Timing in Industry: Power, Finance, Broadcast

WSTS 2019, San Jose

Doug Arnold

Agenda

- The need for time in the power grid
- PTP profiles for electric substations
- Timing requirements for financial regulation
- Timing requirements for HFT
- Timing solutions for Finance
- Migration to IP networks in the broadcast industry
- PTP Profiles for the broadcast industry

Timing in Power

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Challenges of Today's Power Grids

- Power loads becoming more reactive
  - Used to be resistive (incandescent lights)
  - Increasingly capacitive (charges for phones, tablets, laptops, cars)
- Clean energy sources: power generation varies with weather
  - solar
  - wind
- Grid operators often required to buy excess energy from homes and business with clean energy production
  - These sites sometimes generate energy, sometimes need energy

Timing in the Power Grid

Function	Purpose of timing	Accuracy required
Control Room	Log file coordination	1 second
SCADA system	Grid wide monitoring and control	1 ms
Synchrophasors	Measurements more precise than SCADA system. Monitor grid stability. Predict faults	1 us
Travelling wave fault detection	Location of faults to within 100 m. Improves maintenance efficiency	100 ns

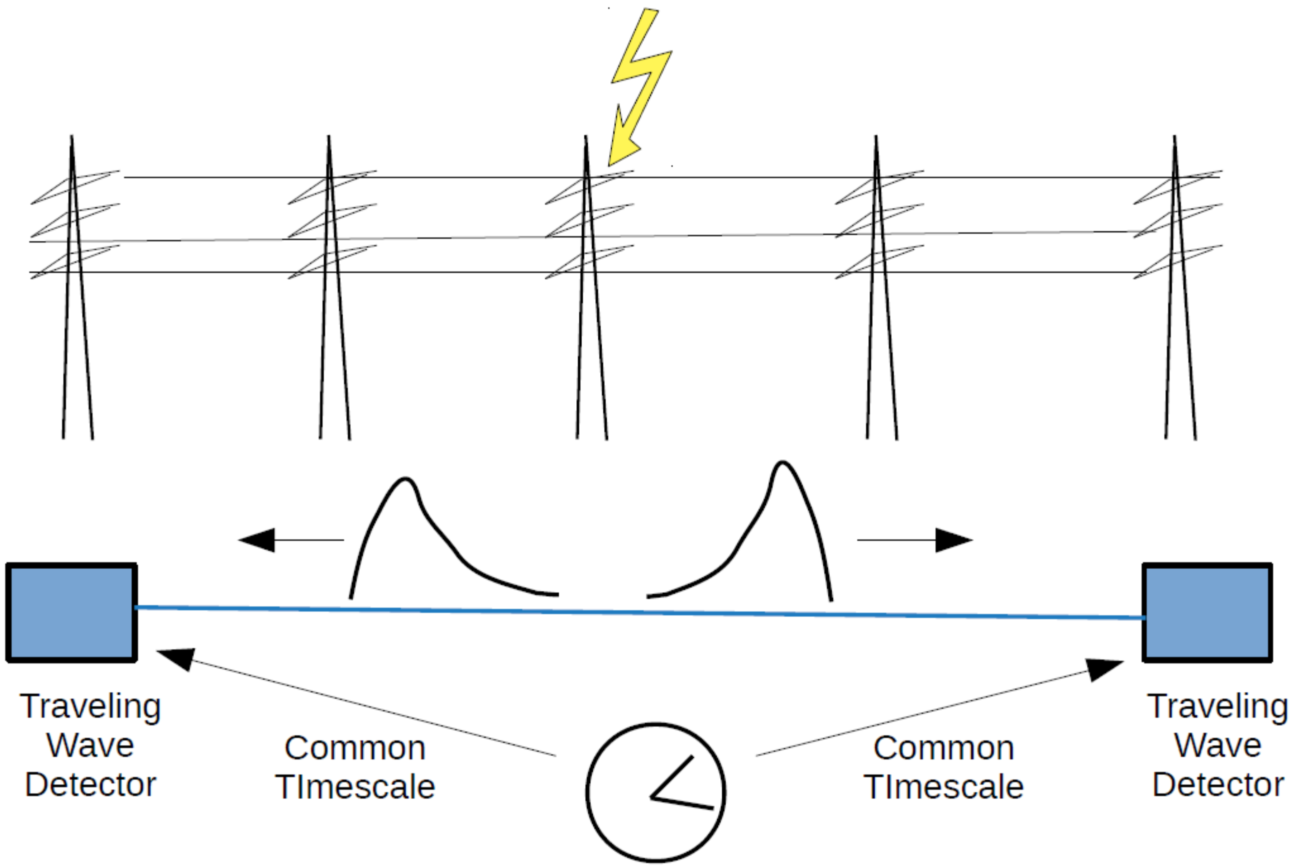
The use of precise timing in power system networks reduces blackouts and allows the grid to be more efficiently monitored and controlled.
Timing used in:

- Intelligent Electronic Devices (IEDs)
- Synchrophasors, also called Phase Measurement Units (PMUs)
- Merging units
- Protective Relays

Timing Accuracy Requirements

- Synchrophasors
  - Need to compare phase at multiple substations to identify growing power instabilities.
  - Measurements must be on the same timescale
  - Voltage phase measurement errors should be below 1% total vector error (According to IEEE C37.118.1)
  - Time error alone would exceed this at 33 us (50Hz) and 26 us (60 Hz)
  - Equipment designers want to reserve most of the error budget for analog voltage measurement circuitry
  - Synchrophasor timing accuracy should be ~ 1 us

Travelling Wave Fault Detection



- 100 ns accuracy ~ 30 m location error
- Repair crews can spend less time finding the damaged equipment

Traditional Power Grid Timing Systems

- IRIG-B
  - Can reliably deliver 1 us accuracy
  - Requires a dedicated timing network in addition to the data network
  - Network delays are not automatically calibrated
- NTP
  - Network delays determined by protocol
  - Uses data network
  - Only 1 ms accuracy typically achieved

PTP for Power System networks

- The best of NTP and IRIG-B
  - 100 ns -1us within a substation
  - Network delays determined by protocol
  - Reuses data network, no extra timing network needed
- PTP profiles
  - Subset of PTP options selected for a specific application in order to guarantee interoperability among equipment by different manufacturers
- Two profiles defined for Power:
  - IEC 61850-9-3, Utility Profile
  - IEEE C37.238, Power Profile

Properties of PTP Profiles for Power

- Layer-2 networks
  - Ethernet
  - High-Availability Seamless Redundancy Protocol (HSR)
  - Parallel Redundancy Protocol (PRP)
- Use the Peer Delay propagation delay mechanism
- All switches have PTP support
  - Either transparent clocks or boundary clocks
  - Transparent clock functionality is more commonly used in the power industry than boundary clocks

