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FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Platform-based Resilience for CPS

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Domain:
Power Transmission and Distribution Systems

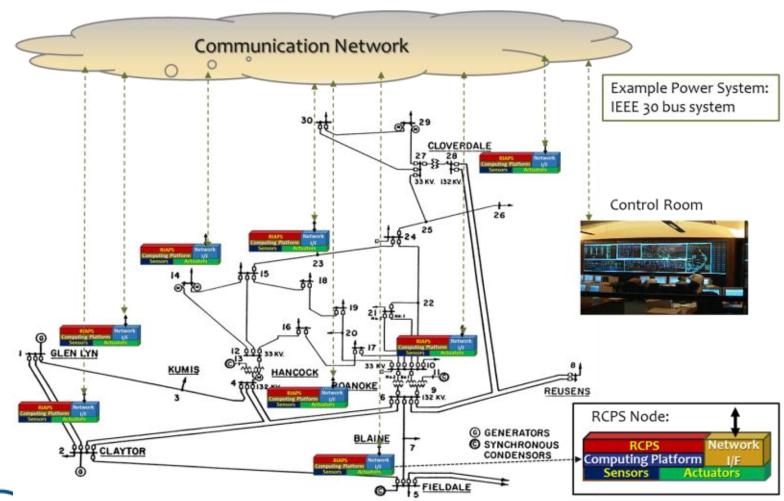
Power systems are potentially vulnerable in all components: generators, transmission and distribution system, end-user loads, protection system, power management systems –

Threat model: Physical faults + …

- Mis-operation of protective equipment
- Integrity/DDOS attack on the network
- Replay attacks, etc.

Resilience challenges:

- Faults in the power system, in computing hardware and software, in the network
- Algorithms for protection, monitoring, control, energy management, state estimation, analytics..
- Defense against and recovery from cyber-attacks



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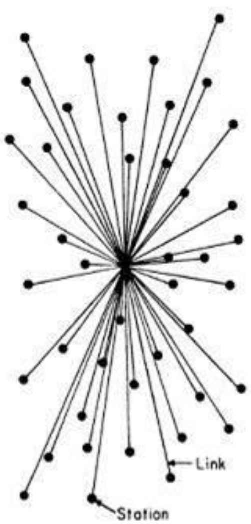
The Evolution of Energy Networks



Traditional networks with transmission system operators, distribution system operators & radial distribution systems to communities

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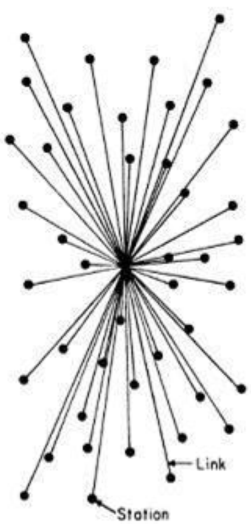

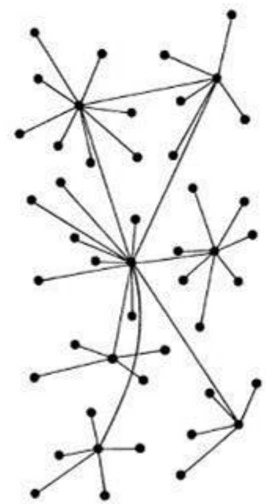

Network of distribution feeders with some microgrids with tightly integrated distributed energy resources

- Advantages of decentralization
  - Improved cyber & physical reliability by removing single point of failures
  - Faster decision making by avoiding network penalties due to round-trip to the cloud
  - Improved scalability
  - Better integration with hierarchical control systems

