Communication and Embedded Systems: Towards a Smart Grid

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• Smart grid communication
  – Key enabling technology
    • Collecting data
    • Control loop

• Challenges:
  – Complex Cyber Physical System
  – Organic growth (hard to integrate new technologies)
  – Stringent security requirements
  – Proprietary protocols
  – Lack of unifying modeling/configuration tools
• Research Interests
  – Support real-time communication
    • Flow-level and per-packet guarantees
  – Correctness
    • Analyze interactions between protocols
    • Verification and validation across all protocol levels
  – Managing large amounts of data
    • Compress, transfer, extract features
  – Reliability of Cyber-Physical Infrastructure
    • Cyber part affects physical part and vice-versa
Narasimha Reddy

- Research Interests: Smartgrid Communications
  - Managing critical infrastructure
  - Need to be simple and cheap for home use
  - Need to be robust, vulnerability proof to prevent mischief
  - Phasor data requires tight QoS
    - Data volumes low, but difficult to support the QOS without a dedicated network
  - Managing the devices will be difficult
    - Once deployed, difficult to replace
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• Ongoing research examples
  • High-Performance Storage and Delivery
  • Hybrid Storage Systems
  • Network Protocols
  • Network Security
  • IP based smart storage
  • Protocols for extreme network environments
  • Routing protocols for improving service availability
  • Statistical techniques for traffic analysis
  • Secure devices on network processors
  • Multimedia Storage
  • Network QoS
• Research Interests
  – Deeply embedded wireless sensor networks; Adhoc and Delay Tolerant Networks
    • Energy efficiency, fault tolerance, security, QoS in large scale networks, with complex network topologies
  – Distributed Systems
    • Big Data, large scale distributed processing systems: infrastructure for MapReduce, Hadoop
    • Mobile Cloud computing
  – Cyber-Physical Systems (CPS)
    • Flow-based CPS: water distribution systems, power grid distribution systems, nanorobot networks for human circulatory system
Radu Stoleru

• Ongoing research examples:
  • Energy Efficient Protocol Design for Sensor Networks with Complex Topology
  • Multi-Channel and Multi-Radio Media Access Control for Coexisting Wireless Networks
  • Resource Allocation for k-out-of-N Computing in MANET
  • Event Detection and Localization in Flow-based Cyber-Physical Systems (Flow-based CPS)
  • Cooperative Intrusion Detection for Resource Constrained Wireless Networks (AMINET)
  • Secure Neighbor Discovery in Mobile Ad Hoc Networks (MSND)
  • A Wireless Sensor, AdHoc, and Delay Tolerant Infrastructure for Emergency and Tactical Networks (DistressNet)
• Research Interests
  • Integration of renewables
  • Demand response
  • Electric vehicles
  • PMU data analysis

• More broadly
  • Wireless networks
  • Cyber-Physical systems
  • Control
  • Information theory
  • Transportation
• Ongoing research examples
  • Demand Security of inertial loads
  • Dimensionality reduction of PMU data and early event detection
  • Utilization of wind energy for data centers
• More broadly
  • A clean slate approach to security of wireless networks
  • Real-time wireless networks
  • Safety of automated traffic
  • ...
U.S. Energy Consumption by Energy Source, 2009

Total = 94.578 Quadrillion Btu

Petroleum 37%
Natural Gas 25%
Coal 21%
Nuclear Electric Power 9%
Renewable Energy 8%
Geothermal 5%
Biomass waste 6%
Wind 9%
Biofuels 20%
Wood 24%
Hydropower 35%

Total = 7.744 Quadrillion Btu

Solar 1%

Note: Sum of components may not equal 100% due to independent rounding.
The context

Supply Sources

- Petroleum: 37%
- Natural Gas: 25%
- Coal: 21%
- Renewables: 8%
- Nuclear: 9%

Demand Sectors

- Transportation: 28%
- Industrial: 20%
- Residential & Commercial: 11%
- Electric Power: 41%

Total: 94.6 quadrillion Btu

Source: Energy Information Administration, Annual Energy Review 2009

(Total: 7.15 billion metric tons of CO2 equivalent)

- Electric Power Industry: 34.2%
- Transportation: 27.9%
- Industry: 19.4%
- Residential: 13.0%
- Commercial: 8.7%
- Agriculture: 7.0%
- U.S. Territories: 0.8%

• How to increase usage of non-greenhouse gas emitting renewables in
  – Buildings, e.g., space heating?
  – Transportation?
Current situation

- Demand drives supply

- Little explicit information is needed for adjusting to demand
- Generators “feel” the increase in demand
Operating reserve

- Supply is adjusted to meet demand
  - Needs an Operating Reserve

Diagram:
- Operating Reserve
  - Non-event
    - Regulating Reserve: Automatic, Within optimal dispatch
    - Following Reserve: Manual, Part of optimal dispatch
  - Event
    - Contingency Reserve: Instantaneous
      - Primary
      - Secondary
      - Tertiary
    - Ramping Reserve: Non-Instantaneous
      - Primary
      - Secondary
      - Tertiary
      - Replace secondary

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The need for a new strategy

• Why not use same strategy for renewables?

• Renewable energy cannot be ramped up
• In fact it is “stochastic”
• Regulating reserve requirements will need to be large
• Negate the benefit of wind power
• Also stability of power system needs to be maintained
• So not feasible to use older strategy of “supply follows demand”
Can we make “Demand follow supply”

• Can we adjust demand in response to supply?
Challenges for Demand Response

• Thermal Inertial Loads
  – Traditionally under thermostatic control
Alternative architectures

- An Aggregator Architecture

  - Sense “home state” (Temperature, pool condition)
  - Transmit information from Building to Aggregator
  - Convey Actuation Commands from Aggregator to Buildings
Research challenges

• Challenges
  – Contract between Aggregator and ISO
  – Contract between Aggregator and Customers
  – Prediction of renewable power at different time scales
  – Optimal control of inertial loads
  – De-synchronization of loads
  – Privacy and Security of load information
  – Communication modalities
  – Development of algorithms
A Fully Distributed Architecture

Challenges

- Closing technological loops with economic mechanisms
- Stability of system
- Design of customer contracts
- Security of system to spoofing and other attacks
Synchrophasors: The Big Data Challenge

• Challenges
  – Point pattern analysis of synchrophasor measurements
  – Dimensionality reduction
  – Event detection using online synchrophasor data
  – Optimal placement of PMUs
Electric Vehicle Charging Infrastructure

- Challenges posed for development of EV charging networks
  - Charging station optimization as a function of
    - Car state, maximum charging rate, deadline, variability of energy price, customer willingness to pay

- Optimal choice of charging stations
  - Bid price, availability, congestion, deadline

Power, price

Optimal utilization of power

Storage
Thank you

- Coal: 45%
- Natural Gas: 23%
- Nuclear: 20%
- Hydroelectric: 7%
- Other Renewables: 4%
- Petroleum: 1%
- Other Gases: 0.3%
- Other: 0.3%