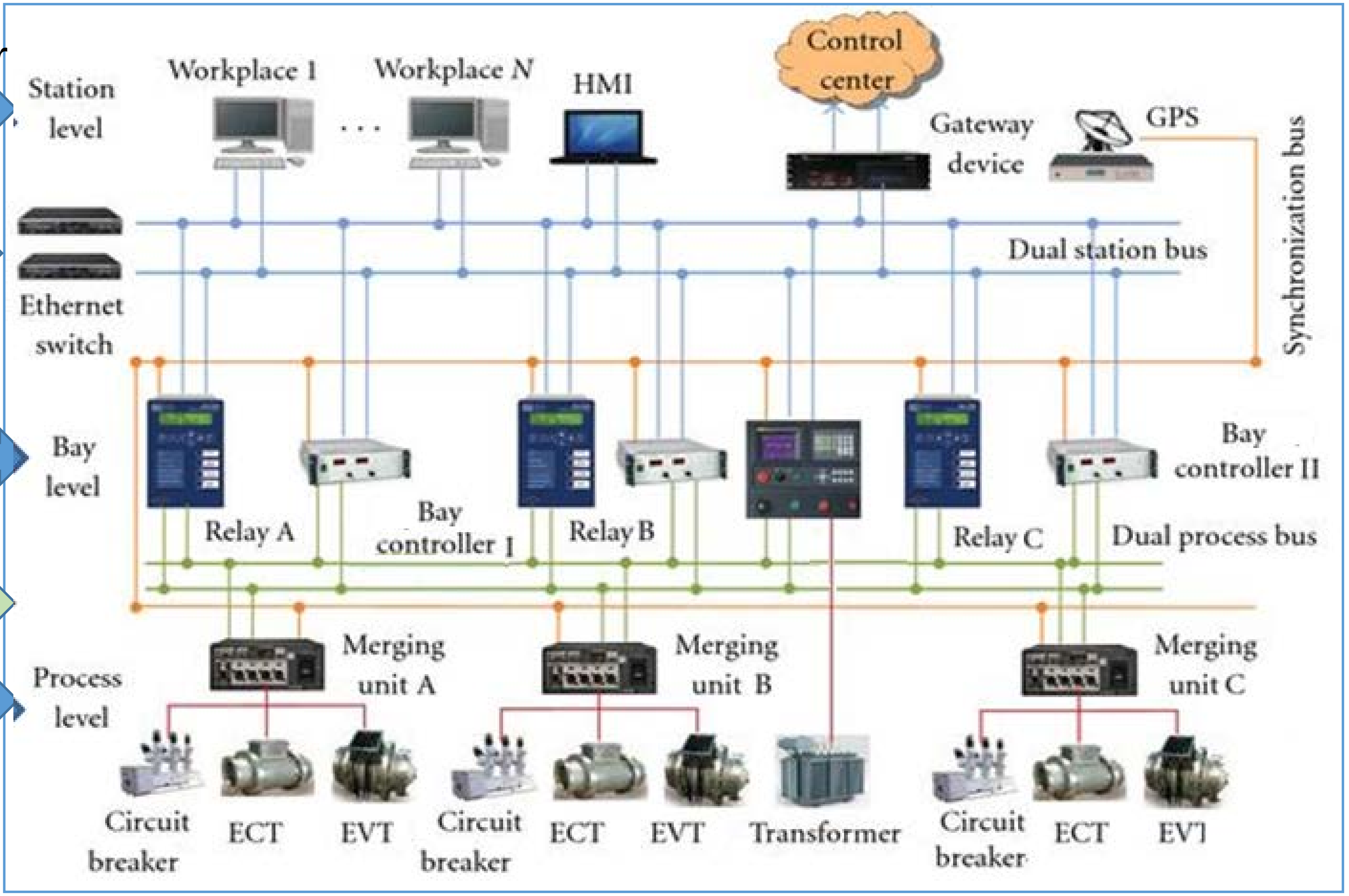
Control Center

Substation Bus (IEC 61850-1)

Protection Relay IEDs

Process Bus (IEC 61850-9-2)

