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Communication Challenges for the Next Generation Power Grid

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Talk Outline

Overview

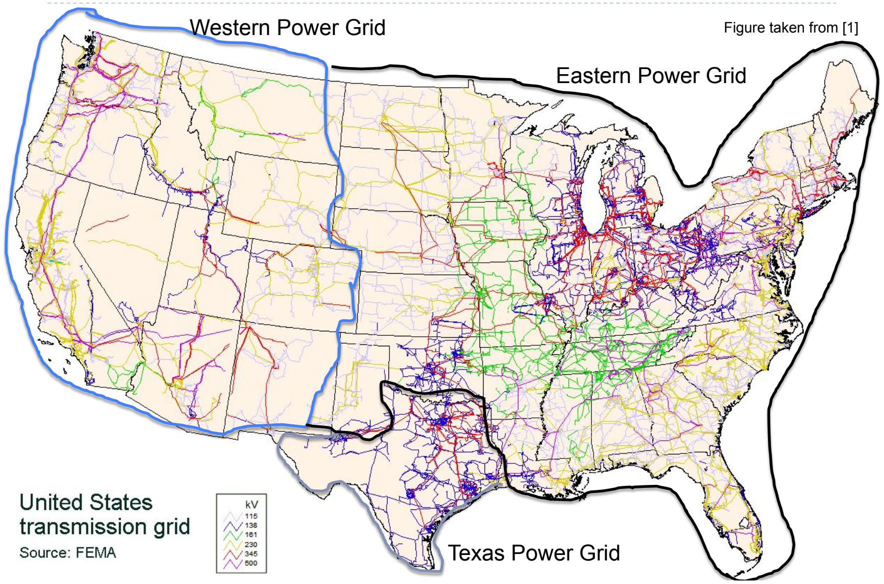
- Electric power Grid part of a states critical infrastructure
- Our modern life depends on the availability of reliable, resilient, stable, and cheap electricity
- Currently generate electricity is generated by large installation using non-renewable fossil or nuclear based fuels
- According to the International Energy Agency (IEA) [4]
  - Currently 70% of the electricity is produced from fossil fuels responsible for 40% of the global CO_2 emission
  - If energy related CO_2 emissions are reduced by 50% before 2050
    - Demand expected to increase by 115% until 2050
  - Else
    - Demand expected to increase by 150% until 2050

Overview (Cont.)

The big question

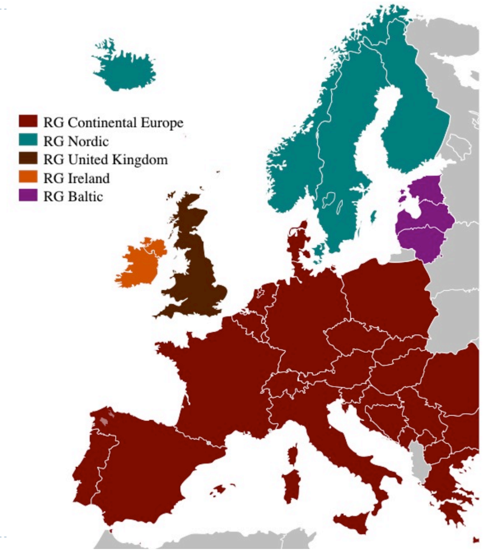
How to support the growing demand of reliable electricity while at the same time reduce the reliance on non-renewable pollutant and/or dangerous fuels

Overview - US Electric Power Grids



Overview - European Power Grids

Figure taken from [1]



Talk Outline

Background - Requirements

- Electric Power Grid requirements
  - Electricity must be transported from the large power plants to the consumers
    - Electricity cannot currently be stored
  - The whole Grid operates as one large system at the same frequency.
  - Demand must be matched by Supply in real time
    - Too much demand, the frequency drops
    - Too much supply, the frequency increases
    - Suppliers must be able to provide Peak-Demand when needed
  - System should be able to handle
    - Temporary lose if power generators
    - Lose of power lines
    - Various equipment failures

