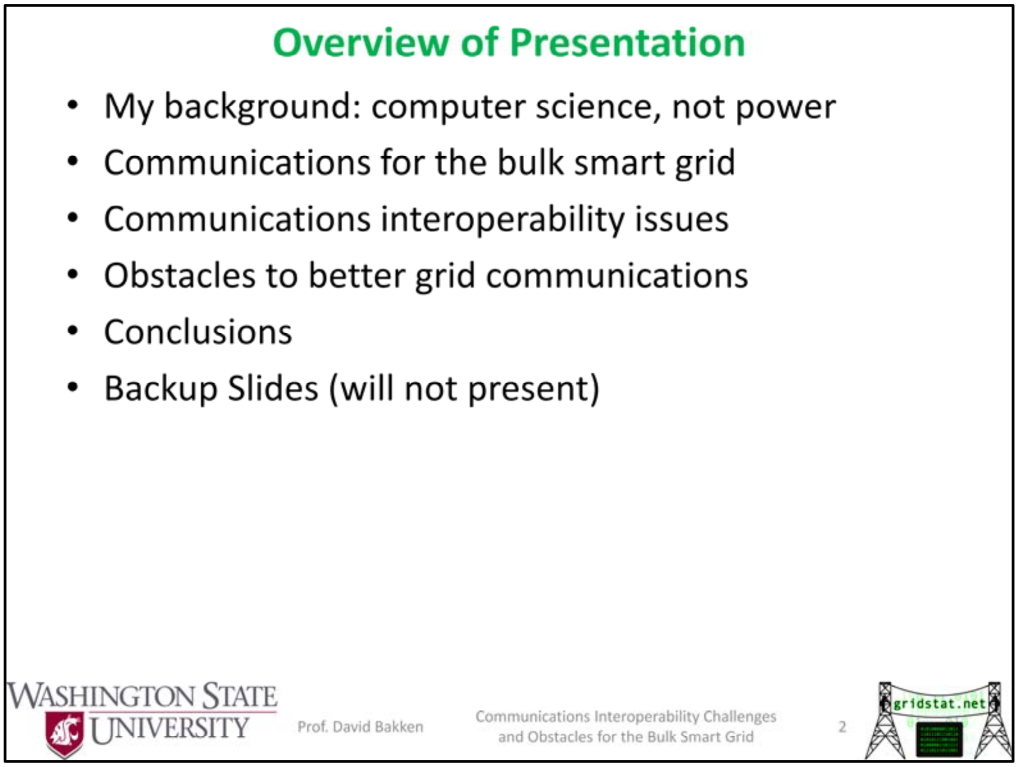
Communications Interoperability Challenges and Obstacles for the Bulk Smart Grid

Prof. Dave Bakken

School of Electrical Engineering and Computer Science
Washington State University
Pullman, Washington, USA

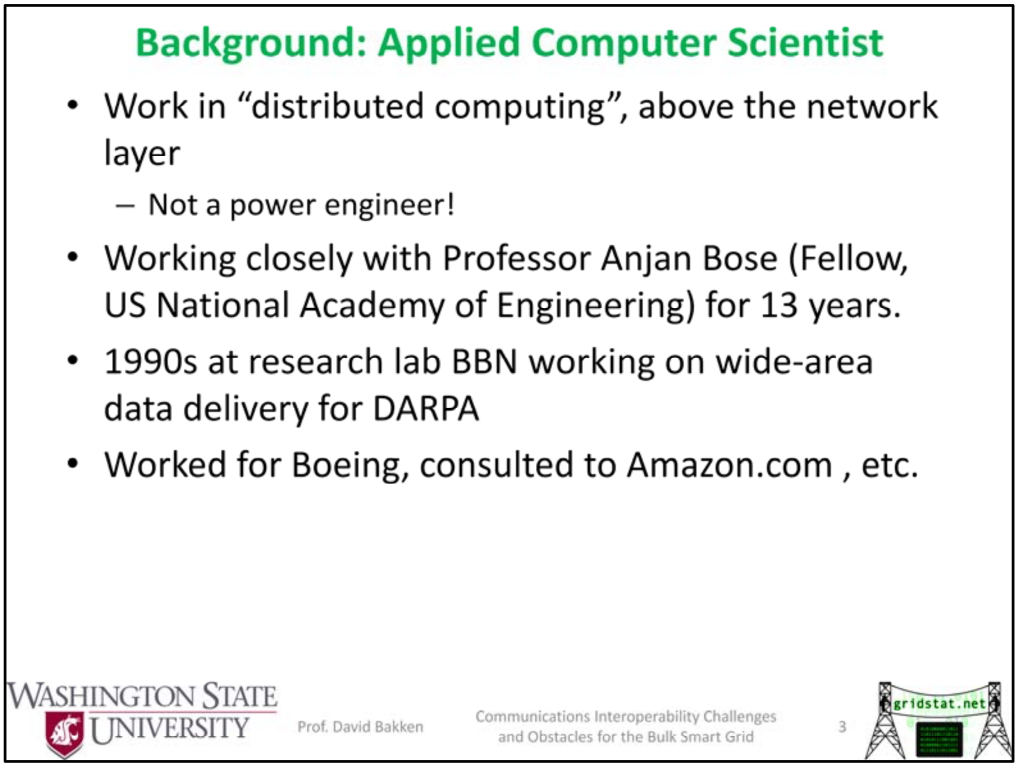
Smart Grid World Forum
Beijing, China
September 29, 2011



Thank you for inviting me to give a plenary talk in this very important meeting for the smart grid.

My presentation will proceed as follows. First, I will remind you that I am a computer scientist, not a power engineer. Second, I will discuss how better communications are needed for the bulk smart grid. Third, I will discuss communications interoperability issues for the bulk smart grid. Fourth, I describe obstacles to better smart grid communications. Finally, I conclude.

I also have backup slides that I will not present, but are there for your later reading or for use with audience questions.



Before I discuss the challenges and opportunities, I want to make something clear. I am not a power researcher. Rather, I am a computer scientist who works in the area of "distributed computing". However, I have worked closely with my department's strong electrical power research group, especially Professor Anjan Bose, for 13 years. Many of you know Prof. Bose, and that he is a member of the US National Academy of Engineering. Before Washington State University I worked at a research lab, BBN, working on wide-area data delivery software above the network layer. I have also worked for Boeing and consulted to Amazon.com and others. So, in summary, my background is of an applied computer scientist, not a theoretical one, or a power engineer.

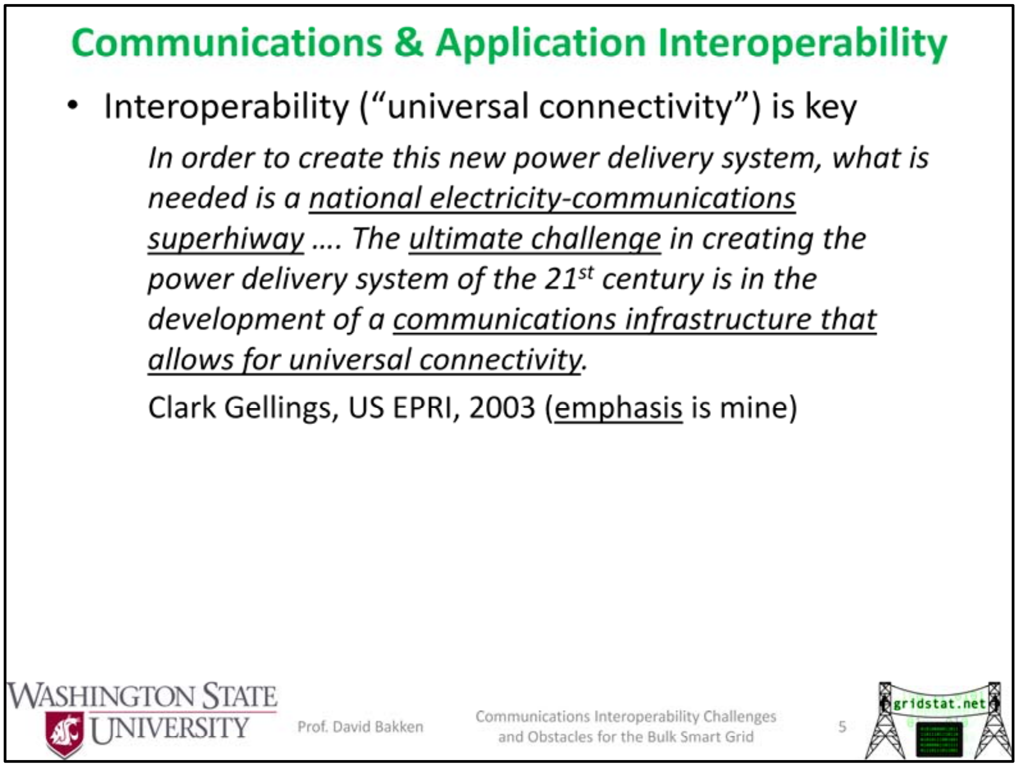
And, before I start with the challenges and obstacles, I wish to quickly remind us of why we need much better communication in the bulk power system.
It is almost universally agreed that power grids the world over are getting more stressed each year. Indeed, Francis Cleveland in 2007 said the following:

With the exception of the initial power equipment problems in the August 14, 2003 blackout [in North America], the on-going and cascading failures were almost exclusively due to problems in providing the right information to the right place within the right time.