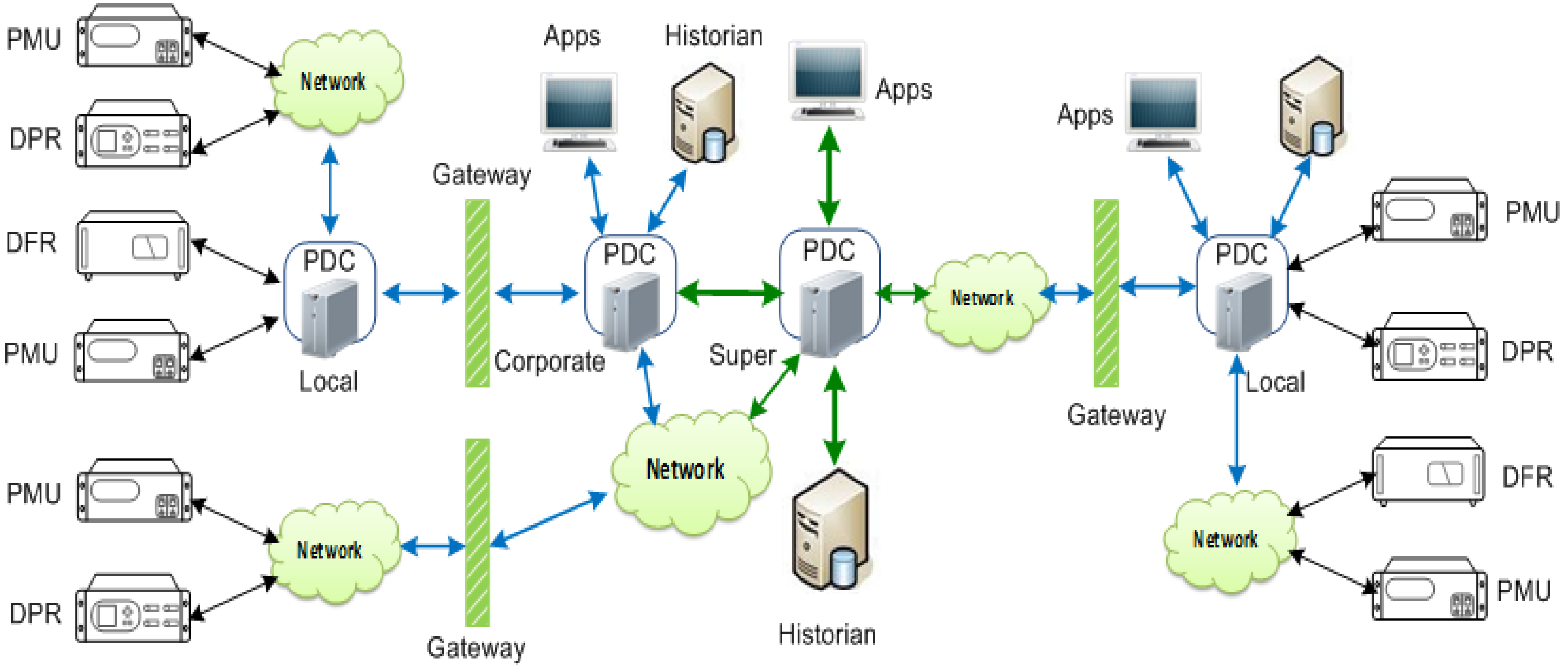
**Merging Units (MUs)**




(Source: http://www.hindawi.com/journals/ijdsn/2012/175262.fig.002.jpg)

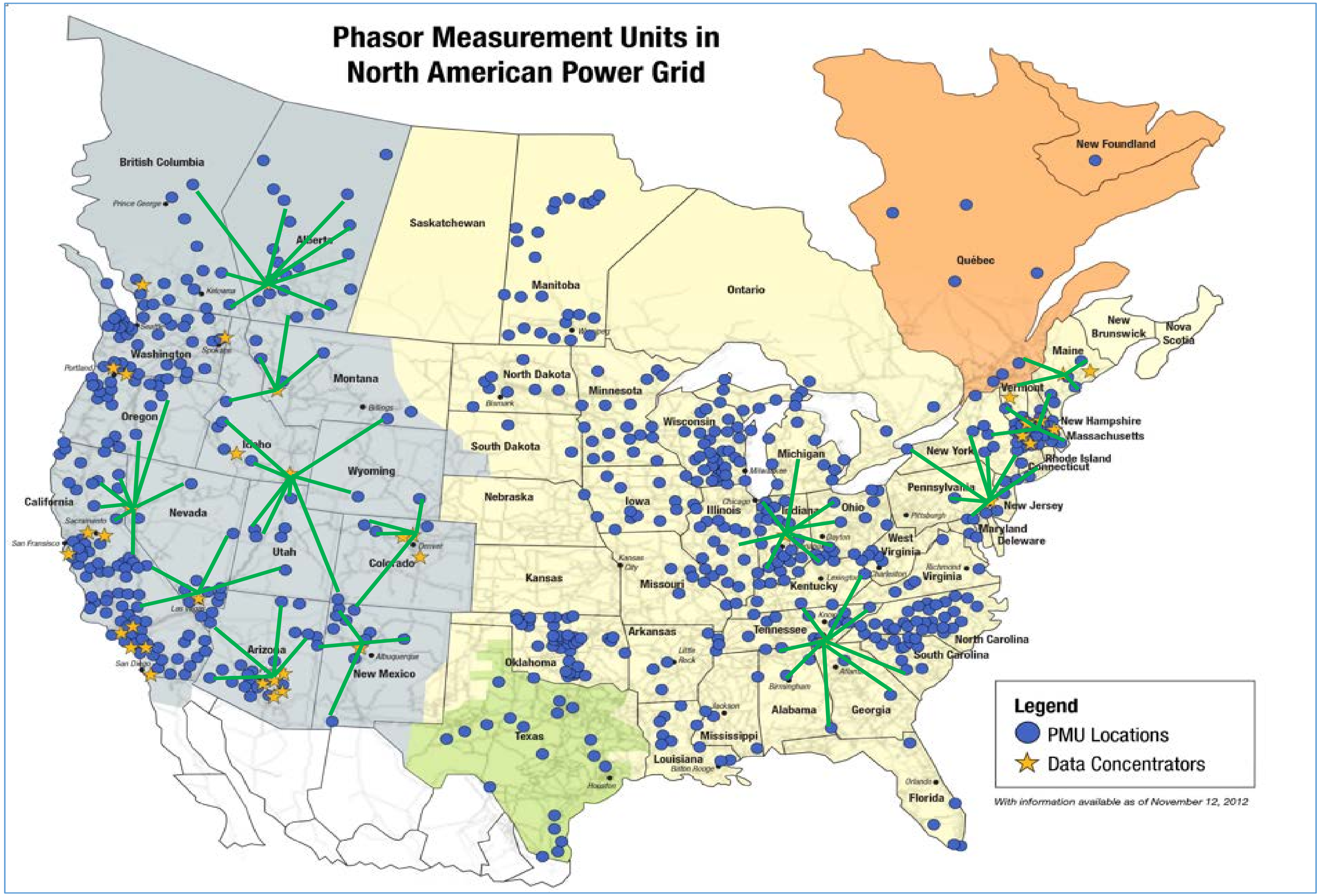
# 2. Smart Sensors in Smart Grids (Cont'd)

**Example of Wide-Area Monitoring, Protection, and Control System (WAMPCS)**




(Source: Electric Power Research Institute (EPRI ))

# 2. Smart Sensors in Smart Grids (Cont'd)




**Source:** North American SynchroPhasor Initiative (NASPI)

# 2. Smart Sensors in Smart Grids (Cont'd)

## Challenges of Monitoring, Protection, and Control (MPC) for SGs

**Challenge 1:**

How do you make thousands of **smart sensors** from different vendors **operate easily** in a MPC System?

