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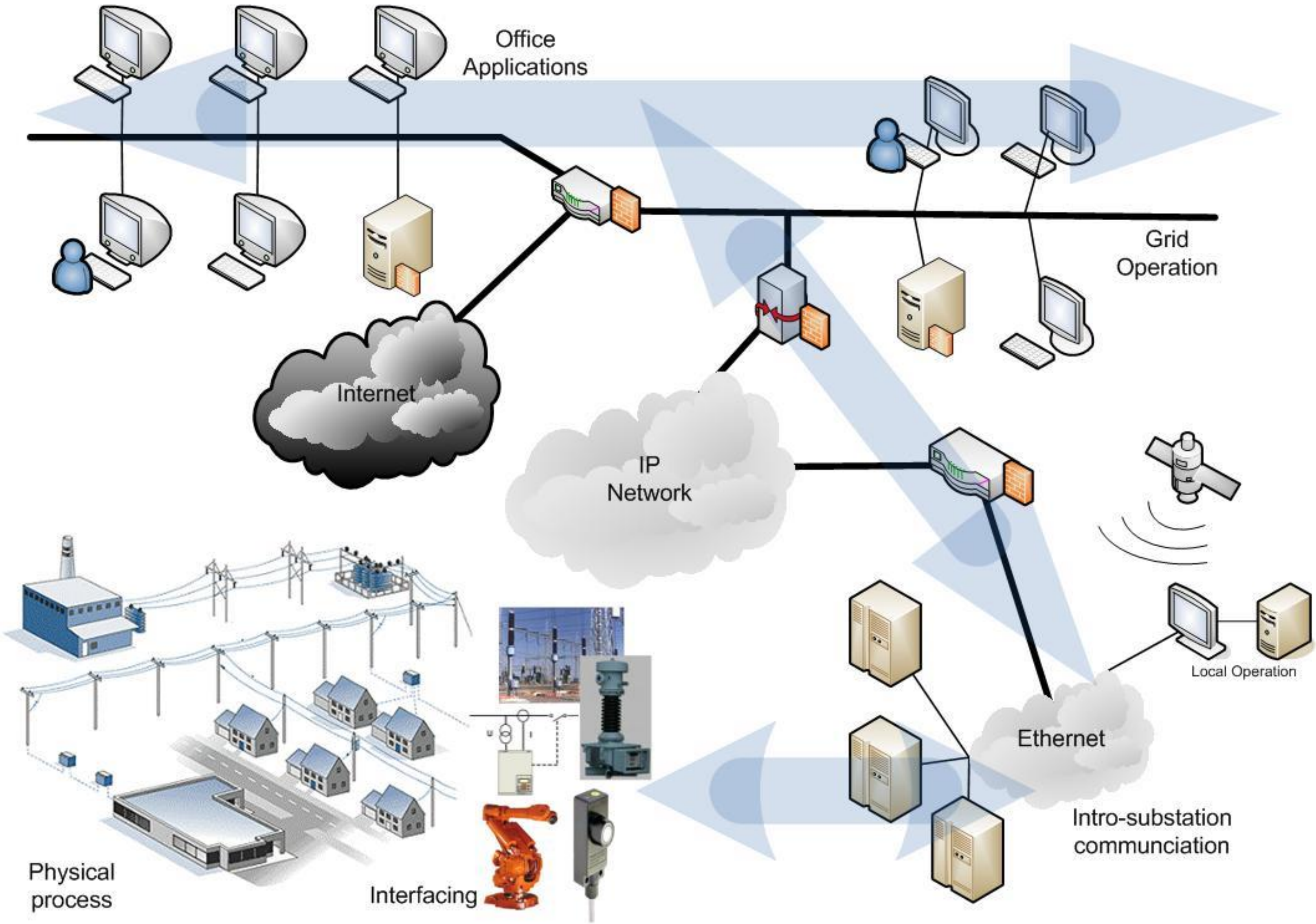
Wide Area Monitoring, Control, and Protection

Course Map



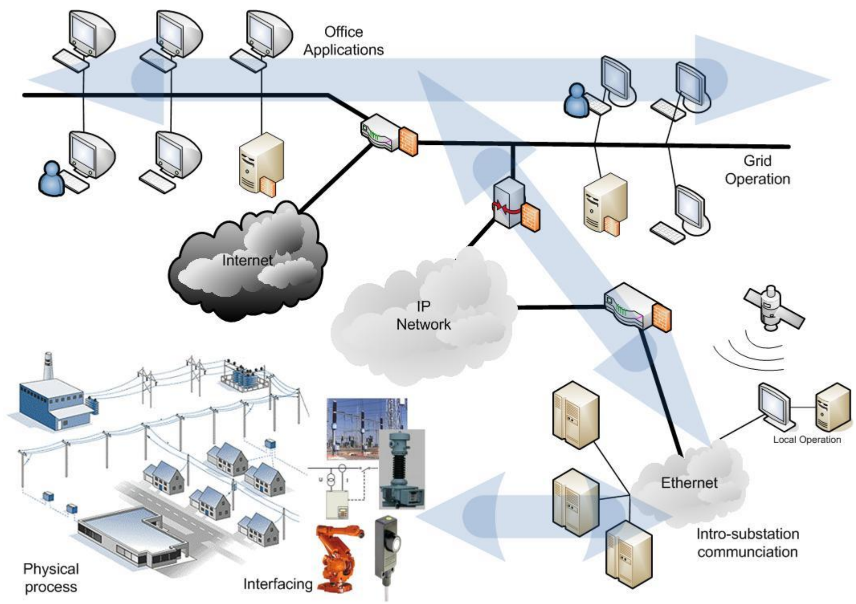
Office
Applications
Grid
Operation
Internet
IP
Network
Local Operation
Ethernet
Intro-substation
communciation
Physical
process
Interfacing

Acronyms

- Wide Area Monitoring Systems (WAMS)
- Wide Area Monitoring Control Systems (WAMCS)
- Wide Area Monitoring Protection and Control Systems (WAMPACS)