Such inadequate communications have been a major contributing factor in virtually all major blackouts in recent decades.

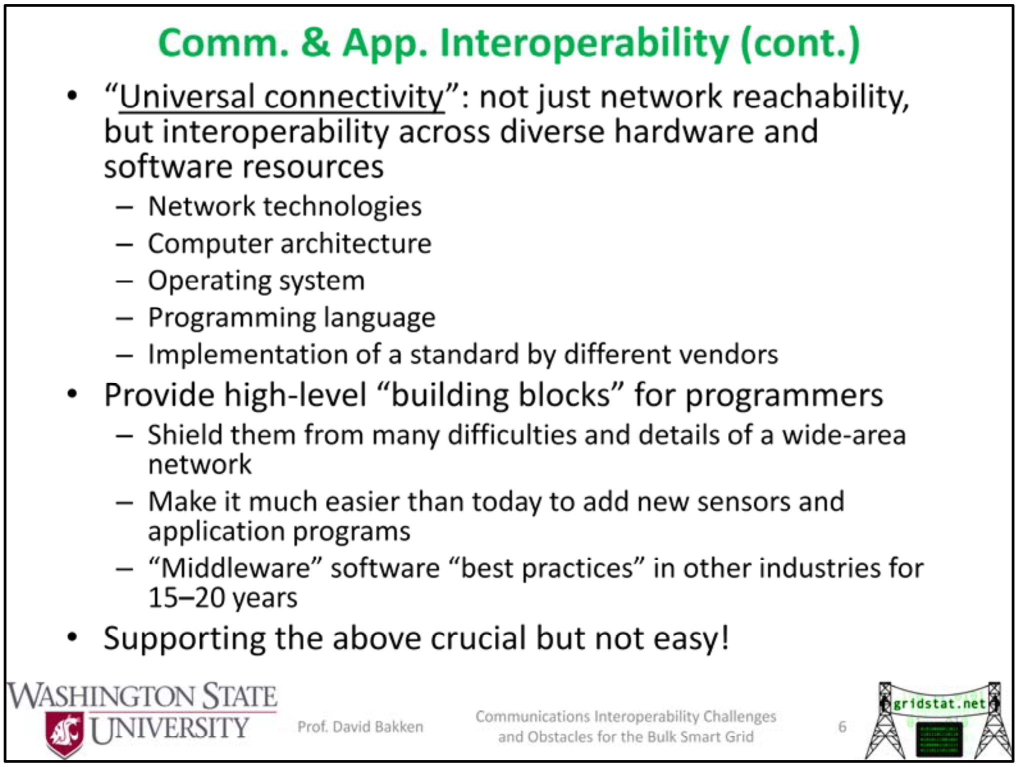
Other problems are inadequate new transmission capacity (at least in North America), integrating renewable sources of energy (which have different and unfamiliar power characteristics), the emergence of distributed control, and (at least in North America) a large number of retiring system operators who operate utility control centers.

All of these problems can be reduced by providing much better communications. SGCC is wise to have better communications and data sharing as key goals for its smart grid plans, and its new project "Information Application Support System" is important for this goal. However, there are many challenges and obstacles in the way of accomplishing this important goal, for China and elsewhere. This is what the rest of my presentation will be about.



One very important challenge is that application programs, sensors, and other producers and consumers of data can interoperate without difficulty. Mr. Clark Gellings of the US EPRI said that

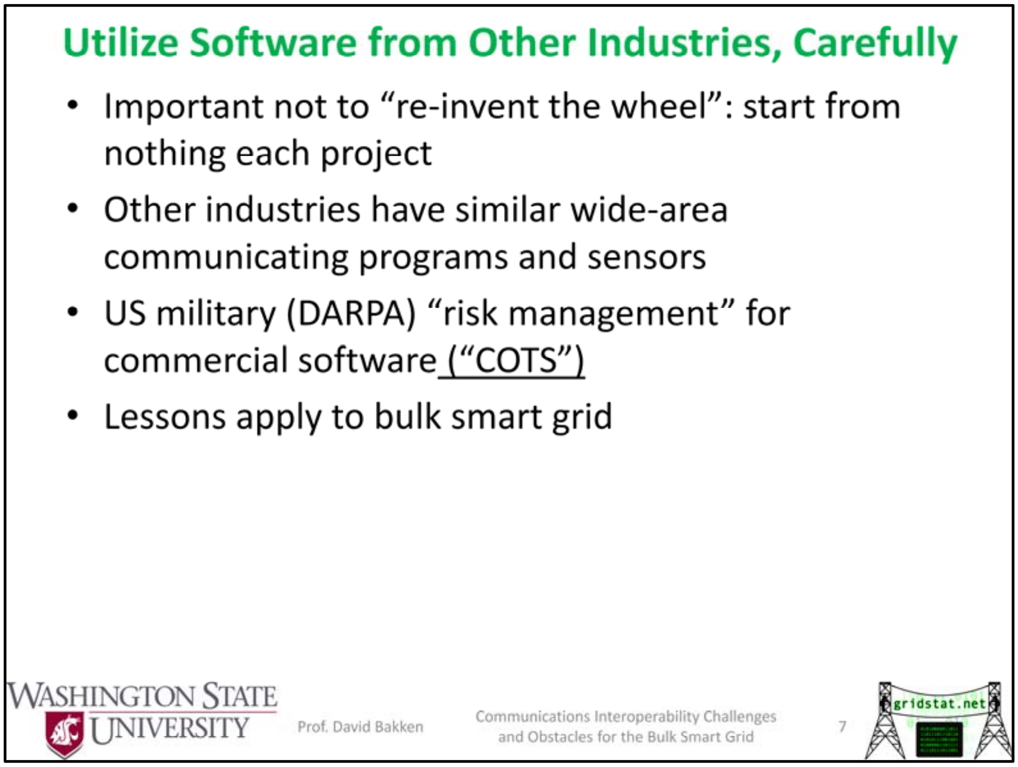
In order to create this new power delivery system, what is needed is a national electricity-communications superhiway that links generation, transmission, substations, consumers, and distribution and delivery controllers…. The ultimate challenge in creating the power delivery system of the 21st century is in the development of a communications infrastructure that allows for universal connectivity.



This "universal connectivity" is not just simple network connectivity. Rather, it is interoperability across diversity within different kinds of hardware and software resources. This includes different network technologies, different computer architectures, different operating systems, different programming languages, and different implementation of the same standard by different vendors.

Additionally, it is important to provide programmers with high-level "building blocks" to help support this interoperability. This shields them from many of the difficulties and details of a wide-area network. It also makes it much easier than today to add new sensors and application programs. Such "building blocks" have been considered "best practices" in other industries for 15–20 years, and we call "middleware". However, for a variety of reasons, these have not been adopted in the electricity sector.

Providing this universal connectivity and programmer "building blocks" is crucial, but it is not easy.



It is important not to develop all interoperability technologies "from scratch" just for power grids, that would take too much time and money for any country. Fortunately, it is not necessary. Other industries such as aviation, railroads, finance, telecommunications, and the military have developed interoperability technologies that do much of what I outlined on the last slide. Their communicating programs, sensors, and users seem similar to the bulk power grid, at least at a superficial level.

Much of the software infrastructure to support this interoperability can be reused from other industries, sometimes with some modifications. However, this must be done with great care, carefully analyzing the data delivery properties it provides. As an example, the US military has funded a lot of (non-secret, unclassified) work via DARPA in the 1990s on "risk management" in using commercial software in military environments with large numbers of programs communicating in very different ways. I believe that many of the lessons from this, and any other similar initiatives elsewhere, would directly apply to communications infrastructure software for the bulk power system.

Provide Extreme “Mission Critical” Data Delivery

- Emerging power applications have extreme data delivery requirements (no “person in the loop”)
  - Delivery latency 10–25 msec over 500–1000 km
  - Availability up to 99.999% or more (99.9999% for some per US EPRI)
  - Very strong cyber-security
  - Very high efficiency
- More extreme requirements than military, electronic commerce, business-to-business, etc
- New control and protection strategies are not possible without this!
- Still must be very flexible for future application programs and sensors
- GridStat project at WSU has done much in this area
  - Large impact on the emerging “NASPInet” initiative in North America
  - Collaborating with European Commission projects