**Challenge 2:**

How do you **exchange and share smart sensor** data with **smart sensor clients** (e.g., protection relays (PRs)) to achieve and assure data interoperability?

# 2. Smart Sensors in Smart Grids (Cont'd)

Solutions to Challenges of Monitoring, Protection and Control (MPC) for SGs

**Solution 1: Standardize smart sensor data formats, communication protocols and interfaces, such as IEC 61850-9-2, IEEE C37.118 to achieve interoperability**

**However: Smart sensors may not be interoperable to smart sensor client (e.g., protection relays (PRs)) even if they conform to the specific standard,** because:

- the standard has mandatory and optional functions;
- some definitions in the standard are ambiguous, not clear; and
- different developers or implementers may have different interpretations of the standards, which result in different implementations

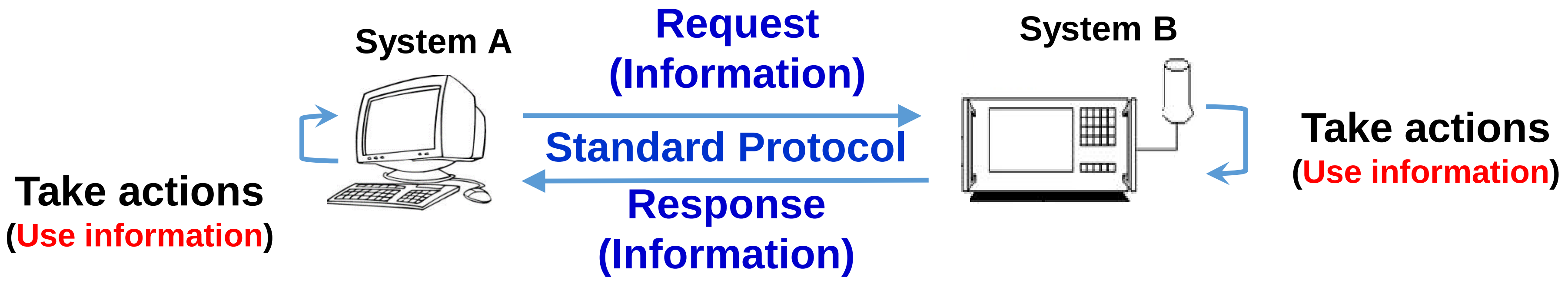
**Solution2: Conduct interoperability test of smart sensor to assure interoperability**

- developing and standardizing interoperability test methods for smart sensors;
- conducting plugfests or interoperability tests of smart sensors;
- certifying smart sensors based on interoperability tests conducted by accredited laboratories

# 3. Interoperability Testbed for Smart Sensors

## Interoperability:

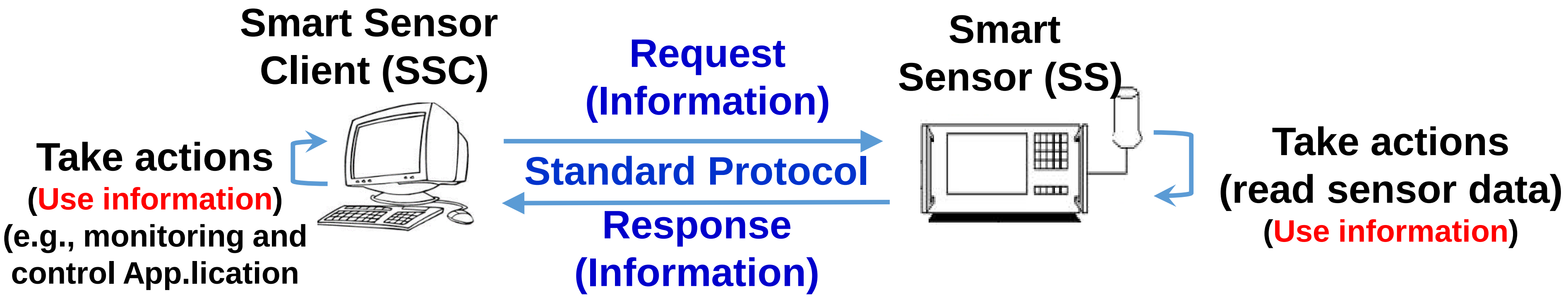
- The ability of two or more systems to exchange and use the information exchanged through a standard communication protocol in order to achieve specific functionality



# 3. Interoperability Testbed for Smart Sensors (Cont'd)

## Interoperability of smart sensors:

- The ability of **a smart sensor (SS)** and **smart sensor client (SSC) to exchange and use information exchanged** through a standardized sensor communication protocol to achieve specific functionality