PTP Profiles for Power

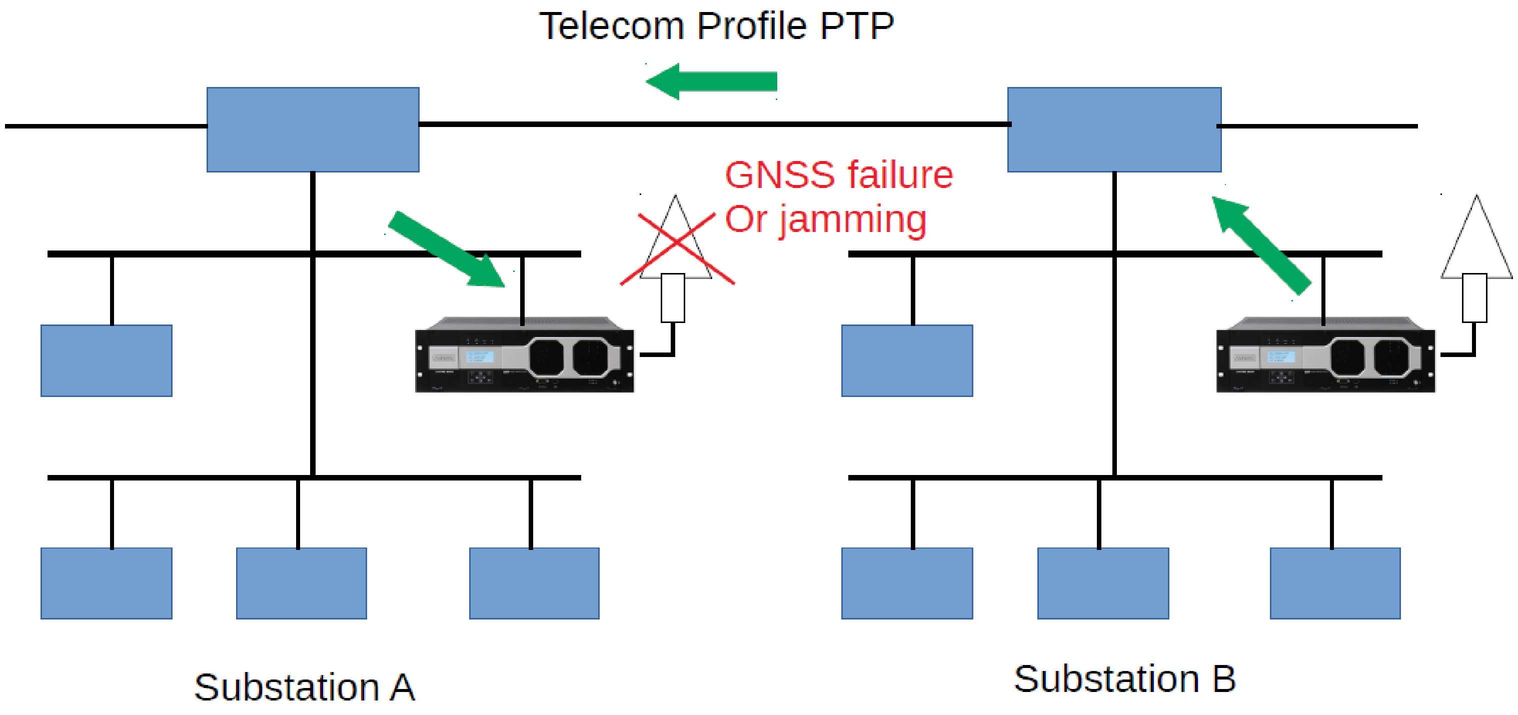
	IEC 61850-9-3	IEEE C37.238
Sync message interval	1 second	1 second
Announce message interval	1 second	1 second
Announce receipt timeout	3 seconds	3 seconds
Peer Delay Request interval	1 second	1 second
Priority 1 and 2 fields	0-255 Default 128 Slave only clocks 255	0-255 Default 128 Slave only clocks 255
Domain	Default 0 0-127	254* 0-255

* Note: Domains 128-255 are defined by IEEE 1588 as reserved for future use by IEEE 1588. So domain values in this range may clash with the usage in future editions of IEEE 1588

IEEE C37-238 2017

- Defines two Announce message TLVs to support power applications
- Required support by all grandmaster capable devices
- Alternative Time Offset TLV: can be used to support local time (optional)
- Time Inaccuracy (required)
  - Expected worst case time error during normal operation
  - Grandmaster loads grandmaster Inaccuracy
  - Each transparent clock adds its inaccuracy to network inaccuracy field
  - Slave can determine total time inaccuracy
  - Raise an alarm if time inaccuracy exceeds limits

Power Grids and the Telecom Profiles



- Time in substations distributed by a power profile
- Substations fail over to time from adjacent substation when local GNSS receiver fails or is jammed
- Time from adjacent substation sent through SCADA network using a telecom profile, e.g. ITU-T G.8275.2

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Finance Industry

- Specialized Enterprise IT
  - Typically site local timing network
- Regulatory compliance is mission critical
- Enterprise IT technical viewpoint
  - IETF is where standards come from
  - Comfortable with non-standard approaches (Especially HFT firms)
- Need time at software layer in standard hardware
  - PCIe cards
  - Software slaves/clients

Software Timing

- Need to timestamp events at software layer
- Challenges
  - Variable delay when executing an operating system call
  - Packet timestamping delay
  - System time retrieval delay
- Solutions
  - Hardware timestamping
  - Linux with no hypervisor preferred
  - Read high resolution processor counter rather than fetch system time
    - TSC counter in Intel processors
    - TSC counter calibrated to standard time in background task

Requirements

- To trade in the United States
  - Financial transactions by traders need to be timestamped by clock accurate to 50 ms
  - 100 μs by exchanges
  - To UTC:NIST
  - Consolidated Audit Trail (SEC, FINRA)
- To trade in the Europe
  - Financial transactions need to be timestamped to 100 μs (MIIFID II)
  - To UTC
  - Most trading firms do business all over the world, so they will need to meet the strictest time accuracy for
- HFT
  - 100 ns – 1 μs
  - To measure network performance, not for regulation

