Data Delivery Mechanisms and Issues for Wide Area Measurement Systems (WAMS)

Prof. Dave Bakken

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

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Overview of Presentation

- **Introduction**
- Emerging Power Applications
- Implementation Issues for WAMS Data Delivery (WAMS-DD)
- NASPI and NASPInet
- GridStat

Lots to cover, not in full detail in every area!

Background: Applied Computer Scientist

- Work in “distributed computing”, above the network layer
  - Not a power engineer!
- Working closely with Prof. Anjan Bose for 13 years.
  - “How can distributed computing (and computer networking and real-time computing) help improve communications for the bulk power grid?”
  - Also Mani Venkatasubramanian (power), Carl Hauser (distributed computing)
- 1990s at research lab BBN working on wide-area data delivery for DARPA
- Worked for Boeing, consulted to Amazon.com , etc.

Better Communications are Needed

- Grids are getting more stressed each year

  "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."

  Francis Cleveland, 2007
- Inadequate communications major contributing factor in recent major blackouts
- Other challenges for the bulk power system
  - Growth in generation and load far more than transmission capacity growth (in North America)
  - Integrating renewable sources of energy
  - Distributed control
  - Retiring operators (in North America)
- **<u>All</u>** can be mitigated by **<u>better communications</u>**

Communications & Application Interoperability

- Interoperability ("universal connectivity") is key

  In order to create this new power delivery system, what is needed is a national electricity-communications superhiway …. 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.

  Clark Gellings, US EPRI, 2003 (emphasis is mine)

- This interoperability ("universal connectivity") can only be achived at the data/middleware layer, not the network layer
  - See our Grid-Interop 2009 paper for more (details at end)

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Wide Range of QoS+ Requirements

- QoS+:
  - network/middleware "QoS" (latency, rate), availability/criticality
  - Also things an implementer/deployer of WAMS-DD needs to know: geographic scope, quantity.
- Comparing Apples and Apples:
  - Normalize each from 1 (very easy) to 5 (very hard)
- Wide ranges
  - Across application families
  - Sometimes within them (each configuration is different)

Normalized Values of QoS+ Parameters

Difficulty (5 : hardest)	**Latency (msec)**	**Rate (Hz)**	**Criticality**	**Quantity**	**Geography**	**Deadline (for Bulk)**
5	5–20	240–720+	Ultra	Very High	Across grid or multiple ISOs	<5 sec.
4	20–50	120–240	High	High	Within an ISO/ RTO	1 min.
3	50–100	30–120	Medium	Medium	Between a few utilities	1 hr.
2	100–1000	1–30	Low	Low	Within a single utility	1 day
1	>1000	<1	Very Low	Very Low (serial)	Within a substation	>1 day

Also what kind of msgs (both I/O): streaming, condition-based, bulk; person or computer in loop

Applications (ProcIEEE Section & NASPInet Class)

1. Traditional State Estimation (III.A)
2. Direct State Measurement (III.A & NASPInet Class B)
3. Operator Displays (III.B & NASPInet Class D)
4. Catch Up For Operator Displays (III.B)
5. Distributed Wide-Area Control (NASPInet Class A)
6. Distributed SIPS (III.C & NASPInet Class A)
7. Synchronous Distributed Control (III.C & NASPInet Class A)
8. Renewable Generation Islanding Control
9. Transient Stability (III.C & NASPInet Class A)
10. Ancillary Services (III.C & NASPInet Class A)
11. Automated Contingency Drill-Down (III.D & NASPInet Class D, sort of)
12. Post-Event Analysis (III.E & NASPInet Class C)
13. Research Traffic (III.F & NASPInet Class E)

Notes

- This normalized parameterization can be considered a (significant) *refinement of the original NASPInet traffic categories*
- Can't go through following tables in great detail due to time

Bottom line: Wide range of QoS+ requirements; not "one size fits all"