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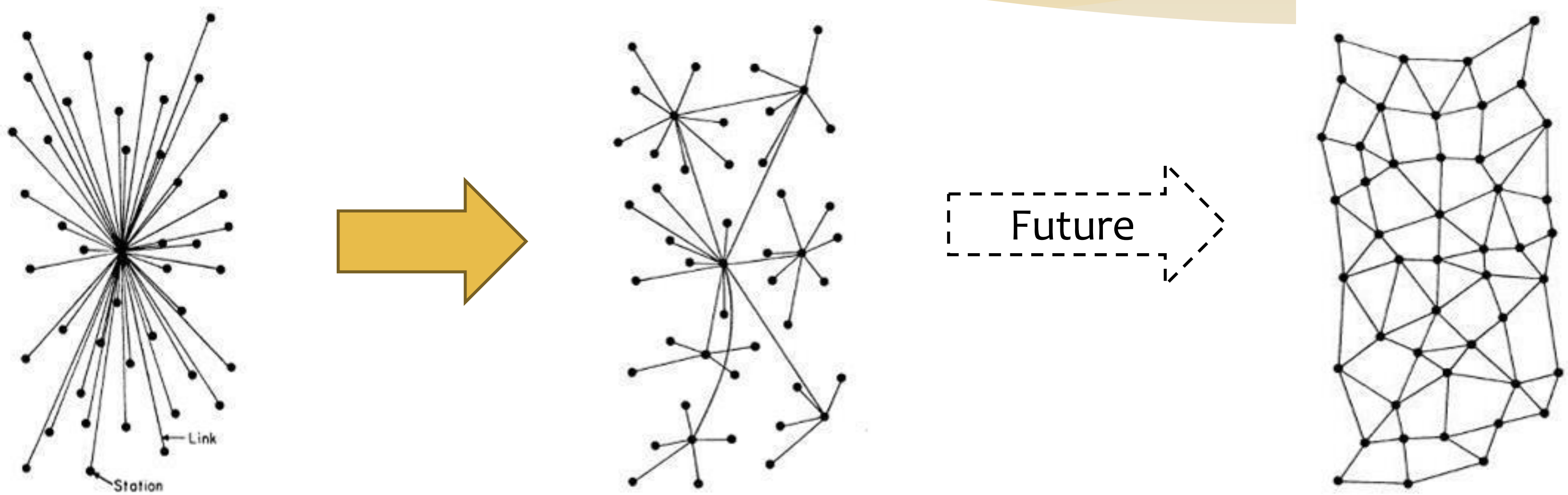

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Network of transactive microgrids with limited role of distribution system operators

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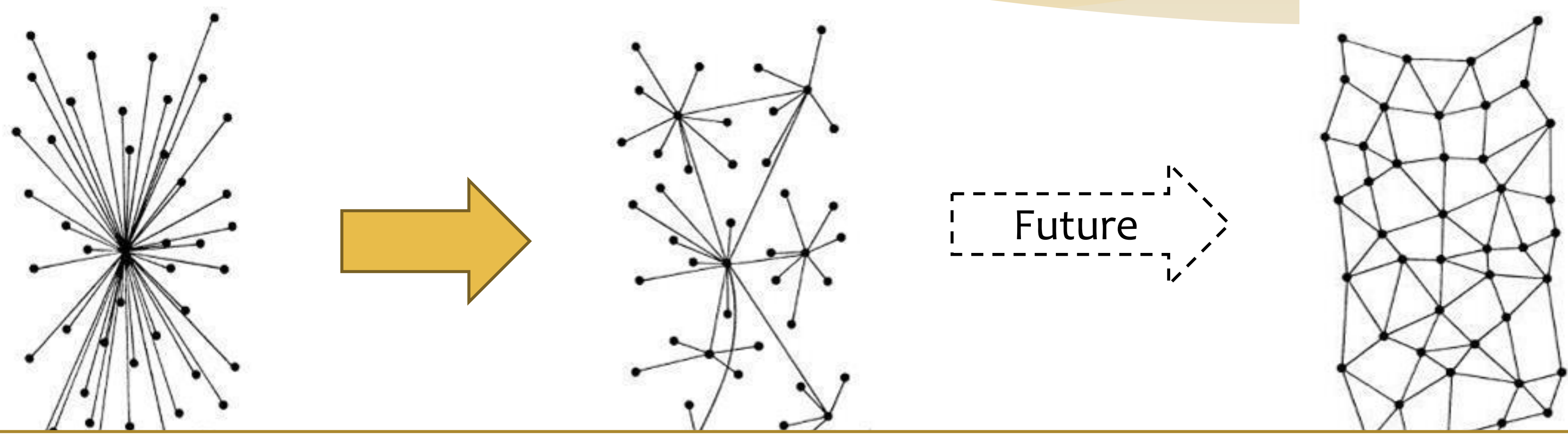
The trend of decentralization



This trend of decentralization can be seen around many other cyber-physical system applications, for example: smart manufacturing, smart cities, etc.