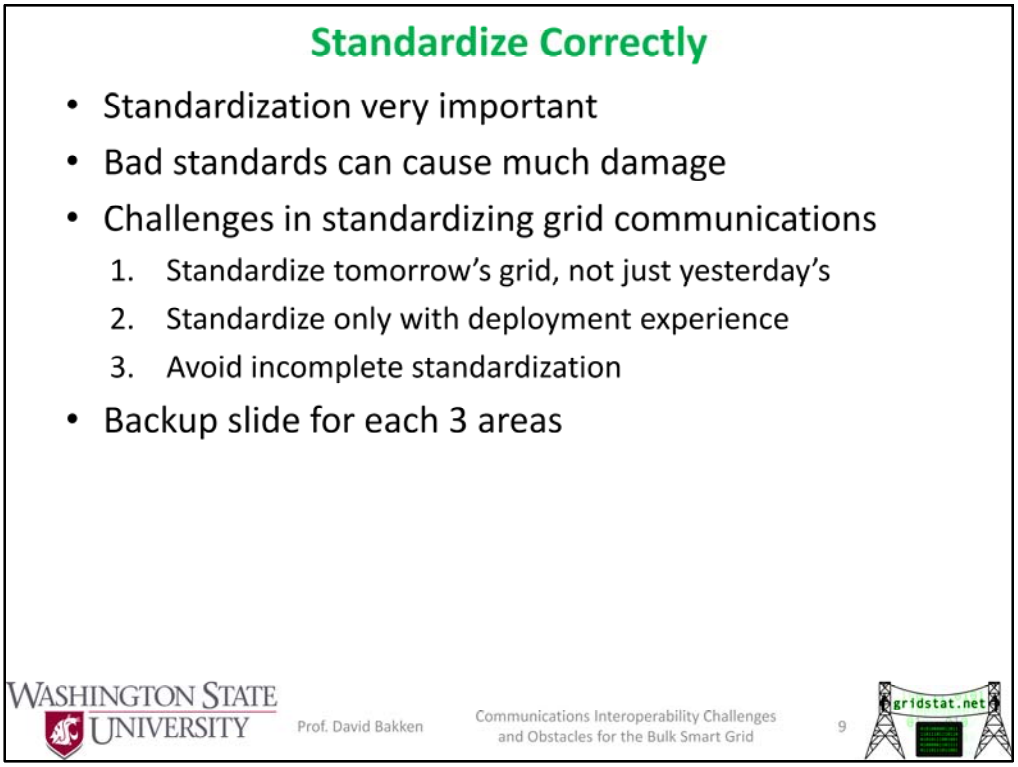
Washington State University Prof. David Bakken Communications Interoperability Challenges and Obstacles for the Bulk Smart Grid 8 gridstat.net

Not all of the software infrastructure for providing interoperability and data delivery for the bulk power system can come from other industries. So another challenge is how to provide extreme “mission critical” data delivery. Emerging power application programs have very extreme requirements. Delivery latencies must be no more than 10–25 msec over 500–1000 kilometers. Availability of data that is required may be up to 99.9999% according to US EPRI. Very strong cyber-security must be provided for obvious reasons. And the protocols must use the network very efficiently in order to support very high data throughput.

These requirements are more extreme than other industries. For example, nowhere in the military does data have to be delivered so quickly over hundreds of kilometers, and the required (and possible!) availability is much lower (though still very important). Business-to-business and electronic commerce applications are much less extreme. Online financial trading does have some stringent delivery requirements, but for a very small number of data streams in very predictable numbers. And lives are not lost (only money) if the system fails.

As difficult as it is to provide such “mission critical” data delivery, it is still very important, because emerging control and protection strategies require them. In other words, some of the most promising new ways to increase grid reliability cannot be deployed unless such low latencies can be provided with extremely high probability, even when (some) failures and cyber-attacks are encountered. Yet this software infrastructure must still be flexible to allow engineers to add application programs and sensors that have not been invented today.

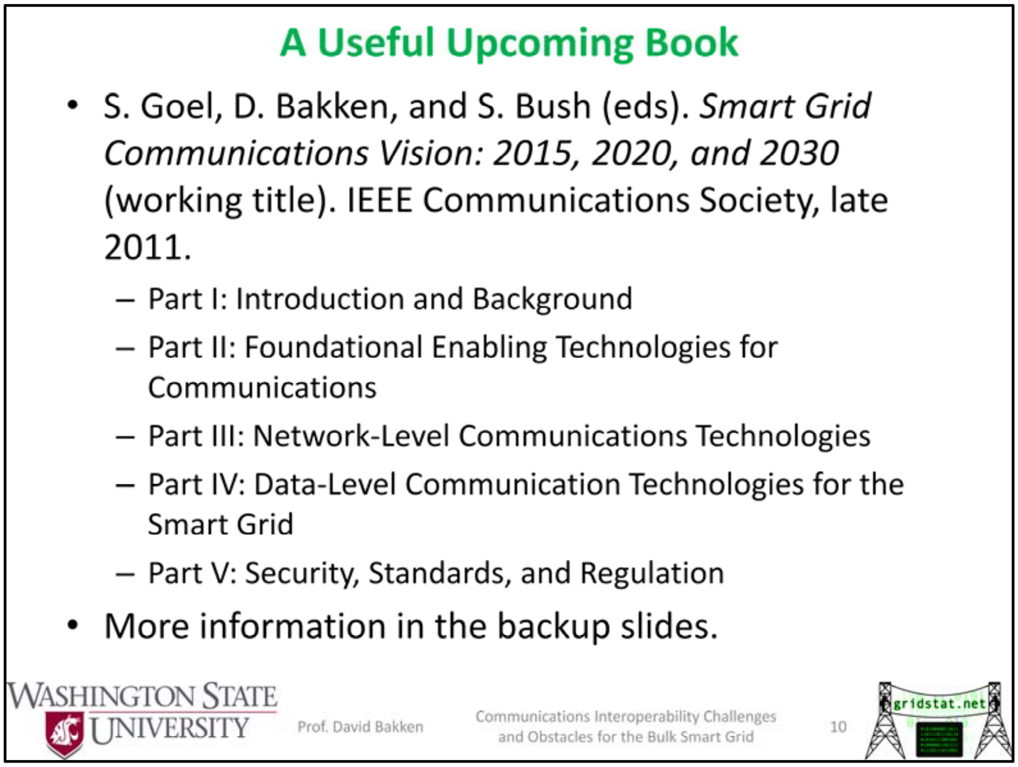
The GridStat project at Washington State University, which I lead, has done much applied research in this area, and meets these requirements. It has had a large impact on the



Standardization is very important, and SGCC is quite correct in identifying it as a priority. However, it is important to standardize correctly, because bad standards can cause much damage.

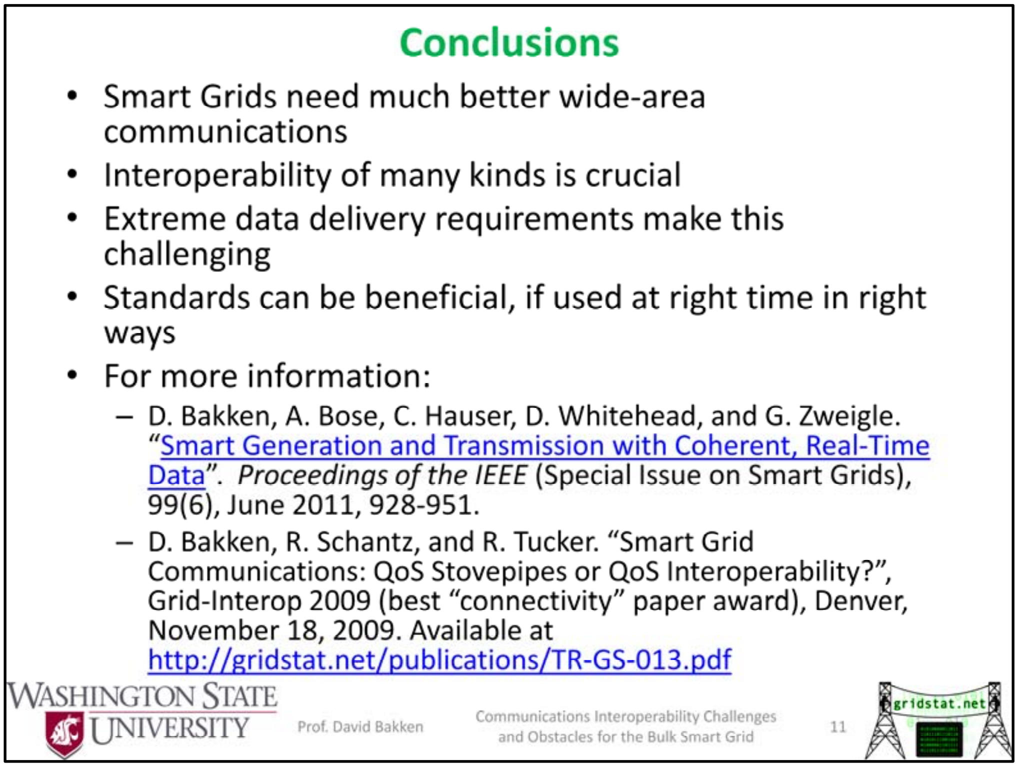
I give three suggestions for standardizing communications for the bulk smart grid. First, standardize for tomorrow's grid, not just yesterday's. Second, standardize only with deployment experience. Third, avoid incomplete standardization.

I do not have enough time to explain each of these three suggestions in detail, but there is a slide for each one in my backup slides.



One useful resource for better understanding the issues I have discussed is a book that will be available in a few months, one which I am an editor for. It is a book describing future communications for power grids over the next twenty years. Part One contains introductory and background material. Part Two describes foundational enabling technologies for communications. Part Three discusses network-level communications technologies. Part Four analyzes data-level communications technologies. Finally, Part Five describes cyber-security, standards, and regulations.

