NASPI 2014 Survey of Synchrophasor System Networks – Results and Findings

NASPI Data and Network Management Task Team,
Network Systems Group

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This technical report was prepared by the Network Systems group of the Data & Network Management Task Team on behalf of the North American SynchroPhasor Initiative (NASPI). The team that designed the survey, interpreted the results, and compiled this report includes:

- Bob Braden (University of Southern California, Information Sciences Institute), team lead
- Dan Lutter (Allied Partners)
- Alison Silverstein (NASPI Project Manager)
- Dick Willson (Allied Partners)

The Network Systems group that compiled the survey and provided insightful interpretation and review includes:

- Team lead Bob Braden (University of Southern California, Information Sciences Institute)
- Dave Bakken (Washington State University)
- Dan Brancaccio (Bridge Energy Group)
- Jeff Dagle (Pacific Northwest National Laboratory)
- Magnus Danielson (Net Insights)
- Ken Martin (Electric Power Group)
- Dave McKinnon (Pacific Northwest National Laboratory)
- Dan Lutter (Allied Partners LLC)
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- Paul Myrda (EPRI)
- Alison Silverstein (NASPI)
- Tim Yardley (Information Trust Institute, University of Illinois-Urbana-Champaign)

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Disclaimer

Executive summary

This report describes a fall 2014 survey of the design and deployment of the synchrophasor data networks used by some of the operational entities of the North American electric power industry. This survey was focused on wide-area networking for real-time streaming of measurement data collected by phasor measurement units (PMUs) in substations and delivered to control room and off-line applications for transmission owners and reliability coordinators. These applications employ complex and sophisticated algorithms to convert PMU field data into high-value operational and planning information.

PMUs make simultaneous electrical state measurements at many points in the grid. The PMU digitizes and packetizes these measurements into data frames, which are streamed in real time across the network to phasor data concentrators and software applications, and then to users in many power system control rooms and engineering offices. PMU measurements are complex numbers called phasors, and may include scalar values such as frequency. PMU measurements are time-stamped to an accuracy of a microsecond using an accurate universal time source such as the signal from global positioning system (GPS) satellites; once time-stamped, the phasor becomes a synchrophasor. Because angle measurements taken by PMUs in different locations are synchronized to a common time reference, once time-aligned, the relative phase angles between different points in the system can be calculated by subtraction. Synchrophasor data from many locations can be combined to provide a precise and comprehensive “view” of an area or even an entire interconnection.

This survey was designed to collect high-level information about synchrophasor network design and operational practices without placing excessive demands on responders’ time. Each of the 32 questions typically requested a set of multiple choices that were optionally supplemented with free-form “Other” fields. The survey was made available in fall 2014 to the members of the North American SynchroPhasor Initiative, and individuals and companies responded on a voluntary basis. After removing responses that were significantly incomplete or irrelevant, there were valid data for about 25 entities, most from North America. Although this sample size is too small for meaningful statistical comparisons, the report offers useful information about today’s synchrophasor networks on some network design and functionality issues.

This report aggregates and presents the respondents’ answers to 23 of the 32 survey questions. These answers address the topics of WAN technology and service provision, synchrophasor data uses, data delivery standards, various network monitoring and management provisions, and more. The report does not indicate which entities or individual representatives responded to the survey (Questions 1 & 2) because the respondents were promised anonymity. This report does not detail the responses to a series of questions (24–27 and 29–31) that addressed various network security and vulnerability topics, in order to avoid public disclosure of potential system vulnerabilities.

The high-level conclusion from the 2014 survey is that current synchrophasor networks and practices do not follow consistent technical standards and that many do not use the most up-to-date, commercially available network technologies. These independently designed networks were built to serve a variety of synchrophasor-related and other purposes and requirements, without a common architecture or formal guidance. But many of the current networks are inadequate to meet long-term expectations for synchrophasor use. These expectations include interconnection-wide geographic network scope, dense interconnectivity, low latency, robust clocking, high accuracy and reliability, and high security, with support for increasingly demanding applications. As synchrophasor technology matures and its use increases, synchrophasor networks will have to mature as well, using better design, technology and management practices to deliver the high reliability, low latency and other requirements that are particular to synchrophasor communication.

Even with high-level survey information, this report offers useful baseline information that can help current and future synchrophasor network planners design and deliver better and better-tailored synchrophasor networks in the future. The report closes with suggested best practices for current and future synchrophasor network design and management.

Acronyms and glossary

ARRA	American Recovery and Reinvestment Act
ePDC	one of several commercially available Phasor Data Concentrators
GPS	Global Positioning System
ICCP	Inter-Control Center Communications Protocol
IEEE 1344	early international technical standard for synchrophasors for power systems, superseded by IEEE 37.118
IEEE 1588	the international technical standard for Precision Time Protocol, which creates a master-slave architecture for networked measurement and control systems
IRIG-B	internationally-adopted formats for inter-range instrumentation group time code, format B, used by GPS and other precision timing receivers
LAN	local area network
MPLS	Multiprotocol Label Switching
NASPI	North American SynchroPhasor Initiative
NASPInet	a proposed synchrophasor data architecture developed under NASPI guidance
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit, a device that measures the electrical waves on an electricity grid, using a common time source for synchronization
Phasor	a complex number representing the magnitude and phase angle of the sine waves found in electricity
QoS	Quality of Service is the overall performance of a telephone or computer network, as seen by its users; measured in metrics such as error rates, bandwidth, throughput, availability, jitter, and latency
SLA	Service Level Agreement, a contractual agreement as to the level of service to be provided for computer and telecommunications services
SONET	Synchronous Optical Network, a standardized protocol for digital data transfer over a network
SyncE	Synchronous Ethernet, an international technical standard for the transfer of clock signals over Ethernet for synchronization
Synchrophasor	Phasor measurements from PMUs that are taken at the same time and time-synchronized from a common time source such as GPS
WAN	wide-area network

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1. Introduction

The North American SynchroPhasor Initiative (NASPI) effort works to improve the reliability, throughput, efficiency, and economics of the electric power grid through the use of synchrophasor technology for grid monitoring, operations, and planning. Synchrophasor monitoring and analysis is enabled by telecommunications and computer networking. This document reports the results of a 2014 survey of the installed base and future plans for networks in these synchrophasor measurement systems. The survey was designed and its results compiled and interpreted by the Network Systems (NetSys) group of NASPI's Data & Network Management Task Team.