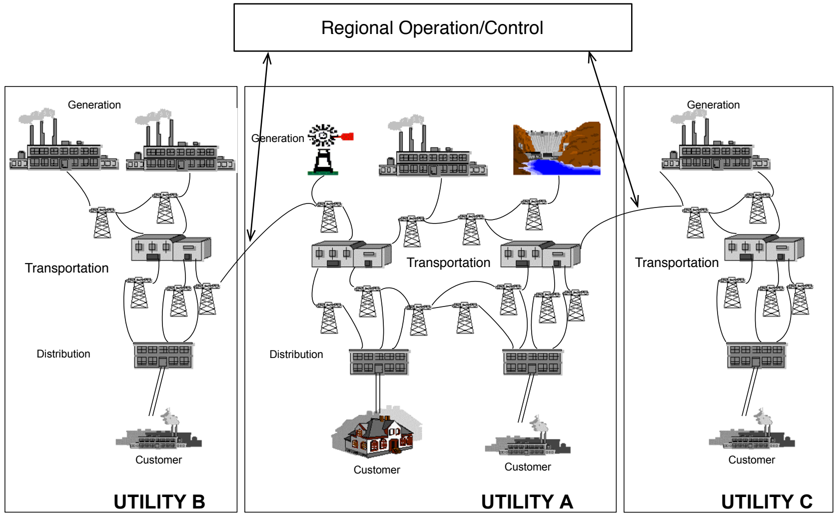
Background - Failures

- Blackouts in the US
  - 5 major blackouts in the last 40 years
  - 3 occurred in the last decade
  - The 2003 North Eastern [2] blackout was mainly due to
    - One sagging transmission line
    - One faulty alarm due to a race condition in the software
    - Lack of situation awareness of the operators
  - Affected about 55 million people in Canada and the US and loss of an estimated $7 – 10 billon
- Blackout in Cyprus [3]
  - One major power plant supplied 47% of the republics needs
  - On July 11th 2011, explosion at the nearby navel base destroyed the plant.

Background – Power Grids

- Traditional Power Grids (Vertically Integrated Electric Utility)
  - Each region (part of a Grid) is owned and operated by one utility (company/organization)
  - Each utility responsible for the entire chain
    - Generation
    - Transportation/Distribution
    - Consumption
  - Collaboration between the utilities through some hierarchy of independent organization/operators.
    - In the US:
      - Regional Transmission Organization (between states)
      - Independent System Operator (within a state)
    - In the EU
      - European Network of Transmission System Operators for Electricity
      - Transmission System Operators (within a state)

Background – Power Grids (Cont.)



Background – Power Grids (Cont.)

- Each Power Grid have their own behavior and controllability determined by
  - Distance from generation to consumption
  - Number and size of generators, i.e. a few big generators or many smaller generators
  - Type of generators: Time needed to start and stop the generators
  - Predictability of the consumption, i.e. few big consumers or many residential homes
  - Seasonal changes in the area for predictability of the load
- One solution may not fit all
- Best practices and solutions must be converted/amended/ modified before applied

Background – Changing Landscape

- Aging infrastructure (part if it more then 40 years.)
- Higher demand for power transmission – miles x megawatts
  - More power and longer distances with little new transmission
  - Charging of Electric Vehicle in the future
- Deregulation of the industry
  - More participants whose actions affect grid stability
- Technology in recent years is adding
  - Many more "intelligent" devices
  - Much more *heterogeneity*
- Protection and control is mostly local today
  - Remedial Action Schemes (RAS): hardwired remote link to trigger a protective relay
  - Otherwise almost exclusively local monitoring (status) & local control
    - Power dynamics are grid wide, and anomalies can affect a wide geographic area

Talk Outline

Smart Grid – Definition

- The concept of Smart Grid have been refereed to as Advanced Metering at the Consumer End, but its much broader then that
- Its broader definition is twofold:
  - "Smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users."
  - "Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability."

