Ethernet for Converged Applications

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# Typical Plant Control Model

## Purdue Reference Model

<table>
<thead>
<tr>
<th>Zone</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise Logistics</td>
<td>5</td>
</tr>
<tr>
<td>Enterprise Logistics</td>
<td>4</td>
</tr>
<tr>
<td>Management</td>
<td>3</td>
</tr>
<tr>
<td>Supervisory</td>
<td>2</td>
</tr>
<tr>
<td>Basic Control</td>
<td>1</td>
</tr>
<tr>
<td>Process</td>
<td>0</td>
</tr>
</tbody>
</table>

### Business Workstations, Servers, Data base, Applications
- Business Workstations
- Servers
- Data base
- Applications
- Firewall
- VPN

### Plant Business LAN

### Plant Supervisory Control LAN
- DCS
- Historians
- HMI
- Configuration Database
- PLCs
- Machine Controllers
- HMIs
- Alarm
- Servers
- Asset Management

### Dedicated Control Network
- Actuators
- Sensors
- Physical Devices
Why Converge the Networks?

- Security concerns – we can no longer rely on the perimeter for security.
- Simplicity - Maintenance and management.
- Connectivity
- Personnel
- Flexibility
- Future proofing (faster upgrades and retrofits)
- Standards convergence, Open Systems
Traffic types in converged networks

- Business transactions/Internet Access
- Physical Security, Plant Maintenance
  - Video, Voice
- Business Communications
  - VOIP
- Asset management/Inventory tracking
  - Blob transfers, database access
- Control
  - Supervisory, Discrete, Process, Coordinated, Safety Critical
  - High speed, periodic & aperiodic, alarms and alerts
  - High reliability, availability
Controls – a diverse set of markets

Industrial Automation

Wind

Nuclear

Power Gen

High Traffic Mix, Deterministic, Low Latency, Secure, Reliable, High Throughput

Healthcare

Aviation

Transportation

Oil & Gas

Water
The Basic Control Cycle

Input

Network Latency

Jitter

Control Computations

Out

10%

80%

Control Frame

10%

Overall Phase Delay Drives System Controllability/Stability

Synchronization of inputs
Synchronization of outputs
Synchronization of control applications
Synchronization of network traffic and flows

Sample Jitter
Sample Jitter
Control Frame
Sample Jitter, Control Frame
Traffic Controlled Networks

- **T1 Slot**: None time slotted traffic
- **T2 Slot**: None Real time Traffic
  - Logging
  - Alerting

- **Real time – non cyclic Traffic**
  - Critical Alarms
  - Discrete/event control

- **Preemption**

-Time Cyclic Control Traffic

Logging
Alerting

- T1
  - High
  - Low
  - T2
Time Synchronization
Accuracy versus Latency/Plant versus Cell

Plant Wide
Good Accuracy – High Latency

GPS

+/−100nsec Accuracy
Millisecond latencies

Local Cell Area
Good Accuracy Good Latency
Wire delays ~2nsec/ft
Each network device can add
between 500 nsec to 100’s of usec

IEEE 1588

Distance <400m
Resolution ~50ns
Jitter ~100ns
Synch ~100nsec

Let Physics Dictate Latency

Physical plant can span miles
Pipelines and Distribution networks can span thousands of miles
Requirements – End User Perspective

Provide access to the data sources within the underlying control systems to allow asset management and perform system wide optimizations that and maximize customer value.

Accommodate a wide array of vendor products that would participate in plant equipment control where access from higher layers within the plant hierarchy will be required.

- Minimize the customer impact and effort when applying products from various application segments; improve the interoperability and integration.
- Provide a more homogeneous experience for the customer.

Accommodate the addition and integration of multi-vendor products based on industry accepted standards.

Provide network security.
- Device authentication
- Network availability
- Access Control
- Confidentiality
- Integrity, traceability
Requirements

Scalable from small systems to large systems.

Flexible – Once installed, can grow as the needs of the system grow.