Synchrophasor technology

A synchrophasor system uses phasor measurement units (PMUs), usually installed at electrical substations, to make simultaneous electrical state measurements at many points in the grid. The PMU digitizes and packetizes these measurements into frames. The data frames are streamed in real time across the network to phasor data concentrators and software applications and then to users, in many power system control rooms and engineering offices. Widespread sharing of PMU data is expected among neighboring utilities, so the PMU data will often be multicast (i.e., replicated for multi-destination delivery).

In a PMU measurement data stream, the magnitude and phase of an AC value—e.g., the voltage or current on a particular grid bus—are represented as a complex number called a phasor and may include scalar values such as frequency. PMU measurements are time-stamped to an accuracy of a microsecond using an accurate universal time source such as the signal from Global Positioning System (GPS) satellites; once time-stamped, the phasor value becomes a synchrophasor. Because angle measurements taken by PMUs in different locations are synchronized to a common time reference, once they are time-aligned the relative phase angles between different points in the system can be determined by subtraction. Synchrophasor measurements from many locations can be combined to provide a precise and comprehensive "view" of an area or even an entire interconnection.

PMU data reporting rates are typically 30 to 60 frames per second, and may be higher. This high data rate contrasts with the standard supervisory control and data acquisition (SCADA) systems that report data every four to six seconds—over a hundred times slower than PMUs. The accurate time resolution of synchrophasor measurements allows unprecedented visibility into system conditions, including rapid identification of details such as oscillations and voltage instability that cannot be seen from SCADA measurements. Complex data networks and sophisticated data analytics and applications convert PMU field data into high-value operational and planning information.

Today there are almost 2,000 production-grade PMUs deployed across the United States and Canada, streaming data and providing very high visibility across much of North America's bulk power system. Most of these PMUs were installed using $340 million in federal grants authorized by the American Recovery and Reinvestment Act of 2009 (ARRA), matched by private industry funds. The U.S. Department of Energy (DOE) and industry investments also funded the installation of high-speed synchrophasor data networks and development of technology interoperability standards for PMU measurement, functionality and data formats. At the same time, DOE funded a variety of research and development projects to develop advanced synchrophasor data applications and analysis tools.

North American SynchroPhasor Initiative

NASPI works to accelerate the maturity and capabilities of synchrophasor technology, to improve the reliability and efficiency of the bulk power system. NASPI is a large volunteer community that brings together the utility industry, manufacturers and vendors, academia, national laboratories, government experts, and standards-making bodies in a collaboration to address and solve technical, institutional, standards development, and other strategic issues and obstacles. The NASPI Work Group meets twice a year, with financial support from DOE and the Electric Power Research Institute, and its task teams work year-round on chosen issues.

NASPI is the forum where industry members identify strategically important challenges and develop recommended solutions and paths forward. NASPI has identified improved communications networks as a critical element for the continuing evolution, effectiveness, and adoption of synchrophasor technology. Early synchrophasor data network concepts were developed within NASPI and its predecessor organizations.

Synchrophasor system elements

A synchrophasor system begins in the substation. PMUs there collect real-time data, usually from existing potential and current transformers. The PMUs are connected to a high-speed communications system to stream the data frames to applications and data archives. Multiple data streams may converge at phasor data concentrators (PDCs) located between the PMU and the application. The PDC compiles measurement samples taken at the same time and time-aligns them for storage and analysis. A PDC generally performs other functions such as rejecting bad data or archiving the data streams.

The data streamed into a PDC may be used for immediate analysis or relayed on a high-speed wide-area communications network to a higher-level PDC.[1] PDCs typically feed the aggregated data into a data archive and to analytical applications such as wide-area visualization tools, state estimators, and alarm processors. The details of these installations can vary greatly, depending on the complexity and scale of the synchrophasor system and on system users' application requirements. These requirements dictate the rigor of system redundancy, latency, cybersecurity, and other implementation details.

Current North American synchrophasor data networks and NASPInet

Highly reliable, secure, high-volume, low-latency data communications networks are essential for synchrophasor system effectiveness. Local area networks (LANs) are used within the substations and control rooms. Wide-area networks (WANs) move the data from a substation LAN to a control room LAN, to a PDC, or to some other wide-area data collection points and applications.

[1] See Question 7, "Data Delivery Architecture" in Section 2.

Each of the ARRA synchrophasor projects established or expanded a data network. Each of these network designs reflected the organizer's planned synchrophasor system uses, goals, and budget availability. Each synchrophasor network uses various elements of current networking technology. Many implement some aspects of NASPInet, a communications network architecture developed in 2009 with DOE funding to outline key concepts of an effective, interoperable synchrophasor data network.[2]

The most ambitious synchrophasor data network, built by the Western Interconnection Synchrophasor Project (now managed by Peak Reliability), has a purpose-built dedicated high-speed, redundant network spanning the entire western interconnection. This network serves an interconnection-wide project that was designed, built, and operated as a unified effort led by one reliability coordinator (Peak Reliability) working with seventeen transmission owners and other partners. Other synchrophasor projects used leased local network facilities to transport data from substations to transmission owner control rooms and up to the reliability coordinator's wide-area applications. Because there was little effort to coordinate across the synchrophasor project designs and goals, there is little consistency of network requirements, design, or ownership among the networks outside the Western Interconnection.