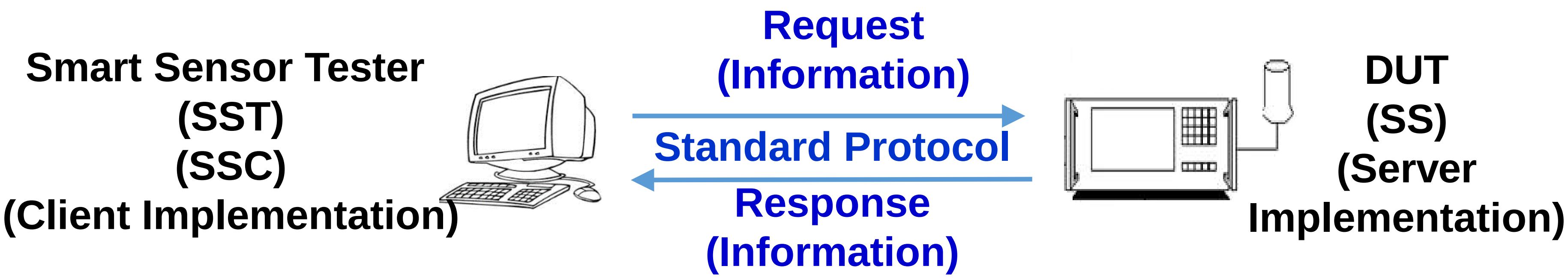
# 3. Interoperability Testbed for Smart Sensors (Cont'd)

## Interoperability Test:

- An activity to verify if two or more implementations (i.e. two devices or systems) can interoperate based on the same standard protocol.

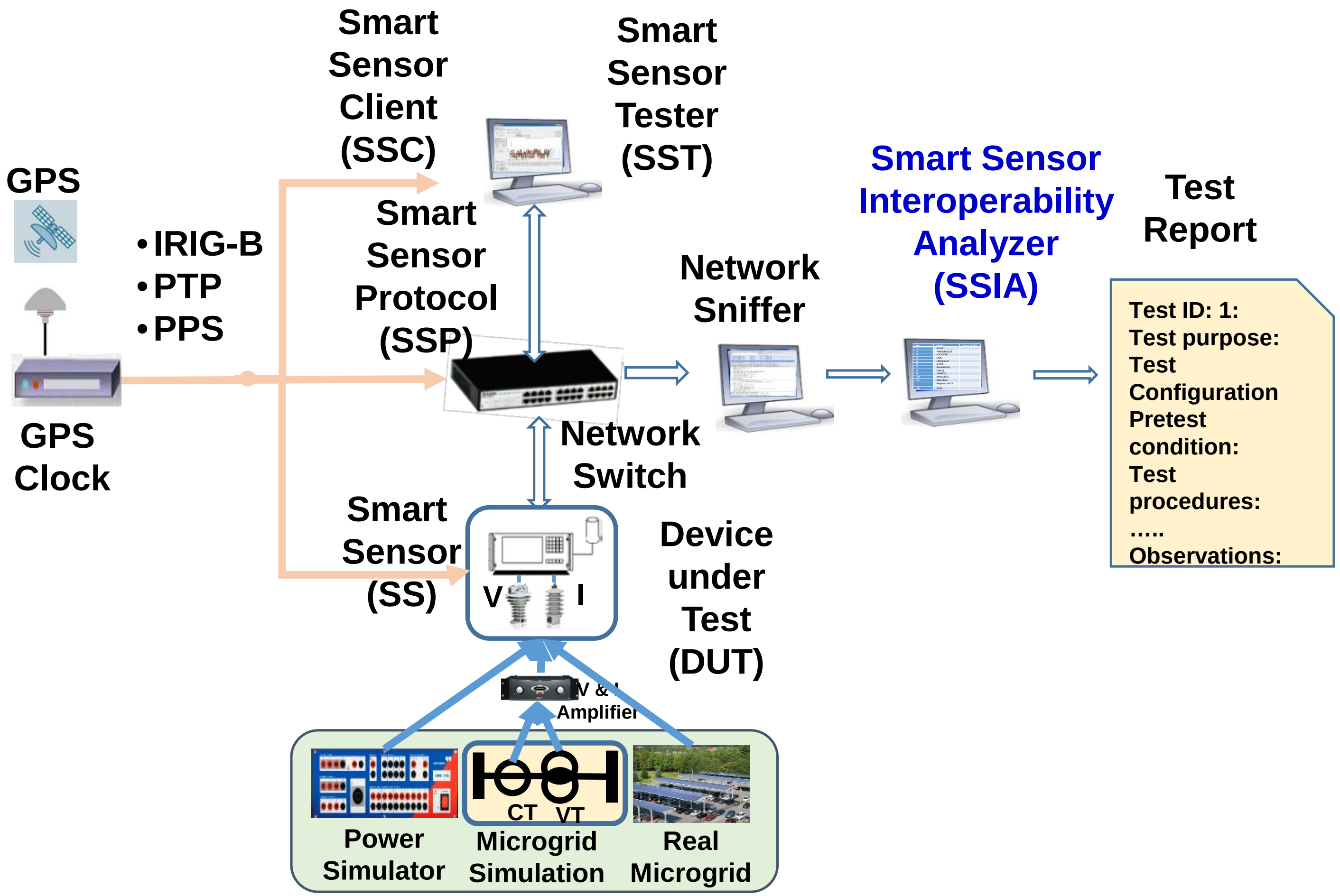
## Interoperability Test of smart sensors:

- An activity to verify if two implementations of a smart sensor (**server implementation**) and the SSC (**client implementation** ) are interoperable based on the same communication protocol