Most Difficult Input for Each App

App	1	2	3	4	5	6	7	8	9	10	11	12	13
Loop Entity	P	P	P	P	C	C	C	C	C	C	P	P	P
Kind	SS	SS	SS	Co	SS	SS	SS	SS	SS	SS	SS	Co	Co
Lat.	1–2	1–2	1	1	2–4	4–5	2–4	2-3	5	1	1	1	1
Rate	1–2	1–2	2–3	—	2–3	5	1-2	2–3	—	—	2–3	—	—
Crit	1-5	1-5	1-5	1–2	5	5	5	4-5	5	1–3	5	1-5	1-5
Quan	3–5	1–2	3–5	1–2	3–5	2–4	1-3	1-3	1–2	1–5	3–5	5	1-5
Geog	5	1-5	5	5	1–5	1–5	1–5	2-3	4-5	3–5	3–4	3–5	3–5
Dline	—	—	—	5	—	—	—	—	—	—	—	2–3	1

Notice: **very wide range** of parameters

- …….. And this is just for applications conceived today, let alone the 30+ year expected lifetime of NASPInet

Most Difficult Output for Each App

App	1	2	3	4	5	6	7	8	9	10	11	12	13
Loop Entity	P	P	P	P	C	C	C	C	C	C	P	P	P
Kind	SS	SS	SS	Bu	Co	Co	Co	Co	Co	SS	SS	Bu	Bu
Lat.	1–2	1–2	1	—	3-5	5	3-5	3–5	5	1–2	1	—	—
Rate	1–2	1–2	1	—	—	—	—	—	—	1–2	2–3+	—	—
Crit	3	3	3	1–2	5	5	5	5	5	1–3	5	1–2?	1
Quan	3–5	1–2	1	2–4	1-2	1	1	1	1	1	3–5	5	5
Geog	1–2+	1–3+	1	1–2+	1–5	1–5	1–5	2-3	3–5	2	3–4	5	5
Dline	—	—	—	5	—	—	—	—	—	—	—	2–3	1

Notice: <u>**very wide range**</u> of parameters

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QoS Requirements

- **Latency**
  - 4 ms within substation, 8-12+
- **Rate** (1/minute to 250/second)
- **Availability of Data** (EPRI IntelliGrid 2004)

Level	Availibility (%)	Downtime/Year
Ultra	99.9999	~ ½ second
Extremely	99.999	~5 minutes
Very	99.99	~1 hour
High	99.9	~9 hours
Medium	99.0	~3.5 days

- Delivered QoS **must** be tailorable per data item & changeable (in SW)

Internet vs. NASPInet environment

Network size	10^9 interconnected hosts worldwide	10^5 hosts in a power grid $10^{3\text{-}4}$ "routers"
Per-Flow state?	Death (RSVP)	Very feasible
Network design goal	Provide best-effort delivery for any user and purpose	Provide guaranteed QoS in several dimensions for specific users and purposes
Admission Cntl Perimeter	None	Complete
Fraction of Managed Traffic	None/Very Little	Almost all. All traffic subject to policing. >>90% periodic.
Central topology knowledge	Not attempted, because of large scale and dynamicity	Feasible, because of small scale and slow changes
Topology changes (!failure)	Often & without warning	Not often & virtually always with warning (except failure)
Frequency of route changes	Frequent; route changes computed using distributed algorithms that may converge slowly in the face of changing topology	Infrequent; route changes computed centrally assuming stable topology

Internet vs. NASPInet environment

Latency Level Achievable	Slow to Medium	Very Fast
Latency Predictability	Poor	Very Good to Excellent
Recovery delay after dropped packet (with "reliable" delivery)	High (timeout waiting for data or acknowledgement)	Zero (redundant copy sent over disjoint path arrives virtually at the same time) **DO NOT USE post-error recovery, be proactive!**
Forwarding Unit	Uninterpreted packet	Update of a variable
Traffic Predictability	Low	Very High
Elasticity of QoS requirements	None/Low	Medium-High
Multicast: multiple subscribers to a single update flow	A small fraction of the overall traffic; does not justify significant optimization	The common case. Multiple subscribers to a single update flow may have different latency and reliability requirements. Significant opportunity for optimization.

