Towards a Resilient Information Architecture Platform for the Smart Grid: **RIAPS**

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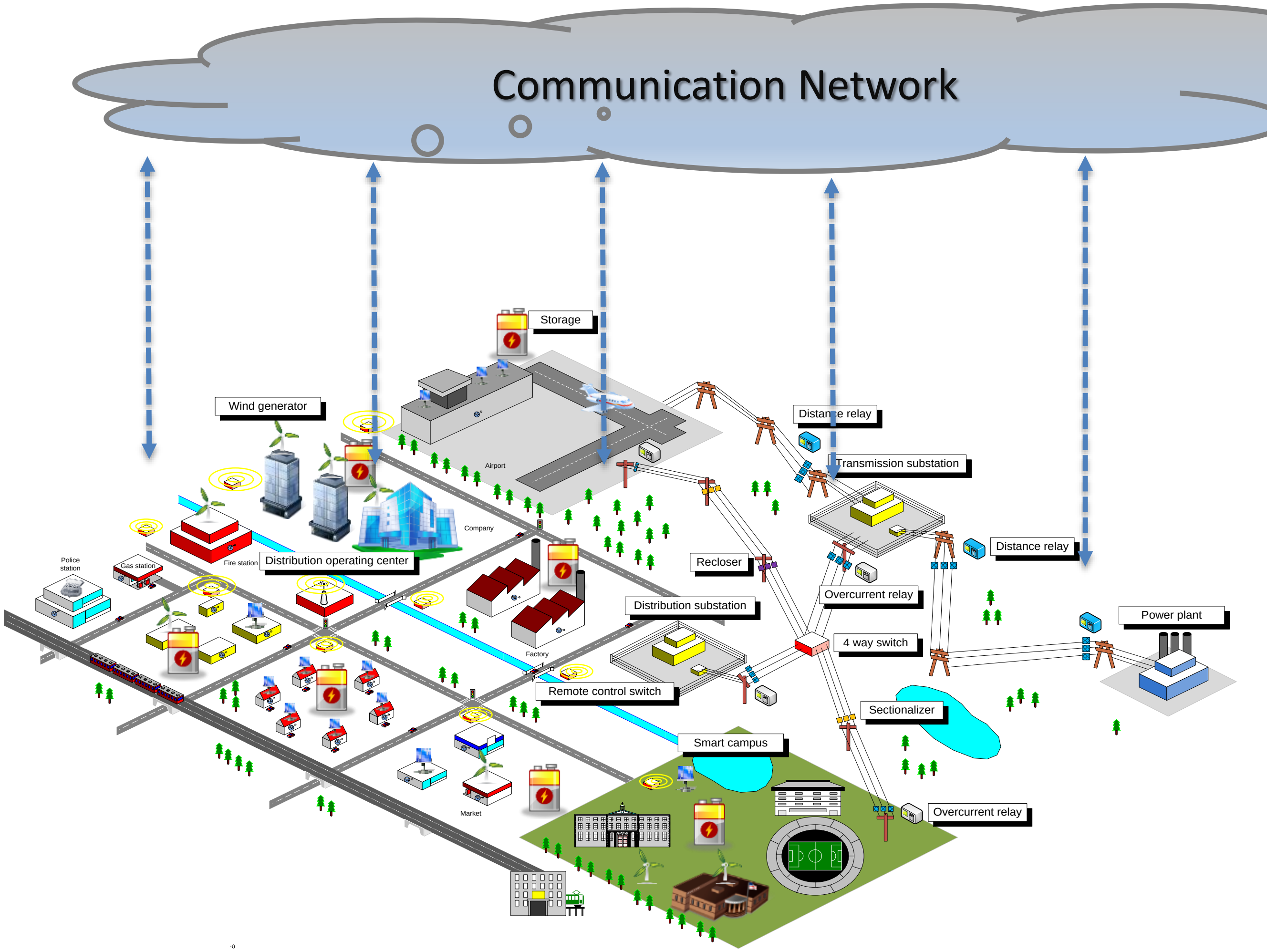
The Energy Revolution: Big Picture