# 3. Interoperability Testbed for Smart Sensors (Cont'd)

## Interoperability Test Method for Smart Sensors



# 3. Interoperability Testbed for Smart Sensors (Cont'd)

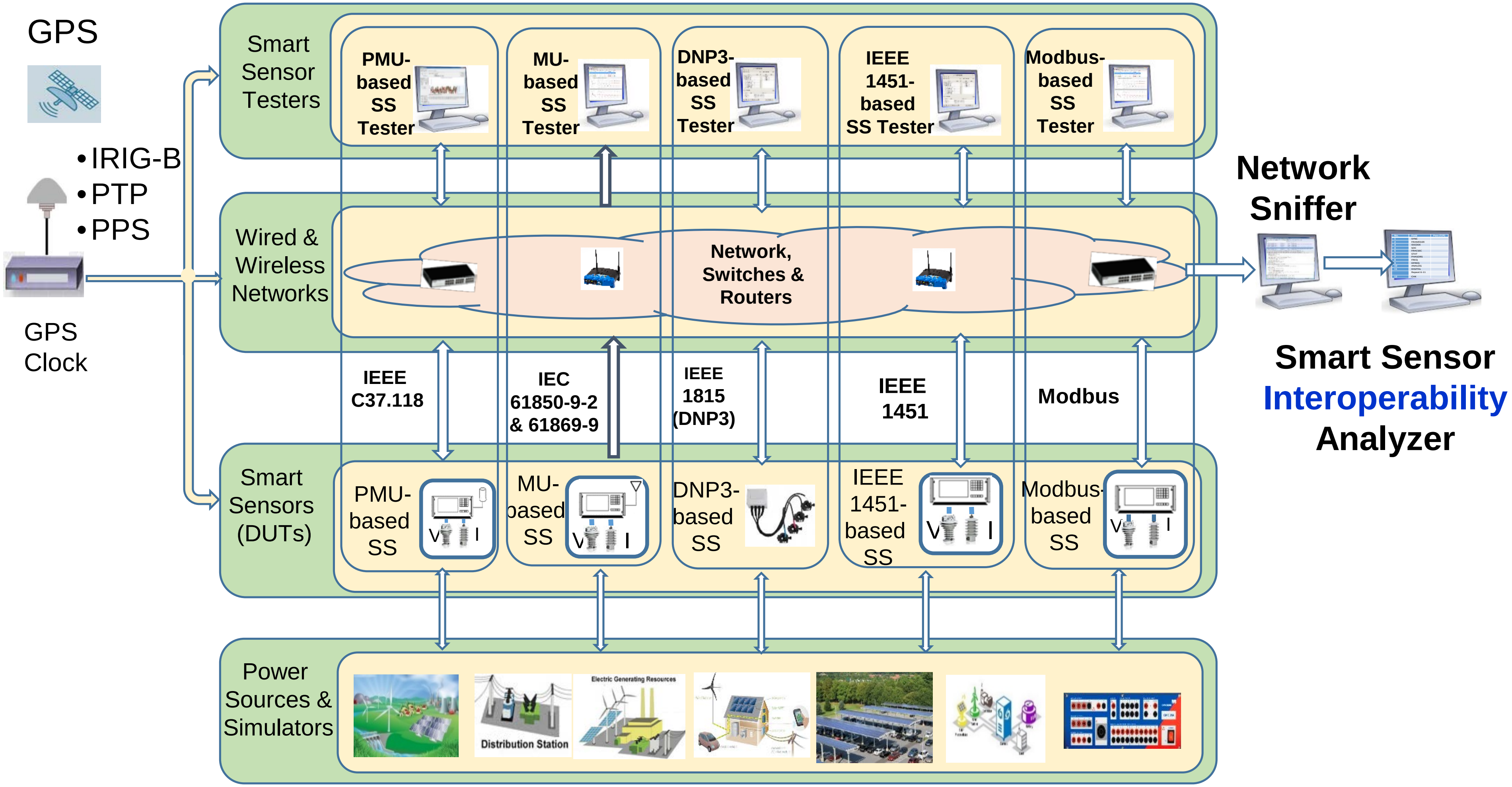
- **A testbed:**
  - **consisting of a set of hardware (devices), software tools, operating systems, instrumentation and tools, and various network configurations that are needed for testing purposes**
  - **A platform or environment for conducting various testing** for products under test, system software and application software.

- **Interoperability testbed provides an environment or platform to test and verify systems are interoperable.**

- **Interoperability testbed of smart sensors:**
  - **An environment or platform to test and verify smart sensors are interoperable to smart sensor client**.