Smart Grid – Definition (Cont.)

- Wikipedia has the following definition

"A ***smart grid*** is a digitally enabled electrical grid that gathers, distributes, and acts on information about the behavior of all participants (suppliers and consumers) in order to improve the efficiency, importance, reliability, economics, and sustainability of electricity services."

Smart Grid – Definition (Cont.)

- Depending on the state of the Grid the smartening of the Grid will be different
- For Industrialized and Economies in Transition Countries
  - The Smart Grid will be an evolutionary process, not a one-time event
  - Sunk cost in legacy systems will result in their usage until decommissioning
- For Developing counties
  - Can take advantage of the new technologies as the countries infrastructure is developed.

Smart Grid – Expectations

- Some of the expectation of a Smart Grid
  - Large portion of the electricity generated from renewable sources
    - Hydro, wind, photovoltaic, tidal technologies, combined heat and power, or future technology
  - Operate the Grid more efficiently
    - Reduce the Peak-demand, i.e. flatten the usage curve
    - Quicker reaction time due to more measuring devices leading to greater situation awareness
  - Automated management
    - More intelligent management of the Grid.
  - Prosumer:
    - Consumers may also become producers, i.e. small wind mills, photovoltaic, reverse EV (Electric Vehicle) charging.

Smart Grid – Expectations (Cont.)

- Demand-Side Management:
  - Due to less predictable generation management must be shifted from Supply side towards Demand side
- Reducing Peak Load will make the Grid more efficient
  - Intelligent devices like: dryers, freezers, air conditions can switch off during peak demand
  - Customers can be informed about current pricing and may choose to change routines to minimize electricity use during peak hours

Smart Grid – Transition

- Smart Grid from the consumers point of view
  - More flexibility and control, but more technological complex for the end user.
  - Analogy of change: Old analog telephones to todays Smart Phones

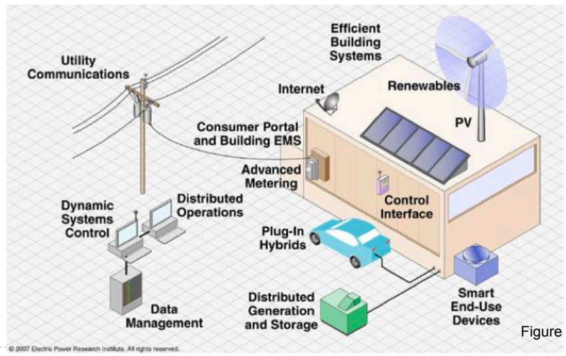


Figure taken from [5]

Smart Grid – Past

- Transition from the power industry point of viewed
- Management done with few instrumentation points and communication between regions done through the Phone system
- During 2003 blackout, Regional operators still communicated through the phone system

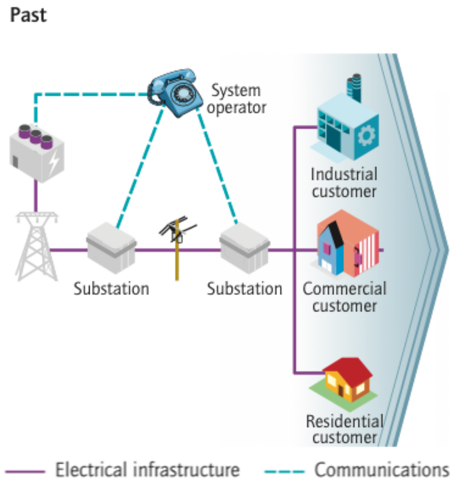


Figure taken from [4]

Smart Grid – Present

- Management still done at the supply side
- More instruments:
  - Phasor Measurement Units (PMU)
  - Supervisory Control and Data Acquisition (SCADA)
- More automated control, but still with relative large time intervals.
  - Information pulled
    - Every 5 minutes
    - Every 30 seconds