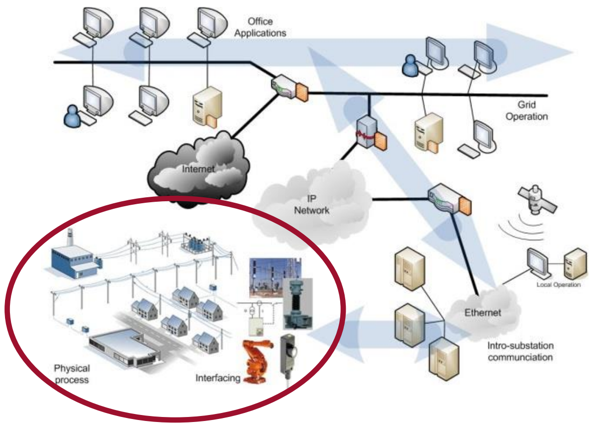
Contents

- Recap of the SCADA and Communication Networks
- WAMCS architecture
- WAMCS components
- Standards relevant to WAMCS
- Quality of Service challenges
- Other frontier architectures

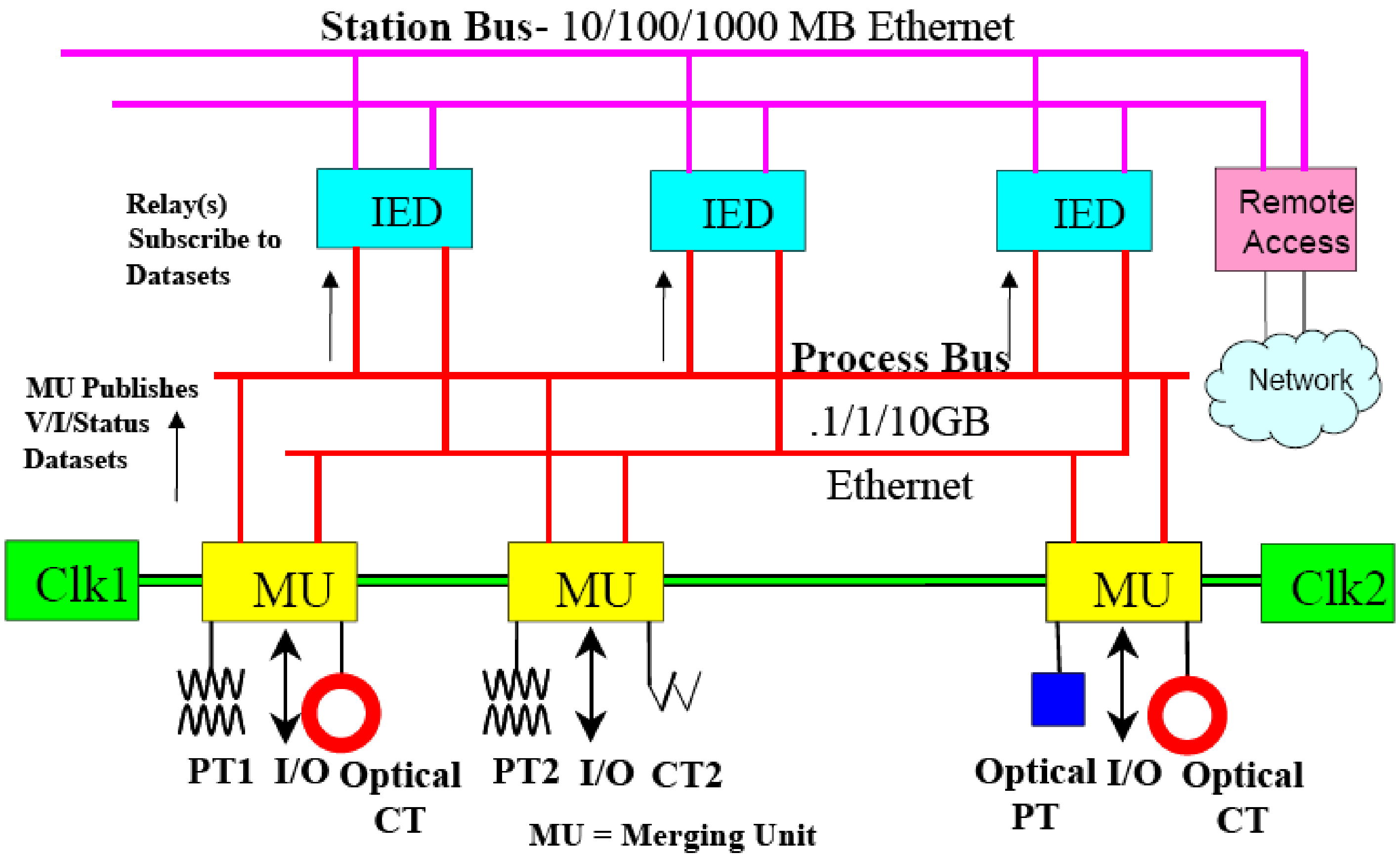


Recap

SCADA and Communication Networks

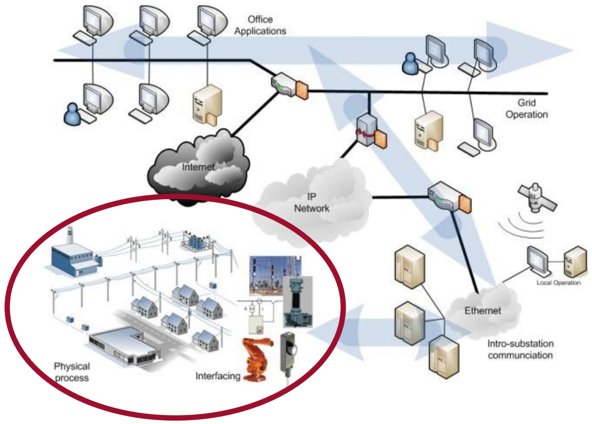


- IEC61850

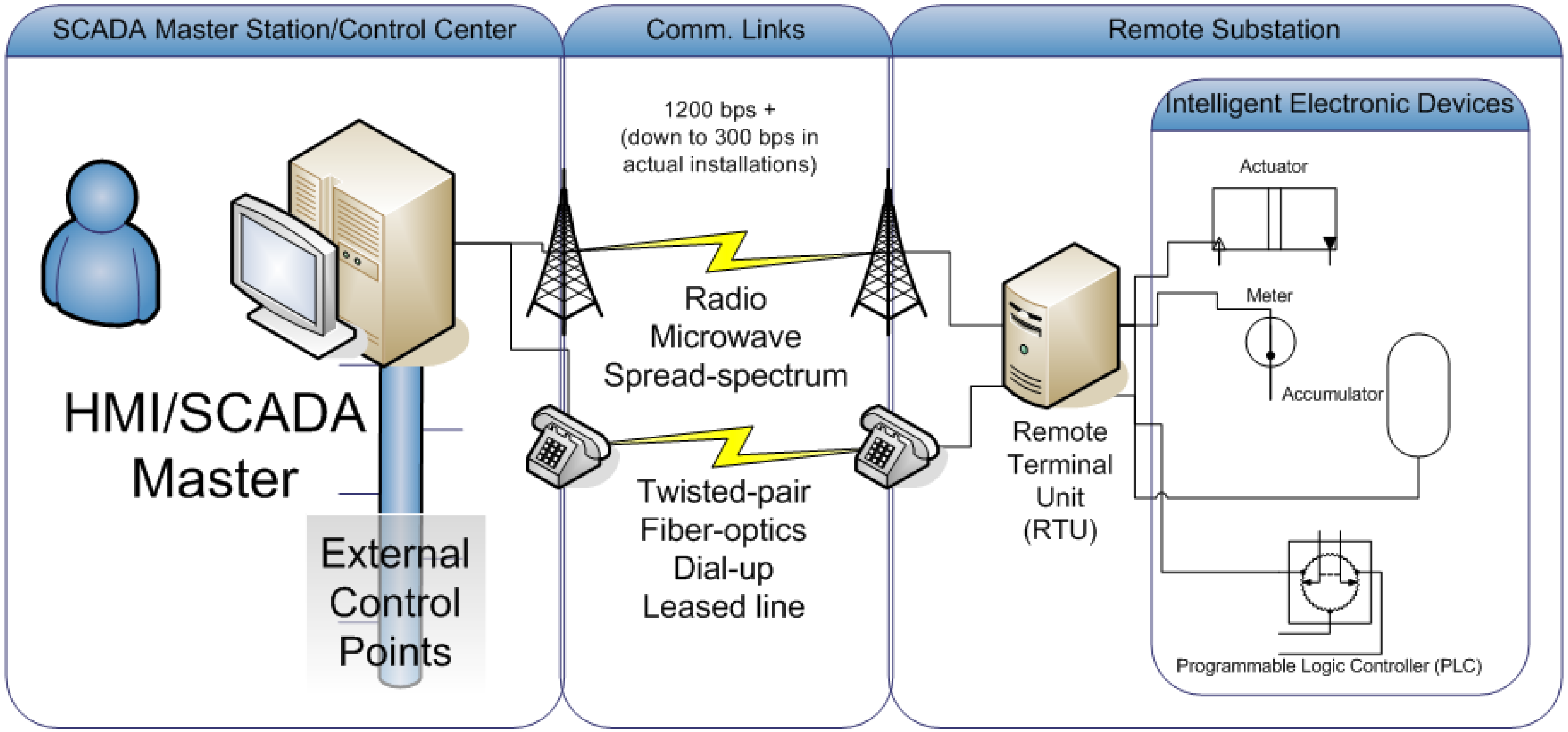


Recap

SCADA and Communication Networks