From centralized to a decentralized and distributed energy systems

Changing Generation Mix | Transactive Energy

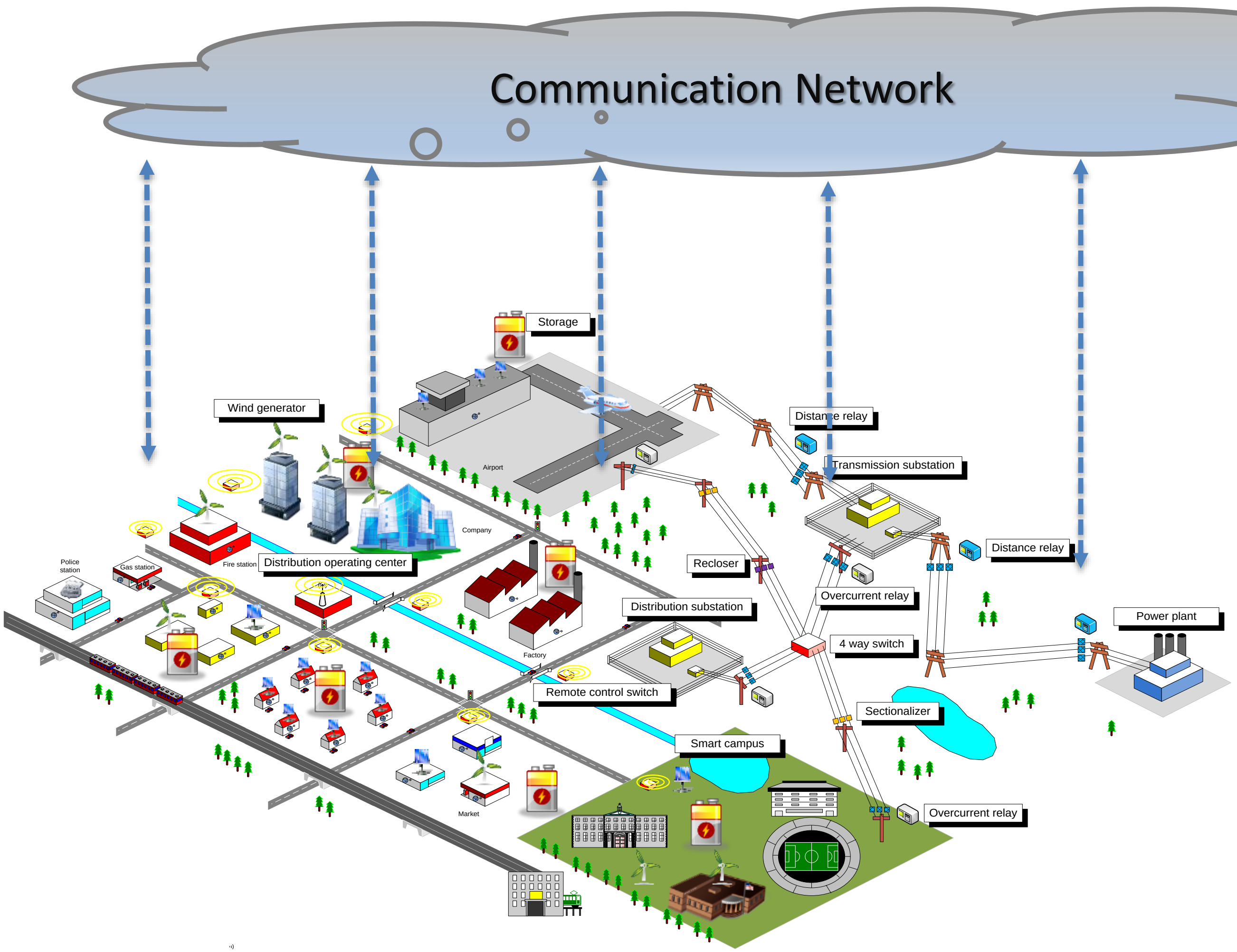
Electrical Cars | Decentralization

The control picture has not changed



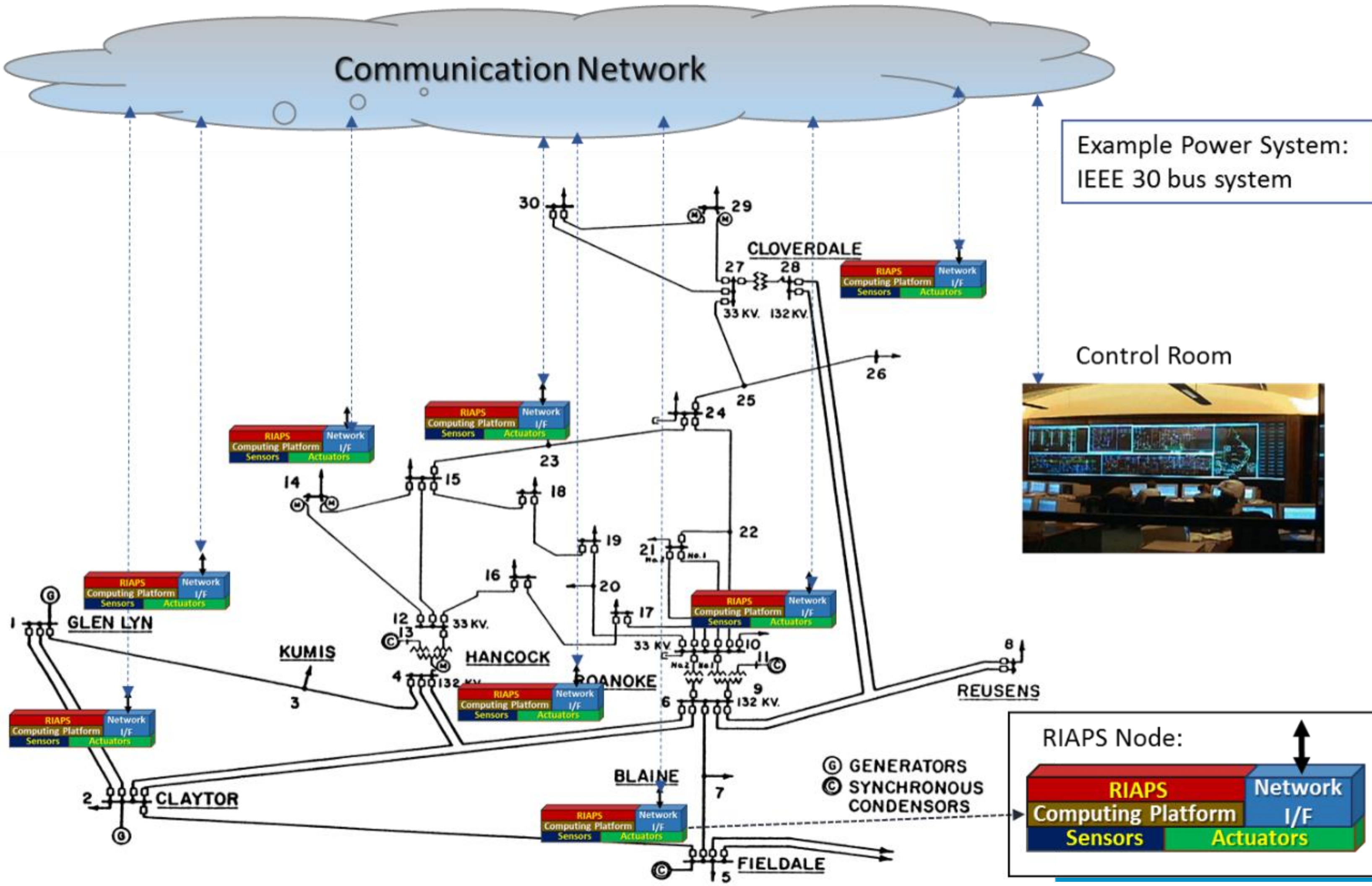
Centralized SCADA supported by a utility company