MiFID II

- Timestamp accuracy (100 μs)
  - Allows government regulators to identify illegal trading activity
  - Standard NTP software can barely meet this with a local timeserver
  - PTP or Non standard NTP preferred
- Archive data
  - Need to prove compliance on past dates
  - Government audits
- Measurements
  - Desire to prove timing accuracy of slaves/clients

Measuring for Compliance

- Archiving service
  - All measurements logged and archived
- PTP slave, NTP clients self reporting
  - Already part of standard implementations
  - Much state information typically available
- Monitoring Nodes
  - Have an independent source of time
  - E.g. GNSS receiver
  - Accurate measure of network at location of probe
  - Could be a backup Grandmaster or NTP server

Measuring for Compliance

- Measuring all PTP slaves or NTP clients
  - No standards support yet
  - Proprietary solutions
- Method 1: send data to monitoring node for analysis
  - Timestamps, calculated offsets, propagation delays
  - Can’t distinguish network asymmetry form clock error
  - This method to be supported in next IEEE 1588 edition
- Method 2: Measurement using dedicated timing infrastructure
  - Convenience of packet timing lost
- Method 3: Measurement using reverse time transfer
  - Subject to similar errors as original time transfer

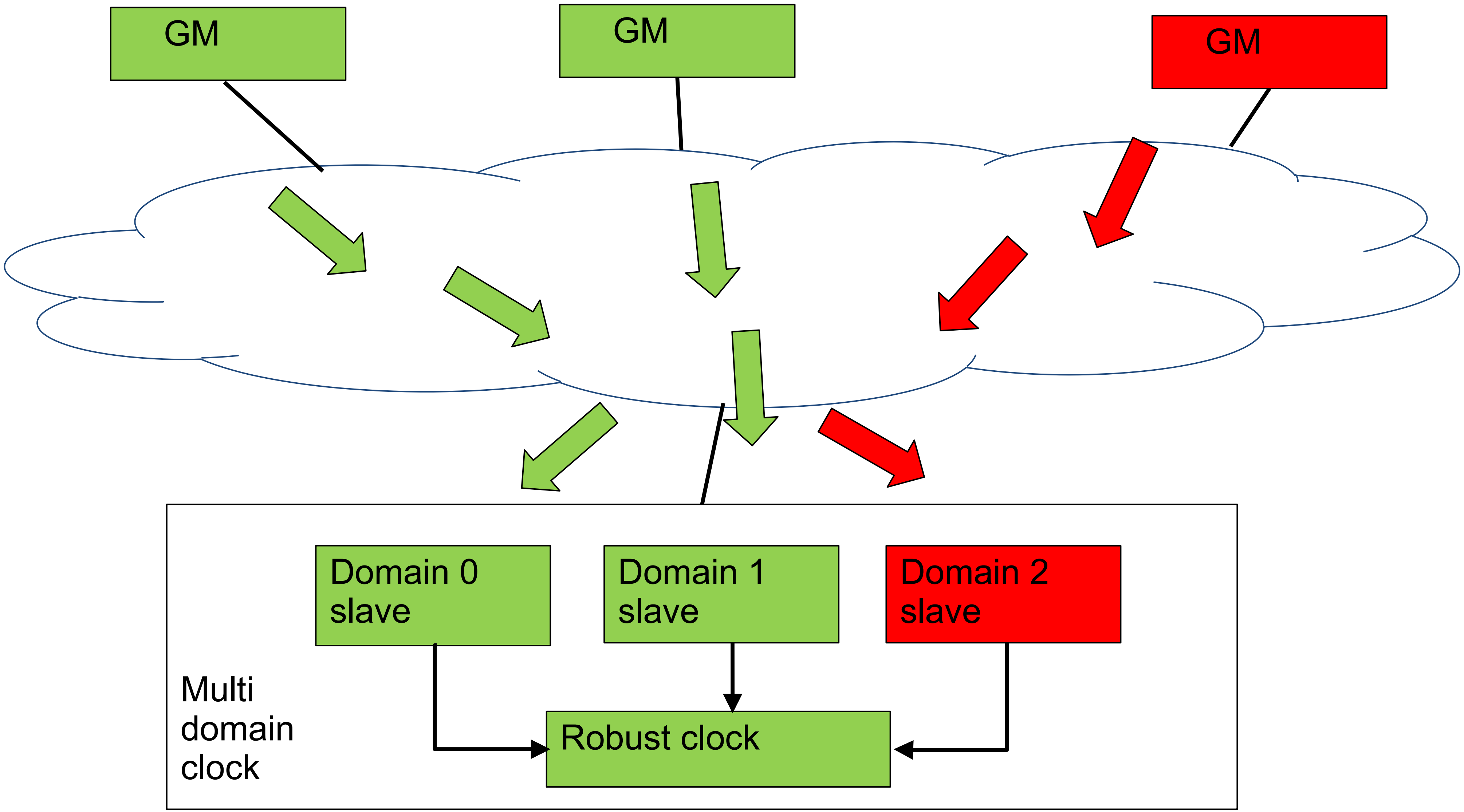
High Frequency Trading (HFT)

