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

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Project Goal

To translate current state-of-the-art centralized processing algorithms for wide-area monitoring of large power grids using high 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

Technical Approach

State-of-the-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.

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.

Envisioned CPS architecture:

• Weighted Consensus
• Distributed Subgradient Method
• ADMM
• Parallel variable method

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

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

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