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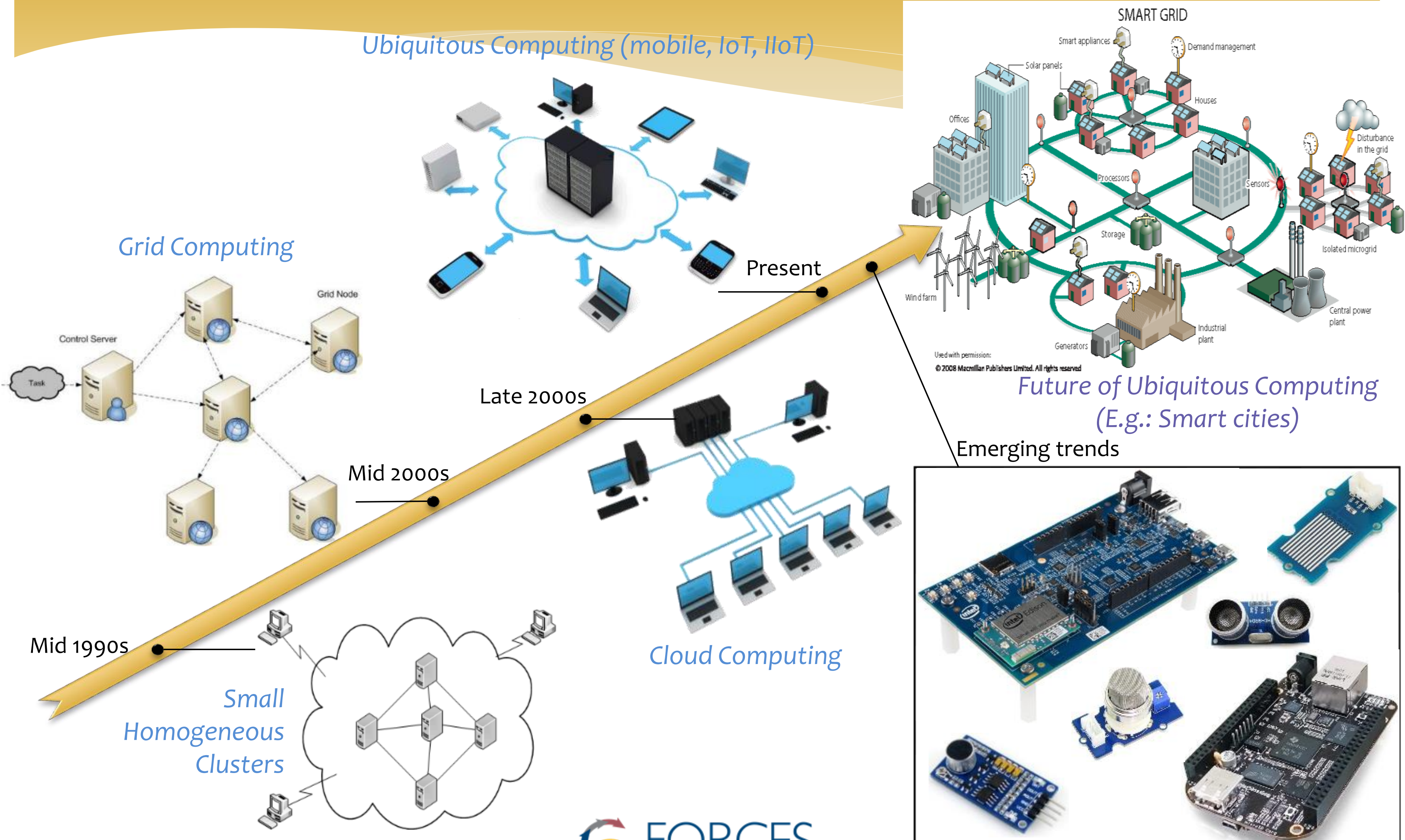
What enables this trend of decentralization?



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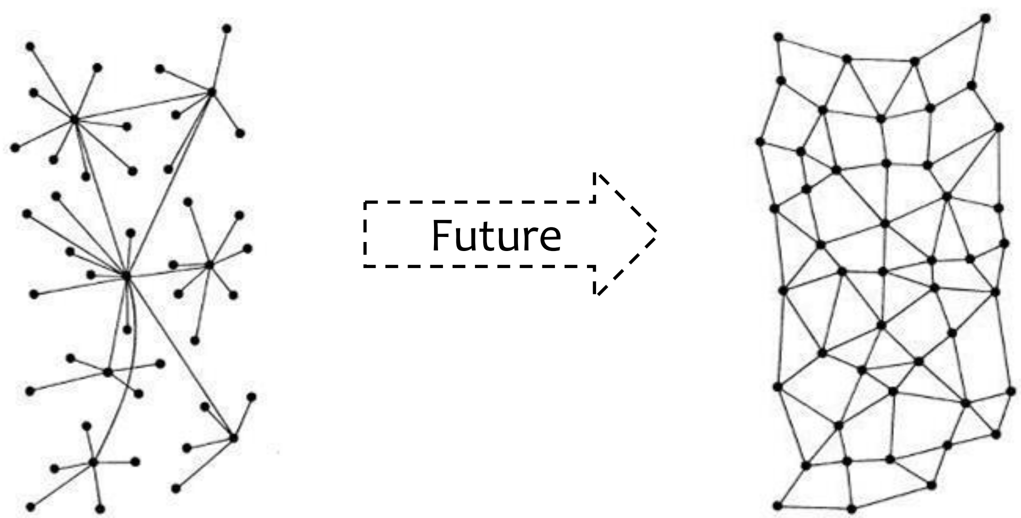
The increased DevOps complexity