- Need for time
  - Measure the trading system
  - Determine the age of data
- Co-located trading
  - Time provided by exchange (usually PTP)
  - New information to posting trades ~ 10 μs
  - FPGAs on PCIe cards sometime used
- Precision needed determined by speed
  - 100s of ns now
  - Some firms investigating White Rabbit PTP (sub ns)

Draft Enterprise Profile

- Designed by a technologist at a trading firm
- Status:
  - Last call in IETF (TICTOC Working Group)
  - Multiple implementations tested at ISPCS Plugfest for several years
- Properties
  - Mixed multicast/Unicast operation
  - IPv4 or IPv6 mappings
  - Allows timing nodes to get time through multiple PTP domains to enable voting algorithms for robustness

Multi-Domain Operation



Non Standard NTP

- Use standard NTP packets
- Higher messaging rates
  - Similar to PTP
  - Allows for “lucky packet filters”
- Hardware timestamping
  - Many commercial NTP servers do this
  - Specialized NICs timestamp all packets
- No on path support needed
  - Fastest switches that money can buy
  - Lightly loaded, e.g. 30% maximum

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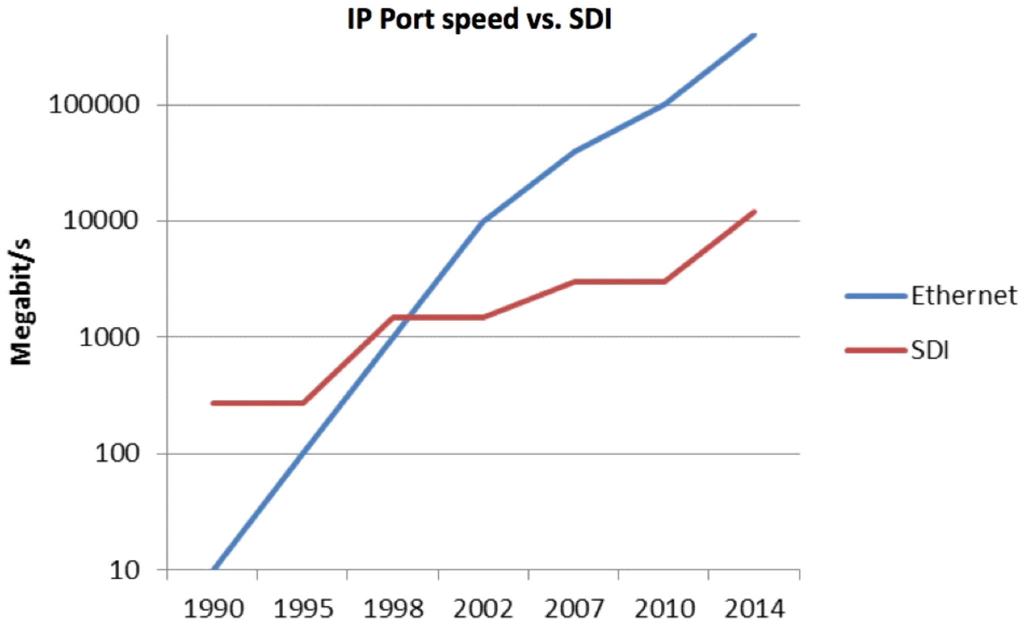
Broadcast Industry moving infrastructure to IP networks

WHY DO WE NEED IP TRANSPORT?