Figure 1 shows installed, networked PMUs and synchrophasor data networks in North America as of March 2015. Most of these networks were built between 2010 and 2015 to support the extensive synchrophasor deployments funded by the Smart Grid Investment Grants and Smart Grid Demonstration Projects, using federal and matching private funds.[3]

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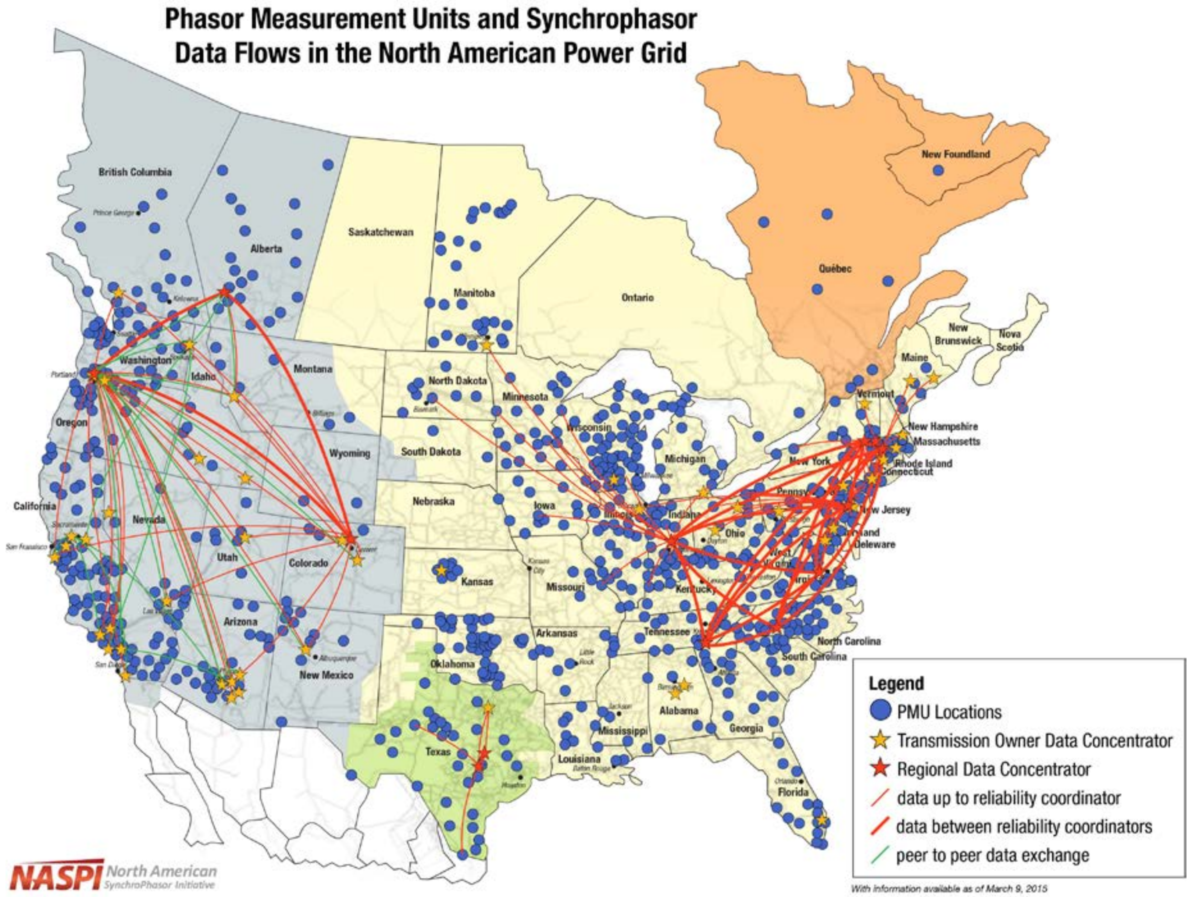
[2] Key NASPInet resource material includes the following (all available at https://www.naspi.org/documents):

- January 2010. Use Case Report for NASPInet Data Bus and Phasor Gateway Specifications, v0.10 (PDF 526KB).
- May 2009. Data Bus Technical Specifications for North American Synchro-Phasor Initiative Network (NASPInet) (PDF 1,863KB).
- May 2009. Phasor Gateway Technical Specifications for North American Synchro-Phasor Initiative Network (NASPInet) (PDF 2,000KB).
- Chassin, D., Carroll R., Bakken, D. July 2008. NASPI Phasor Gateways and Their Relationship to Phasor Data Concentrators (Word 31KB).
- Hu, Y., Donnelly, M. June 2009. Report on final NASPInet Architecture Specifications (PDF 563KB).
- Bobba, R., Heine, E., Khurana, H., Yardley, T. Exploring a Tiered Architecture for NASPInet (PDF 287KB).

[3] All of the Smart Grid Investment Grant (SGIG) and Smart Grid Demonstration Program (SGDP) projects are listed at https://www.smartgrid.gov/recovery_act/project_information.html .

Figure 1 – Synchrophasor data networks in North America, March 2015



Different entities in the power industry play different roles with respect to synchrophasor technology and thus will have differing networking needs. These differences are relevant to their NetSys survey responses:

- Transmission owners (TOs) own and install PMUs and may use their information for such tasks as visualization, situational awareness, model validation, local event analysis, and equipment operation monitoring. TOs build the local area networks (LANs) within substations and a wide-area network (WAN) to aggregate local PMU data to the TO's control room for local use.
- Many TOs serve as Balancing Authorities (BAs), which are responsible for maintaining a balance between load and generation across a specific territory.
- Reliability Coordinators (RCs) manage grid operations and markets in real time across wide stretches of the grid, coordinating the activities of both generation and transmission within their systems and with neighboring systems. RCs do not own any PMUs but aggregate PMU data from many member TO PMUs and use these data for real-time purposes, including wide-area visualization and situational awareness, oscillation detection, voltage stability monitoring, system and power plant model validation, and wide-area event analysis. RCs need a high-speed,

high-volume, high-accuracy WAN to pull data from every TO data hub up to the RC for real-time monitoring and analysis of the PMU data. Some RCs also serve as BAs.

- Most generation owners (GOs) today do not own any PMUs, but that is changing as more TOs and RCs establish requirements that a PMU be installed at the point of interconnection between large and/or new generators and the grid, to improve power plant models using PMU data. When a GO installs a PMU at a TO's substation, the TO builds the network to deliver that data up to the TO data hub (PDC) and control room.

NASPInet and future synchrophasor networks

The NASPInet architecture contains many good ideas, but networking technologies and capabilities as well as expectations about the scale and functions of synchrophasor systems have changed since 2009, and the current NASPInet architecture can be improved. But without greater cooperation and rigorous agreement on synchrophasor network system design and data sharing between PMU owners, it will be difficult to build and maintain a fully interoperable, low-latency, highly reliable synchrophasor data network that spans a full interconnection with many diverse asset owners and data contributors and users.

The basic protocols for packet-switched communication have been under development for the last 40 years, and their remarkable scalability has been well demonstrated by the world-wide Internet. The most effective future synchrophasor data network will be based on the Internet protocol suite. Nevertheless, synchrophasor data networks have requirements that differ from the commodity Internet. Relative to the Internet, synchrophasor data networks have relatively modest requirements for scale and bandwidth, but they demand very low latency and jitter, extremely high reliability and robustness, and high security.