* Programming, developing, managing decentralized & distributed networks is hard
* A number of services that are orthogonal to the application logic are required
  * Time synchronization
  * Messaging middleware
  * Consensus & coordination mechanisms
  * Discovery & deployment mechanisms
  * Fault-detection & recovery mechanisms
  * Distributed security mechanisms



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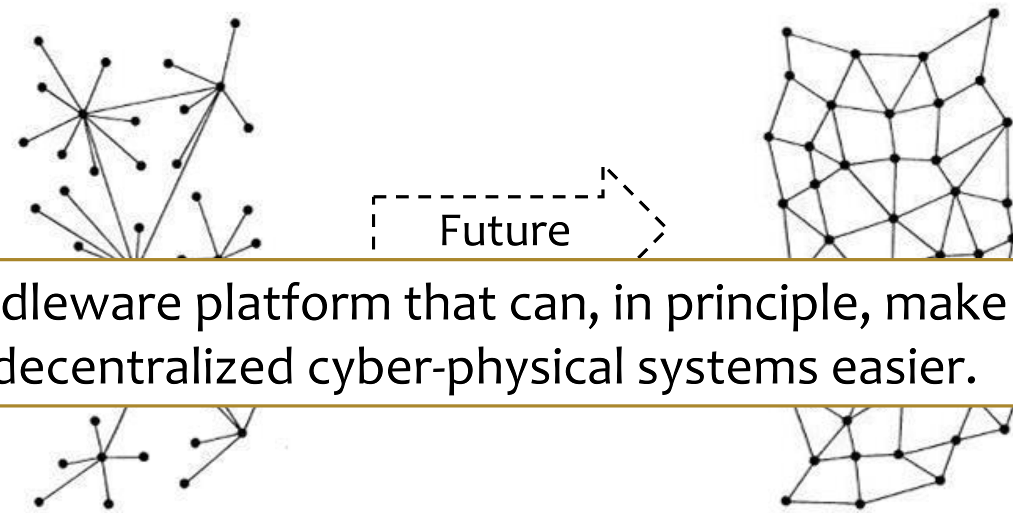

This motivates the need for a middleware platform that can, in principle, make the task of programming these decentralized cyber-physical systems easier.

  - Consensus & coordination mechanisms
  - Discovery & deployment Mechanisms
  - Fault-detection & recovery mechanisms
  - Distributed security mechanisms