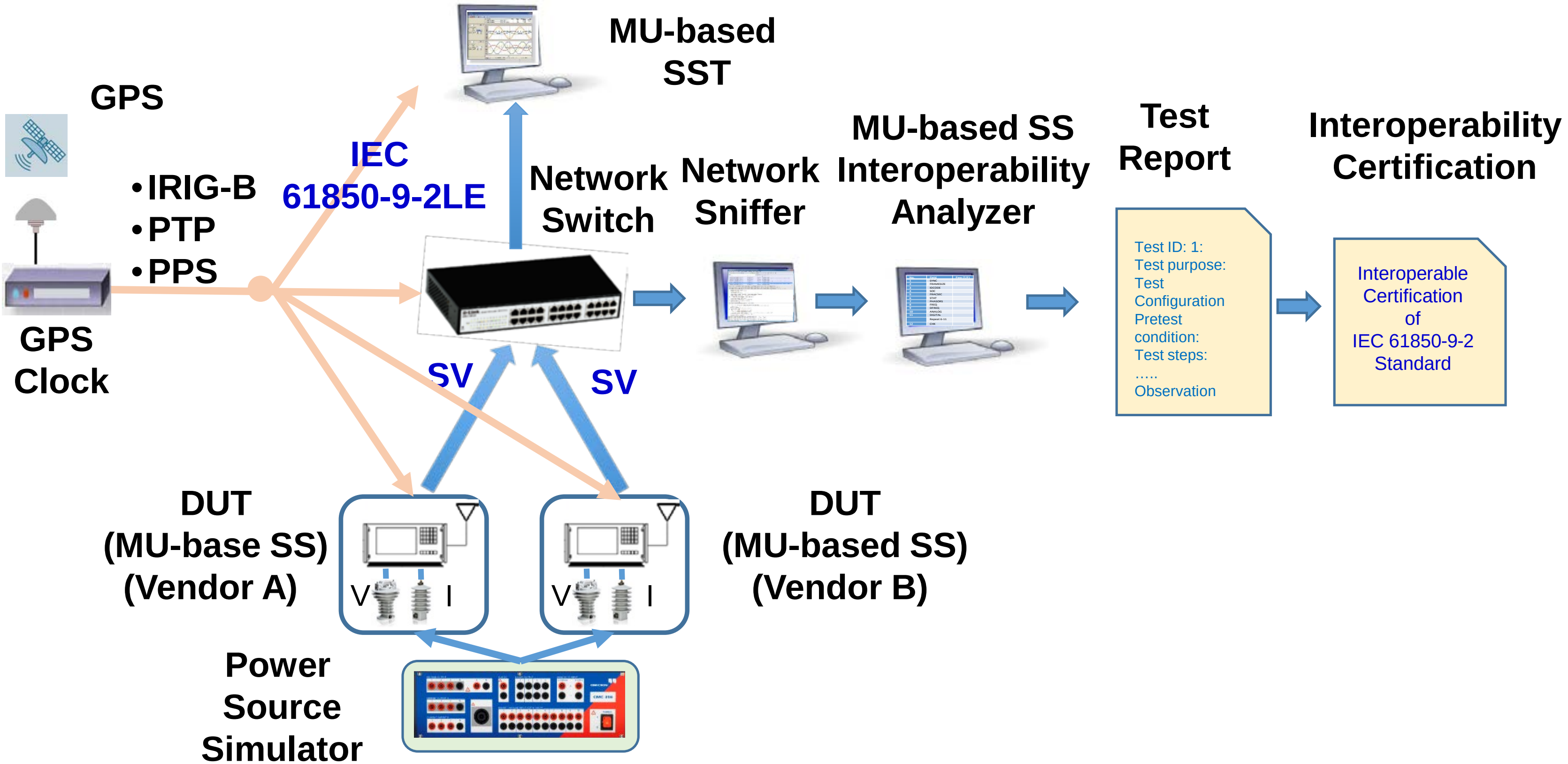
# 3. Interoperability Testbed for Smart Sensors (Cont'd)

## Interoperability Testbed for Smart Sensors



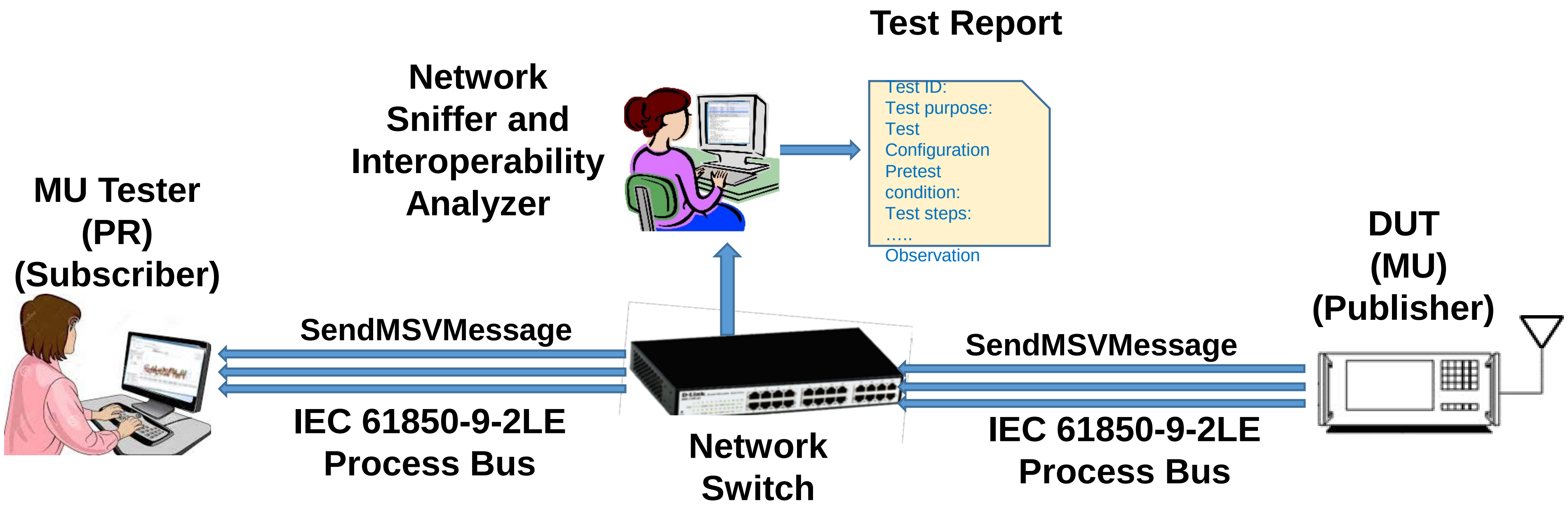
# 4. Test Case of MU-based Smart Sensors