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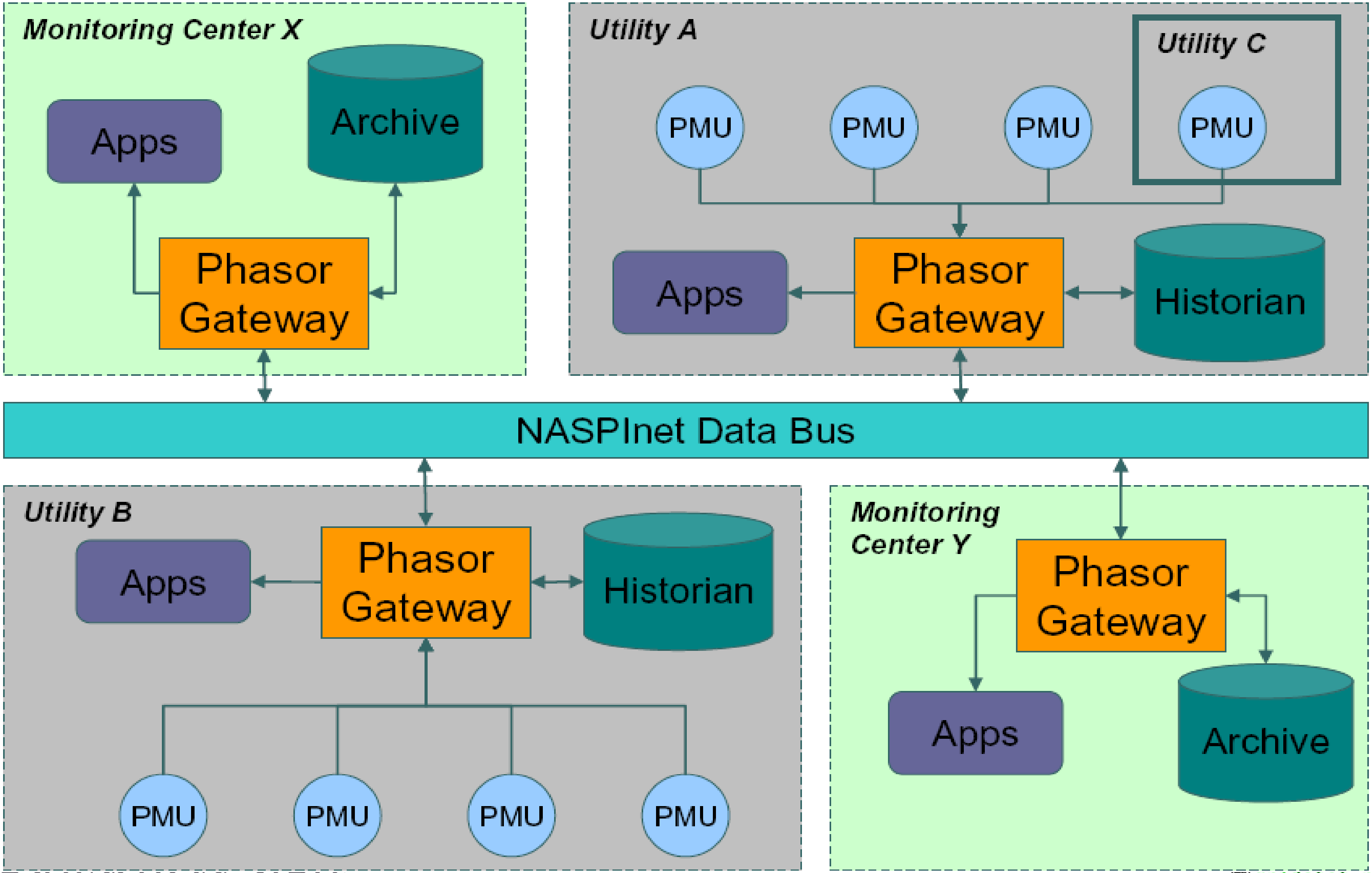
NASPI

- 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”
  - Many requirements come from GridStat research (cited)