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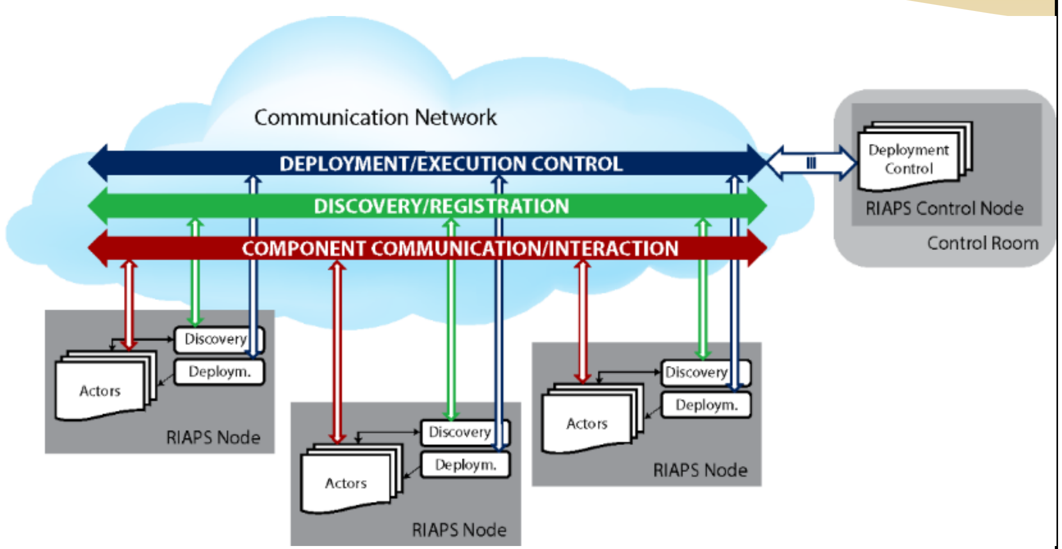
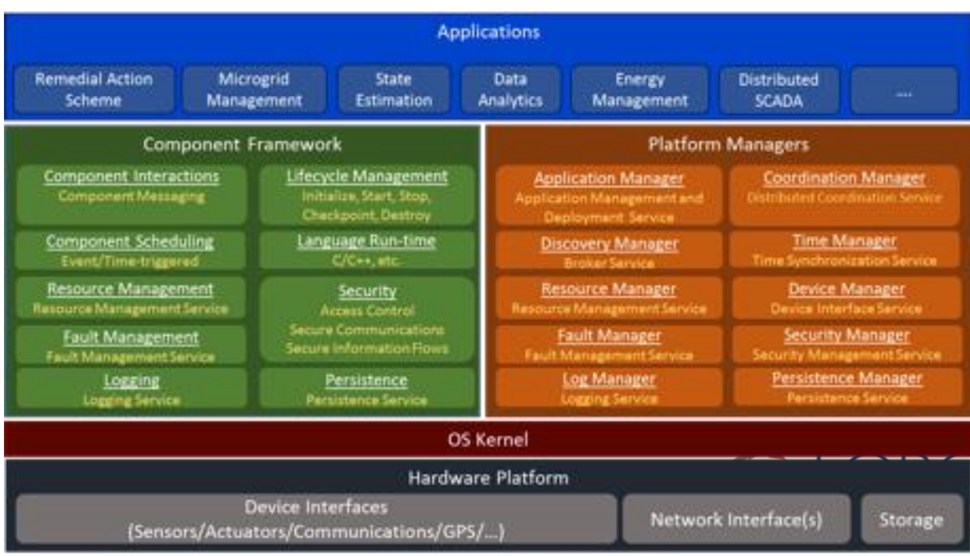
RIAPS: Middleware for Decentralized Computing





- Goal: Build a *software platform* to run Smart Grid applications and demonstrate it through *selected applications*
- This software platform defines:
  - Programming model (for distributed real-time software)
  - Services for
    - Time synchronization
    - Messaging middleware
    - Robust consensus and coordination
    - Secure discovery and deployment
    - Fault-detection and recovery
    - Distributed security
  - Development toolkit (for building and deploying apps)
- Uniqueness:
  - Focus on distributed applications not only on networking
  - Focus on **resilience** – fault recovery
  - Focus on **security** – maintain confidentiality, integrity, availability

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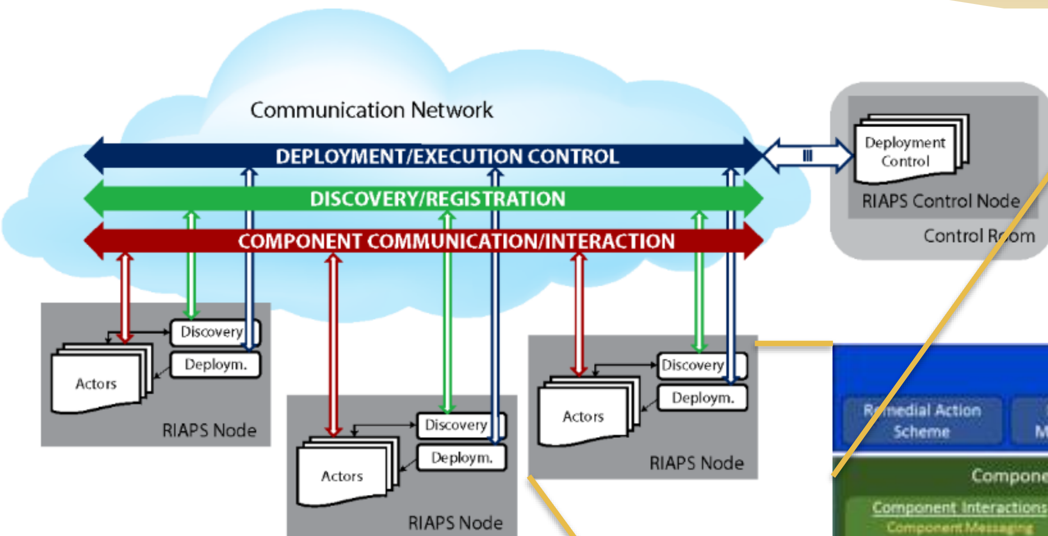