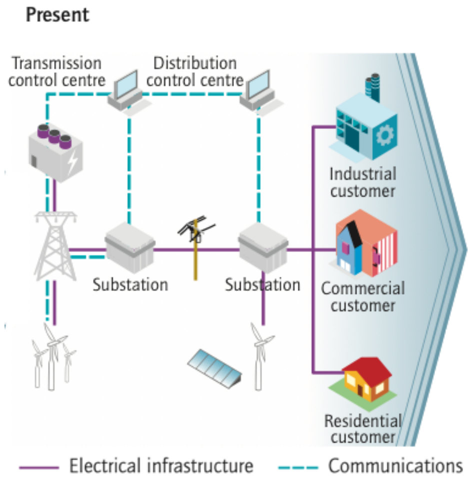


Figure taken from [4]

Smart Grid – Future

- Many more:
  - Devices
  - point of control
  - participants
- All involved in operating the Grid
- Much more exchange of information is required

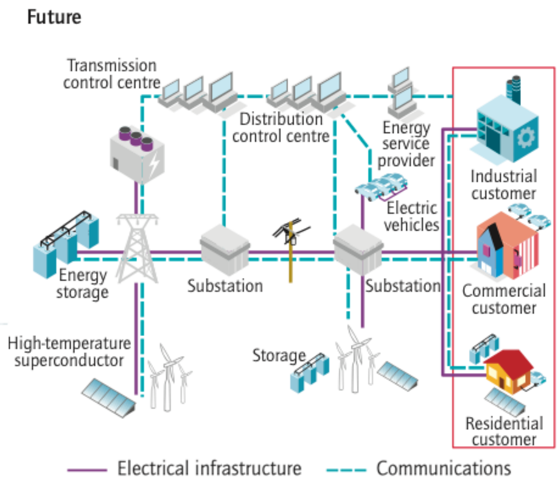


Figure taken from [4]

Smart Grid – Multidisciplinary Challenges

- Power System Engineering
  - Must operate a reliable, stable, and resilient 'smart' power grid
- Telecommunication
  - The new 'Smart' is due to digital devices that must communication.
  - Must operate a reliable, stable, and resilient communication infrastructure
    - Should this be a dedicated infrastructure for the Critical Infrastructures?
- IT - Covers the whole stack
  - Network layer
  - Middleware layer
  - Application layer
- Business
  - How will power be traded in the Smart grid
  - More importantly: How will it be regulated?

Talk Outline

- Overview
- Background
- Smart Grid
- Information and Communications Technology
  - Needs
  - Telecommunication
  - Information Technology
- Research Examples & Standardization Efforts
  - GridStat Framework
  - Inspire Project
  - International Collaboration & Standardization
- Talk Summary

Information and Communications Technology

- The changing landscape for the Grid
  - Many more entities that need two-way communication
  - Many more generators, but their availability is not deterministic
  - Introduction the flexibility to store electricity
  - Greater flexibility of end user to "plan" their electricity usage
  - Introduction of a "market" to trade electricity
- All of this exchange of information will rely on a future ICT infrastructure

Telecommunication

- The physical layer of the Communication Infrastructure
- Some options for the telecommunication infrastructure
  - Dedicated telecommunication infrastructure for the Critical Infrastructures.
  - Piecemeal of different systems for different purposes
  - Share infrastructure with other application areas such as the phone and/or Internet
  - Hybrid part of it is using dedicated a infrastructure while parts are using shared infrastructures like the Internet

Telecommunication – Dedicated Infrastructure

- Dedicated infrastructure with complete separation from other networks
  - Shared with all the participants in the Smart Grid
  - Possible more predictability and controllable than other solutions
  - Need to differentiate traffic and provide different QoS
  - Many participants will have access which can complicate security issues
- Compartmentalized and/or Virtualized dedicated infrastructure
  - The control and monitoring with stringent QoS requirements are compartmentalized/Virtualized from the information system that could be offered different QoS guarantees
- Most expensive solution, but have some clear advantages