NASPI synchrophasor network survey

In late 2012, NASPI's Data & Network Management Task Team (DNMTT) conducted an initial survey about the synchrophasor system network designs being built by the new synchrophasor projects. Those survey results were reported in October 2013.[4]

DNMTT undertook a new survey (hereinafter called the NetSys survey) in late 2014 to update the 2012 work with greater detail on the installed network implementations and practices. NASPI members and other experts will be able to use this information about current baseline synchrophasor networks to:

- identify potential gaps between the network technologies being used in these deployments and current and emerging networking and security technologies that might be able to serve synchrophasor data network needs more effectively,
- identify unmet technical requirements, and

[4] The survey results are presented in a presentation, "Synchrophasor Data Communications Questionnaire," presented by Jim McNierney and Dan Brancaccio on October 22, 2013, posted for the October 2013 NASPI meeting at https://www.naspi.org/meetingarchives.

- provide a baseline for gauging future progress.

Within substations and control centers, the existing LAN technology is fairly mature and well understood (see, for example, Question 14 in Section 2 of this report). This survey therefore emphasizes WAN issues.

Highlights of this 2014 survey were presented at the March 2015 NASPI working group meeting.[5] The present document contains a more detailed account of the results and findings from the 2014 survey.

The NetSys survey

The design of the NetSys survey was a compromise among competing objectives, to collect useful information while minimizing effort for responders. Although its primary purpose was to examine wide-area networking designs and practices in some depth, the survey also included broad but shallow coverage of several related issues. These included application requirements, network management, and security. The final NetSys survey instrument contained 32 questions and 170 subquestions.

Since responding to the survey was voluntary, the survey designers tried to avoid imposing excessive time demands upon the respondents. The survey was therefore designed to be largely multiple-choice, with the survey designers selecting the answer choices based on educated guesses about the most likely responses. In most cases there was an “Other” option that accepted free-form text, so respondents could indicate choices not listed or clarify a particular choice.

Some of the networking issues are technically complex and could pose some difficulty for respondents who are not networking practitioners. In light of that fact, while the NetSys team encouraged respondents to recruit networking experts to respond to the survey, they expected that some questions on advanced and projected networking technology might be left unanswered. Because the team expects the technology behind these teaser questions to become important in the future, these items were included in the survey to build a baseline of information about the current use (or lack thereof) of these technologies.

The survey was conducted on-line using a survey engine provided by the Pacific Northwest National Laboratory (PNNL). NASPI sent a notice about the survey to its Work Group e-mail list in the fall of 2014, asking synchrophasor data network owners to fill out the survey. NASPI’s 1,000 member e-mail list has both North American and international members; many organizations have numerous individuals participating in NASPI. Ultimately, the team received 55 full or partial survey responses. The NetSys team modified the collected survey responses by eliminating responses that did not come from a TO or RC, deleting fragmentary or unclear responses, and combining well-informed responses that came from more than one person within an organization to produce one compound response per entity. This data cleanup exercise left 25 valid responses from TOs and RCs.

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[5] The presentation, “DNMTT Networking Systems Survey Results,” was presented by Bob Braden on March 24, 2014, posted on the NASPI website at https://www.naspi.org/meetingarchives.

Section 2 of this report presents the primary results of this survey. For each question, the report offers:

- the question statement as shown to the responder, in quotes,
- a table of the multiple-choice answers and responses, containing a title and count for each answer, and
- the total number of responders for the question.

For some questions, we included the responses to one or two interesting subquestions. Because almost every survey question offered multiple-choice answers, and respondents were not limited to choosing a single answer, there are numerous instances where a single respondent chose two or more answers for a single question. This may be because many networks were built with then-available technology, and several different solutions could be used at different parts of the same system. Thus, there are many questions where the number of answers exceeds the number of respondents (25) and the percentages totaled among the responses exceeds 100%. There are also some questions for which fewer than 25 respondents gave any response. This leaves a potential ambiguity about whether the failure to give any answer is because the respondent didn't know the answer or because the implicit answer is, "no, we don't do that."

NASPI collected but will not be sharing the names of the responding organizations nor the contact information for the person who completed the survey for that organization; we made this commitment to encourage industry participation and to avoid releasing any information that might compromise the security of an organization's data networks.

Questions 24 through 31, which address various aspects of security, have been omitted from this published report. These answers reveal important information about both strengths and potential vulnerabilities of these data networks and could be used to harm synchrophasor networks. Although this information will not be made public, it will be used within NASPI to inform the development of cybersecurity best practices and future synchrophasor network design recommendations.

The end result of this survey offers valid, but not statistically significant, insights into the middle tier of North American synchrophasor network deployments. The survey did not receive responses from either the most sophisticated nor the most rudimentary of the 100-plus synchrophasor data networks now operating across North America, and a sample of 25 usable responses is too small a sample to offer statistically valid responses—particularly after the sample was further broken down between TOs and RCs. However, even small sample sizes and limited answers offer useful information and can indicate trends. Thus, the reader should assume that these answers are representative of many synchrophasor networks now in use within North America but should neither assume that these answers characterize the full range of respondents nor assign significant weight to the statistics reported for each survey question.

2. Survey results

Interpretation reminders:

- In some cases in this section, we do not provide percentage responses within a specific answer because several of the respondents provided more than one multiple-choice answer; this means that percentages would be misleading since the number of affirmative choices exceeds the number of respondents (as in Question 3 below, where the count totals 50 from 23 respondents).
- There are many cases where not all 25 respondents who filled out the survey answered a specific question; we do not know whether those who did not give a specific answer (e.g., didn't identify a QoS mechanism) did not know the answer or because the implicit answer is "no, we don't do that." It would be a stretch to assume that every non-answer is equivalent to a "no".
- Where percentages (in the "Frequency" column) are provided, the percentage is calculated as the Count for that answer divided by the total respondents for that question (rather than by the sum of the Count column).

Comments under "* Other" are additional information provided by the respondents. Comments under "NOTES" are observations from the NetSys team.

Question 3: Type of organization

3. "Please tell us about your company or organization (or the entity for which you are answering the survey)."