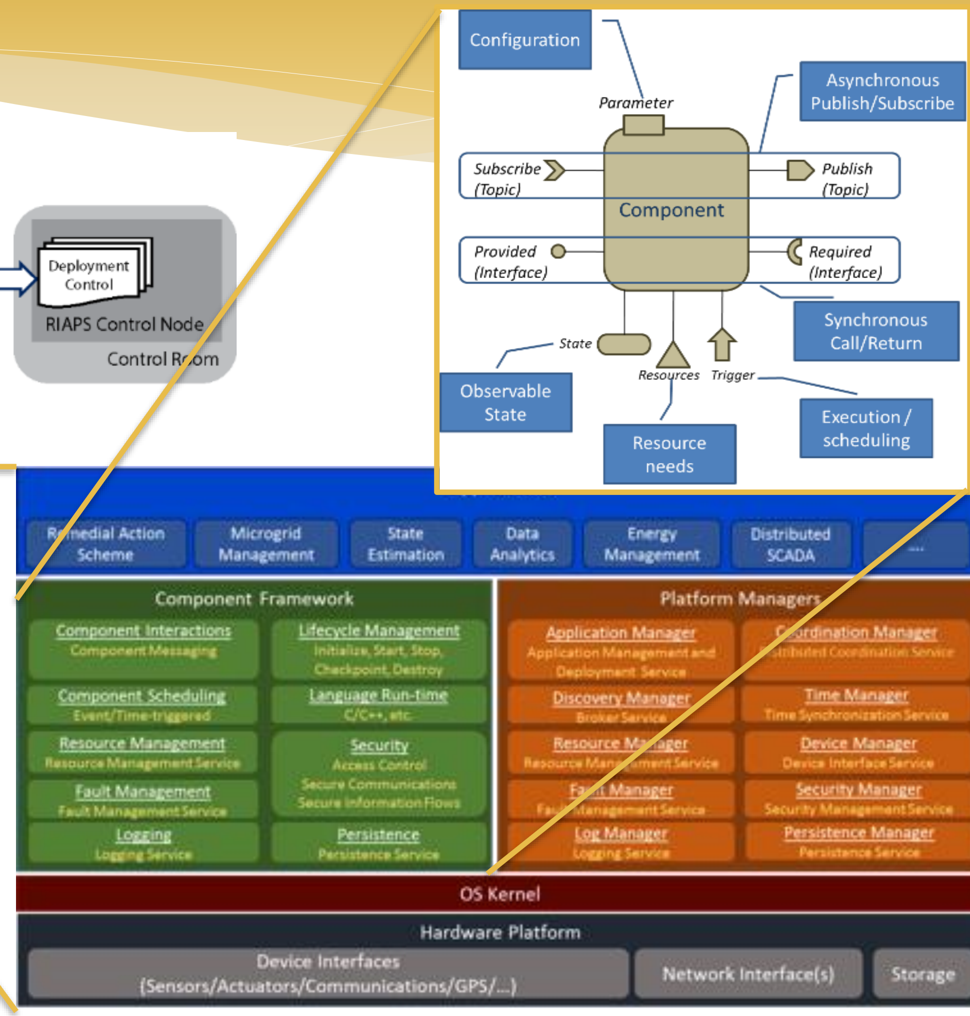

Loosely connected componentized applications are important for portability, interoperability, modularity & maintainability