The control picture has not changed

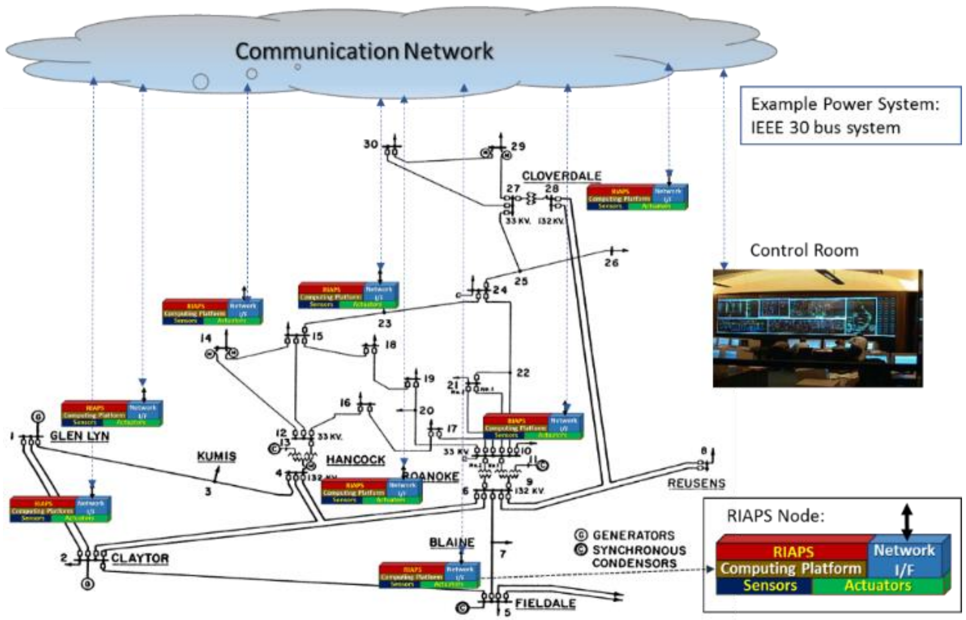


Problems
- Integration challenge
- Reliability issues
- Management issues

RIAPS Vision



RIAPS Vision

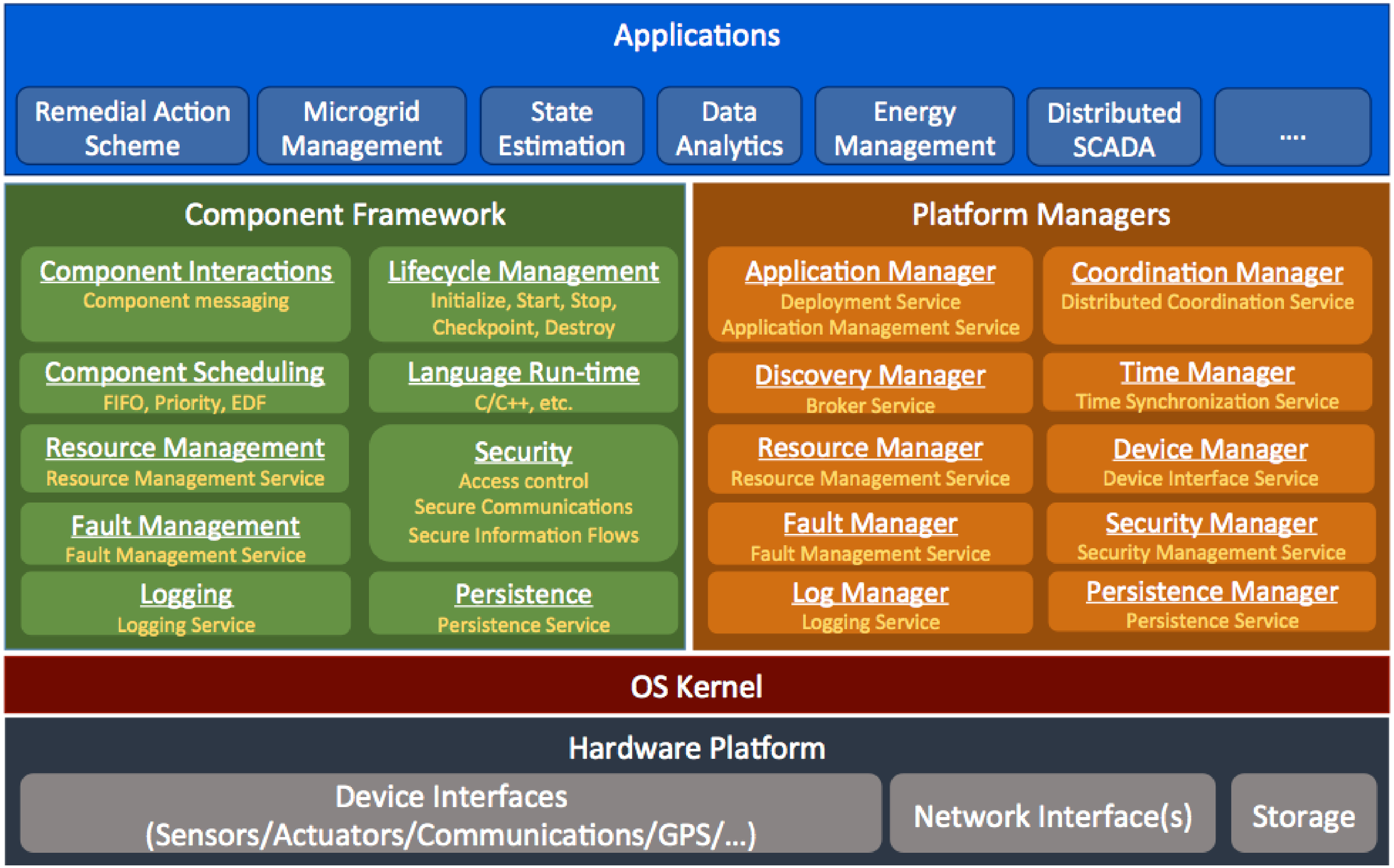


- Push computation to the edge
- Enable common technology stack across the ecosystem
- Provide core services to enable the *rapid* development of *smart* apps

RIAPS Software Platform

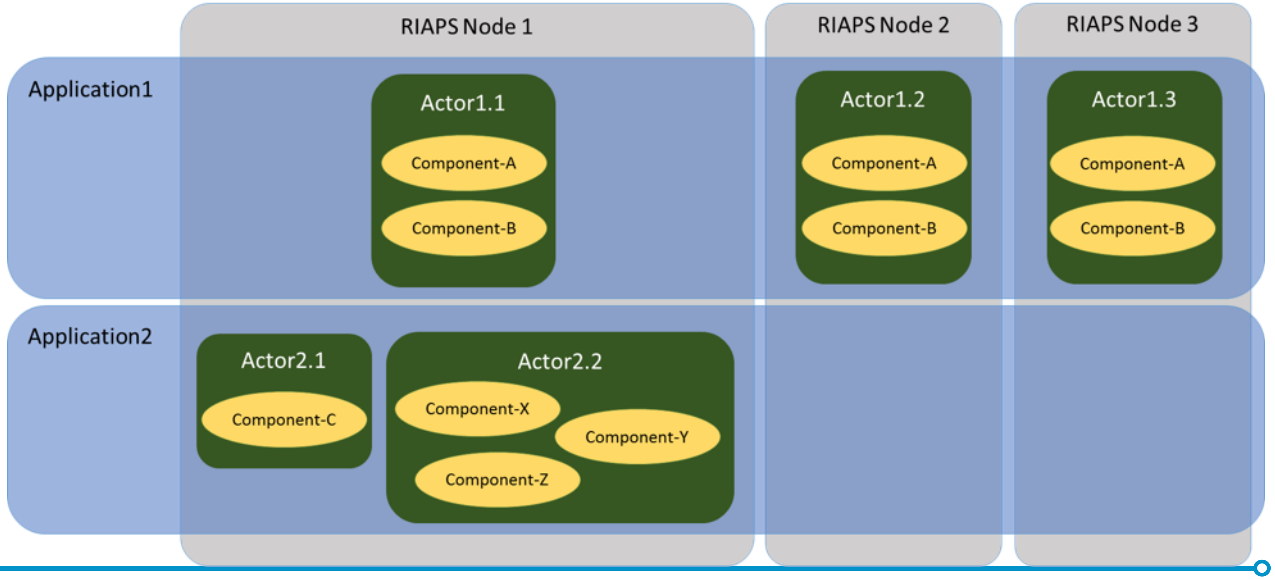
- At the core of the RIAPS vision is **a reusable technology** stack to run **Smart Grid applications** A software platform defines:
  - Programming model (for distributed real-time software) on embedded nodes **dispersed throughout the power grid**
  - Services (for application management, fault tolerance, security, time synchronization, coordination, etc.)
  - Development toolkit (for building and deploying apps)