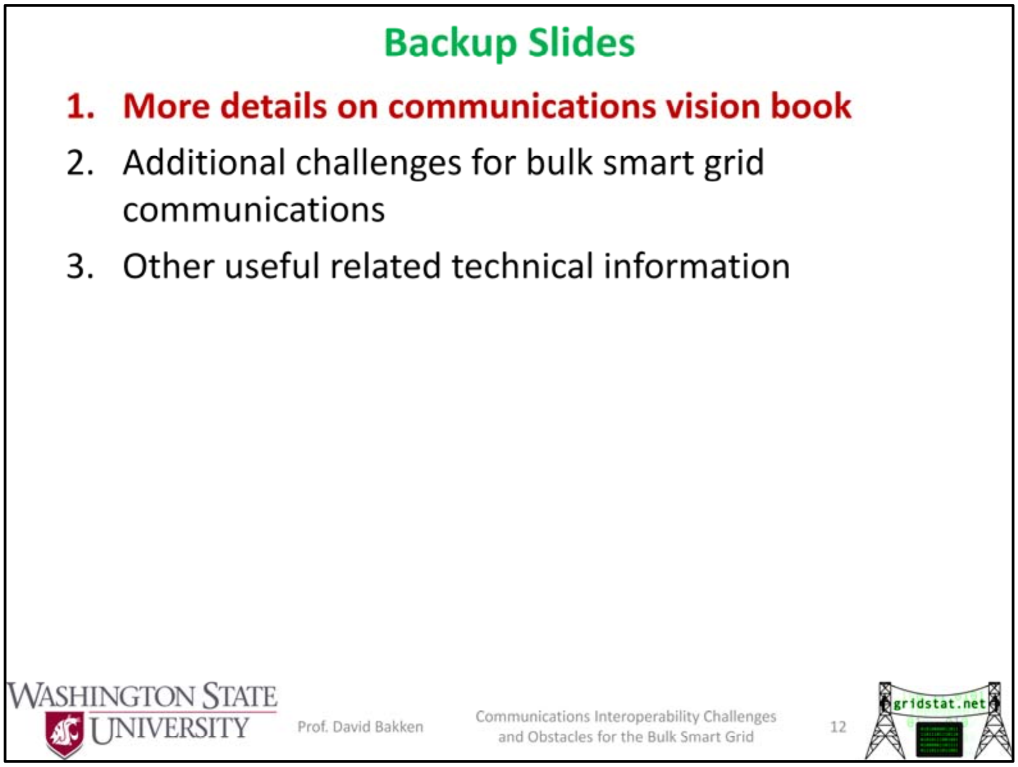
Due to time limitations, I will not list the individual chapters, but they are listed in my backup slides.



Before I summarize my presentation, let me thank the organizers of this important meeting for inviting me to give this presentation. I also thank the State Grid of China Corporation, who has been gracious hosts not only at this meeting but in my visit there Tuesday. We had many excellent technical discussions and excellent Chinese food that is very different than what I can find in the USA!

Providing much better and more pervasive communications is extremely important for the bulk power grid in the future. However, many challenges and obstacles make this difficult. Providing interoperability of many kinds is very important. However, the data delivery requirements of the emerging bulk smart grid are much more extreme than any other industry. They must be met with great care. Finally, standards are very beneficial, but they must be used at the right time in the right ways or they can be extremely harmful.

For more information on these topics, you can see two recent papers I have written that are displayed on my slide.



I would like to finish by noting that I have many backup slides that you may look at later. They are in three main categories. First, there are more details on the communications vision book. Second, there are more slides on additional challenges for bulk smart grid communications. Third, there is other useful related technical information.

Book Part I: Introduction and Background

- Chapter 1 **Smart Grid of the Future: Vision for Year 2030** -- by Sanjay Goel (University at Albany, SUNY) and Dave Bakken (Washington State University)
- Chapter 2 **How the Power Grid Currently Operates** -- by Jeff Dagle (Pacific Northwest National Lab)
- Chapter 3 **Opportunities for Better Communication in the Smart Grid** – Anna Scaglione and Zhifang Wang (UC Davis)

Book Part II: Foundational Enabling Technologies for Communications

- Chapter 4 **Communication Medium (Layer 1-2)** -- by Lorenzo Vangelist (Univ. of Padova), Lutz Lampe (Univ. of British Columbia) and Andrea Tonello (University of Udine), Javed I. Khan (Kent State University), and Edmond Jonckheere (University of Southern California)
- Chapter 5 **Information and Graph Theory** -- by Stephen Bush (General Electric)
- Chapter 6 **Signal Processing and Control** -- by Tim Johnson (General Electric) and Sekhar Tatikonda (Yale University)

Book Part III: Network-Level Communications Technologies

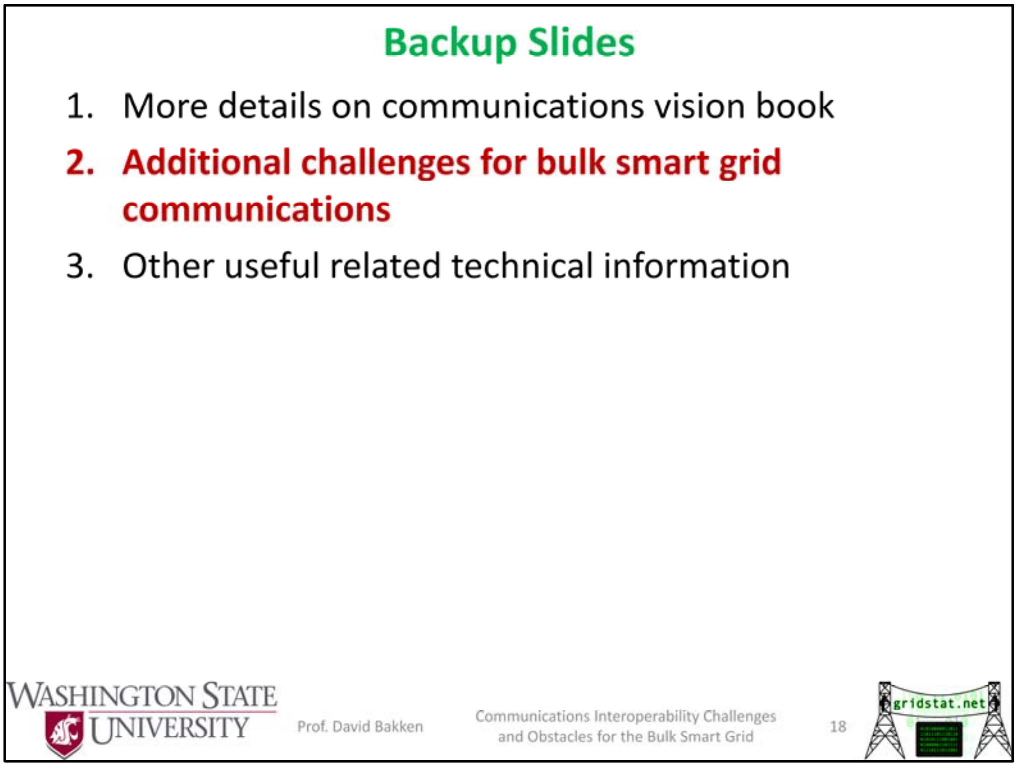
- Chapter 7 **Layer 2-4 Enabling Technologies** -- by Michele, Nicola Bua, and Michele Zorzi (all University of Padova)
- Chapter 8 **Quality-of-Service Mechanisms and Traffic Characteristics** -- by Ajay Mohindra (IBM)

Book Part IV: Data-Level Communication Technologies for the Smart Grid

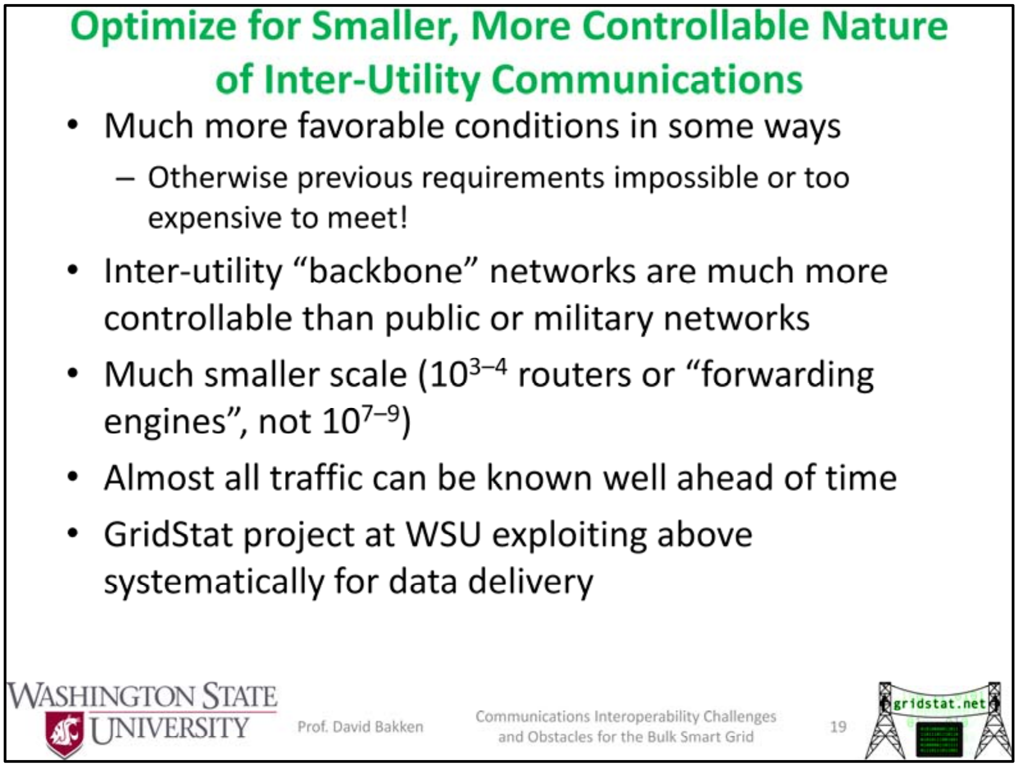
- Chapter 9 **Hard Real-Time Overlay Networks** -- by Chris Develder (University of Ghent)
- Chapter 10 **Peer-to-Peer Techniques at Edges of System** -- by, Neeraj Suri, Daniel Germanus, and Khelil Abdelmajid (all from Technical University of Darmstadt)