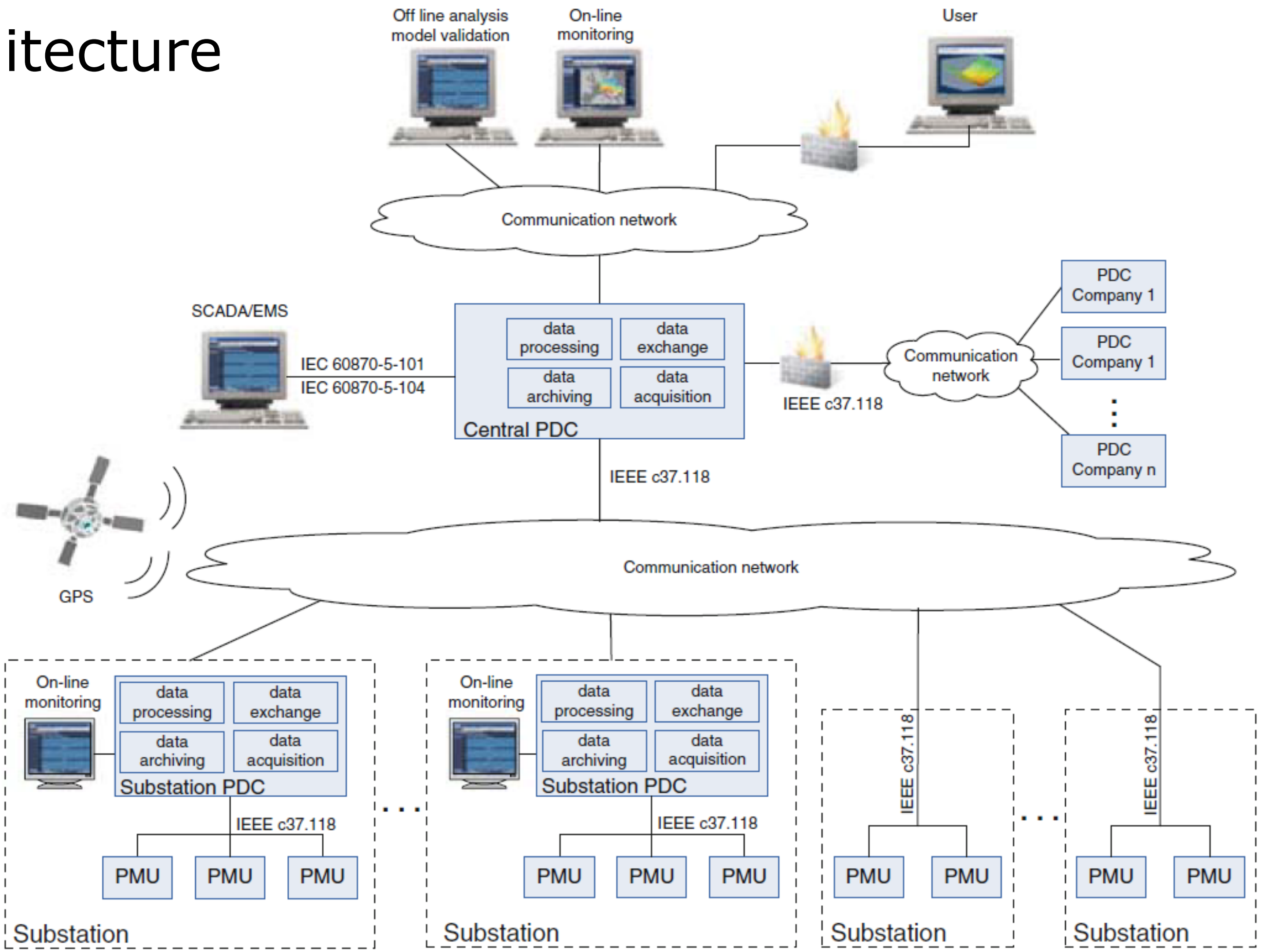
- IEC 60870-5-x



WAMS

Wide Area Monitoring, Control and Protection Systems

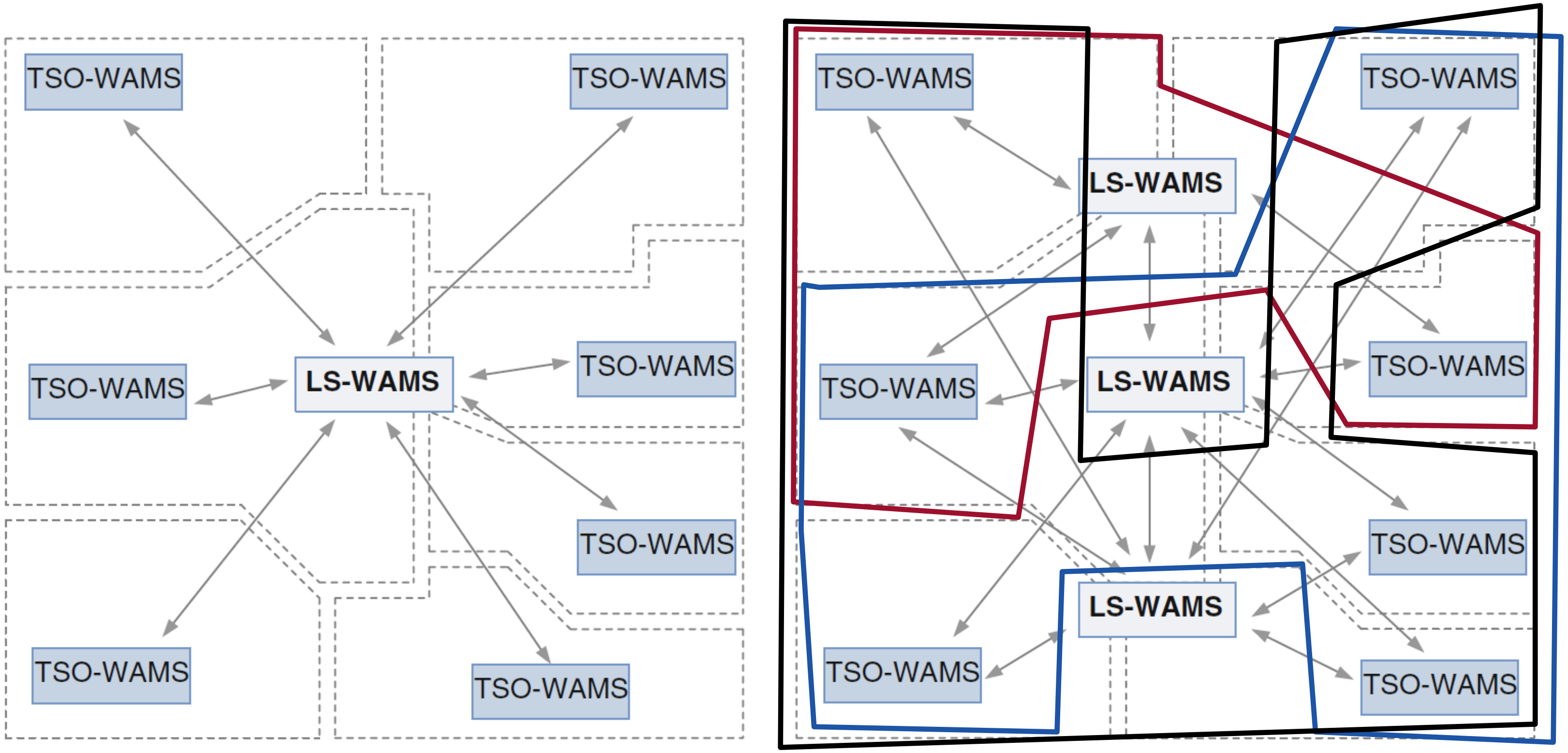
- Architecture



WAMS

Wide Area Monitoring, Control and Protection Systems

- Large Scale WAMS Concept



Centralized

Decentralized

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WAMS

Wide Area Monitoring, Control and Protection Systems

- Large Scale WAMS Concept
  - Centralized LS-WAMS
    - Advantages:
      - easy for data acess, coordinated alarming and remedial actions, and administration for data exchange
    - Disadvantages:
      - Single node failure
  - Decentralized LS-WAMS
    - Advantages:
      - Reliability, regional coordinating functions
    - Disadvantages:
      - Limited extend of stability analysis, higher communication cost, coordinating the event in wide area is complexed, and higher implmentation costs