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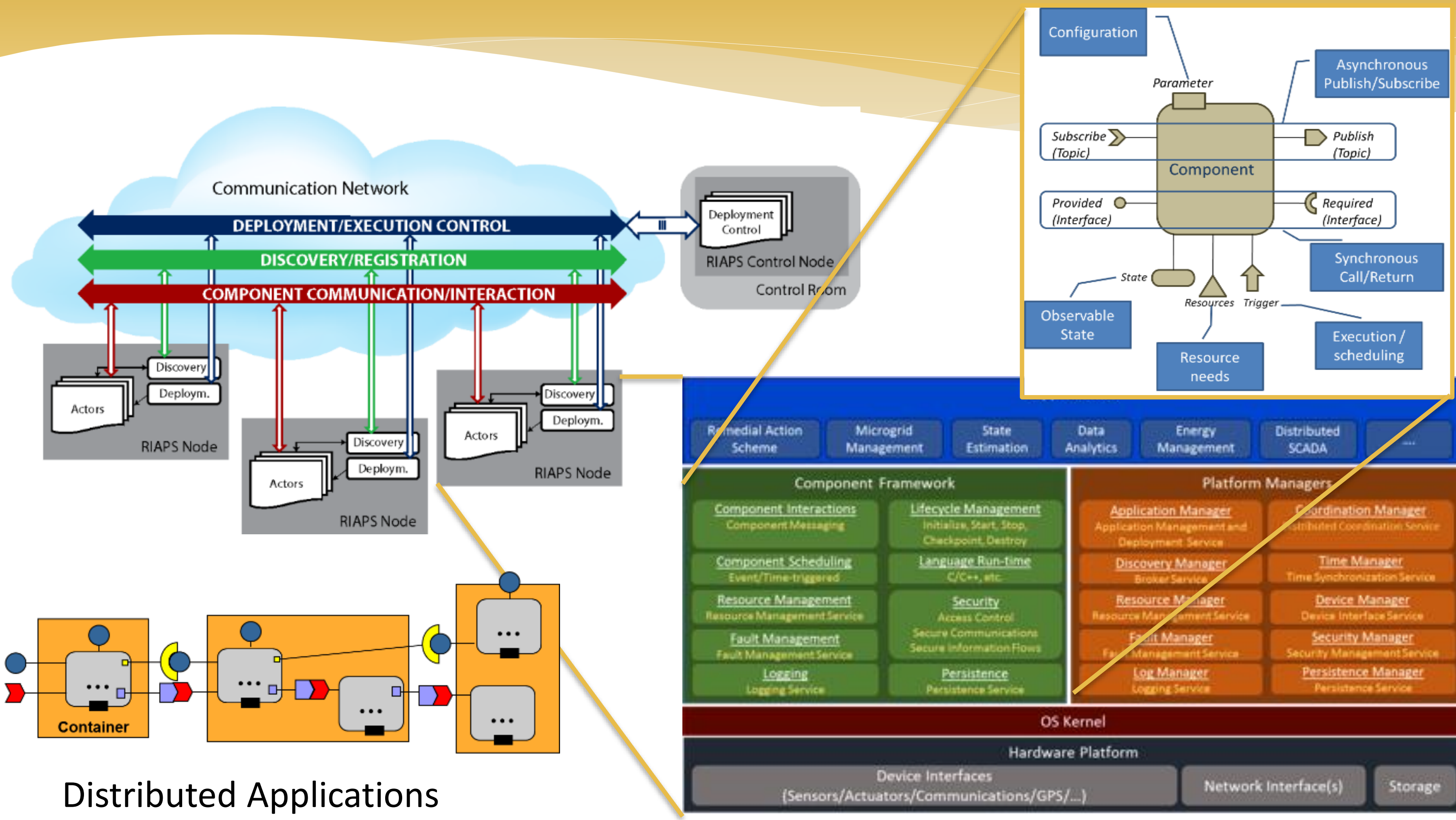

https://riaps.isis.vanderbilt.edu

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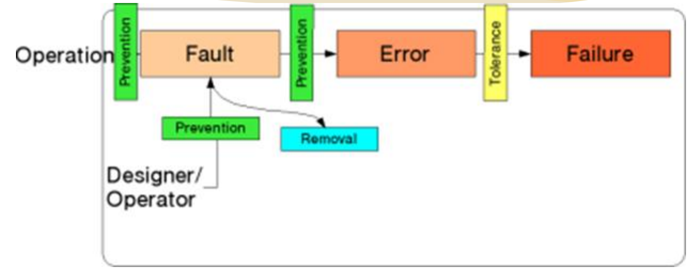
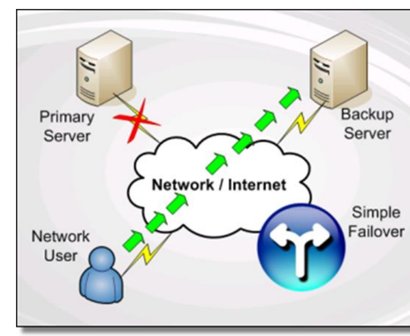
RIAPS: Middleware for Decentralized Computing
Steps Towards Resilience

Fault management

- Assumption: Faults can happen anywhere: application, software framework, hardware, network
- Goal: Developers must be able to develop apps that can recover from faults anywhere in the system.
- Use case: An application component hosted on a remote host stops permanently, the rest of the application detects this and 'fails over' to another, healthy component instead.
- Philosophy: The platform provides the mechanics, but app-specific behavior must be supplied by the app.