A Reusable Software Platform for Smart Grid



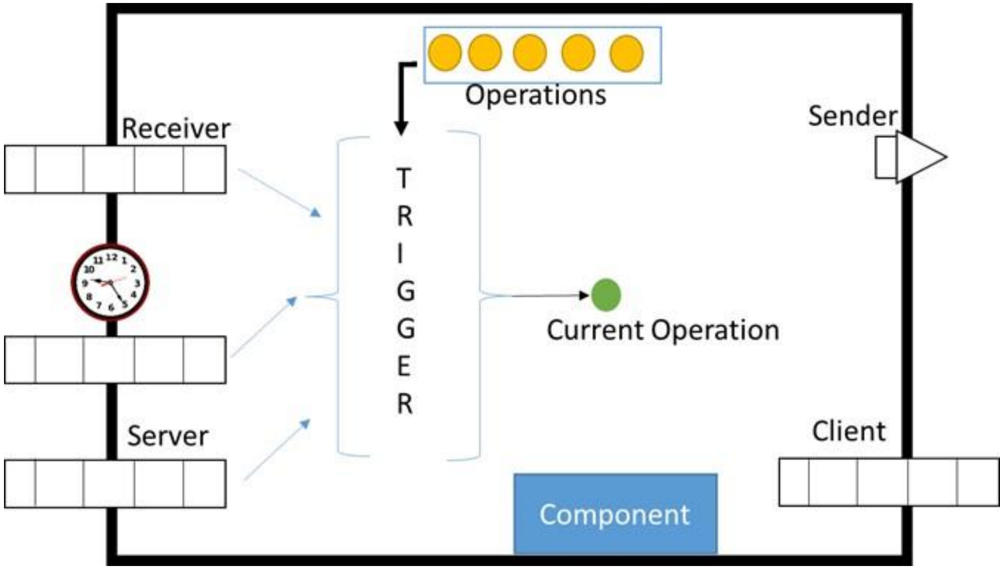
Core RIAPS Concepts: RIAPS System

- RIAPS Nodes: Networked Embedded Computers
- Applications consists of actors that contain components
- Component communicate and interact using well-defined patterns: publish/subscribe + client/server
- Expected scale: ~10^2 nodes



Design: Component Framework

- Software components are the reusable building blocks of applications (actors group them into a single process)
- Components have a *state* and interact via *ports*
  - *Receiver* of messages ('subscriber')
  - *Server* of client requests
  - *Sender* of messages ('publisher')
  - *Client* of servers
- Components are single-threaded: one operation at a time
- Components are triggered by the arrival of a *message*, a *request*, or a *timer event*

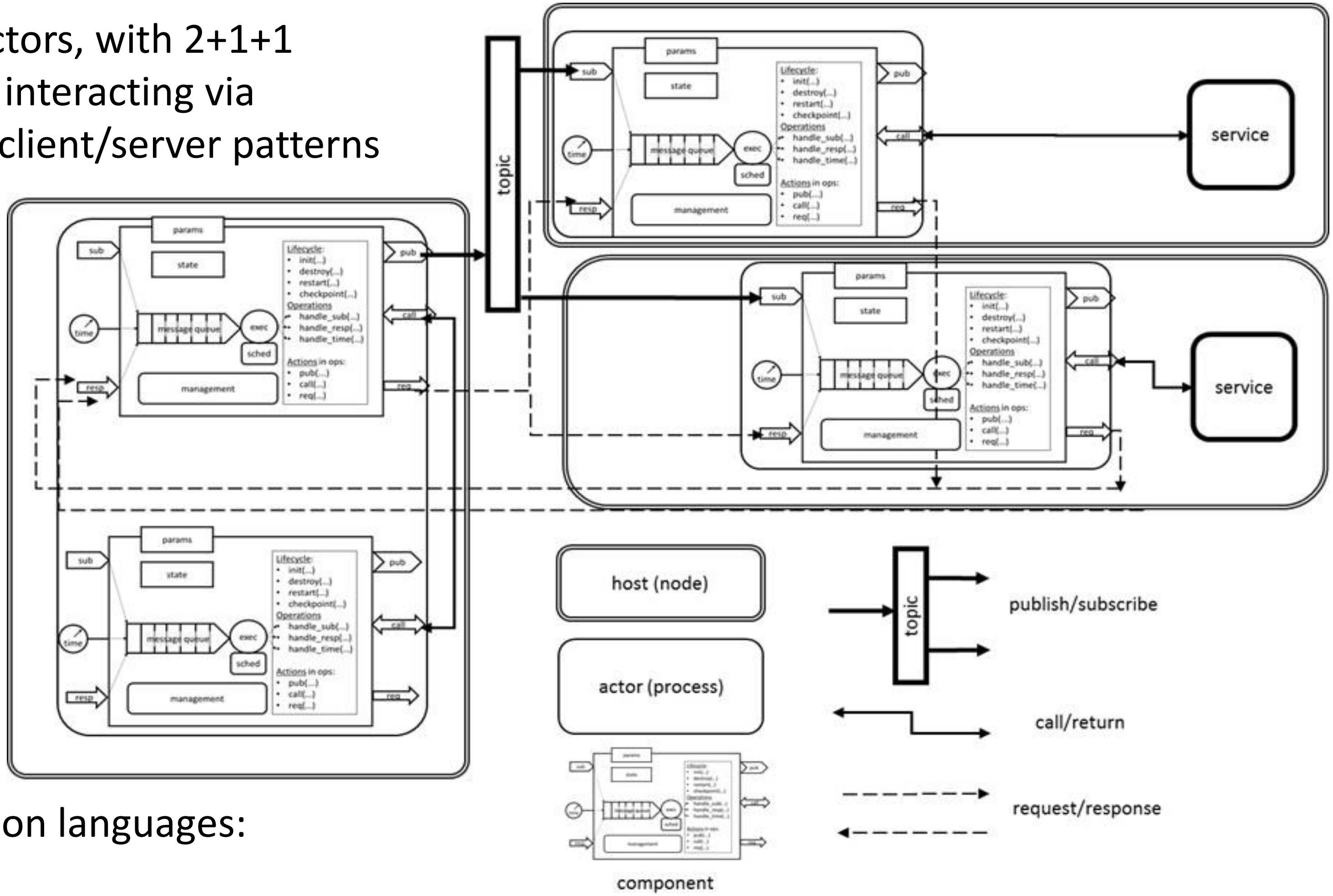


- Component triggering logic is encapsulated in a function that can include complex decisions

Benefits: Reusable components + concurrency is handled in the framework (not in the 'business logic') + lends itself to timing analysis