Company function	Count
Generation Owner/Operator (GO)	12
Transmission Owner/Operator (TO)	22
Balancing Authority (BA)	7
Reliability Coordinator (RC)	7
Other*	2

NOTES: There were 23 respondents to this question, but the counts total 50 because many respondents reported multiple company functions. Two of the respondents operate networks outside North America and use terminology different than the classifications above.

Question 4: WAN service provider

4. "Who provides your wide-area network (WAN) service (check all that apply)?"

Response	Count
Your company	**14**
Telephone company (telco)	13
Third-party private network (not a telco – e.g., Harris)	6
Internet service provider (ISP)	4
Other*	3
Total respondents	22

*Other:

- "Utility-owned telecom network"
- "Parent company's telecom department"
- "Private network for PMU communications, [third-party private network] for sharing partner data"

NOTES: Most of the transmission owners indicated that their own companies provided the WAN service, while only one of the reliability coordinators self-provides network service. This reflects the fact that TOs own diverse field assets, including communications assets, but RCs tend to lease these from a variety of third-party providers. Almost every respondent uses more than one type of WAN service provider.

Question 5: WAN technology

5. "Your wide area network transport is based upon (check all that apply):"

	Frequency	Count
MPLS *[Multiprotocol Label Switching]*	**64%**	**14**
Wide-area Ethernet	32%	7
SONET	**55%**	**12**
Frame Relay	14%	3
Other*	23%	5
Total respondents		22

*Other:

- "Digital microwave, RF PTP, wimax"
- "T1, 56kBs"
- "VPLS"
- "Microwave"
- "T3/T1"

NOTES: Almost every respondent uses more than one WAN transport mechanism. Almost all of the RCs use MPLS, and a majority of the TOs use SONET and/or MPLS plus other transport mechanisms. Responses "RF PTP" and "VPLS" are assumed to refer to "radio frequency point-to-point" and "virtual private LAN service," respectively.

Question 6: Uses of synchrophasor data

6. "What are your intended use categories for synchrophasors?"

Usage Category	Current usage -- count	Planned usage -- count	No plan to use -- count
Off-line engineering analysis (e.g., equipment monitoring or model validation)	13	9	0
Mission-critical real-time operations uses (e.g., situational awareness)	3	18	1
Automated asset operations (e.g., closed-loop controls)	0	6	15

* Other (Current usage):
- Voltage stability monitoring
- System restoration
- Measurement-based load modeling
- Oscillation detection

* Other (Planned usage):
- Line parameter calculation
- CT/PT calibration=
- Linear state estimation

Additional intended uses specified for question 6:
- Power system monitoring research
- Line parameter calculation, CT/PT calibration, linear state estimation.
- Dynamic state estimation, islanding detection, system model validation, determining stability margin, dynamic stability assessment
- Protection
- Voltage stability monitoring, system restoration, measurement-based
- Load leveling, oscillation monitoring

NOTES: CT and PT are assumed to refer to "current transformer" and "potential transformer," respectively.

Question 7: PMU data delivery architecture

7. "PMU Data Delivery Architecture (check all that apply):"

	Frequency	Count
PMU data is aggregated and time-aligned by at least one PDC before reaching the control room**	**77%**	**17**
PMU data is sent simultaneously and directly to all PDC levels	14%	3
PMU data is sent directly to control center, where it may be time-aligned for application(s)	27%	6
Other	5%	1
Total respondents		22

**(whether device or functionality)

Question 8: Data delivery standards

8. "Which standards are you now using for transmitting synchrophasor data (check all that apply)?"

Response	Frequency	Count
C37.118	23%	5
C37.118-2005	**55%**	**12**
C37.118.2-2011	23%	5
IEC 61850-90-5	0%	0
Other*	14%	3
Total respondents		22

*Other:

- Gateway Exchange Protocol (GEP)
- IEEE 1344

NOTES: C37.118.2-2011 was still under development while these networks were being designed. Some of the respondents may have used "C37.118" to mean either the earlier or later version of that standard. While none of the survey respondents were using 61850-90-5, that standard was under modification at the time these networks were being designed and built. The new 61850-90-5 standard may now be gaining use by companies building newer synchrophasor networks, particularly at the substation level.

Question 9: Non-synchrophasor data that shares WAN with synchrophasor data

9. "Is the wide-area network carrying synchrophasor data used to transport other data for non-synchrophasor substation applications, or do you intend to expand its uses to include other applications?"

Response	Frequency	Count
None. WAN is dedicated to synchrophasor data	22%	5
IEDs	30%	7
Protection relays	22%	5
Merging units	4%	1
Digital fault recorders (DFRs)	**52%**	**12**
IEC 61858-controlled substation applications	4%	1
Volt/VAR controls	13%	3
Transformer protection	4%	1
Grid metering (not PMU)	22%	5
SCADA	**57%**	**13**
Storage servers	9%	2
Video surveillance cameras	30%	7
Other*	26%	6
Total respondents		23

*Other:

- Engineering access, door locks
- General corporate and PQ
- Hosted EMS apps - planned but not in use yet
- Device Management
- Market data, ICCP
- The SONET [pipe] carries other data, but the PMU communications circuits are dedicated.

NOTES: The most significant finding here is that only 5 respondents (including many of the reliability coordinators) have WANs dedicated to synchrophasor data. 75% of the TOs report using the network that carries PMU data to carry DFR data (large file block downloads), and 68% of TOs use that network for SCADA data (small messages) as well. However, the structure of question was somewhat ambiguous with respect to current versus future data carried, so readers should not place too much weight on these answers being specific to current versus future data content.

Question 10: Reliability and resilience features

10. "What kinds of reliability/resiliency features are deployed by your WAN arrangement (check all that apply)?"

Response	Frequency	Count
Multiple WAN vendors	15%	3
Redundant WAN access links	35%	7
Redundant links and/or packet switches within WAN	30%	6
SONET rings	**50%**	**10**
MPLS multipath core with aggregation	30%	6
Other *	30%	6
Total respondents		20

*Other:

- Most substations do not have redundancy
- None, single path
- Typically non-redundant
- The A PMU has a dedicated link to the A Control Center, and the B PMU has a dedicated link to the B control center.

Question 11: Redundancies to improve resilience

11. '"Which of the following redundancies do you use to improve the resiliency of your systems (check all that apply)?"