Easy to implement – does not require a great deal of user configuration or intervention. Customers who are not network traffic engineers can use it.

A single device can have various applications, applications within a device have different QOS needs but may share the same protocol.

Redundancy must be scalable at the network level as well as the application level. Future high reliability systems will contain both wired and wireless to prevent common mode failures. Best effort traffic can be sacrificed when failures occur. Failure detection/reporting is as important as failover protection.

Physical clock level point to point synchronization (Use 1588 for time/phase lock and use physical clock for frequency lock of local clocks: ITU-T G.8261, ITU-T G.8262 ITU-T G.8264)

Able to integrate legacy equipment (NICs, bridges and switches) without sacrificing AVBG2 features.

Allow traffic convergence with a wide variety of application protocols including proprietary protocols.
Security

- Relying on physical security (within the fence) is no longer enough. Devices are mobile, wireless or wired.
- Converged networks with mixed traffic increase the threats from multiple users both malicious as well as accidental.
- Denial of service, flooding, babbling devices, viruses, snooping, cloning, etc. all become issues.
- The control mission cannot be compromised.
- Authentication for devices as well as users. Access control & authentication for resource allocations.
- The bridge is the first line of defense for attacks.
- Security attacks and threats must be logged and reported.
- Trust must be established between all devices.
Configuration – Use cases

1. Fixed Systems (autos, aviation), rarely change, fixed capacity. Configured once at point of manufacture. System manager not a requirement.

2. Large Flexible Systems (Manufacturing plant), change occurs slowly. Various subsystems and applications can be added. System can be reconfigured or re-engineered, upgraded overtime. System management required, resource planning tools may be needed.

3. Small Systems (Small custom machines), cost and complexity really matters. User must perceive no additional effort or cost.
Application Protocols for Control

Motion
- Ethercat
- SERCOS III
- Powerlink
- Profinet IRT
- SynqNet

Industrial
- Modbus TCP
- OPC
- Profinet
- Foundation Fieldbus HSE
- Ethernet/IP

Transportation
- ARINC 664
- Flexray
- AS6802 (TTE)

Distribution
- IEC 61850
- IEC 60870
- DNP 3.0

Not a complete List

Note: There are many proprietary protocols not on this list
Vision: Converged Networks on the plant floor

Control Fabric:
- 802.3 physical connection
- 802.3 MAC protocol
- Ethernet protocol suite
- Managed QOS – various levels
- Redundancy
- Security
- Market specific application protocols
- Third party device support
- Single network
- Scalable from very small to very large systems
- Built on standards based switch technology
- Optional network manager eliminates manual configuration
- Optional security manager controls access
Bonus Material
<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Enterprise Zone</strong></td>
<td></td>
</tr>
<tr>
<td>Level 5</td>
<td>Enterprise</td>
<td>Corporate level applications (for example, ERP, CRM, document management) and services (Internet access, VPN entry point) exist in this level.</td>
</tr>
<tr>
<td>Level 4</td>
<td>Site business (planning and Logistics)</td>
<td>Manufacturing facility IT services exist in this level and may include scheduling systems, material flow applications, manufacturing execution systems (MES), and local IT services (phone, E-mail, printing, security/monitoring).</td>
</tr>
<tr>
<td>DMZ</td>
<td></td>
<td>Provides a buffer zone where services and data can be shared between the Manufacturing and Enterprise zones. In addition, the DMZ allows for easy segmentation of organizational control.</td>
</tr>
<tr>
<td></td>
<td><strong>Manufacturing Zone</strong></td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>Site manufacturing operations and control</td>
<td>Includes the functions involved in managing the work flows to produce the desired end products. Examples include detailed production scheduling, reliability assurance, site-wide control optimization, security management, network management, and potentially other required IT services such as DHCP, LDAP, DNS, and file servers.</td>
</tr>
<tr>
<td></td>
<td><strong>Cell/Local Area Zone</strong></td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>Area supervisory control</td>
<td>Control room, controller status, control network/application administration, and other control-related applications (supervisory control, historian)</td>
</tr>
<tr>
<td>Level 1</td>
<td>Basic Control</td>
<td>Multidiscipline controllers, dedicated HMIs, and other applications may talk to each other to run a part or whole control system.</td>
</tr>
<tr>
<td>Level 0</td>
<td>Process</td>
<td>Where devices (sensors, actuators) and machines (drives, motors, robots) communicate with the controller or multiple controllers.</td>
</tr>
<tr>
<td></td>
<td><strong>Safety Zone</strong></td>
<td></td>
</tr>
<tr>
<td>Safety Critical Functions</td>
<td>Devices, sensors, and other equipment used to manage the safety functions</td>
<td></td>
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</table>
System Complexity – Industrial Plant Cogeneration Example