Design: Component Framework

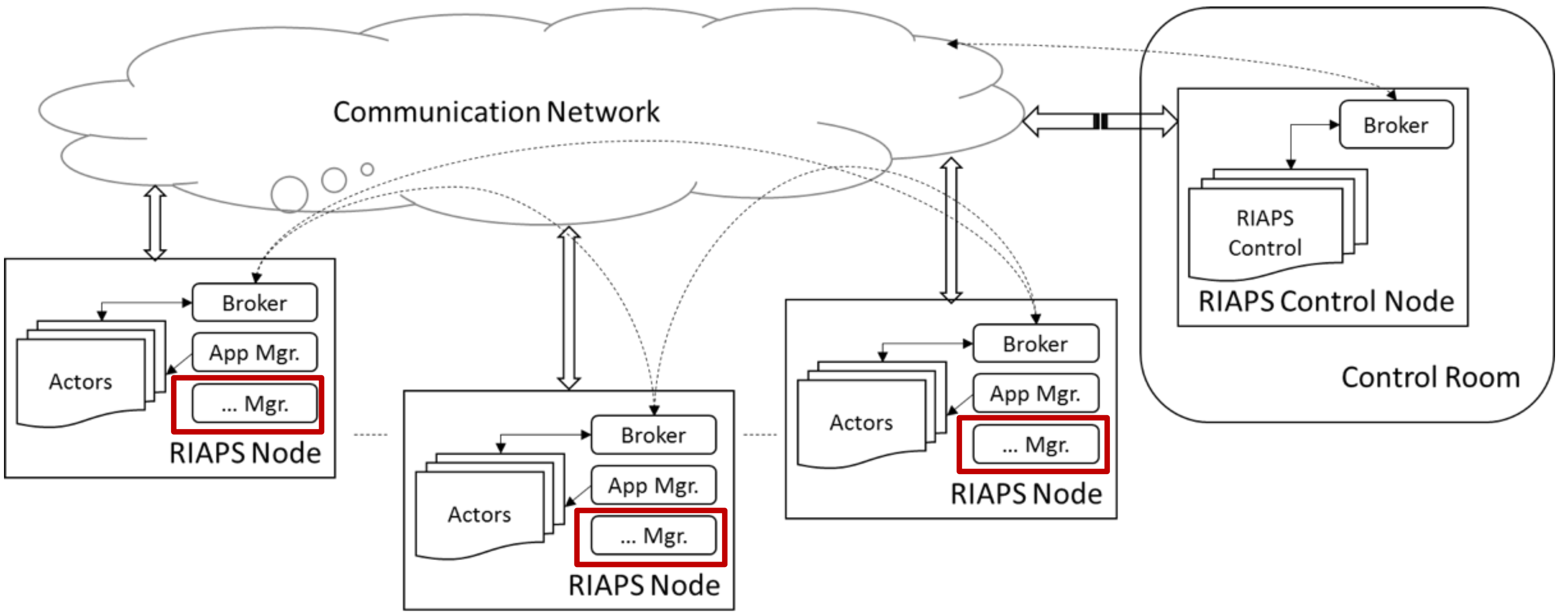
Example: 3 actors, with 2+1+1 components, interacting via pub/sub and client/server patterns



Implementation languages:
Python, C++

Design: Platform Services

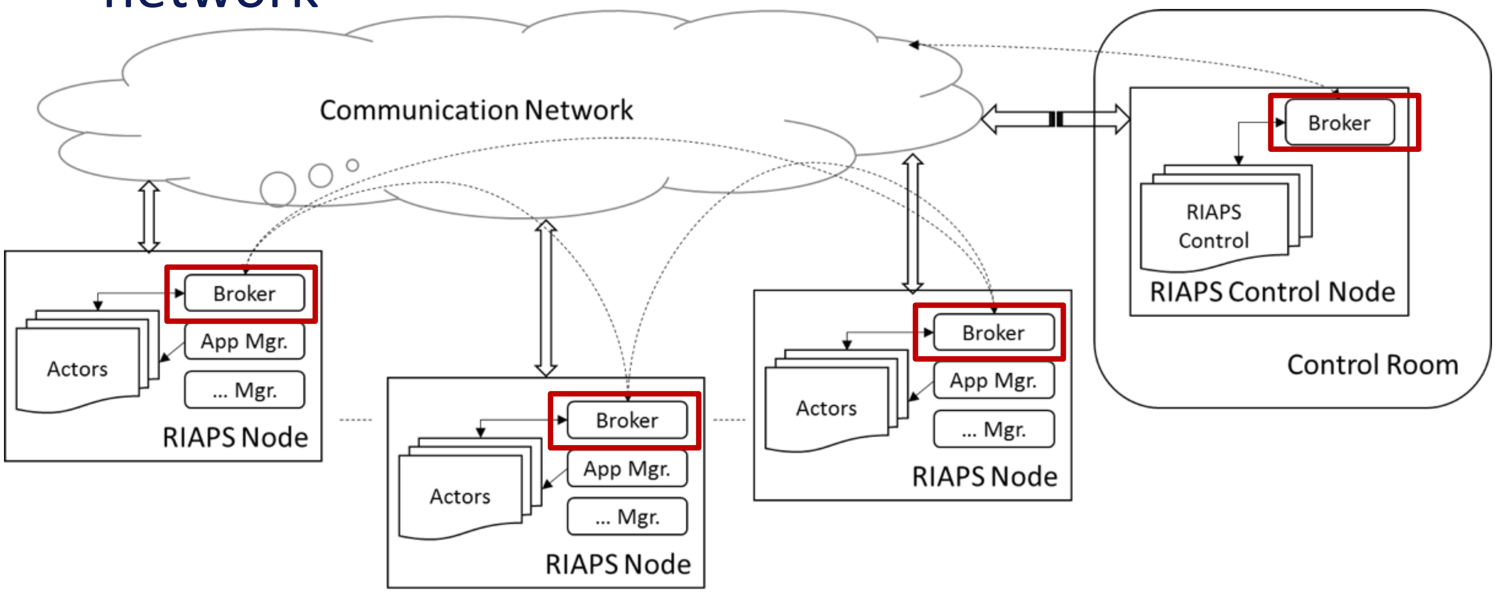
- Application Deployment and Management
  - Function: Remotely installs and manages apps



Benefit: Authoritative control over all software deployed on the RIAPS network.

Design: Platform Services

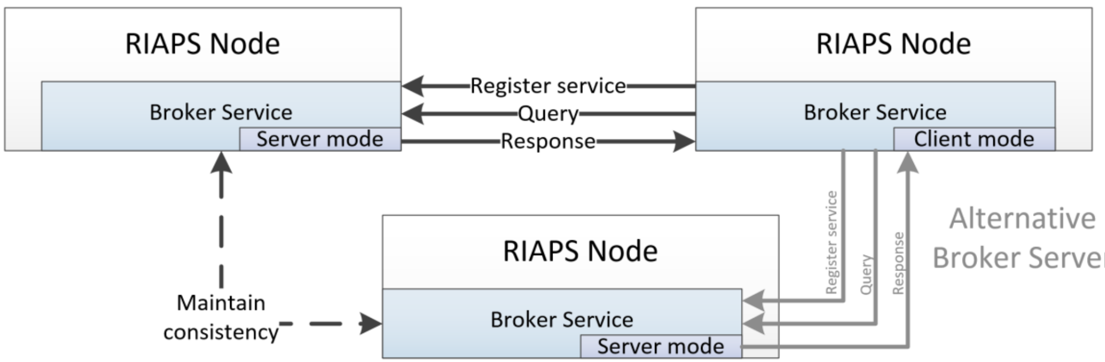
- Discovery: The Broker Service
  - The ‘matchmaker/housekeeper’ – how the components/actors of an app find each other on the network



Benefit: Actors of a RIAPS app can come and go at any time – they are still able to connect to the group reliably.