Book Part V: Security, Standards, and Regulation

- Chapter 11 **Security and Resilience** -- by Sanjay Goel (University at Albany, SUNY), Stephen Bush (General Electric), and Jeff Dagle (Pacific Northwest National Lab)
- Chapter 12 **Standards for the Smart Grid** -- by John Boot (General Electric)
- Chapter 13 **Policy and Regulatory Impact on Communications** -- by John Boot (General Electric), John Malkin (General Electric) Sanjay Goel (University at Albany, SUNY)
- Chapter 14 **Emerging Technologies and Applications (Disruptive Technologies)** - Editors



I would like to finish by noting that I have many backup slides that you may look at later. They are in three main categories. First, there are more details on the communications vision book. Second, there are more slides on additional challenges for bulk smart grid communications. Third, there is other useful related technical information.

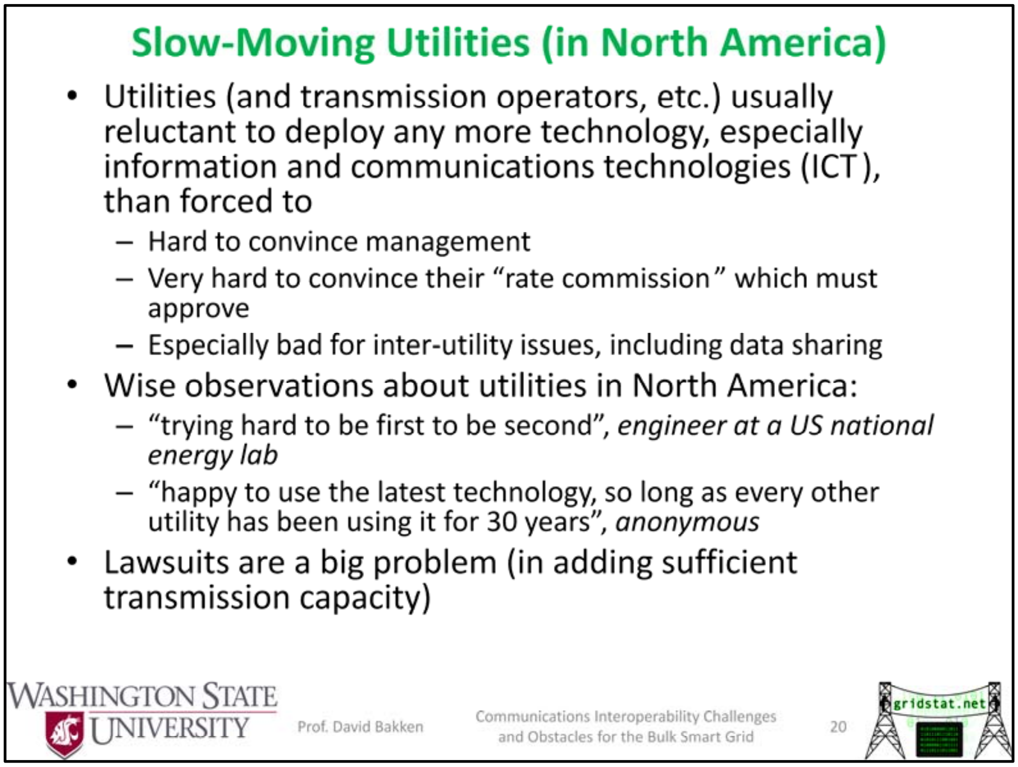


To meet the challenge of providing such "mission critical" data delivery, it is very important to not over-design the software infrastructure. Fortunately, this is possible for the bulk smart grid.

Despite the extreme latency and availability requirements I discussed, in a number of other ways the data delivery problem for the bulk power grid is less challenging than more general internet applications. To meet the extreme requirements, these areas in which it is less challenging are opportunities for optimization that must be exploited. If they are not, the data delivery software will be impossible to meet, or at least far too expensive.

One area is the "backbone" data delivery networks are much more controllable than public or even military networks. Another way is that the number of "routers" (or "publish-subscribe forwarding engines") is far fewer: on the internet it is 10^{7-9} the internet, while in a large power grid it would be only 10^{3-4}. Further, on the internet traffic patterns can vary widely and are not known ahead of time, while on power grids the exact opposite is the case.

The GridStat data delivery software exploits these opportunities for optimization.

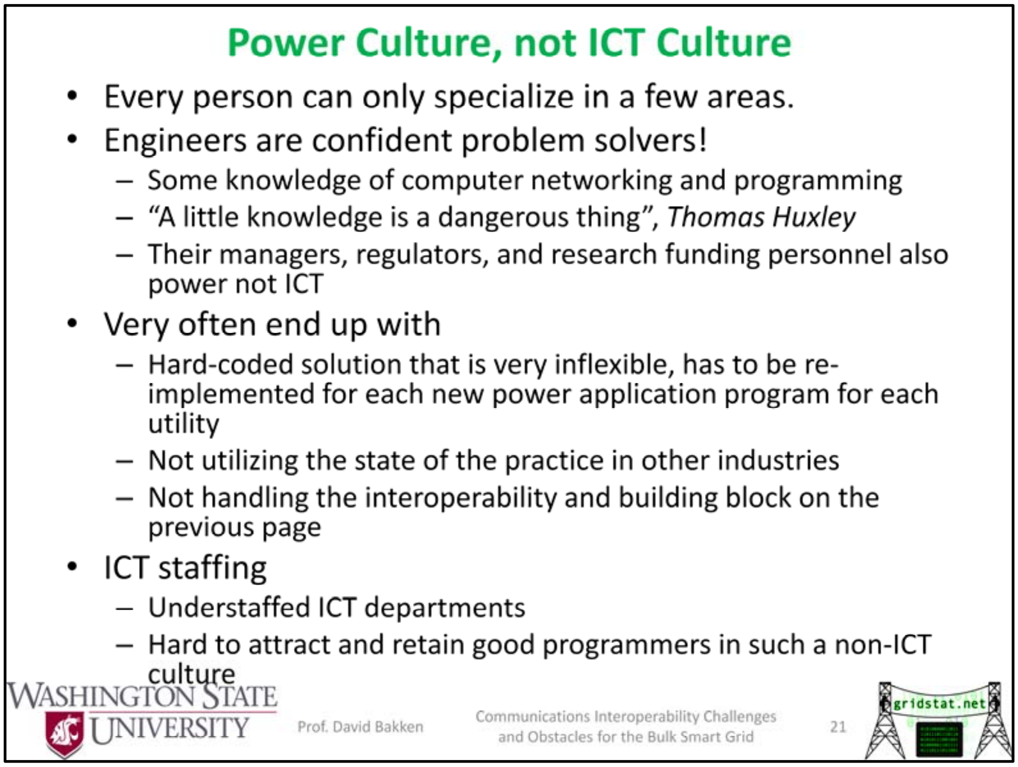


In North America, electrical utilities (and transmission operators) move very slowly. They are usually reluctant to deploy any more technology, especially information and communications technologies (ICT), than they are forced to. One reason for this is that it can be very hard to convince their executive managers. Another reason is that it is very hard for them to convince their "rate commission", which must approve it. This reluctance is especially bad for inter-utility issues, including data sharing.

This problem is well known, and has been remarked upon by a number of people. One engineer at a national energy lab in the USA whom I know said that utilities are "trying hard to be first to be second". That is another way of saying they don't want to be first. A common saying in the industry is that "utilities are happy to use the latest technology, so long as every other utility has been using it for 30 years".

Another big problem is that adding new transmission capacity is delayed for a decade or more by lawsuits.

China is fortunate that it does not have this problem! If the Chinese people decide the power grid needs to be upgraded, it will happen in a very reasonable amount of time. This is a significant advantage in many ways.