## Interoperability Test
## for IEC 61805-9-2LE MU-based Smart Sensors



# 4. Test Case of MU-based Smart Sensors (Cont’d)

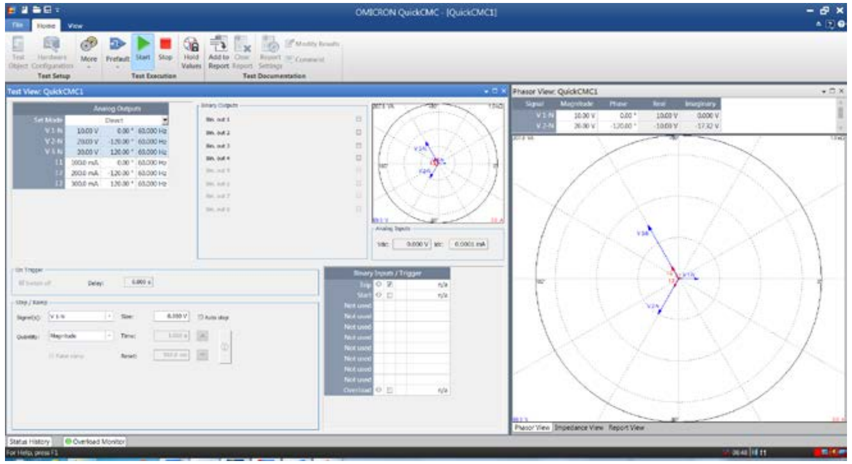
## Interoperability Test Case: SendMSVMessage