Telecommunication – Piecemeal of systems

- Current practice today
- Different infrastructure and systems for
  - different regions, utilities, and vendors use different systems
  - control and monitoring of critical component
  - various non-critical information systems
  - smart metering, power trading
- Pros:
  - Clear separation between the systems, could help with protection and security
  - Greater predictability with respect to systems usage (but this could change)
- Cons:
  - Scalability: Does not scale well.
  - Flexibility: How will new systems be added and to what part of the system
  - Extensibility: Will become a patchwork if the 'smartness' of the Grid is added to existing systems some of which is more then 20+ years old

Telecommunication – Shared Infrastructure

- Must keep in mind that this is for a states Critical Infrastructure
  - A shared infrastructure have potentially more vulnerabilities
  - Who will have priority when resources are limited
  - For control systems with stringent latency requirements it has been shown that the TCP/IP protocol is not adequate
    - Small part of the control will have to use a dedicated infrastructure
- Part of the non-critical information could be exchange using infrastructures like the Internet
  - End users smart meters
  - Power buyers and sellers
  - Dissemination of predicted future prices, usages, etc.

Telecommunication – Hybrid

- Slow convergence from current practice to a generic dedicated infrastructure
- Will keep the current system running, while upgrading to a universal dedicate infrastructure.
- Cost will be a factor
  - In the construction business it is cheaper to tear down a hotel and build a new one instead of upgrading the old

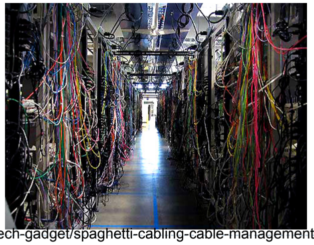


Figure taken from:
http://www.techeblog.com/index.php/tech-gadget/spaghetti-cabling-cable-management-gone-wrong

Telecommunication – Summary

- Whatever is chosen
  - It should be extensible as it should have a very long lifetime.
    - Large investment that must be amortized over time
  - Should be scalable
    - Hybrid Vehicle Charging stations
    - New electricity generation technology
  - It should follow standards as to be interoperable and avoid vendor lock in
    - Competition and the use of COTS components will drive costs down
  - Security and Protection
    - Resilient to both physical and cyber-attacks
    - The Smart Grid will not operate without the telecommunication infrastructure, there should be no weak links

Information Technology

- Trusted Dissemination of information with strong QoS requirements
  - All entities must exchange information
  - The right information must be securely delivered to the right end-point at the right time with a high confidence that it is indeed the right information.
- Distributed Intelligence
  - The smart Grid will need intelligence, i.e. Artificial Intelligence, to operate
  - Should automatically operate the Grid more reliably, securely, and efficiently then today.
  - How much control can/should we give up?
  - Who is accountable when unforeseen conditions/events occur?

Information Technology – Network Layer

- Must provide QoS classes subject to the payload
  - Predictability
    - Predictable hop and routing latency
  - Reliability
    - Redundancy with heterogeneous technology
      - Bug in firmware or vulnerability in the hardware design
    - Should also have their own backup power source
      - If the power Grid fails then we don't want the control system to fail as well
  - Adaptability
    - Murphy's law will always apply
    - What to do when it happens
  - Security
    - Integrity, confidentiality, source authentication

Information Technology – Network Layer (Cont.)