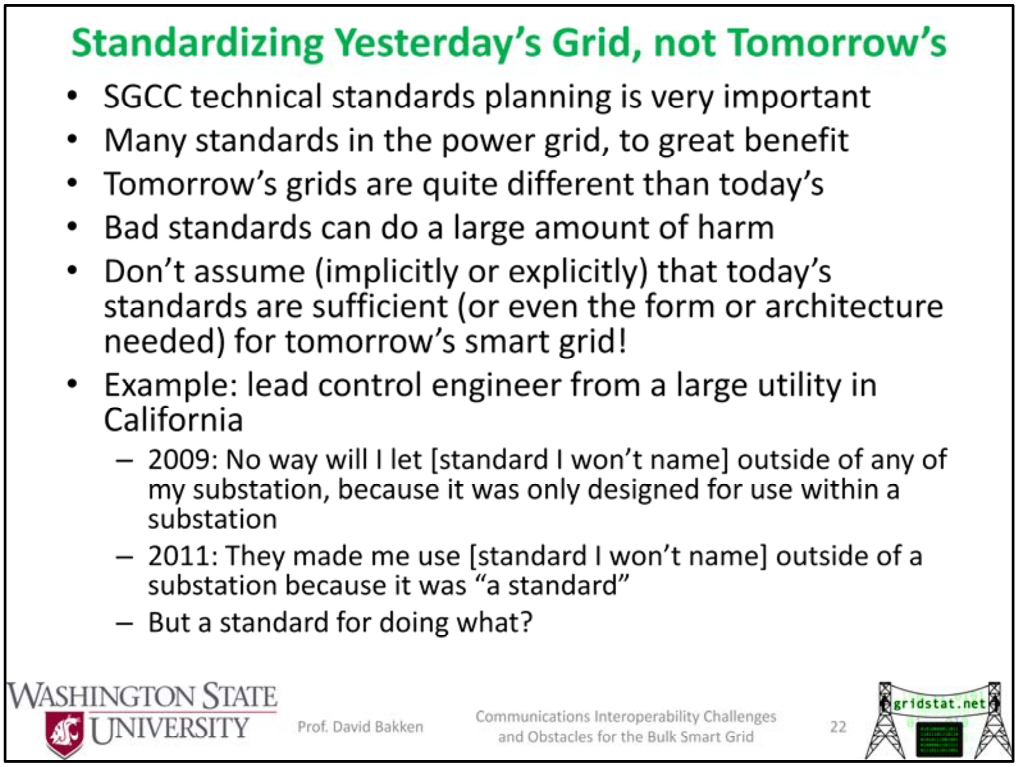


Before I describe this challenge, let me say that I think that power engineers and researchers are extremely intelligent people. But any one person can only specialize in a few areas…

Another large challenge in achieving better interoperability of application programs and sensors in the bulk power grid is not directly technical, but it is the technical culture. Electric utilities have a power engineering culture, not a culture of information and communications technology (ICT), which is very different. This applies to not only the engineers, but their managers, regulators, and research funding personnel. Power engineers also have a some knowledge of computer networking and programming. However, as Thomas Huxley said, "A little knowledge is a dangerous thing". Further, engineers are usually confident problem solvers. As a result, they often are not aware of their limitations in ICT, and are generally very unaware of much better "best practices" in other industries.

Very often then, what results is a "hard-coded" data delivery solution that is very inflexible, and has to be re-implemented for each new power application program for each utility. It also does not utilize "best practices" in other industries. And it does not support the interoperability across different kinds of ICT resources that I described earlier.

One final problem involving the lack of an ICT culture is that ICT departments tend to be understaffed, sometimes quite severely. Additionally, it can be hard to attract and retain good programmers in such a non-ICT culture. Without top programmers with good experience in other industries, it is almost impossible to provide the kind of interoperability that I have described.



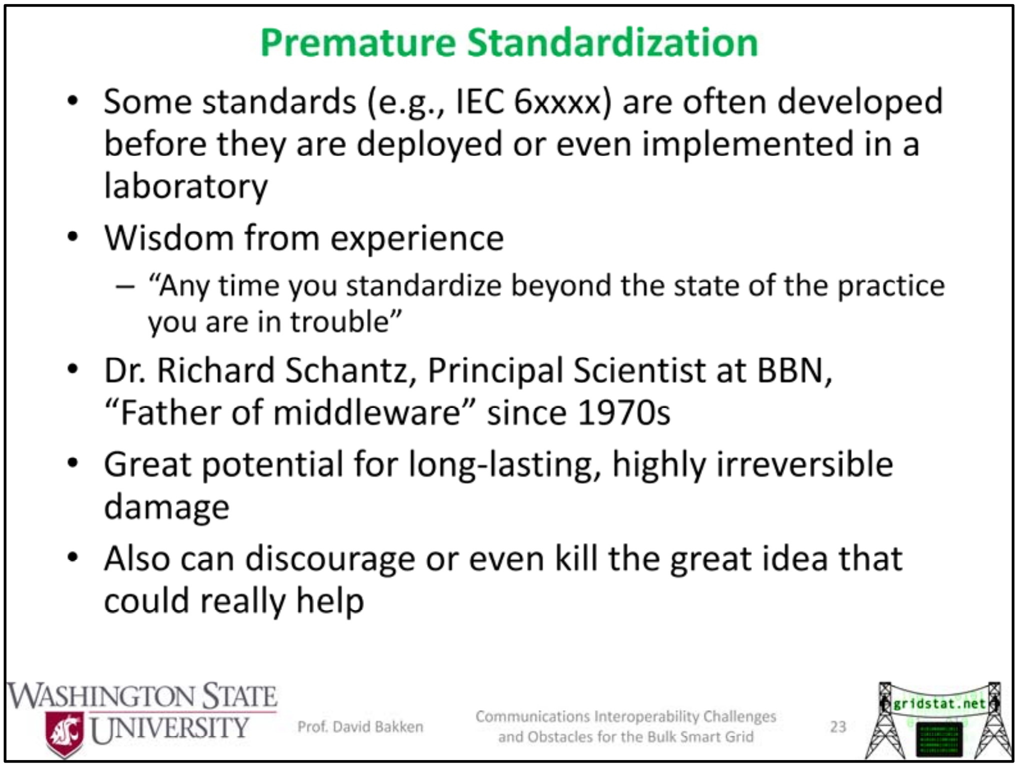
SGCC is very wise to be developing a plan for technical standards for China's smart grid. Standardizing is very important, but must be done the right way or it can do much more harm than good.

One challenge here is that the smart grid of the future is in some ways very different from yesterday's power grids. However, there is sometimes an implicit assumption that the same standards will be sufficient. It is important no not assume that yesterday's standards are sufficient. Indeed, the way in which standardized data delivery services are used will in some ways be very different, so it would be impossible to have yesterday's standards be adequate.

Let me give you a simple but sad example. About two years ago I was talking with the lead control engineer for a very large utility in California, whom I had known for years. I asked him what he thought of a particular standard, [standard I won't name]. He said that no way would he let it be used outside of any substations, because it was only designed for a substation scope. Two years later I asked him how this worked out. He said, regretfully, that he was forced to use this by his management "because it was a standard". It was superficially similar to the managers, but in technical detail and usage it was very different.

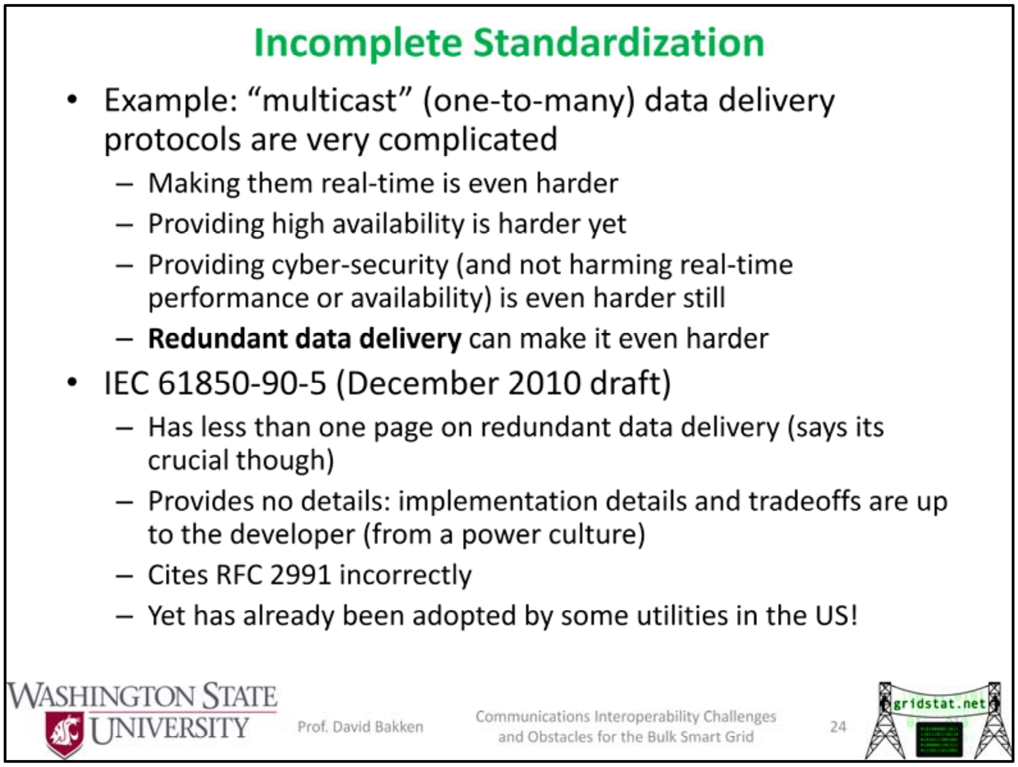
But it is a standard for doing what? The kinds of data delivery mechanisms you use, and the way you structure data delivery services, is very different within a single substation compared to across a power grid. However, [standard I won't name] has many assumptions and tradeoffs built into it that assume data are delivered only over a local network, and Ethernet in particular. These different assumptions cannot be handled properly by implementing an interface in a different way, this is impossible.