Response	Frequency	Count
Currently do not use any redundant systems	32%	6
Redundant PMUs in the substations	11%	2
Redundant LAN(s) in the substation	11%	2
Redundant PDCs	**63%**	**12**
Redundant GPS antennas and receivers	16%	3
Other redundancy*	11%	2
Total respondents		19

*Other redundancy:

- Present projects are pilot only
- Redundant ePDCs
- Inter-control center link passes PMU data from one control center to the other, so each control center has redundant PMU data

NOTES: See also Question 15 (WAN links between substations).

Question 12: Quality of Service (QoS) mechanisms

12. "What Quality of Service (QoS) mechanisms have you deployed to protect real-time data in the WAN (check all that apply)?"

Response	Frequency	Count
MPLS-TP	16%	3
DiffServ Code Point (DSCP)	5%	1
QoS is the responsibility of the WAN service provider	10%	2
Other (please specify)	5%	1
None	**68%**	**13**
Total respondents		19

NOTES: Quality of Service metrics are used to monitor and report real-time delivery of data. Over half of the RCs are using QoS mechanisms. A large majority of the TOs that answered this question are not using QoS metrics (possibly because many of them are self-providing their networks); this does not mean that QoS metrics are not relevant and useful on self-provided networks.

Question 13: PMU data volume

13.1 "How much data are your PMUs gathering (typical number of phasors per C37.118 frame)?"

Responses: 1, 2, 3, 3-4, 6, 8, 8, 10, 13, 16, 18, 52, 67, 171, don't know

13.2. "Typical number of <u>digital or analog status points</u> per frame?

Responses:

- 50% are collecting zero status points per frame
- 15% are collecting 2 status points per frame
- 35% are collecting other values: 0, 2, 3, 8, 10, 15 (but few are used)

13.3. " Data reporting rate (frames per PMU per second)?"

Responses:

- 13 responded 30 frames per PMU per second
- 8 gave other responses: 10, 25, 50, 60

NOTES: The 10, 25, and 50 frames per second responses are likely associated with 50-Hz electric systems.

13b. "Are reporting rates from all PMUs the same?"

Responses:

- Yes: 18
- No: 1

Question 14: Network technology within substations

14. "What networking technologies are used within your substations (check all that apply)?"

Response	Frequency	Count
Ethernet	**95%**	**19**
"Real-time" Ethernet (e.g., Profinet)	0%	0
Bridged Ethernet segments (e.g., Ethernet switch)	10%	2
Serial lines (e.g., RS232)	40%	8
Wireless	0%	0
Other *	10%	2
Total respondents		20

* Other:

- In the substation, the A PMU has A switch and router. The B PMU has its own switch and router.

NOTES: Ethernet is essentially universal within substations, but almost half of the respondents still use serial lines for some purpose within their substations; but the way the question was framed, this may not be for synchrophasor data. "Bridged Ethernet segments" logically includes "Ethernet." See also Question 15: WAN links between substations

Question 15: WAN links between substations

15. "Do you have direct WAN links between substations? "

Responses**:**

- Yes: 9
- No: 9

Question 16: Transport layer protocols

16. "Which transport layer (OSI Layer 4) protocols do you use in your WAN (check all that apply)?"

For PMU data streaming

Response	Frequency	Count
UDP/IP	**57%**	**12**
IP multicast	0	2
TCP/IP	**52%**	**11**
Other	0	0
Total respondents		21

For PMU configuration and control

Response	Frequency	Count
UDP/IP	15%	4
IP multicast	4%	1
TCP/IP	**58%**	**13**
Other (specify below)	0%	0
Total respondents		21

* Other:
- We use TCP/IP internally from substations to our PDC and the UDP/IP to Reliability Coordinator.
- UDP-S for streaming, no remote configuration/control

Question 17: Middleware

17. "If you are using middleware or plan to use it, which functions will it include (check all that apply)?"

Response	Frequency	Count
Application-layer publish/subscribe	16%	3
Application-layer multicasting	5%	1
Down-sampling	0%	0
Other (please specify)	5%	1
No middleware	**79%**	**13**
Total respondents		17

NOTES: While few of the respondents are using middleware, most of the entities that report using it are reliability coordinators.

Question 18: WAN management

18. "Who is responsible for managing the WAN at your organization?"

Response	Frequency	Count
Vendor under contract	16%	3
In-house	**74%**	**14**
Other*	11%	2
Total respondents		19

* Other:

- Managed by utility

Question 19: Network management tools

19. "What tools are used to manage the network (check all that apply)?"

Response	Frequency	Count
SNMP	**58%**	**11**
Proprietary CLI	32%	6
REST API with Web Browser	0%	0
Centralized management application	47%	9
Other *	26%	5
Total respondents		19

* Other:

- Orion Solarwinds Monitoring

Question 20: SLA with WAN provider

20. "What does the SLA with your WAN service provider cover?"

Response	Frequency	Count
Availability	28%	5
Bandwidth	33%	6
Latency	22%	4
Jitter	11%	2
Resiliency	0%	0
Other*	11%	2
No SLA	**56%**	**10**
Total respondents		18

*Other:

- Still determining as the WAN network is new, developing procedures and SLA currently.

- We manage our own network

NOTES: Out of 18 respondents, six respondents indicated that they have SLAs with performance metrics, five of which SLAs cover three or more metrics. Bandwidth and availability are the most common SLA metrics, with latency is gaining in importance. Half of the TOs don't use an SLA, but that may reflect the fact that many TOs self-provide their data networks. All of the above network performance features will be important for future mission-critical synchrophasor networks.

Question 21: SLA violation alerts

21. "Does your service provider alert you if the SLA is violated?"

Responses:

- Yes: 2
- No: 15

Question 22: Monitoring latency and jitter

22. "Do you monitor network latency and jitter performance for specific applications?"

Responses:

- Yes: 4
- No: 11
- Other: 3

*Other:

- We are working to establish monitoring procedures and matrix

NOTES: As synchrophasor systems become mission-critical and PMU data are to be used for automated closed-loop protection and control, it will be more important to manage network latency and jitter closely.

Question 23: Excessive latency and jitter

23." What actions do you take when latency or jitter reach unacceptable levels?"