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WAMS

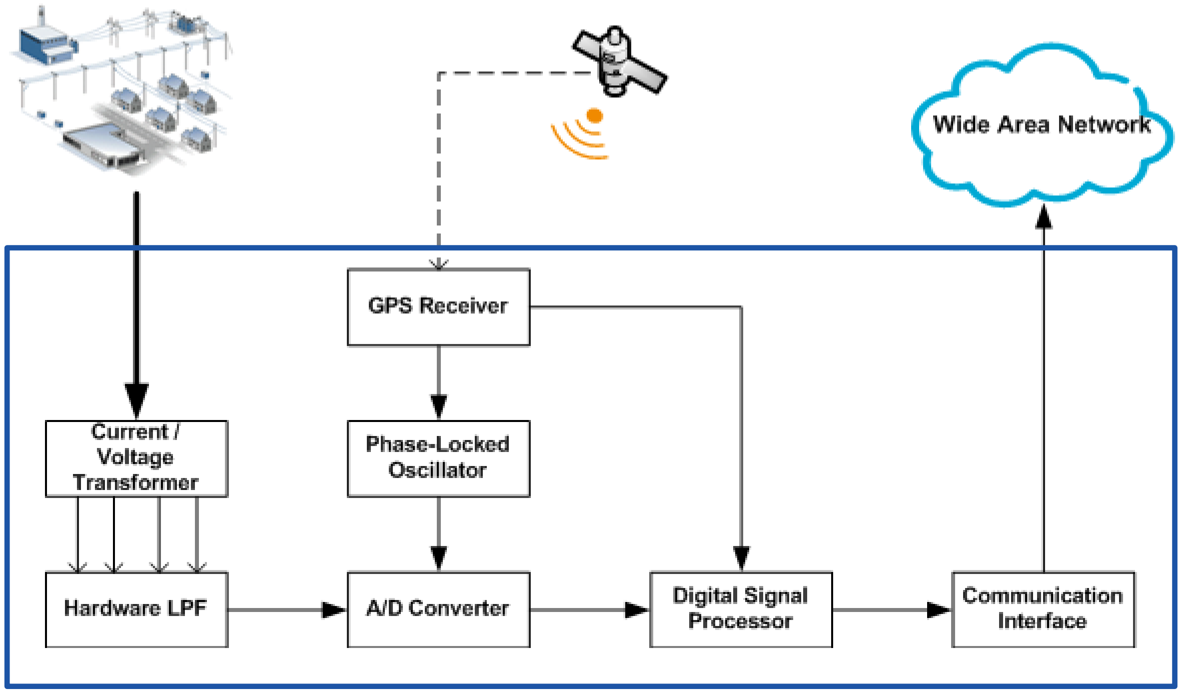
Wide Area Monitoring, Control and Protection Systems

- Components
  - PMU (Phasor Measurement Unit)
  - PDC (Phasor Data Concentrator)
  - Synchronization Clock
  - Communication Infrastructure
  - Communication principle

WAMS

Wide Area Monitoring, Control and Protection Systems

- PMU – Phasor Measurement Unit
  - CT and VT
  - Sampling
  - A/D convert
  - Signal Process
  - Data Server



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WAMS

Wide Area Monitoring, Control and Protection Systems

- PDC – Phasor Data Concentrator
  - Real-time data exchange
    - Data acquisition from PMUs
    - Data exchange with other PDCs, SCADA/EMS systems, control and protection application, system visualization
  - Real-time data processing-detection functions
    - Angle difference detection
    - Low frequency oscillation detection
    - Oscillation source location
    - Islanding detection
    - Voltage statbility detection
  - Data Storage
  - Data visualization

WAMS

Wide Area Monitoring, Control and Protection Systems

- Synchronization clock
  - IRIG-B (InterRange Instrumentation Group Time Code Format B)
  - GPS (Global Positioning System)
    - PPS (Pulse per second)
  - IEEE1588 PTP (Precision Time Protocol)
    - Accuracy less than 1 microsecond via Ethernet network
  - Format
    - Coordinated Universal Time (UTC): the time of day at the earch’s prime meridian (0 degree longitude).
    - As the number of seconds since at 1970-01-01 00:00:00.000

WAMS

Wide Area Monitoring, Control and Protection Systems

- Communication Infrastructure and Principle
  - Infrastructure
    - IP based communication network (Wide Area Network)
  - Communication principle
    - Client-Server
      - PMU: server
      - PDC: server or client
      - Other devices receives phasor data: client
  - Modes of operation
    - Spontaneous: server send data directly to the client
    - Commanded: client request, server send
  - TCP, UDP, and multicast communication

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Standard

IEEE Std C37.118 (2011)

- IEEE standard C37.118 (2011)

IEEE Standard for Synchrophasor Measurements for Power Systems

- C37.118.1

1.1 Scope

This standard is for synchronized phasor measurement systems in power systems. It defines a synchronized phasor (synchrophasor), frequency, and rate of change of frequency (ROCOF) measurements. It describes time tag and synchronization requirements for measurement of all three of these quantities. It specifies methods for evaluating these measurements and requirements for compliance with the standard under both static and dynamic conditions. It defines a *phasor measurement unit* (PMU), which can be a stand-alone physical unit or a functional unit within another physical unit. This standard does not specify hardware, software, or a method for computing phasors, frequency, or ROCOF.

- C37.118.2

1.1 Scope

This standard defines a method for exchange of synchronized phasor measurement data between power system equipment. It specifies messaging including types, use, contents, and data formats for real-time communication between *phasor measurement units* (PMU), *phasor data concentrators* (PDC), and other applications.