I must mention that I believe that this standard is extremely useful as a data model, a



Another obstacle for better interoperability is the way that some standards are developed. Some standards are designed by a committee of engineers without anyone having deployed, or even implemented, what was being standardized. For example, this is what is done with many of the electricity standards from the IEC.

This is very dangerous. Dr. Richard Schantz of BBN, who is considered to be the "Father of middleware", has worked on similar systems for the military since the 1970s. He told me many times that "any time you standardize beyond the state of the practice you are in trouble". This is because there is no direct experience with what is being standardized. As a result, there is great potential for long-lasting and highly irreversible damage. Such premature standards can also discourage or even kill the development of a great idea that could really help.



Another barrier to proper interoperating data delivery is incomplete standards.

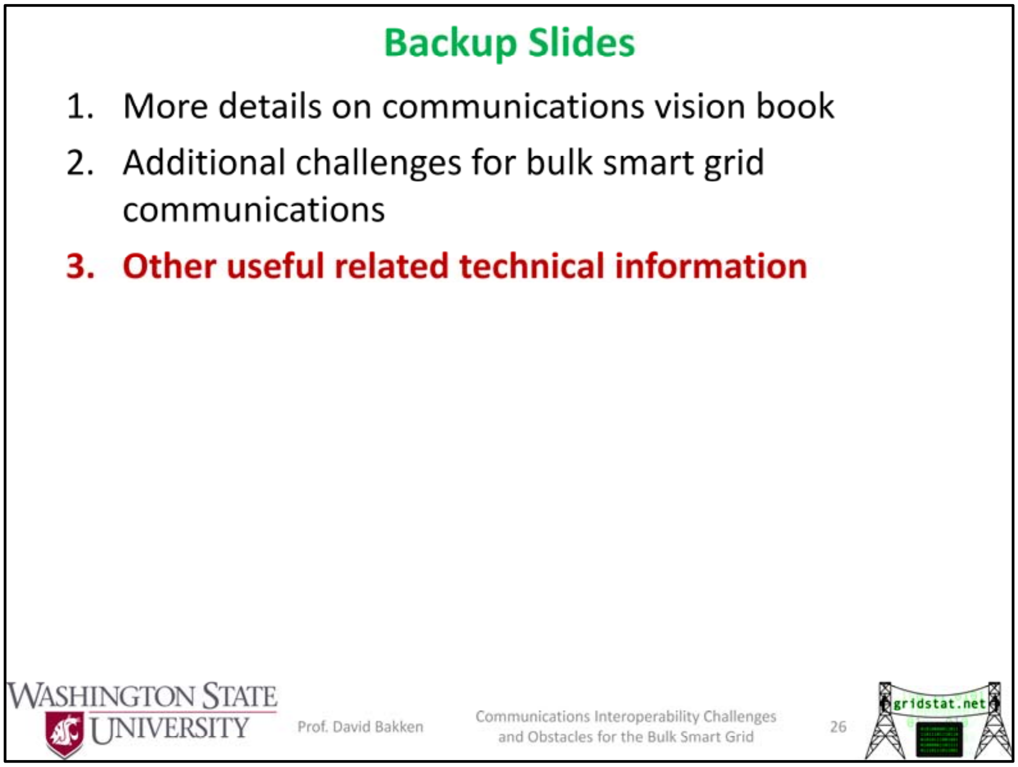
As an example, developing one-to-many "multicast" data delivery protocols is very complicated. Making them real-time with very low delivery latencies is extremely difficult. Providing high availability for them is harder yet. And providing cyber security is even harder, especially because when you do it you have not harm real-time performance or high availability. Further, redundant communiation is extremely important.

Yet the IEC 61850-90-5 draft standard (of December 2010) is very incomplete. It has less than one page describing redundant delivery, even though it describes it as being crucial (Section 8.8). It provides no useful details. It cites RFC 2991, but gets the details very wrong. Thus, the implementation details and the tradeoffs any IEC 61850-90-5 implementation must necessarily make are left to the developer, whose background is in a power culture, not sophisticated data delivery software.

Unfortunately, this standard has already been adopted by some utilities in the US! They will regret this over the next decade.

IEC 61850-90-5

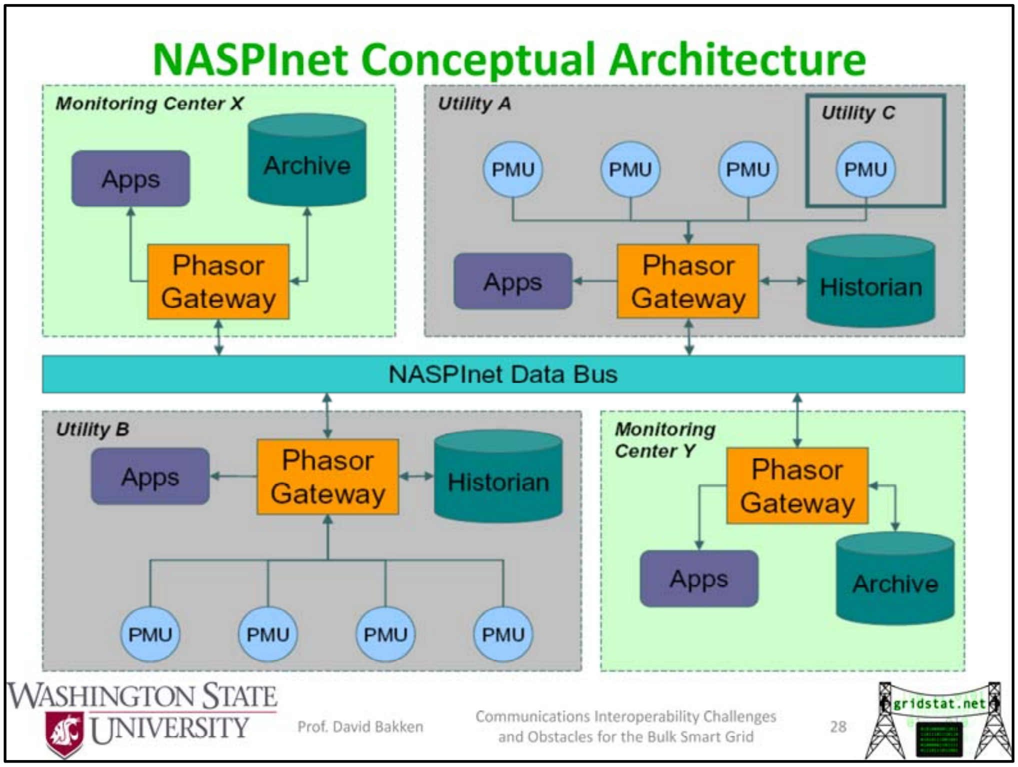
- States **communications redundancy crucial** (Sec 8.8)
- Overviews (<1 page) 3 different network configurations
- First two: redundancy design mechanism "out of scope"
- Third flavor: "The mesh network then provides parallel multi-path delivery of the packets"
  - Says to determine paths with RFC 2991
  - Unfortunately, RFC 2991 only superficially similar: does not discuss, let alone solve, parallel multi-path delivery
  - Only discusses non-parallel multi-path forwarding decisions
  - Each implementation is on its own to figure this (very hard problem) out!



I would like to finish by noting that I have many backup slides that you may look at later. They are in three main categories. First, there are more details on the communications vision book. Second, there are more slides on additional challenges for bulk smart grid communications. Third, there is other useful related technical information.

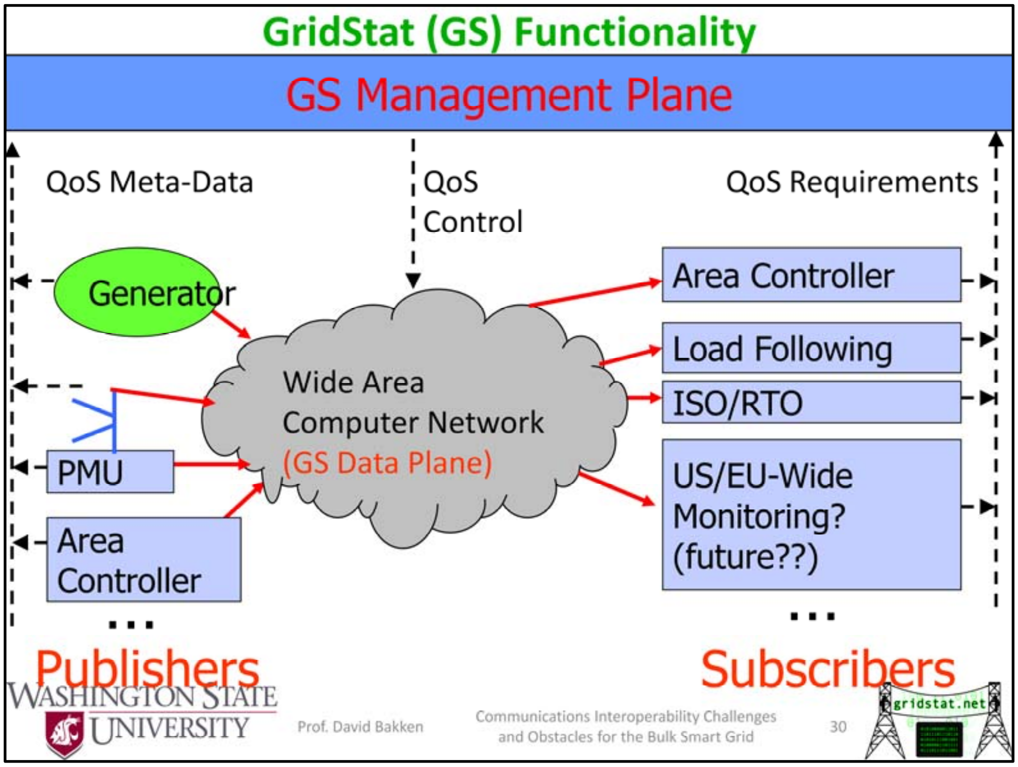
NASPI

- Vision: "The vision of the North American SynchroPhasor Initiative (NASPI) is to improve power system reliability through wide-area measurement, monitoring and control."
  - Synchrophasor: a sensor with a very accurate GPS clock…
  - Becoming much more deployed in US, Europe, …
- Great need for much better data delivery services
  - Can no longer send "all data to control center at the highest rate anyone might want to"
- Very involved with spec of "NASPInet" services
  - Many requirements come from GridStat research (cited)