Responses:

- The network services team works with stakeholders as well as with our Service Provider to resolve when issues arise.
- I have to contact IT/Telco to resolve them. Meanwhile, I may have to notify the users of such an incident and remind them the application may not be reliable until network service is normal again.
- Contact asset owner, contact service provider.
- Open a ticket with the service provider.
- Look at alternate WAN connectibility.
- Review with Network Support group.

Question 28: Clock source for timing

28. "What clock source do you use for timing?" (specify all that apply)

Response	Frequency	Count
SONET BITS clock	0%	0
GPS	**95%**	**19**
IEEE-1588	0%	0
IRIG-B	55%	11
SynchE	0%	0
Other	0%	0
Total responses		20

Question 32: Future plans

32. "What are your future plans for wide-area communication of synchrophasor data?"

Response	Frequency	Count
Interconnect with other user networks	**50%**	**8**
Switch [change] vendors	13%	2
Modify design	38%	6
Reduce latency	25%	4
Double synchrophasor data sampling rates	13%	2
Increase redundancy	**56%**	**9**
Other*	25%	4

*Other:

- Develop a long-term strategy for the utility-owned telecom network in [our area]. Provision synchrophasor, SCADA, voice, protection, and radio data over it in a purely utility-owned network.
- 5–10 year plan to update and replace
- We are getting PMU data from one partner, plan to add more partner data in the future.
- Sharing phasor readings via ICCP

NOTES: Within a few years, it is probable that all synchrophasor data networks will have to interconnect with neighboring networks to support wide-area real-time visualization and situational awareness uses and support redundancy and resilience.

3. NetSys team observations and comments

These survey responses allow us to identify both what is presently being done for synchrophasor network provision, and what should be done in terms of best practices. This section offers observations about current practices and suggests some best practices for synchrophasor network design and implementation.

While all of today's synchrophasor data networks are controlled by the user, Question 4 (WAN service provider) shows that many of those networks are provided and owned by third-party entities other than the RC or TO user—whether a telephone company, Internet Service Provider, or a private dedicated network provider—under contract to the network user. But after that, reliability coordinators and transmission owners use PMU data in different ways, and those differences affect their network designs.

Among current PMU network implementations, it appears from Question 7 of the survey (PMU data delivery architecture) that most PMU data is time-aligned by at least one PDC (probably at the substation or at the TO's PDC) before it is delivered to a control room (TO or upstream to an RC) for use in an application. Only 24% of the respondents (presumably, all TOs) have chosen the alternative architecture in which the PMU data is sent directly to the control center, where it will be time-aligned for applications.

Question 8 (data delivery standards) shows that most of the PMU data streaming today is occurring under older implementations of technical standard C37.118—only 24% report using the newer C37.118-2011 standard. None of the NetSys survey respondents are presently using IEC 61850-90.5. The standards community has recently harmonized C37.118 and 61850; both were independent standards at the time these synchrophasor deployments were being designed and implemented. It is likely that as synchrophasor networks mature and there is a full substation implementation of IEC 61850-90.5, North American synchrophasor networks may migrate to this newer, harmonized standard for data transport and messages.

Those respondents with SLA agreements (see Question 20, SLA with WAN provider) are using those contractual provisions to ensure that the network provider is meeting their bandwidth, availability, latency, and jitter performance requirements. These will become more important as synchrophasor systems become mission-critical and real-time applications require low latency and high data quality.

Different uses dictate different network needs

A high proportion of TOs use company-owned or contracted data networks. Those networks often carry several types of data traffic, such as relay data, control commands and surveillance video, in addition to (and likely predating the addition of) PMU data traffic.

In general, RCs use more sophisticated, purpose-built networks for synchrophasor data only, and they are using factors such as redundant networks and business practices such as Service Level Agreements and detailed Quality of Service network performance requirements to ensure that their synchrophasor data networks perform adequately. The RCs are also using more advanced technologies, such as middleware for application-layer publish-subscribe, to enhance system performance and make the system more resilient and flexible over time. The RCs use more security provisions and already use or intend to implement more network redundancy than TOs.

Among all of the respondents, the MPLS and SONET WAN transport mechanisms dominate (Question 5, WAN technology). Some TOs use frame relay transport for their WANs; but since many telecommunications carriers are dropping this transport mechanism, this may change soon.

Today two-thirds of the respondents are using PMU data for off-line analysis. Half plan to interconnect with other networks in the future for wide-area PMU data transport, and three-quarters plan to use PMU data for mission-critical real-time operations. These uses will demand higher levels of network capability and performance than are available to many of the NetSys survey respondents today.

Security observations

The survey asked about network encryption, network access control, use of an electronic security perimeter (as defined by North American Electric Reliability Corporation Critical Infrastructure Protection standards), syslog maintenance, the ability to detect compromised time data, and other security provisions and practices. While this report will not address the security provisions of the existing North American synchrophasor data networks in any detail, it is worth noting that the RC synchrophasor data networks generally have stronger security provisions than many of the TO networks. This is due in part to the fact that some of the TO networks were not originally designed for delivery of data to serve mission-critical operations purposes.

Network security requirements, provisions, and practices have advanced since these networks were first designed and implemented. It is likely that now that the capabilities and opportunities for synchrophasor technology are better understood, new network implementations will use different and more stringent networking and security approaches.

Changing network technologies relative to those reported in the survey

Future synchrophasor networks will need to be highly secure with high reliability and availability with low latency and packet loss. They will need to support multiple types of applications, including real-time visualization, real-time grid protection and closed-loop control, real-time diagnostics and operator decision support, and off-line engineering and forensic analysis tools. As currently implemented, most of the existing synchrophasor data networks cannot support these requirements.

Networks that can deliver data effectively for all these needs will likely have SLA performance monitoring and logging and high levels of physical security, cybersecurity, and redundancy. They will likely share common design principles, common security policies, and full-time WAN performance and data quality monitoring and reporting.