- Two recent trends may be looked at
  - Peer-to-peer Overlay Networks
    - Pro: Scalable, decentralized, and robust
    - Cons: Unpredictability, i.e. often best effort
  - Hardware Virtualization
    - Used to maximize the resources of servers
    - Provides for flexibility and compartmentalization of services
- Potential for Virtualization of Networks
  - Provide great flexibility if the Physical Network Infrastructure can be virtualized
  - Different systems will be given dedicated virtual resources with different QoS guarantees

Information Technology – Middleware Layer

- Middleware
  - A layer above the OS/Network and below the Application
  - Masks heterogeneity and provides higher abstractions
- End-to-end QoS
  - Taking advantage of the semantic of the information to be disseminated
    - Routing can be done at the middleware level
    - Can also be done in hardware with Network Processors
  - Per-flow state can be maintained in the dissemination network to provide End-to-End QoS
    - Possibility for multicast if enough is know of the information flows

Information Technology – Middleware Layer (Cont.)

- Adaptability
  - If routing/forwarding is done at middleware layer, mechanisms can be provided to adapt the dissemination flows
  - Policies at the application layer can be specified to use these mechanisms
- Future Extensions
  - Provide new functionality and service at the middleware layer, no need to change the underlying hardware infrastructure
  - Changes to the underlying infrastructure can be masked by the middleware layer

Information Technology – Application Layer

- Monitoring and Control
  - EIOC: Electricity Infrastructure Operations Center at PNNL
  - Automatic response, but also Human-in-the-loop

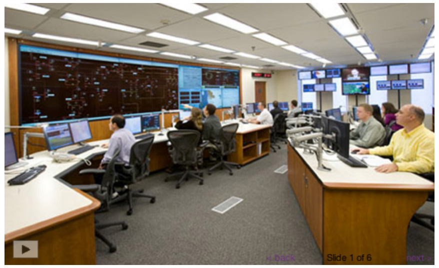


Figure taken from [6]

Information Technology – Application Layer (Cont.)

- Monitoring and Control
  - Situation awareness: Global Snap-shot of the state of the Grid
  - Run simulations for State Estimation and Contingency Analysis in real time.
    - Today High-performance Computing is needed to do this
    - What will be needed with a more unpredictable power supply?
  - With all the new devices and unpredictable power sources the stability and contingence analysis is greatly complicated
    - The need for distributed intelligence

Information Technology – Application Layer (Cont.)

- Distributed Intelligence
  - Distributed stability and contingence analysis must run in real time.
    - The dissemination infrastructure is of paramount importance
  - May not be possible to get an prediction of the stability of the Grid
    - Incomplete information about certain part of the Grid.
    - No way to know if it will be cloudy in the next 2 minutes
  - Collective agreement as to how to react in any given situation, like instability, lose of major generation, etc.
    - Many secondary problem here:
      - Who should get affected
      - Who will scarifies their profit for stability
      - Many different trade-offs with parties with competing interests
    - The technical mechanisms can be distributed voting algorithms etc.
    - But how will the policy be regulated?

Information Technology – Application Layer (Cont.)

- HCI: Human Computer Interaction
  - The control centers
    - Will the humans be able to keep up in a Smart Grid?
    - Maybe the machines will need to be in control with a safety kill-switch
  - The end-users
    - Current state: "The electricity just works and is always there"
    - The idea of the smart grid is to provide the end users with more flexibility => might result in more complexity
    - Need a very user friendly interface if the user are supposed to "program"/"schedule" their appliances
    - Most end-user may just leave all their systems in the default configuration
      - Defying a major motivation for the Smart Grid

Information Technology – Cyber Security

- Perfect Security is:
  - A system that is turned off and disconnected from all networks
  - Not feasible for the Smart Grid
- Multiple threats exists for the Smart Grid ICT infrastructure
  - More participants with legitimate reasons to receive and disseminate information
  - More physical access points to the control system, i.e. smart meters, prosumers, etc.
  - Distributed intelligence may be used to take control decision
    - This can be manipulated to take the wrong decisions

Information Technology – Cyber Security (Cont.)