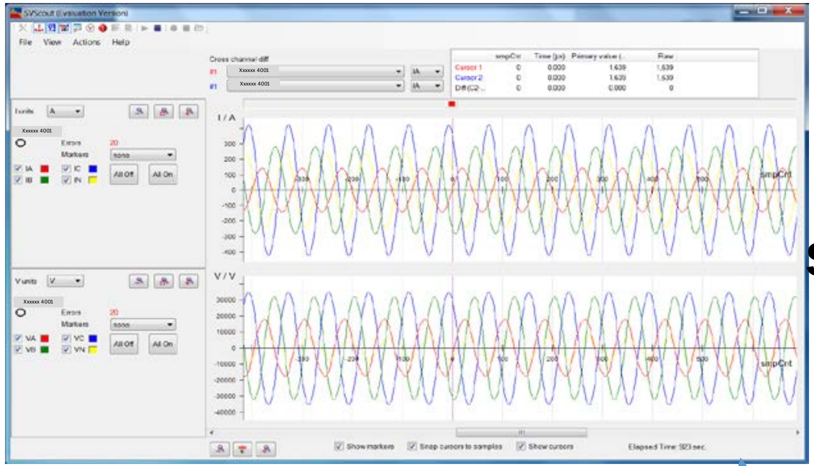


# 4. Test Case of MU-based Smart Sensors (Cont'd)

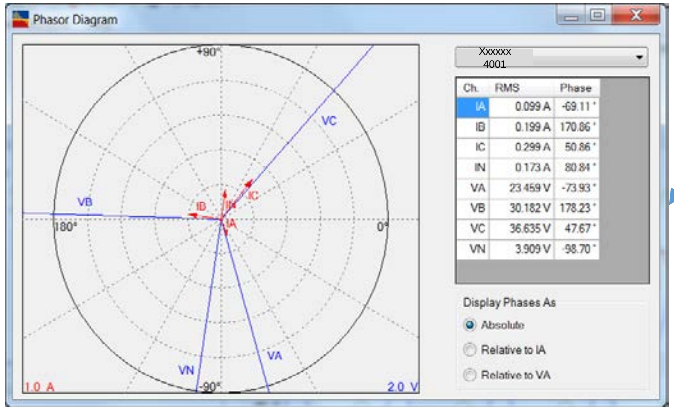
## Test Case Setup: `SendMSVMessage`

**Power Source setup**




**Current & Voltage Sinusoidal Waves**

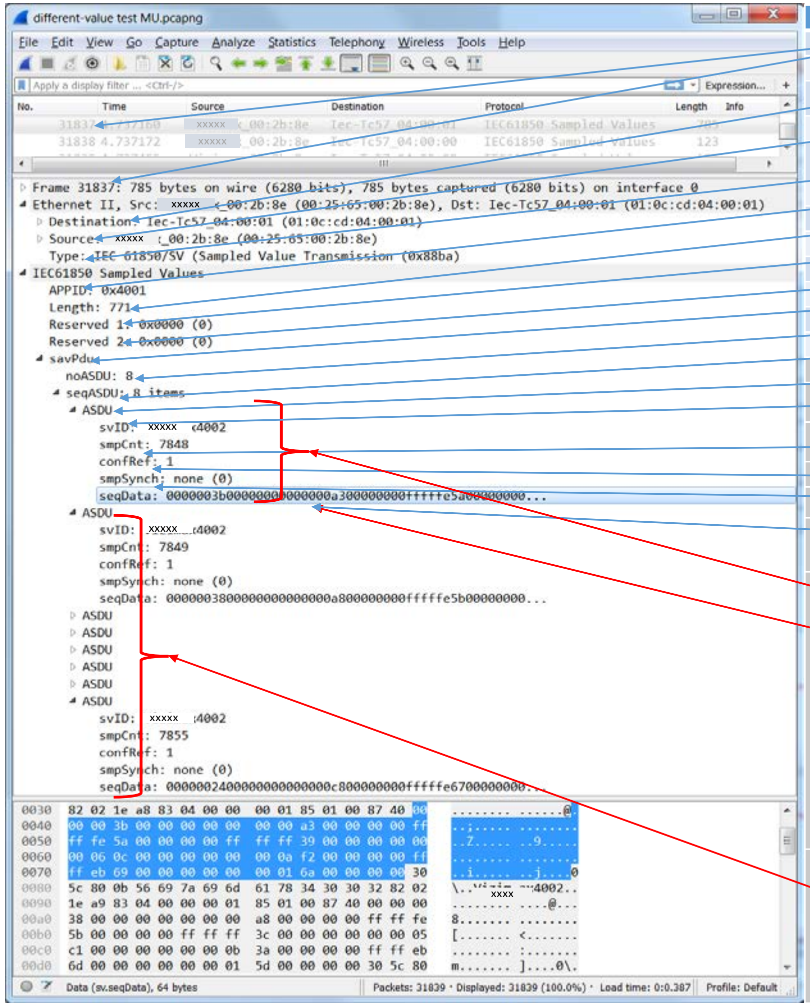



**SV Subscriber**

**Current & Voltage Phase Angles**

# 4. Test Case of MU-based Smart Sensors (Cont'd)

## Interoperability Analysis: SV Message Format




| Octet | Name/Tag | length | value | | | P or F |
|---|---|---|---|---|---|---|
| | frame | 785 | 31837 | | | |
| | Ethernet II | | | | | |
| 0-5 | Destination | 6 | Iec-Tc57_04:00:00 **01:0c:cd:04**:00:00 (for broadcast SV) | | | P |
| 6-11 | Source | 6 | xxxxxxx 00:2b:8e 00:25:65:00:2b:8e | | | P |
| 12-13 | EtherType IEC 61850/SV | 2 | 0x88 ba ( 0x88ba -Ethernet Type) | | | P(SV) |
| 14-15 | APPID | 2 | 0x40 01 (16385) (0x4000) | | | P |
| 16-17 | Length | 2 | 0x03 03 (771) | | | P |
| 18-19 | Reserved 1 | 2 | 0x00 00 (0) | | | P (0) |
| 20-21 | Reserved 2 | 2 | 0x00 00 (0) | | | P (0) |
| | savPdu (60) | 751…943 | 0x80 01 … | | | P |
| | noASDU (80) | 1 | 0x08 (8) (eight ASDUs) | | | P |
| | Seq. of ASDU (A2) | 744…963 | 30 5c 80 0b … | | | P |
| | ASDU 1 (30) | 91…115 | 30 5c 80 0b … | | | P |
| | svID (80) | 10…34 | xxxxxxx **4002** (10-34 characters)<br>(56 69 7a 69 6d 61 78 34 30 30 32) | | | P |
| | smpCnt (82) | 2 | 0x1e a8 (7848) (0-15359 for 256 sample/cycle and 60Hz) | | | P<br>(0-15359) |
| | confRef (83) | 4 | 0x 00 00 00 01 (1- count of revision ) | | | P (1) |
| | smpSynch(85) | 1 | 0x00 (0- not synchronized, 1-synchronized) | | | P (0) |
| | datSet (87) | 64 | Raw Data (Hexidecimal) | Raw data (Decimal) | Reading value with scale factor (0.001 for I, 0.01 for V) | P |
| | | | DataSet (PhyMeas1)<br><br>00 00 00 3b (Ia Meas.)<br>00 00 00 00 (Ia Quality)<br>00 00 00 a3 (Ib Meas.)<br>00 00 00 00 (Ib Quality)<br>ff ff fe 5a (Ic Meas.)<br>00 00 00 00 (Ic Quality)<br>ff ff ff 39 (In Meas.)<br>00 00 00 00 (In Qulaity)<br><br>00 00 06 0c (Va Meas.)<br>00 00 00 00 (Va Quality)<br>00 00 0a f2 (Vb Meas.)<br>00 00 00 00 (Vb Quality)<br>ff ff eb 69 (Vc Meas.)<br>00 00 00 00 (Vc Quality)<br>00 00 01 6a (Vn Meas.)<br>00 00 00 00 (Vn Quality) | Dataset<br><br>IA = 59<br><br>IB = 163<br><br>IC = -422<br><br>IN = -199<br><br>VA = 1548<br><br>VB = 2802<br><br>VC = -5271<br><br>VN = 362 | Dataset<br><br>IA = 0.059A<br><br>IB = 0.163A<br><br>IC = -0.422A<br><br>IN = -0.199A<br><br>VA = 15.48V<br><br>VB = 28.02V<br><br>VC = -52.71V<br><br>VN = 36.2V | P |
| | ASDU 2<br>ASDU 3<br>ASDU 4<br>ASDU 5<br>ASDU 6<br>ASDU 7<br>ASDU 8 | | | | | |

# 4. Test Case of MU-based Smart Sensors (Cont'd)

**Preliminary Results of Interoperability Test of IEC 61850-9-2 LE Standard-based Commercial MUs**

| Test case SendMSVMessage | Vendor A MU | Vendor B MU | |
|---|---|---|---|
| | SV Stream 1 (80 samples/cycle) | SV Stream 1 (80 samples/cycle) | SV Stream 2 (256 samples/cycle) |
| **Test procedures** | Passed | Passed | Passed |
| **MSVMessage** | Passed | Passed | Passed |
| **overall** | Passed | Passed | Passed |

One interoperability issue we encountered in the test is that the **svID** (**xxxxMUnnnn**) does not conform to IEC 61850-9-2LE specification.

# 5. Summary

- Presented a generic model for smart sensors
- Defined an interoperability test method for smart sensors
- Described an interoperability testbed for smart sensors
- Detailed an interoperability test case of MU-based smart sensors
- Provided interoperability testing results.

Future work:

- Conduct more interoperability testing of commercial standards-based smart sensors from additional vendors
- Verify the interoperability test method, and contribute to the standardization of interoperability test specifications
- Support interoperability testing and certification of smart sensors.

# Questions???