Some emerging commercial networking technology trends that may be valuable for synchrophasor implementations include the following:

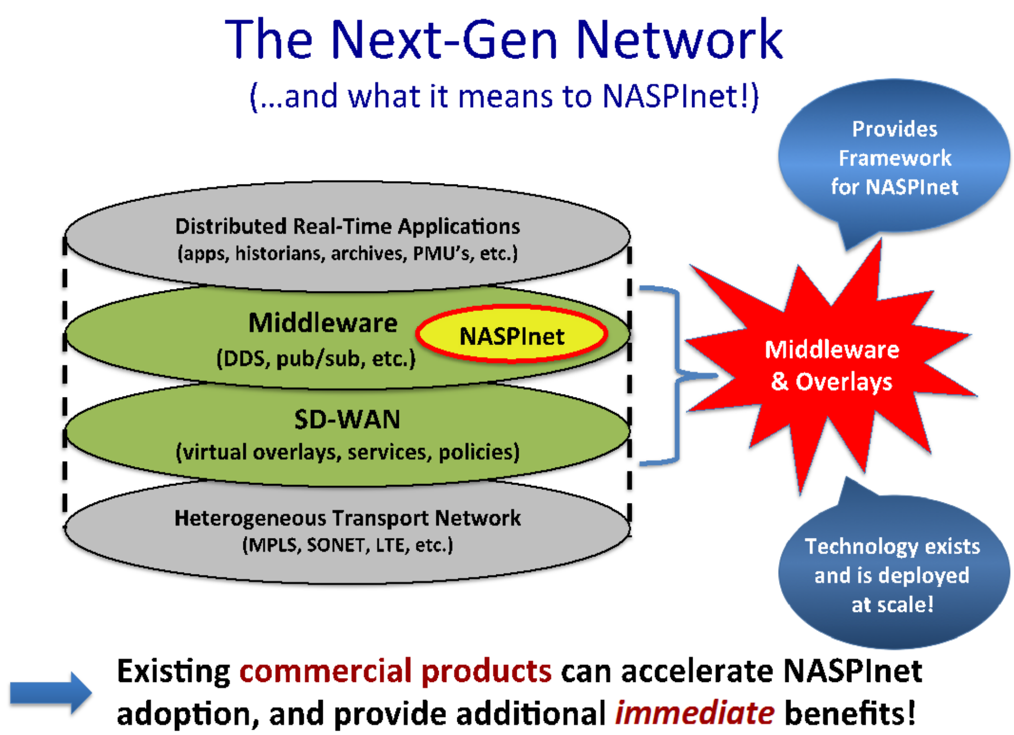
- “Application-aware” routing and forwarding, independent of underlying transport networks, utilizing Software-Defined Wide Area Network (“SD-WAN”), and

Network Function Virtualization ("NFV"; also called "Service Chaining") technologies
- Service Overlay Networks or Virtual Overlays over heterogeneous transport, using a variety of transport technologies including MPLS, SONET, LTE ("long-term evolution" wireless standard) and others
- Secure virtual network segmentation for multi-tenant applications (i.e., separating and securing multiple disparate users who utilize a shared network infrastructure)
- Single Frequency Networks to provide very accurate, cost-effective timing and synchronization of network services
- Distributed real-time and off-line applications to meet a variety of user needs in many locations and time-frames
- Centralized policy-driven network and security orchestration
- Middleware, which is a software layer (e.g., Data Distribution Service or "DDS" and Publish/Subscribe software) that lies between distributed applications and the network to improve the security, scalability, and performance of, and ease the configuration and maintainability of, these networked applications.

Figure 2 illustrates some of these concepts.

Figure 2 – Next-generation network concepts

(Source: Dan Lutter, Allied Partners, October 2014)



Because so many of these practices and technologies are already in use in other industries, they are commercially available for synchrophasor network use. In particular, many of these newer technologies involve changes to software and business practices rather than to existing physical communications infrastructure elements, making it easier and faster to configure and deploy without extended, costly delays for physical infrastructure upgrades.

4. Conclusions

The 2014 NASPI NetSys survey offers information that characterizes synchrophasor data networks designed in 2010 and 2011. The survey responses collectively describe the broad middle group of North American synchrophasor networks but exclude both the best and least of the synchrophasor data networks in operation today. Because the survey sample size is small, the answers reported here are not statistically significant and should not be viewed as definitive for the overall state of synchrophasor networks in North America. However, the sample size and the representative respondents to the survey are sufficient to facilitate some valid conclusions and to highlight key areas in need of work.

It will be useful to repeat this survey regularly as synchrophasor network implementations evolve. Future surveys could include questions targeted to address issues not covered in this survey, including data network performance and user experience, to help identify network design and operation issues and challenges that need improvement. A future survey should also cover current experience, to provide a clear path to identify the most problematic areas first and develop a better overall network structure for the long term.

Best practices

Based on the information collected from the NetSys Survey and the NetSys team's experience, we can identify a few best practices for synchrophasor network design and implementation from the NetSys survey. Those best practices include the following:

- Networks should be designed to satisfy the requirements of the user's current and planned applications, as well as general performance goals for unspecified future development. These requirements will dictate needed and acceptable levels of network bandwidth, availability, latency, jitter, and other performance factors.
- To maximize interoperability and effective data flows between participants, network designs and implementations at every level should reflect the most up-to-date technical standards and guidelines.
- Since there are likely to be multiple network owners and providers across each electric interconnection, clear coordination and governance agreements will be needed between the network partners at the design and implementation stage to ensure that everyone uses consistent technical network designs and protocols and that the network design will be able to meet all of the users' requirements.
- Timing sources for networks, PMUs, and PDCs need to be recognized as potential points of vulnerability that need to be redundant and protected for reliability and security purposes.
- Network acquirers should use Service Level Agreements and Quality of Service requirements with explicit performance levels in their contracts with third-party

network providers (or even peer providers within the user's own company), to ensure that the provider understands and commits to deliver a network that meets the owner's and users' needs. The provider should alert the owner and users if any SLA performance terms are violated.

- Although most current synchrophasor systems are not being used for mission-critical purposes, high levels of physical security and cybersecurity should be built into synchrophasor data networks from the first design step on, with the assumption that any network built today will be used soon for mission-critical purposes.
- Electric industry members should look at prevailing network practices and designs in the broadcast, healthcare, and financial industries in particular, since those industries have comparable networking needs but have more advanced technology experience and business practices.
- Network technologies and practices continue to evolve. Although many of the current TO and RC synchrophasor networks do not leverage all applicable modern network technologies, the adoption of readily available solutions such as middleware and best practices such as careful network service-level provisioning and performance monitoring will make it easier for RCs and TOs to implement and maintain secure, reliable, future-proof and cost-effective synchrophasor data networks.