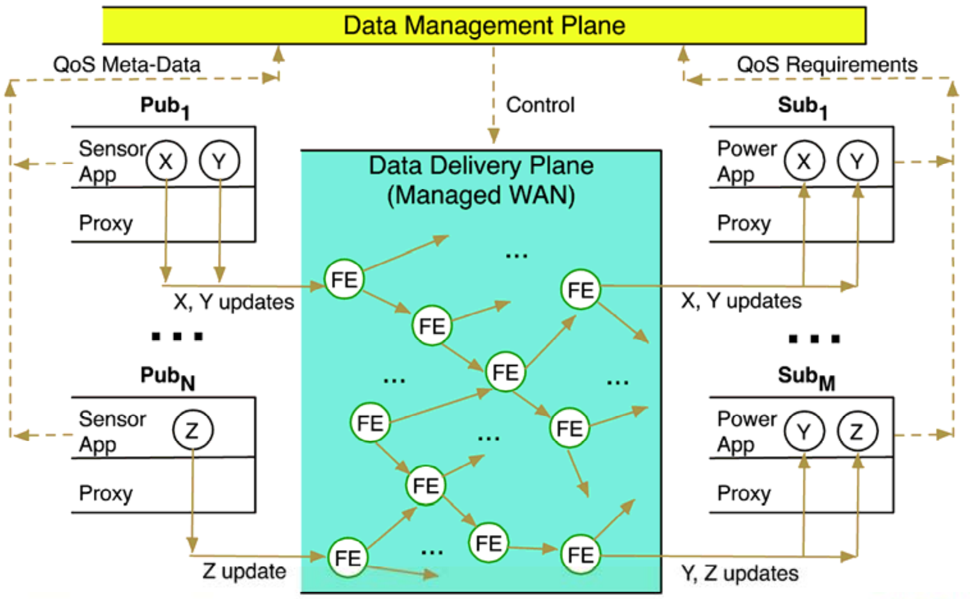

NASPInet Conceptual Architecture
Monitoring Center X
Apps
Archive
Phasor Gateway
Utility A
Utility C
PMU
PMU
PMU
PMU
Apps
Phasor Gateway
Historian
NASPInet Data Bus
Utility B
Apps
Phasor Gateway
Historian
PMU
PMU
PMU
PMU
Monitoring Center Y
Phasor Gateway
Apps
Archive
WASHINGTON STATE UNIVERSITY
Prof. David Bakken
Communications Interoperability Challenges and Obstacles for the Bulk Smart Grid
28
gridstat.net

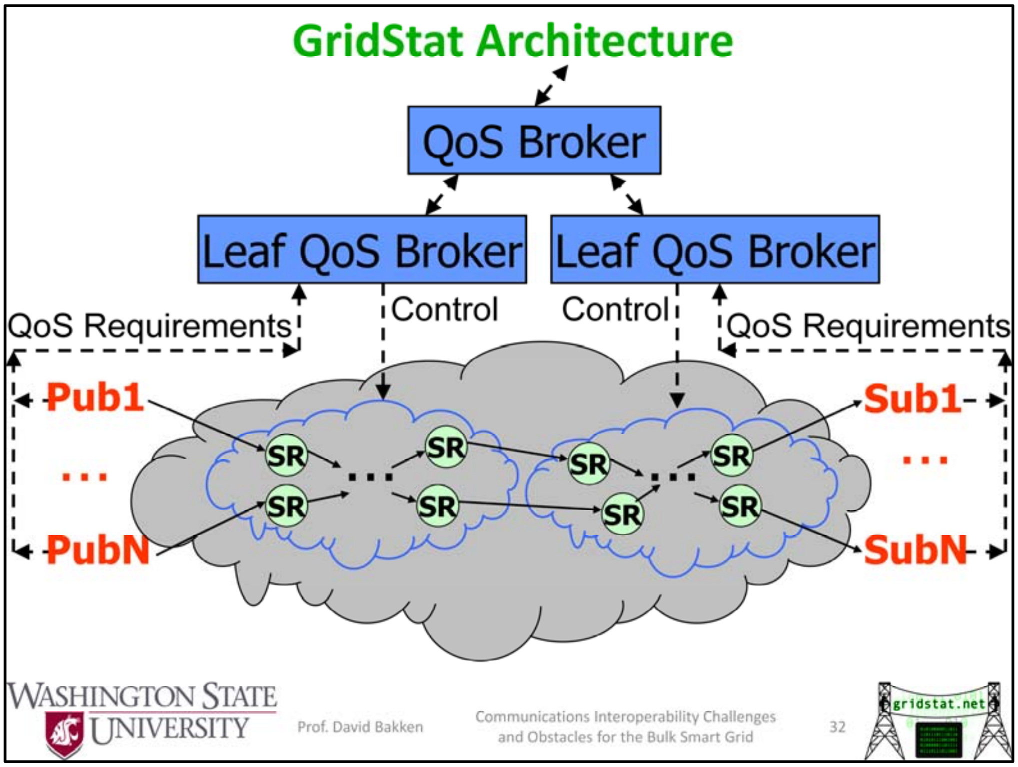
What is GridStat?

- Bottom-up re-thinking of how and why the power grid's real-time data delivery monitoring services need to be
- Comprehensive, ambitious data delivery software suite in coding since 2001
  - Rate-based pub-sub, different subsribers to same variable can get different QoS+ {rate, latency, #paths}
- Rare collaboration of EE (power) and CompSci (distributed computing, networking, …) researchers
- Influencing NASPI's emerging data delivery requirements and architecture


GridStat (GS) Functionality
GS Management Plane
QoS Meta-Data
QoS
Control
QoS Requirements
Generator
Wide Area
Computer Network
(GS Data Plane)
PMU
Area
Controller
...
Area Controller
Load Following
ISO/RTO
US/EU-Wide
Monitoring?
(future??)
...
Publishers
Subscribers
WASHINGTON STATE
UNIVERSITY
Prof. David Bakken
Communications Interoperability Challenges
and Obstacles for the Bulk Smart Grid
30
gridstat.net

GridStat Architecture





Clouds different administration organizations
Publisher might be a breaker somewhere
Subscriber might be a control center
    The control center might again be a publisher of some of its calculation
A subscriber may also be a publisher
Communication resources need to be managed
Role of the QoS to manage security, trust, etc

GridStat Modes

- Observation
  - Path allocation algorithms complex, not for a crisis 10^3+
  - But power grid plans way ahead of time
- GridStat supports **<u>operational modes</u>**
  - Can switch forwarding tables very fast
  - Avoids overloading subscription service in a crisis
- Hierarchical
  - can define at Level j, in force at levels ≥ j
  - Implies multiple modes in effect at once in a given FE
  - Coarse way to provision resources
- Two change algorithms: flooding & multi-level commit

Multi-Level Contingency Planning & Adapting

- Electricity example: Applied R&D on coordinated
    1. Power dynamics contingency planning
    2. Switching modes to get new data for contingency
    3. New PowerWorld visualization specific for the contingency

  involving contingencies with
    A. Power anomalies
    B. IT failures
    C. Cyber-attacks
- State of art and practice today: 1 & A only, offline
- Very possible: {1,2,3} X {A,B,C} and online

Data Load Shedding

- Electric Utilities can do **load shedding** (I call **power load shedding**) in a crisis (but can really hurt/annoy customers)
- GridStat enables **Data Load Shedding**
  - Subscriber's desired & worst-acceptable QoS (rate, latency, redundancy) are already captured; can easily extend to add priorities
  - In a crisis, can shed data load: move most subscribers from their desired QoS to worst case they can tolerate (based on priority, and eventually maybe also the kind of disturbance)
  - Works very well using GridStat's operational modes
  - Note: this can prevent **data blackouts**, and also does not irritate subscribers
- Example research needed: systematic study of *data load shedding* possibilities in order to prevent *data blackouts* in contingencies and disturbances, including what priorities different power apps can/should have…
- Lets critical infrastructures adapt the data communications infrastructure to benign IT failures, cyber-attacks, power anomalies,