NASPInet Conceptual Architecture



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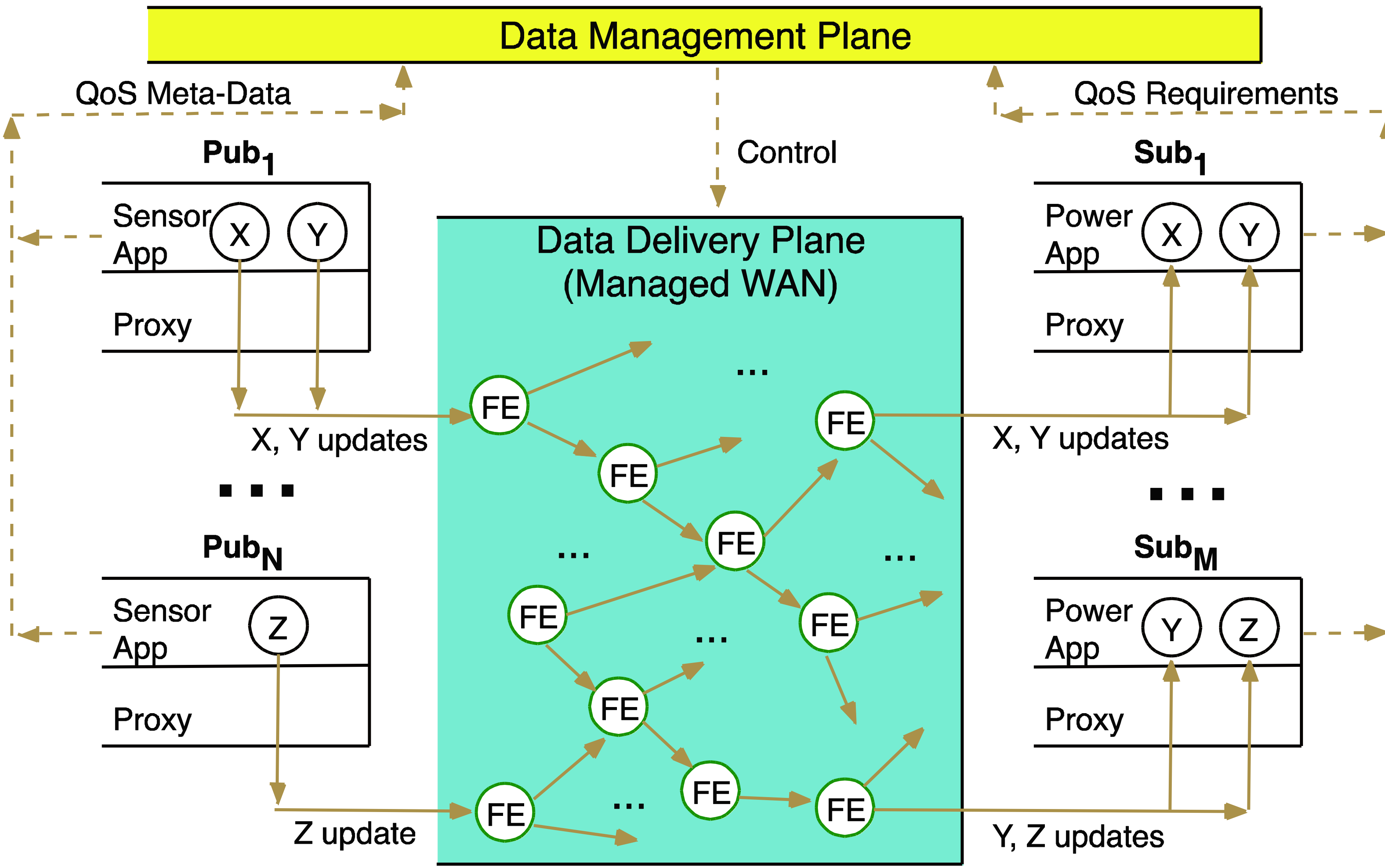
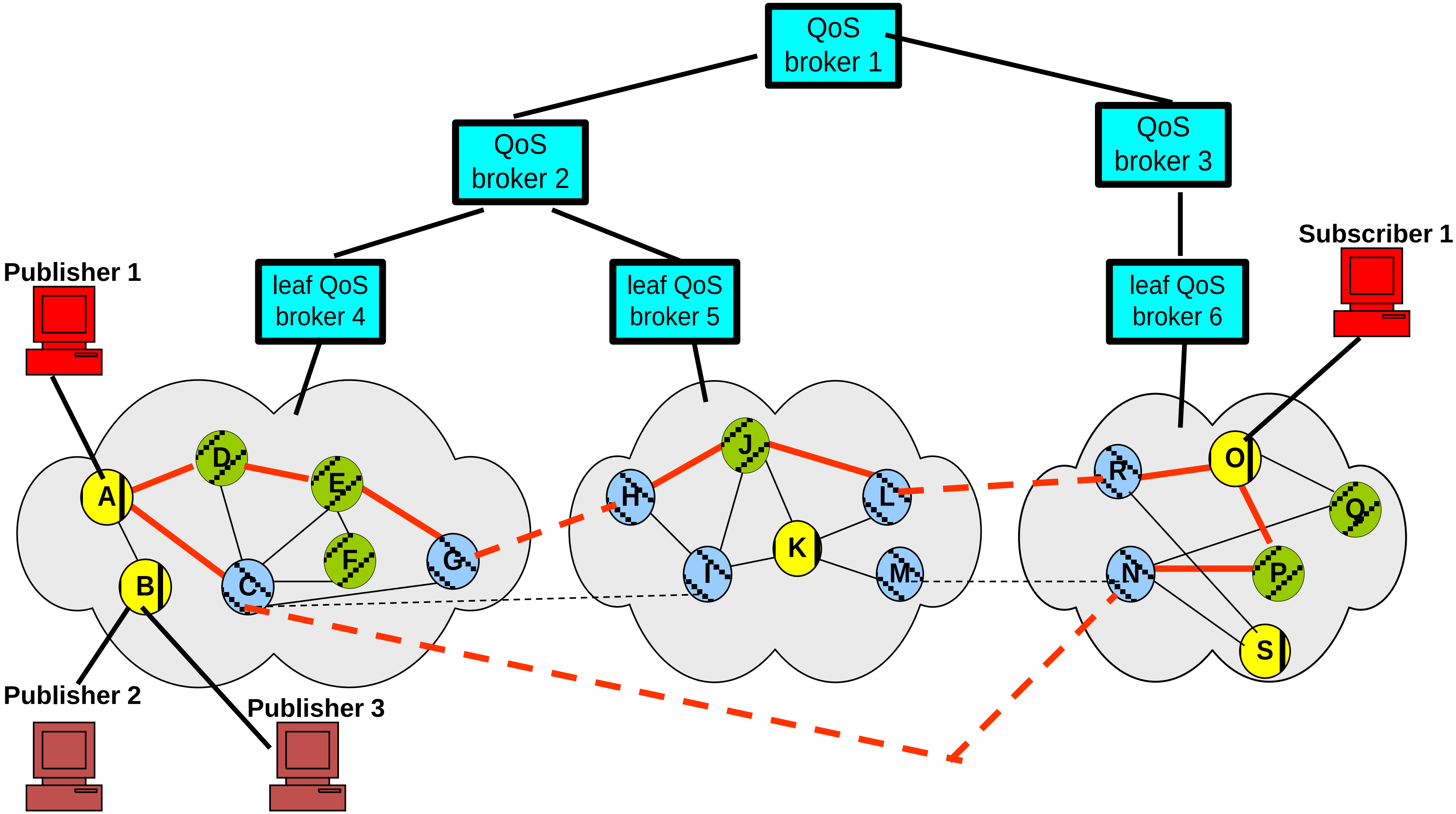
GridStat Architecture