- Denial Of Service attacks
  - More legitimate entities in the loop
    - Can be used to start a DoS attack.
  - Possible to get various systems stuck in a "thrashing" state.
    - If EVs are used for storage of electricity, then a "thrashing" state could be to rapidly switch between using the EVs as consumers and produces.
  - The entities can play the system for monetary/competitive advantages
    - Need for strong regulatory oversight
- If the dissemination decisions are taken at the middleware layer, i.e. middleware layer routing
  - More knowledge available at the end-point to stop unwanted traffic

Information Technology – Privacy Protection

- Control of large quantity of information is Power
- A Smart Grid needs more information from the consumers
  - Information is collected when the consumer is consuming electricity as to provide differentiated pricing schemes
  - If consumers becomes produces, much more information is collected
  - This information may also be distributed to "all" the other participants as it is needed for the distributed intelligence algorithms
- Missus of information
  - The collected information can be mined by government agencies, utilities, and other consumers
- How will this 'power' be regulated

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  - GridStat Framework
  - Inspire Project
  - International Collaboration & Standardization
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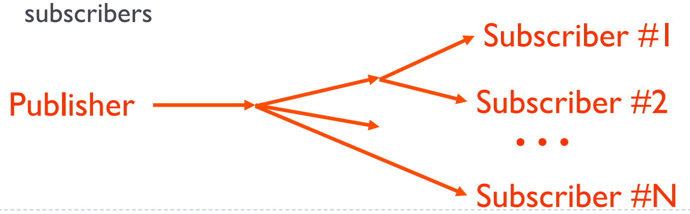
GridStat Framework

- GridStat is a wide-area publish/subscribe middleware developed for disseminating streams of status information for the electric power grid
  - Optimized for the domain of critical infrastructures that makes it possible to take advantage of the semantics of the status info.
  - Convey status data in a reliable, timely and secure manner (QoS)
  - Provides end-to-end QoS guarantees
  - Also applicable to needs of other infrastructures: transportation, water, gas, etc.
- Expects
  - Dedicated infrastructure, completely controlled by GridStat
  - Needs this to store per-flow information in the forwarding engines
- Appropriate for the control and protection system

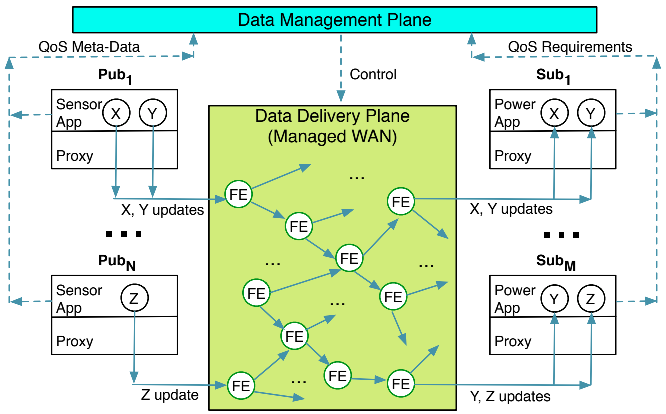
GridStat is Publish-Subscribe Middleware

- Publish-subscribe architecture
  - Publish: periodically announce status values
  - Subscribe: periodically receive status values
- Network of internal servers managed for QoS
  - Optimized for semantics of status items
  - Provides snap-shot of a set of variables if they are published at the same time, i.e. deterministic filtering of events.
  - Multicast with of events that are to be delivered to multiple subscribers