Design: Platform Services

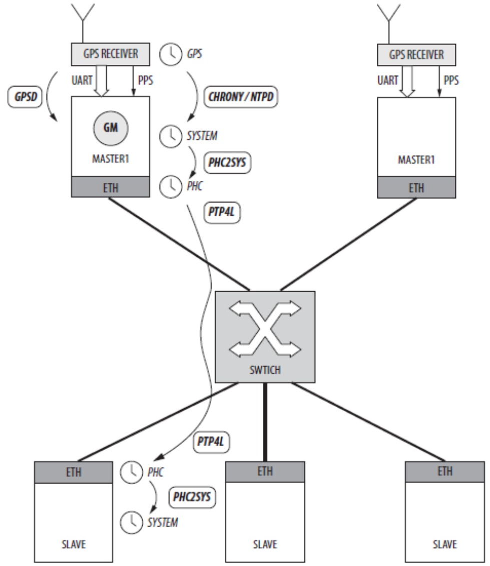
- Discovery: The Broker
  - A fault-tolerant distributed database where component register themselves and look up other components



  - Publishers ←→ Subscribers + Clients ←→ Servers
  - Implementation: distributed hash table

Design: Platform Services

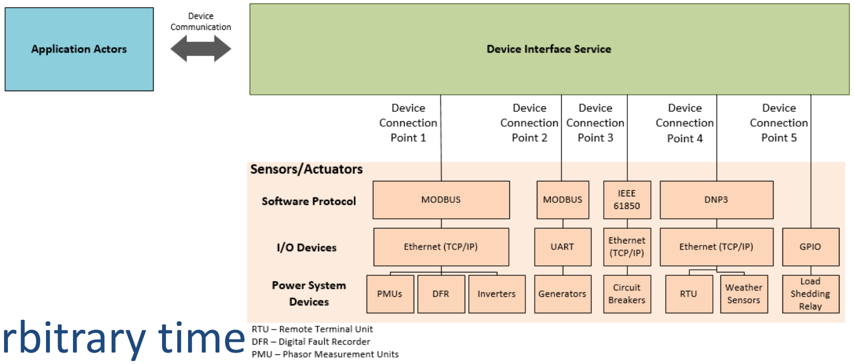
- Time Synchronization
  - Maintains a cluster-wide synchronized notion of time
  - Applications can: (1) query the global time, (2) sleep until a specified point in time, (3) query the status of the service
  - Architecture:
    - Use PTP (IEEE-1588)
    - Some nodes may have a GPS
    - GPS clock is distributed
    - Fallback: NTP
    - Accuracy: ~10 usec



Benefit: Precisely synchronized time base available to all apps on the RIAPS network.

Design: Platform Services

- Device interface
  - Encapsulates ‘power system devices’ that use specific protocols (e.g. Modbus, DNP3, IEC 61850etc.) and hardware interfaces (RS-232, TCP/IP, etc.) and provides a (RIAPS-compliant) messaging interface to the device



- Device interactions:
  - Sporadic input: sensor reading at an arbitrary time
  - Periodic input: periodic sensor reading (stream)
  - Sporadic output: actuator command at an arbitrary time
  - Periodic output: actuator periodically updated
  - Scheduled output: actuator is updated at a specific point in time

Benefit: Portable applications – device dependencies are encapsulated in the service.

Design: Platform Services

- Distributed coordination
  - For coordinating applications distributed on the network
  - Features:
    - *Group membership*: join/leave group, query membership, get notified when membership changes
    - *Leader election*: elect a leader for centralized functions, when leader becomes unavailable elect another one automatically
    - *Distributed consensus*: participants agree on a 'value'
    - *Time-coordinated action*: execute a control action on many nodes simultaneously (up to time synchronization accuracy)
  - Algorithms: Paxos/RAFT

Benefit: Reusable implementation of difficult algorithms – available as a service.

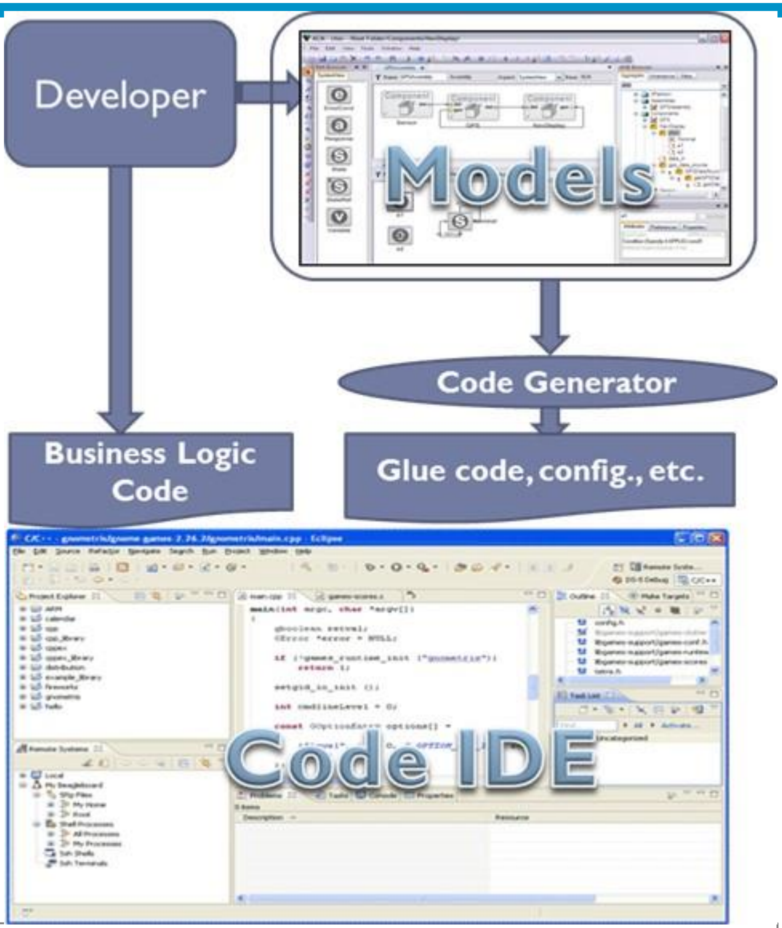
Design: Platform Services

- Resource management
  - Keeps track of resource usage (CPU, memory, files space, I/O)
  - Manages quotas and access
  - Signal errors/terminates applications if resource restrictions are violated
- Logging
  - Efficient, low-overhead logging of events in apps and managers
  - Global management of all logs
- Persistence
  - Efficient, low-overhead database for node-local real-time data
  - Global management of the database
- Fault management
  - Monitors apps/managers/system for faults
  - Mitigates fault effects (e.g. automatic restart, checkpoint, etc.)
- Security management
  - Secure information flows among app components
  - Global management of security keys

Benefit: Complex housekeeping functions – apps don't need to implement them.

