Distributed Asynchronous Algorithms & Software Systems For Wide-Area Monitoring of Power Systems

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Project Goal
To translate current state-of-art centralized processing algorithms for wide-area monitoring of large power grids using large volumes of Synchrophasor data to a completely distributed cyber-physical architecture.

Intellectual Merits:
1. Distributed oscillation monitoring
2. Distributed voltage monitoring
3. Distributed middleware
4. Fault-tolerance
5. Experimental verification using Exo-GENI network
6. Real-time testing of QoS and cyber-security

Problem statement: Compute power flow oscillation frequencies (eigenvalues), mode shapes (eigenvectors), damping, residue, participation factors, and mode energy of electro-mechanical swing dynamics from PMU measurements using distributed algorithms implemented via DRCP and DLAP.

Problem statement: Develop distributed middleware to support DRCP and DLAP algorithms for oscillation monitoring and transient stability.

- Need recent PMU data from PDCs
- Idea: Develop real-time distributed storage
  - Fault-tolerant network overlays
  - RT-DHT: real-time distributed hash table
  - Chord-like ring + finger pointers
  - multiple replicas of data → faults OK
  - need deterministic wide-area networks
- Infrastructure: 1. Cloud computing
  2. Software Defined Networks (SDN)
- Experiments: BEN, Exo-GENI, and GENI
- Study viability of DHT for fault resilience, bandwidth, latency in estimation

Fault-Tolerance & Cyber-Security
- Design application specific fault-tolerance mechanisms to meet real-time needs of the DRCP and DLAP monitoring algorithms
  - Crash failures
  - Byzantine failures
  - Leverage the redundancy of sensors and the correlation among sensor data to reduce the cost of fault-tolerance
  - Protecting a small subset of PMU data may be necessary and sufficient to detect false data injection attacks
  - Leverage application characteristics to design approximate or safe algorithms that can tolerate asynchrony and message loss

Technical Approach
State-of-art Centralized Processing Architecture:
1. Regional PMU data sent to regional PDC
2. Independent local analysis and storage
3. Regional PDCs send data to super-PDC for archival

Proposed Distributed Cyber-Physical Architecture for PMU-PDC Communication:

- Dynamic Rate Control Problem (DRCP):
  - Find optimal PMU data exporting rates, and frequency of information exchange between local PDCs and inter-regional PDCs to minimize computation error between centralized and distributed estimation
- Dynamic Link Assignment Problem (DLAP):
  - Find optimal communication topologies in real-time connecting local and inter-regional PDCs to maximize computational speed for the overall global estimation/monitoring/control problem.

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Experimental Testbed
- BEN-WAMS: Multi-vendor PMU-based hardware-in-loop simulation testbed at NCSU
- High-fidelity dynamic models of IEEE 39-bus New England system & 115-bus WECC
- PDC connected to 10 Gbps Breakable Experimental Network (BEN)
- Execute distributed algorithms in BEN-WAMS
- Test QoS, fault tolerance, cyber-security

Broader Impacts
- Undergraduate, K-12 and minority education via Science House and FREEDM ERC programs at NC State
- Undergraduate summer internship programs at Information Trust Institute at UIUC
- Industry collaborations with power utilities and vendors such as SCE and ABB
- Research Initiative Task Team outreach via NASPI