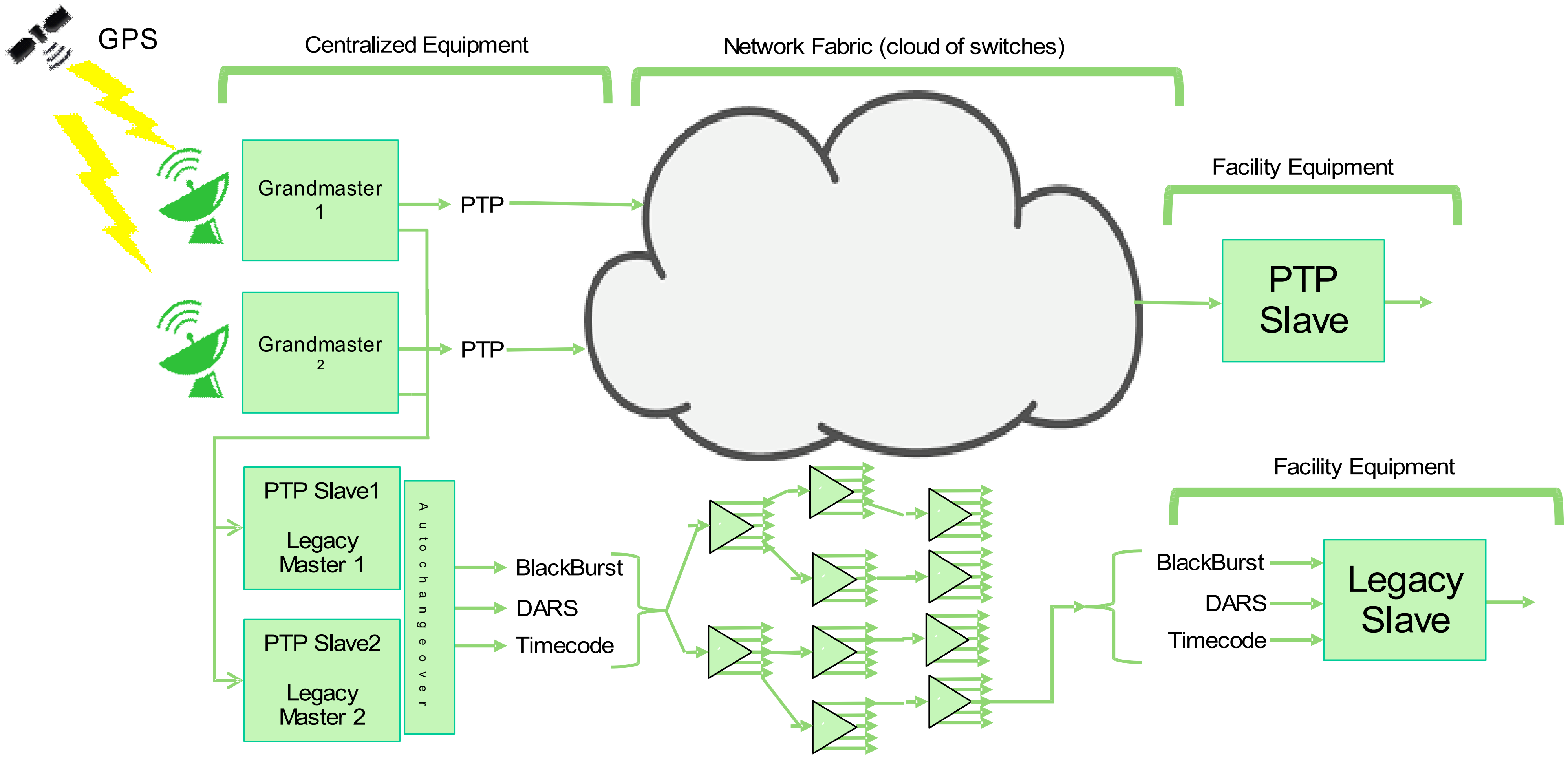
- IP enables
  - Scale to thousands of signals
  - Better resource sharing
  - Path to virtualization
  - COTS Switches, Optics, Cabling
  - Distributed “Top-Of-Rack” architectures
  - Signal-Path redundancy architecture