Design: Model-driven Development

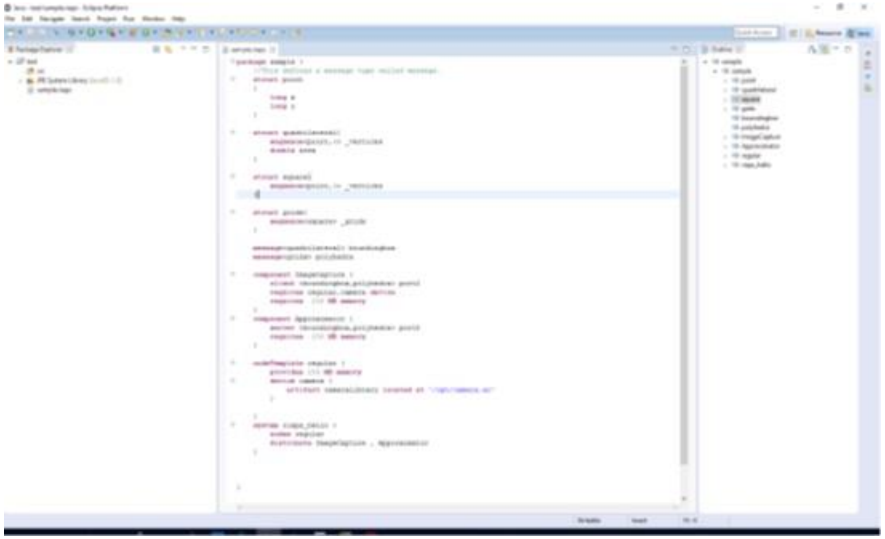
- Goal: Average software developers are productive in developing complex RIAPS apps
- Developers build:
  - Application ‘business logic’ – the algorithms
  - Models to represent the components and their composition to form an app
- Toolchain generates:
  - Intermediate code, software engineering artifacts
- Model-based toolchains are effective (Simulink/Stateflow)
  - But they are ‘closed’ and not suited for distributed systems



Benefits: Developer can focus on the core logic of the application (the ‘algorithms’) – the composition and configuration is done on a higher-level of abstraction.

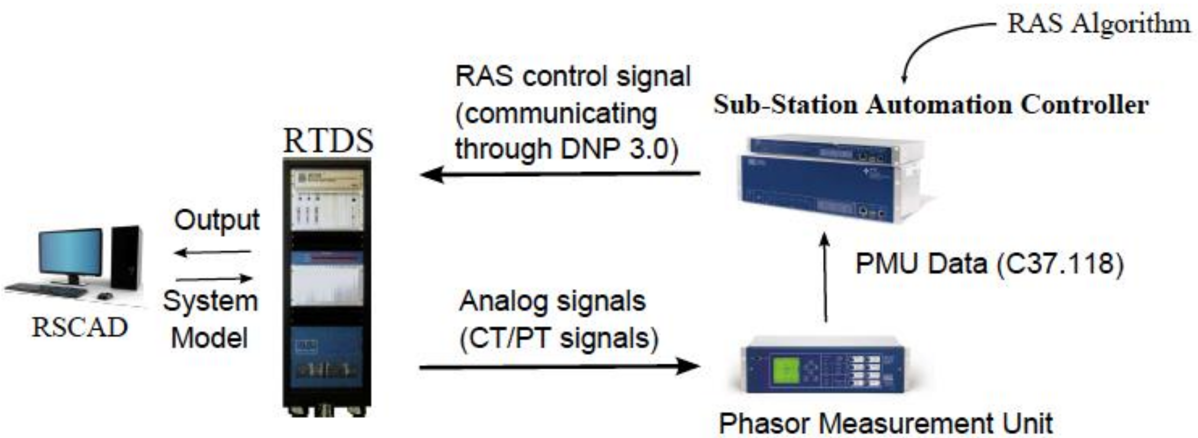
Design: Model-driven Development

- Approach:
  - Use a simple, text-based language for the models (diagrams, if needed, can be rendered automatically)
  - Integrated it with the code-based IDE (Eclipse) where the application logic is entered (as C++ code)
  - Develop code generators and integrate them into the IDE (for a seamless workflow)
  - Prototype: Eclipse



Application1:
Response Based Remedial Action Scheme (WSU)

- RAS is a key mechanism to protect electric power grid, generally used as the last line of automatic defense
- Existing RAS are pre-determined, inflexible and do not factor in changing system conditions and might take control actions good for small system but not optimal for the overall power grid
- RIAPS will enable dynamic coordinated response based RAS (DCRB-RAS), which will use measurements, changing network conditions, control settings to dynamically decide control decisions



Application1:
Response Based Remedial Action Scheme (WSU)

Two applications:

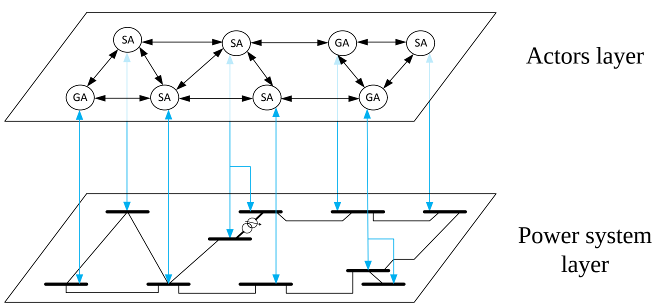
RAS I for managing wind generation: curtailment

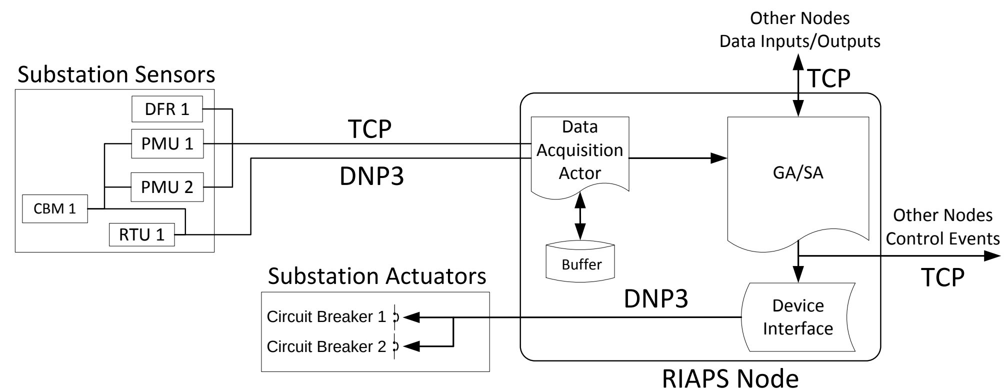
Data acquisition actor: Protocol conversion, periodic and event data input , time stamping, buffer input data, time aligning

DLSE actor: Noise filtering, bad data, topology processing, WLS

RAS actor: Initialization, obtain state variable, optimization, solution update, generate control actions