- Grid connected Substation
  Sell & buy power

- Multi fuel power plant
  HRSG, multi-fuel boilers
  Process steam

- Material Handling & Chipper

- Digester & Paper machines

- Inventory and Material Handling

- Water treatment
  (In and out)
Controlled equipment in a power plant
Power Plant Network

- Historians
- Asset Monitoring
- Cyber Security
- Plant Level Analytics
  - Plant Performance
  - Asset Management
  - Visualization
- Real time machine controllers
- Real time equipment protection
- Process Controllers
- Smart Field Device (Process, Electrical)
- Multi vendor general purpose IO
- Condition Monitoring Systems
- Integrated Safety Systems
- Various Field busses (Profinet Foundation Fieldbus)
- Power Distribution Networks - IEC 61850
Coordinated Drives - Metals

- Each drum is driven by a separate high speed motor
- A rolling mill can have 45 synchronized motors, shaft rotation speed and position is tightly controlled.
- Material speeds can vary from 0 to 2km/min (75 mph) or more
Aviation

Low Data Rate, Interior Applications:

**Sensors:** Cabin Pressure - Smoke Detection - Fuel Tank/Line - Proximity Temperature - EMI Incident Detection - Structural Health Monitoring - Humidity/Corrosion Detection

**Controls:** Emergency Lighting - Cabin Functions

• Low Data Rate, Outside Applications:


• High Data Rate, Interior Applications:

**Sensors:** Air Data - Engine Prognostic - Flight Deck/Cabin Crew Still Imagery / Video

**Comm.:** Avionics Communications Bus - FADEC Aircraft Interface - Flight Deck/Cabin Crew Audio / Video (safety-related) - Flight - Operations related Digital Data (e.g. EFOS...)

Audio / Video / Data Passenger entertainment

• High Data Rate, Outside Applications:

**Sensors:** Structural Health Monitoring - Imaging Sensors (Still and Video)

**Controls:** Active Vibration Control

**Comm.:** Avionics Communications Bus, Engine controls
Rail

Operations Optimization
- Railroads
- Terminals & Ports
- Shippers & 3PLs

Multiple Missions
- Optimized for throughput

Command and Control
- Freight Trains
- Passenger Trains

Mission Execution
- Safety Critical

Asset Optimization
- Locomotives
- Cars
- Wayside & Crossing
- Track
- Crew

Command and Control
- Available for a mission
Power Distribution - Substations & Switchgear

- Ethernet Switch
- C/CPU A
- HMI
- Ethernet Switch
- C/CPU B
- Relay & Terminal Block
- Redundant HMI optional
- Ethernet to SCADA
- I/O Network
- Discrete I/O
- Redundant I/O optional
- Synch

- PTs
  - One per phase.
  - One set per Main breaker. More optional based on PQ Needs.

- CTs
  - One per phase.
  - Neutral optional. One set per breaker. ITI developed.
Energy Generation

Typical Power Island 40K input 40K output points
Control Frame 5msec; Latency <1msec
Network Traffic:
Automatic and Manual Train Control
Video
Voice
Diagnostics
Trip Recorder

Engine Controls

Traction Control
Cab Control, SCADA & Comms
Braking Controls
Wayside Signaling
Voice/Radio

Video