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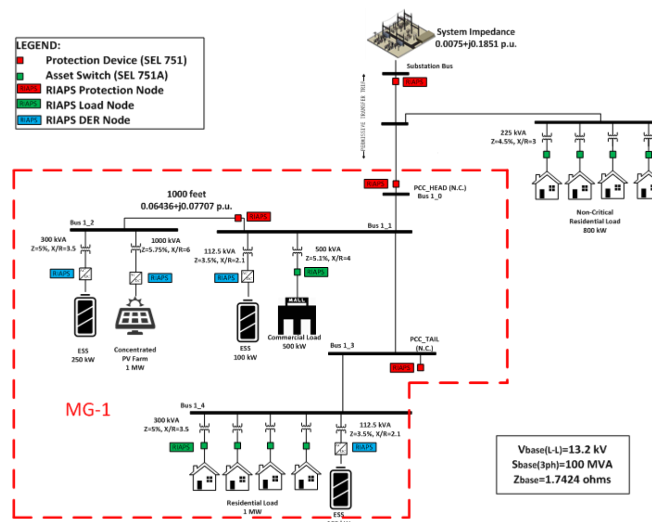
RIAPS: Middleware for Decentralized Computing Steps Towards Resilience

Distributed Coordination

* The need: Reusable distributed coordination algorithms implemented in the framework
* Use case: Nodes implementing a microgrid controller need to dynamically form a group for the purpose of disconnecting from the main grid. They need to reach consensus on the future point in time when the disconnection happens.



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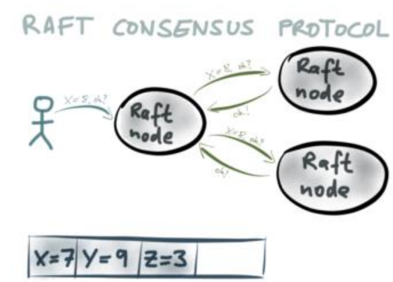
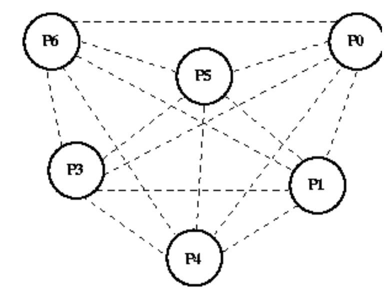
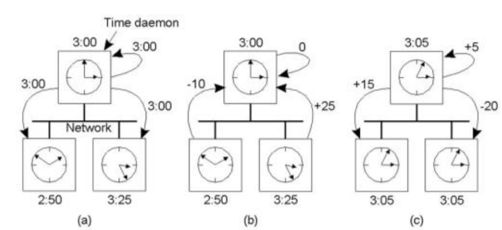
RIAPS: Middleware for Decentralized Computing Steps Towards Resilience

Distributed coordination

* Group membership
  * During run-time, application components can dynamically generate and form a group
  * Features: communication among group members, tracking membership changes
  * Dynamic group membership is maintained by the service in a fault-tolerant manner
* Leader election
  * Group members start a leader election process that results in a leader
  * When the leader drops out (fails or leaves the group) a new leader will be elected
  * Members are notified about leadership changes
* Consensus
  * Nodes attempt to reach agreement on a value, submit proposals
  * Each node can accept or reject the proposed value of the other nodes
  * The process stops when nodes reach consensus
* Time-synchronized action
  * Nodes are to execute a coordinated (control) action in the future
  * Each application component schedules an operation for itself
  * Fault tolerant, high-precision time synchronization service ensures that the operation is executed at the right time, on all nodes involved







RIAPS: Middleware for Decentralized Computing
Steps Towards Resilience

Security features

* Secure deployment and application management
  * Secure interactions with control nodes
  * Strong, cert-based authentication on everything
  * HW-based root of trust in the platform
* Secure communications
  * Secure messaging among application components
  * Secure discovery service
  * Secure information flows: process separation, isolated file systems
* Security management
  * Monitoring and logging
  * Renewable security

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Summary and Future Work

* A robust *software platform* is essential for implementing resilient systems
* The platform should provide features and services for
  * Fault management
  * Distributed coordination
  * Security defense and mitigation
* Application examples:
  * Microgrid Control
  * Remedial Action Schemes
  * Transactive Energy
  * Distributed SCADA
  * Real-time Analytics
* Development is in progress, early demonstrations are available

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