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Standard

IEEE Std C37.118.1 (2011)

Phasor representation of sinusoidal signals is commonly used in ac power system analysis. The sinusoidal waveform defined in Equation (1):

$$x(t) = X_m \cos(\omega t + \phi) \tag{1}$$

is commonly represented as the phasor as shown in Equation (2):

$$\begin{aligned} \boldsymbol{X} &= (X_m/\sqrt{2})\, e^{j\phi} \\ &= (X_m/\sqrt{2})(\cos\phi + j\sin\phi) \\ &= X_r + jX_i \end{aligned} \tag{2}$$

- Definition of synchrophasor, frequency , and ROCOF
- Measurement evalutaion
  - Algorithm relevant errors
  - Response time and process delay time
  - Reporting latency
  - Measurement error and operational error
- Reporting rates

System Frequency	50 Hz			60 Hz					
Reporting Rates (frames per second)	10	25	50	10	12	15	20	30	60

- Measurement compliance
  - Performance classes (P class and M class)
  - Steady-state compliance
  - Dynamic compliance – Measurement bandwidth

Standard
IEEE Std C37.118.2 (2011)

- Synchrophasor message format
  - Data frame
  - Configuration frame
  - Header frame
  - Command frame

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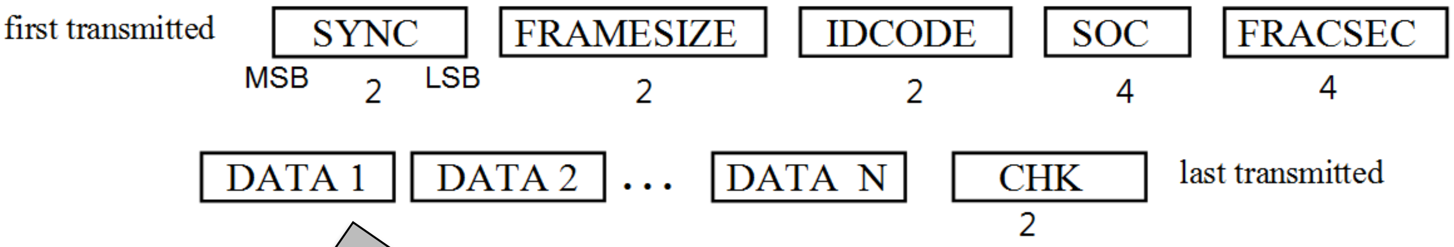
Standard

IEEE Std C37.118.2 (2011)

- Data Frame



- Synchronization word
- Total number of bytes in the frame
- Data Stream ID number
- Time Stamp
- Fraction of second and Time Quality
- Check word

6	STAT	2	Bit-mapped flags.
7	PHASORS	4 × PHNMR or 8 × PHNMR	Phasor estimates. May be single phase or 3-phase positive, negative, or zero sequence. Four or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the FORMAT field in the configuration frame. The number of values is determined by the PHNMR field in configuration 1, 2, and 3 frames.
8	FREQ	2 / 4	Frequency (fixed or floating point).
9	DFREQ	2 / 4	ROCOF (fixed or floating point).
10	ANALOG	2 × ANNMR or 4 × ANNMR	Analog data, 2 or 4 bytes per value depending on fixed or floating-point format used, as indicated by the FORMAT field in configuration 1, 2, and 3 frames. The number of values is determined by the ANNMR field in configuration 1, 2, and 3 frames.
11	DIGITAL	2 × DGNMR	Digital data, usually representing 16 digital status points (channels). The number of values is determined by the DGNMR field in configuration 1, 2, and 3 frames.

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Standard

IEEE Std C37.118.2 (2011)

- Configuration frames
  - CFG-1: denotes the PMU/PDC capability, indicating all the data that the PMU/PDC is capable of reporting
  - CFG-2: indicates measurements currently being reported (transmitted) in the data frame
  - CFG-3: indicates measurements currently being reported in the data frame

Table 8—Configuration frame 1 and 2 organization

No	Field	Size (bytes)	Short description
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	Stream source ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Message Time Quality, defined in 6.2.
6	TIME_BASE	4	Resolution of FRACSEC time stamp.
7	NUM_PMU	2	The number of PMUs included in the data frame.
8	STN	16	Station Name—16 bytes in ASCII format.
9	IDCODE	2	Data source ID number identifies source of each data block.
10	FORMAT	2	Data format within the data frame.
11	PHNMR	2	Number of phasors—2-byte integer (0 to 32 767).
12	ANNMR	2	Number of analog values—2-byte integer.
13	DGNMR	2	Number of digital status words—2-byte integer.
14	CHNAM	16 × (PHNMR + ANNMR + 16 × DGNMR)	Phasor and channel names—16 bytes for each phasor, analog, and each digital channel (16 channels in each digital word) in ASCII format in the same order as they are transmitted. For digital channels, the channel name order will be from the least significant to the most significant. (The first name is for bit 0 of the first 16-bit status word, the second is for bit 1, etc., up to bit 15. If there is more than 1 digital status, the next name will apply to bit 0 of the second word and so on.)
15	PHUNIT	4 × PHNMR	Conversion factor for phasor channels.
16	ANUNIT	4 × ANNMR	Conversion factor for analog channels.
17	DIGUNIT	4 × DGNMR	Mask words for digital status words.
18	FNOM	2	Nominal line frequency code and flags.
19	*CFGCNT*	2	Configuration change count.
	Repeat 8–19		Fields 8—19, repeated for as many PMUs as in field 7 (NUM_PMU).
20+	DATA_RATE	2	Rate of data transmissions.
21+	CHK	2	CRC-CCITT.