- SDI has served us well but does not offer the flexibility of IP



Hybrid Timing Infrastructure

- PTP Can Coexist with Legacy References in Same Facility



SMPTE ST2059-2

- SMPTE
  - Society of Motion Picture and Television Engineers
  - Standards for broadcasting, film, audio recording, medical imaging, etc.
- ST2059-2
  - SMPTE Profile for Use of IEEE-1588 Precision Time Protocol in Professional Broadcast Applications
  - Published in 2015
  - Goal is 1μs synchronization within 5 seconds of connection

AES67 Media Profile

- Audio Engineering Society
  - Standards
  - Conferences
  - Publications
- AES67
  - AES standard for audio applications of networks - High-performance streaming audio-over-IP interoperability
  - Annex A is IEEE 1588 Media Profile

ST2059-2 Network properties

- PTP mappings
  - UDP/IPv4
  - UDP/IPv6
- Management
  - Native PTP management messages required
  - Avoid this if you can
    - except for synchronization metadata message
    - Unsecure
    - Prone to message flooding
    - Use https, snmpv3, ssh, etc instead

ST2059-2 Clock Types

- All clock types allowed
  - Boundary clocks
  - Transparent clocks
  - Ordinary clocks (GM capable)
  - Ordinary clocks (Slave only)
- Grandmaster (GM) frequency must be ±5ppm or better
  - Note: Good commercial time servers are 3-5 orders of magnitude better than this

ST2059-2 PTP Properties

- Communication model
  - Default is multicast
  - Unicast allowed (with or without unicast negotiation)
  - Mixed multicast allowed
- Propagation Delay measurement
  - Default is End-to-end
  - Peer Delay allowed
- Domain number
  - Default is 127 (use this)
  - 0-127 allowed
- One and two step clocks allowed

AES67 Media Profile and ST2059-2 Message Rates

Message Type	Allowed range
Announce, ST2059-2	1 every 2 seconds to 8/second
Announce, AES67	1 every 16 seconds to 1/second
Announce interoperability	1 every 2 seconds or 1/second
Sync, St2059-2	2/second to 128/second
Sync, AES67	1/second to 16/second
Sync interoperability	2/second to 16/second

ST2059-2 BMCA

- Priority1 and Priority2 fields
  - Default to 127 (use this)
  - 0-255 allowed
- Clock Class
  - 4 new values defined for clocks in holdover
  - Based frequency stability characteristics defined in AES11-2009
- Clock variance
  - 1 second averaging time
  - No averaging time defined in IEEE 1588

ST2059-2 Synchronization Metadata Message

- Management message sent by ports in MASTER state
  - Includes boundary clock master ports
  - Sent once per second + upon lock status change
- Includes
  - Default video frame rate
  - Master locking status
  - Time address flags
    - Drop frame/non-drop frame
    - Color frame in use/not in use

ST2059-2 Synchronization Metadata Message

- Current local offset
  - Offset from PTP GM time in seconds
- Jump seconds
  - Size of next discontinuity in local time, in seconds
- Time of next jump
  - Time of PTP GM of next local time jump (granularity of seconds)
- Time of next jam (PTP GM seconds)
- Time of previous jam
- Previous jam local time offset (seconds)

ST2059-2 Synchronization Metadata Message

- Daylight savings flags
  - Current daylight savings in effect/not in effect
  - Daylight savings at next discontinuity in effect/not in effect
  - Daylight savings at previous jam in effect/not in effect
- Leap second jump flag
  - Indicates that the next discontinuity is a leap second

Summary

- Precise time can improve the reliability of power grids
  - Microsecond timing driven by increase use of Synchrophasors
- Two similar PTP profiles are defined for power applications
  - Benefit of extra TLVs defined in IEEE C37.238 still under debate
- Power Profile in substation can be combined with telecom profile in larger network
- Two kinds of timing in Finance
  - Legal time for compliance
  - Sub µs timing for HFT

Summary

- Software layer timing important and challenging
- Measurements to document compliance
- Precise timing for HFT
- Broadcast industry moving to IP networks
- ST2059-2 and AES67 Media Profiles for PTP timing
  - Allow a lot of variation in PTP parameters - Interoperability not guaranteed!
  - Run on Layer 3 networks
- ST2059-2 includes synchronization metadata message to support legacy broadcast timing systems and local time zone awareness

Thank you for your attention

For more information please feel free to contact:
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