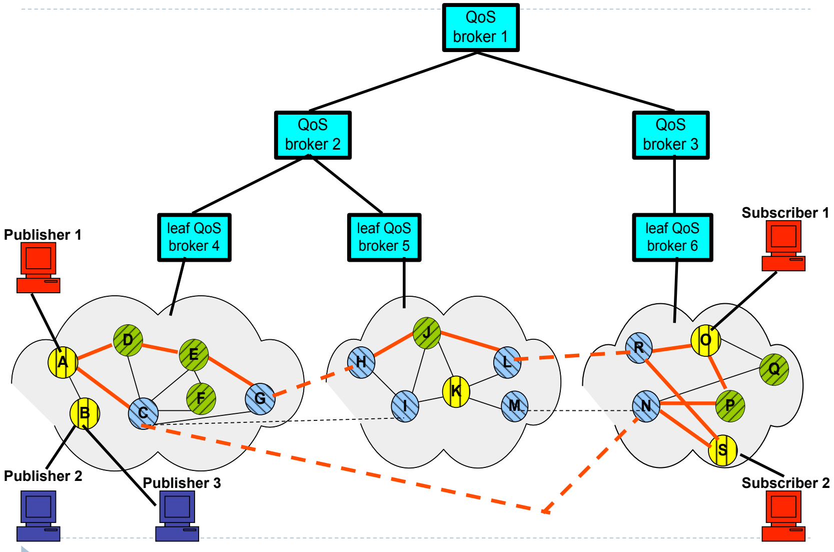


GridStat Architecture

- Management plane: controls the resources in the data-plane
- Data plane: forwards events as efficiently as possible in order to provide end-to-end QoS



GridStat Architecture (Cont.)



Inspire

- INcreasing Security and Protection through Infrastructure REsilience (INSPIRE)
- Data dissemination middleware with goal of providing high availability and data protection
- Interconnections among SCADA systems can use COTS and public networks like the Internet.
  - Idea is to increasing the security and protection through infrastructure resilience
  - Using an P2P overlays as it
    - mask the heterogeneity of large scale topologies
    - provides robustness due to the redundancy of paths
    - provides data availability as data storage is replication on several nodes

Inspire Architecture

- Easier to deploy than GridStat,
- Appropriate for less time sensitive control and management
  - Maybe the control and management system for the Prosumers

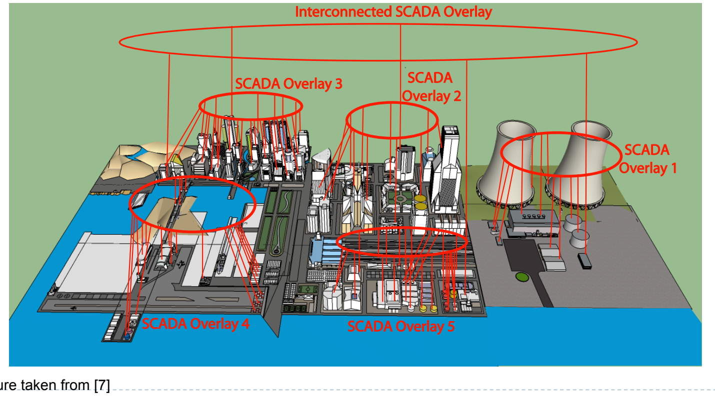


Figure taken from [7]

International Collaboration & Standardization

- Industry and Government Initiatives
  - GridWise Alliance
  - North American SynchroPhasor Initiative (NASPI) Net
  - European Electricity Grids Initiative (EEGI)
  - European network for the Security of Control and Real-Time Systems (ESCoRTS)
- Government and Standard Organization
  - US: Energy Independence and Security Act (EISA) 2007
    - NIST Smart Grid Interoperability Standards Framework
  - EU: European Joint Working Group for Standardisation of Smart Grids
    - European Committee for Standardization (CEN)
    - European Committee for Electrotechnical Standardization (CENELEC)
    - European Telecommunications Standards Institute (ETSI)

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Talk Summary

- Smart Grid the dream
  - Can it deliver the dream of a sustainable flow of renewable energy to the World?
- Lots of research possibility from everybody
  - Engineering
    - Renewable energy fuels
    - Stable power delivery from unpredictable power generators
  - Information and Communications Technology
    - Trusted dissemination infrastructures
    - Distributed intelligent systems for operating the Smart Grid
  - Business
    - How to make a sustainable business model for the Smart Grid
  - Law
    - Privacy and regulatory needs

Sources for this talk

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Thank you for your attention!

Questions?

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