Table 10—Configuration frame 3 organization

No	Field	Size (bytes)	Short description
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC data stream ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Message Time Quality, defined in 6.2.
6	CONT_IDX	2	Continuation index for fragmented frames.
7	TIME_BASE	4	Resolution of FRACSEC time stamp.
8	NUM_PMU	2	The number of PMUs included in the data frame.
9	STN	1–256	Station Name—in ASCII format with field index (see Table 12).
10	IDCODE	2	Data source ID number identifies source of each data block.
11	G_PMU_ID	16	Global PMU ID.
12	FORMAT	2	Data format within the data frame.
13	PHNMR	2	Number of phasors—2-byte integer (0 to 32 767).
14	ANNMR	2	Number of analog values—2-byte integer.
15	DGNMR	2	Number of digital status words—2-byte integer.
16	CHNAM	1–256 per name	Phasor and channel names—in ASCII with field index (see Table 12). Minimum of 1 byte for each phasor, analog, and digital channel. Names are in the same order as they are transmitted: all phasors, all analogs, and all digitals. For digital channels, the channel name order will be from the least significant to the most significant. (The first name is for bit 0 of the first 16-bit status word, the second is for bit 1, etc., up to bit 15. If there is more than 1 digital status, the next name will apply to bit 0 of the second word and so on.)
17	PHSCALE	12 × PHNMR	Conversion factor for phasor channels with flags.
18	ANSCALE	8 × ANNMR	Conversion factor for analog channels.
19	DIGUNIT	4 × DGNMR	Mask words for digital status words.
20	PMU_LAT	4	PMU Latitude in degrees, 32-bit floating point, WGS84 datum.
21	PMU_LON	4	PMU Longitude in degrees, 32-bit floating point, WGS84 datum.
22	PMU_ELEV	4	PMU Elevation in meters, 32-bit floating point, WGS84 datum.
23	SVC_CLASS	1	Service class, as defined in IEEE Std C37.118.1, a single ASCII character that is M or P for IEEE Std C37.118.1.
24	WINDOW	4	Phasor measurement window length including all filters and estimation windows in effect. Value is in microseconds, 4-byte integer value (to nearest microsecond).
25	GRP_DLY	4	Phasor measurement group delay including all filters and estimation windows in effect. Value is in microseconds, 4-byte integer value (to nearest microsecond).
26	FNOM	2	Nominal line frequency code and flags.
27	CFGCNT	2	Configuration change count.
	Repeat 9–27		Fields 9–27, repeated for as many PMUs as in field 8 (NUM_PMU).
28+	DATA_RATE	2	Rate of data transmissions.
29+	CHK	2	CRC-CCITT.

Standard

IEEE Std C37.118.2 (2011)

- Header frame
  - Human-readable infomration about the PMU
    - The data sources
    - Scaling
    - Algorithms
    - Filtering
    - Other information

Table 13—Header frame organization

No	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number (AA11 hex).
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC data stream ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2.
6	DATA 1	1	ASCII character, 1st byte.
K+6	DATA k	1	ASCII character, Kth byte, K>0 is an integer.
K+7	CHK	2	CRC-CCITT.

Standard

IEEE Std C37.118.2 (2011)

- Command frame
  - A data sending device (PMU or PDC) shall be able to receive commands and take appropriaate actions.

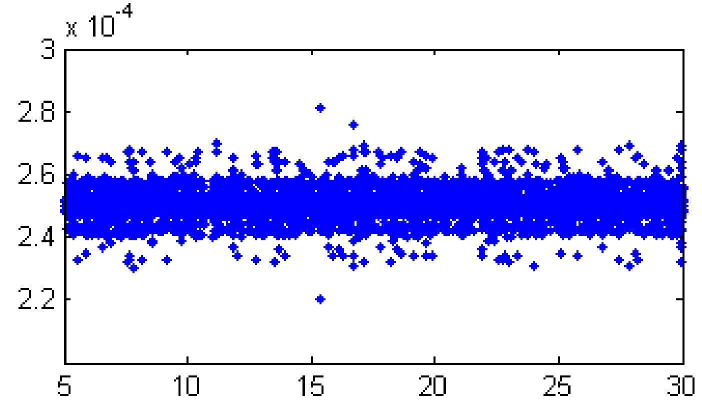
Table 14—Command frame organization

No	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number (AA41 hex).
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC ID data stream number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2.
6	CMD	2	Command being sent to the PMU/PDC (0).
7	EXTFRAME	0–65518	Extended frame data, 16-bit words, 0 to 65518 bytes as indicated by frame size, data user defined.
8	CHK	2	CRC-CCITT.

Table 15—Commands sent to the PMU/PDC

Command word bits	Definition
Bits 15–0:	
0000 0000 0000 0001	Turn off transmission of data frames.
0000 0000 0000 0010	Turn on transmission of data frames.
0000 0000 0000 0011	Send HDR frame.
0000 0000 0000 0100	Send CFG-1 frame.
0000 0000 0000 0101	Send CFG-2 frame.
0000 0000 0000 0110	Send CFG-3 frame (optional command).
0000 0000 0000 1000	Extended frame.
0000 0000 xxxx xxxx	All undesignated codes reserved.
0000 yyyy xxxx xxxx	All codes where yyyy $\neq$ 0 available for user designation.
zzzz xxxx xxxx xxxx	All codes where zzzz $\neq$ 0 reserved.

QoS challenges



- Quality of Service
  - End-to-end delay
    - Referes to the time taken for a packet to be transmitted across a network from source to destination.
  - Packet loss
    - When one or more packets of data travelling across a computer network fail to reach their destination.
  - Packet jitter
    - The variation in latency as measured in the variability over time of the packet latency across a network
  - Data rate