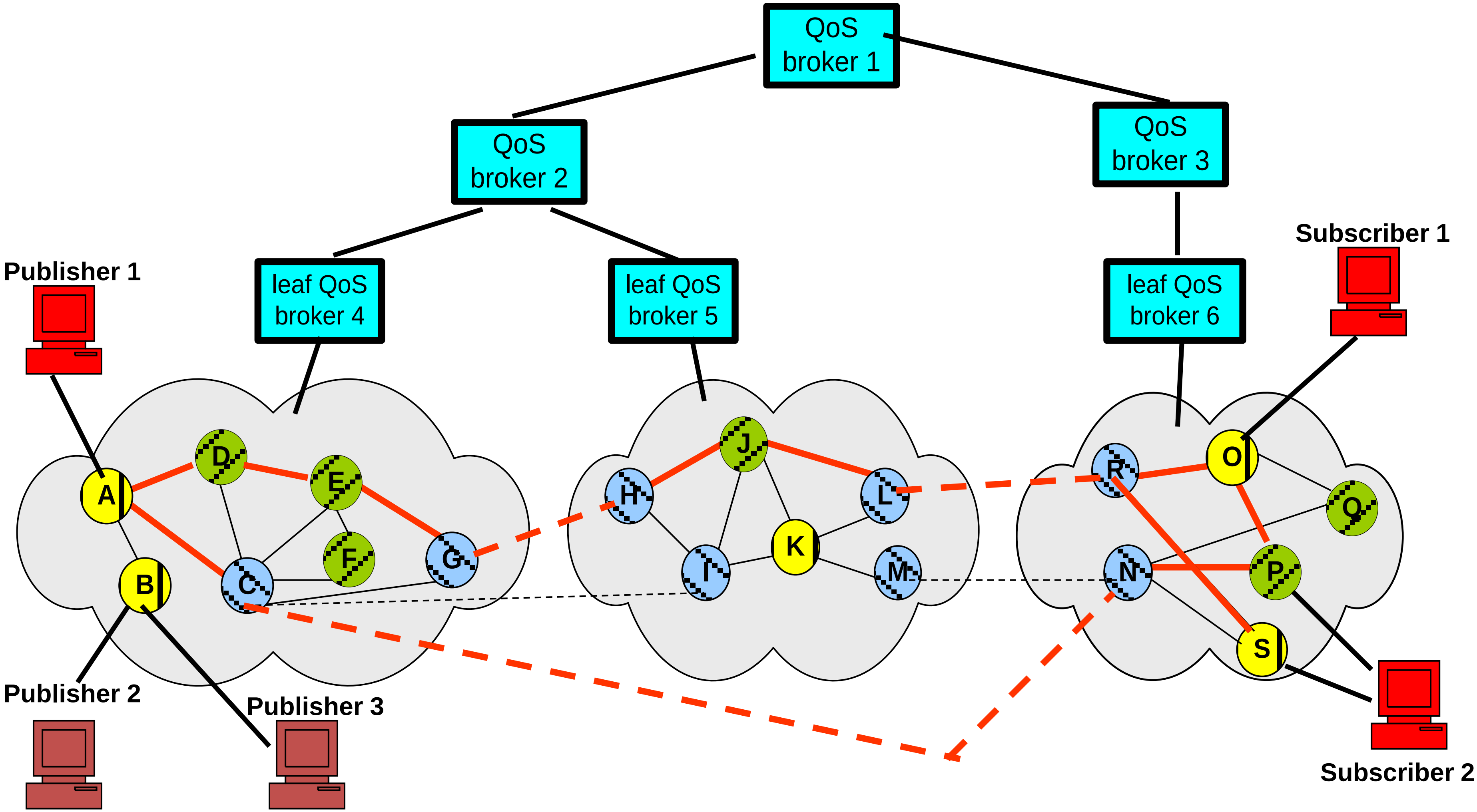


Route Allocation to Subscriber 1



Note: GridStat, not app programmer, figures route/path

Route Allocation to Subscriber 2



Note: Sub2 may have different latency, rate, #paths than Sub1

Overview of GridStat Performance

- Forwarding Latency through one status router between 50-100 microseconds (2007 vintage mid-range PC)
  - Very little jitter
  - Scales to >100K/second in Java
  - Even much faster with "network processors"
  - In custom HW (ASIC) should scale about same as IP router
- So forwarding across an entire grid would be **less than a millisecond** over the speed of light
  - 8-10 hops over a wider area would be typical
  - You ***can*** afford a millisecond (IMHO; YMMV)
- You cannot buy COTS products that give you the complete required flexiblity and QoS control (including rate filtering)

Conclusions

- Better WAMS-DD can help the bulk power system
- WAMS-DD has more extreme requirements than any other; need to be careful here
- For more information (bakken@eecs.wsu.edu):

  - D. Bakken, A. Bose, C. Hauser, D. Whitehead, and G. Zweigle. "Smart Generation and Transmission with Coherent, Real-Time Data". *Proceedings of the IEEE* (Special Issue on Smart Grids), 99(6), June 2011, 928-951.
  - D. Bakken, R. Schantz, and R. Tucker. "Smart Grid Communications: QoS Stovepipes or QoS Interoperability?", Grid-Interop 2009 (best "connectivity" paper award), Denver, November 18, 2009. Available at http://gridstat.net/publications/TR-GS-013.pdf