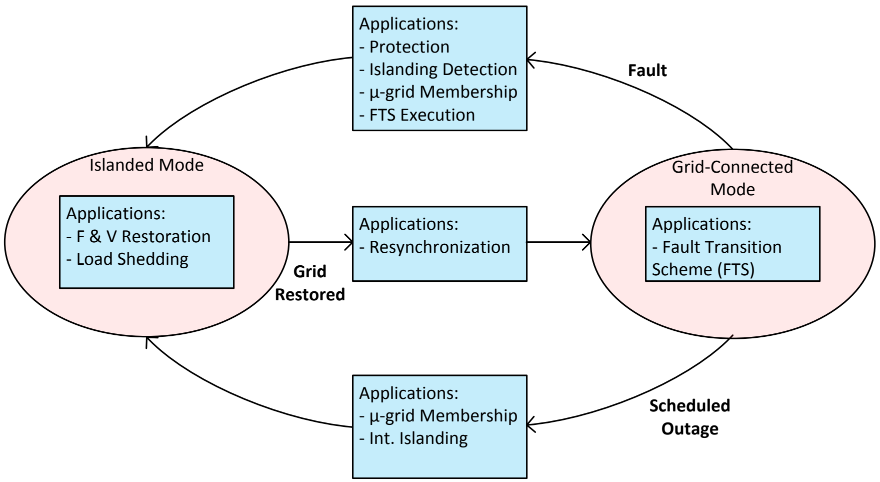
RAS II for under-frequency control: load shedding

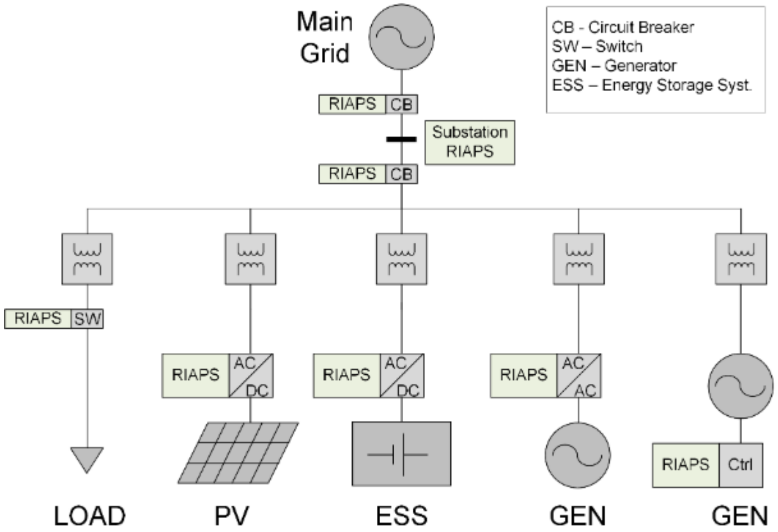




Application2: Microgrid Islanding (NCSU)

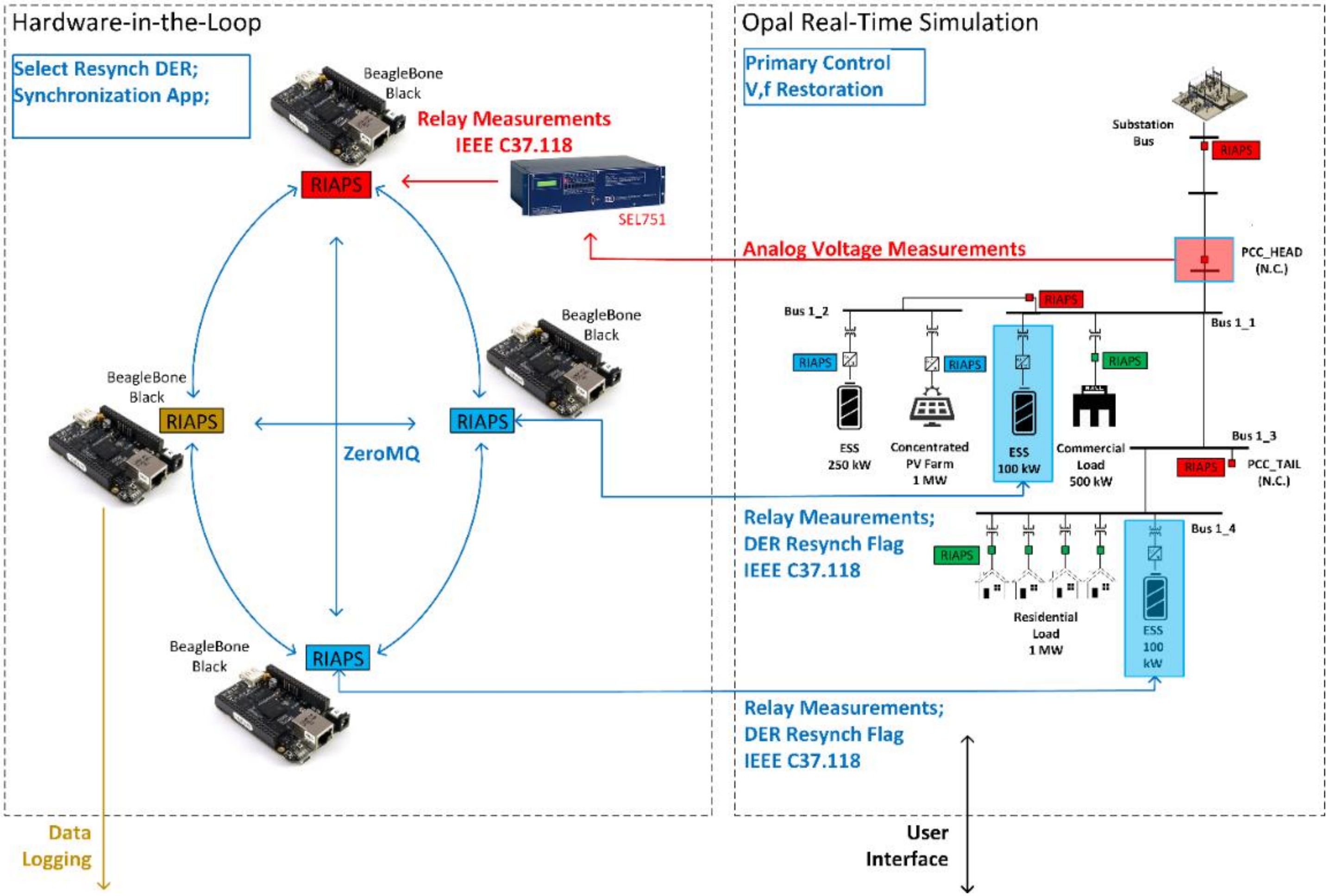
- Application of interest: Formation and interactions of microgrids on a distribution feeder
- Focus: power management
- Main application scenario:
  - Unplanned transition from grid-connected to islanded mode and re-synchronization.
  - Distributed control and protection framework will be used to implement a fast transition scheme





Demo of an Early Prototype: Synchronization Application

https://riaps.isis.vanderbilt.edu/blog/



Project Summary

- Expected outcomes
  - The platform will enable developers – sanctioned by utilities - to build reusable components and applications
  - The platform specification and its prototype implementation is open source, but industrial partners will provide software development services for it
  - A new open standard that will change how software for the smart grid is developed

Resilient Information Architecture Platform

for the

Smart Grid