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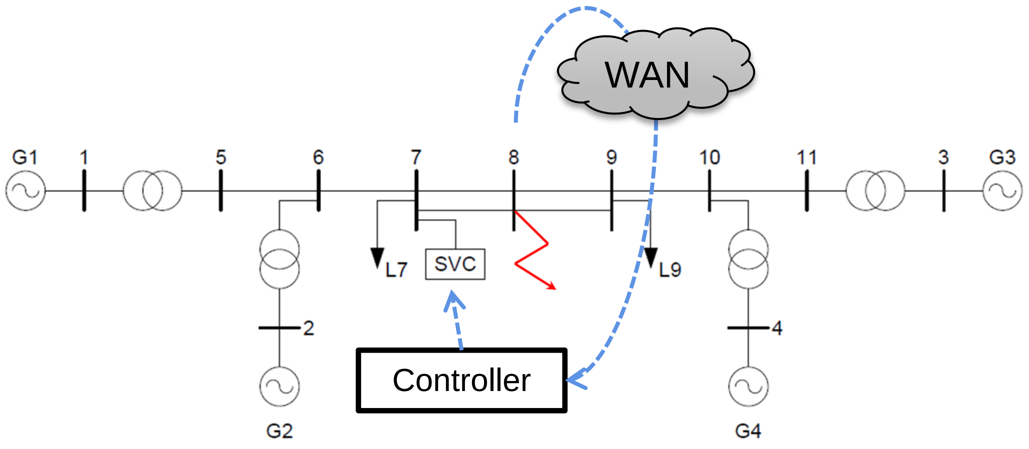
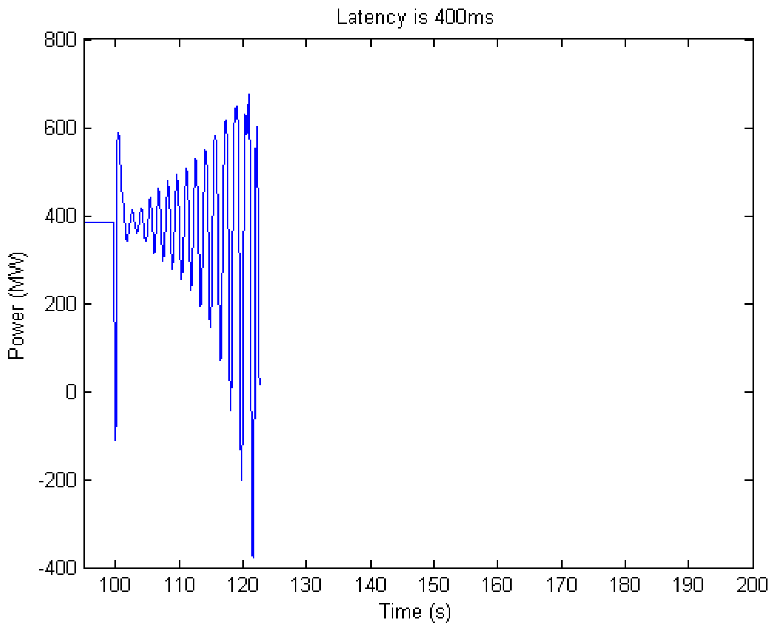
QoS challenges

- Example: Latency Effects on WAMC applications





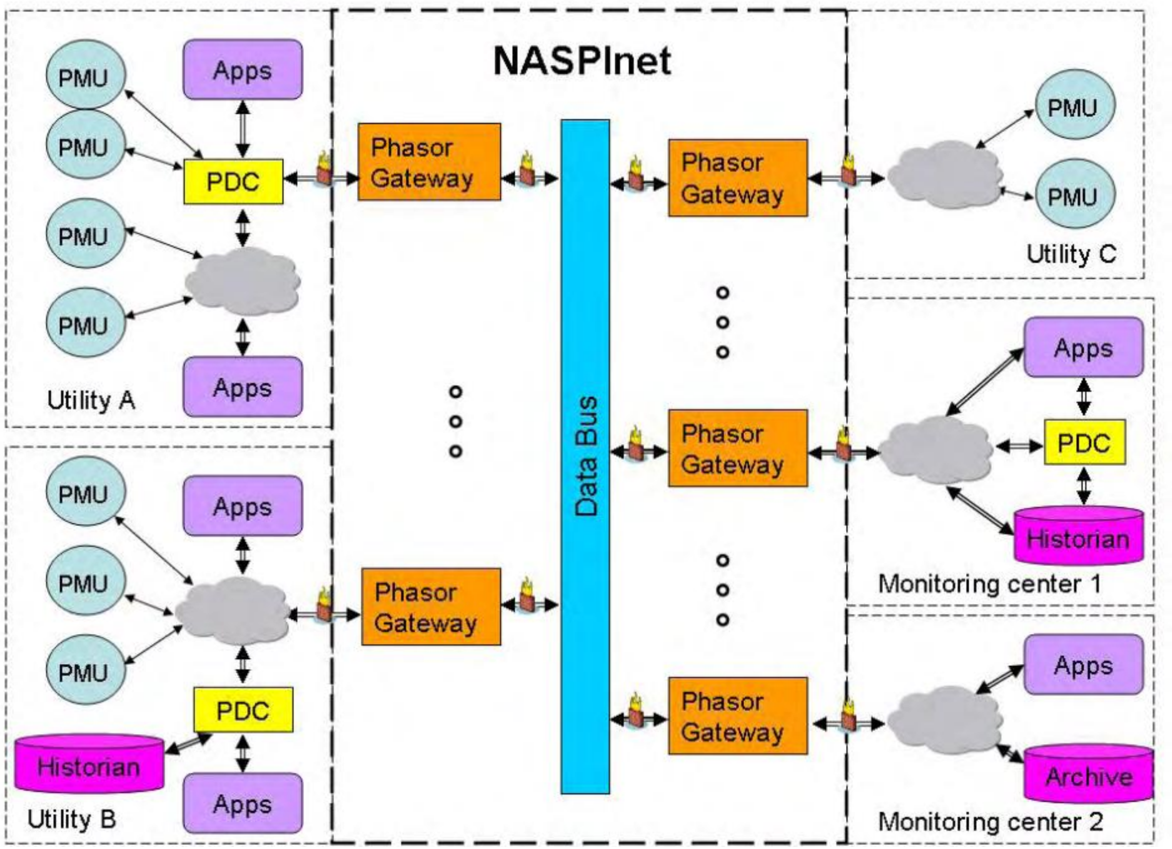
QoS challenges

- Mechanism
  - WAMC application design
    - QoS fault tolerant
  - Communication network management
    - Priority control
    - Data link path duplication
    - Data scheduling

WAMCS

Wide Area Monitoring, Control and Protection Systems

- Other frontier architectures - NASPInet



WAMCS

Wide Area Monitoring, Control and Protection Systems

- Other frontier architectures - GridStat