Machine Control using EtherNet/IP
CIP Motion 1-Cycle Timing Model

Drive Timer Events

Drive Interrupt Service

Drive-to-Control Connection (Input)

Control-to-Drive Connection (Output)

Controller Task

Controller Timer Events

Input Traffic  No Motion Traffic  Output Traffic

Coarse Update  Drive Update Period

250 µsec

Actual Position

Cmd Position

Motion Planner

Motion Planner

Coarse Update Period (1 msec)

Motion Task Phase Offset ~330 µsec

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Life of an D2C Input Packet

Automation Controller

- Stack is Bottleneck
- Bus Xfc Output Queue
- Input Stack Queue
- NIC Bus Xfc Delay
- Packet Processing Delay
- Controller Bus Xfc Delay
- Input Data Ready!

Ethernet Switch

- Switch Port Queue
- Ethernet Switch & Media Delay
- Packet Processing Delay
- Packet Pos Calc Delay

EtherNet/IP Drives

- Position Update Time
- Packets are Sent Back-to-Back
- Packets are Sent Simultaneously

Packets are Sent Back-to-Back

Technical Track 2011 ODVA Industry Conference & 14th Annual Meeting

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CIP Motion Cycle Utilization Metrics

- Each of the 3 Intervals of the CIP Motion Timing Model present a Timing Constraint that can Limit System Performance.

- 3 Timing Constraints ➔ 3 Cycle Utilization Metrics.
  - Input Cycle Utilization ([yellow]) - % of CIP Motion update cycle allotted to D2C input packet transfer. This value should be less than 100% to insure D2C data delivered to controller before Motion Task starts.
  - Output Cycle Utilization ([light blue]) - % of CIP Motion update cycle allotted to C2D input packet transfer. This value should be less than 100% to insure C2D data delivered to drive before next cycle starts.
  - Motion Task Cycle Utilization ([purple]) - % of CIP Motion update cycle allotted to process input packets, run planner, and assemble output packets. This value should be less than 100% for timely C2D data delivery.
System Component Utilization Metrics

3 Component Utilization Metrics.

- Automation Controller Utilization (dark blue) - % of Automation Control processor capacity used to execute Motion Task. Generally this value should be less than 50% to allow for Application Program execution, I/O and Message data processing, and other controller tasks. The Automation Controller Utilization limit may or may not be enforced.

- Communications Controller Utilization (magenta) - % of Communications Control (or NIC) processor capacity used to process motion packets. This value should be less than 100%, perhaps less than 50% if significant non-motion Class 1 connection data processing is required. The Communications Controller Utilization limit is often enforced for Class 1 connections by the Transmission Specification (T-Spec).

- Ethernet Media Utilization (brown) - % of Ethernet media capacity consumed by CIP Motion packet traffic. This value should be less than 100%, perhaps less than 50% if significant non-motion Class 1 connection data transfer is required over the same network segment.
System Description:
- 50-axis System
- 50-byte CIP Payload
- 1-Cycle Timing Model

Performance Limit:
- Min CUP = 2.5 msec
- 25 axes/msec
- Bottleneck = Cycle Utilization

Recommendation:
- 2-Cycle Timing Model.
CIP Motion System Utilization Plot

System Description:
- 50-axis System
- 50-byte CIP Payload
- 2-Cycle Timing Model

Performance Limit:
- Min CUP = 1.5 msec
- 33 axes/msec
- Bottleneck = Automation Controller Utilization

Recommendations:
- Faster Automation Controller.
- Dedicated Core for Motion in Multi-Core CPU.
CIP Motion System Utilization Plot

System Description:
- 50-axis System
- 50-byte CIP Payload
- 2-Cycle Timing Model
- 2x Automation Controller Performance

Performance Limit:
- Min CUP = 1 msec
- 50 axes/msec
- Bottleneck = Cycle Utilization & Comm. Controller Utilization

Recommendations:
- 3-Cycle Timing Model.
- Dual-Core, Full Duplex Packet Processing
CIP Motion 3-Cycle Timing Model

Drive Timer Events

1. Drive Interrupt Service
2. Drive-to-Control Connection (Input)
3. Controller Task
4. Control-to-Drive Connection (Output)
5. Command Position

Controller Timer Events

Motion Planner

Motion Task
Phase Offset
0 μsec

Full Duplex Input & Output Traffic
250 μsec

Coarse Update Period (1 msec)

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System Description:
- 80-axis System
- 50-byte CIP Payload
- 3-Cycle Timing Model
- Full-Duplex Processing
- 2x AC Performance

Performance Limit:
- Min CUP = 1 msec
- 80 axes/msec
- Bottleneck = Cycle Utilization & Ethernet Media

Recommendations:
- Gigabit Ethernet
- Distributed Control
Performance Limits at Wire-speed

Fast Ethernet (50-byte CIP Motion Payload)

- 1-Cycle Timing Model  ➔ Performance Limit = 28 axes/msec
- 2-Cycle Timing Model  ➔ Performance Limit = 44 axes/msec
- 3-Cycle Timing Model  ➔ Performance Limit = 88 axes/msec

Gigabit Ethernet (50-byte CIP Motion Payload)

- 1-Cycle Timing Model  ➔ Performance Limit = 280 axes/msec
- 2-Cycle Timing Model  ➔ Performance Limit = 440 axes/msec
- 3-Cycle Timing Model  ➔ Performance Limit = 880 axes/msec
CIP Motion System Utilization Plot

System Description:
- 80-axis System
- 50-byte CIP Payload
- 3-Cycle Timing Model
- Full-Duplex Processing.
- 2x AC Performance
- Gigabit Ethernet

Performance Limit:
- Min CUP = 0.8 msec
- 100 axes/msec
- Bottleneck = Comm. Controller Utilization

Recommendations:
- Faster Comm. Controller
- Distributed Control
Impact of Non-Motion Traffic

Non-Motion Packet Delay = 80 nanoseconds/byte * Non-Motion Packet Size
End-to-End QoS Solution

Ethernet DSCP (Differentiated Service Code Point)
- Layer 3 Protocol
- No Backward Compatibility Issues
- Recommended by ODVA for EtherNet/IP

Ethernet QoS Must Extend to CIP Layer.
- Assign Ethernet QoS Priority and CIP Priority based on Type of CIP Data Traffic.
- Must Process All Queued Data based on CIP Priority Level.
## End-to-End QoS Priority Mapping

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>CIP Priority</th>
<th>DSCP</th>
<th>CIP Traffic Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTP event (IEEE 1588)</td>
<td>n/a</td>
<td>59 (‘111011’)</td>
<td>PTP event messages, used by CIP Sync</td>
</tr>
<tr>
<td>CIP Class 0 / 1</td>
<td>Urgent (3)</td>
<td>55 (‘110111’)</td>
<td>CIP Motion</td>
</tr>
<tr>
<td></td>
<td>Scheduled (2)</td>
<td>47 (‘101111’)</td>
<td>Safety I/O, I/O</td>
</tr>
<tr>
<td></td>
<td>High (1)</td>
<td>43 (‘101011’)</td>
<td>I/O</td>
</tr>
<tr>
<td></td>
<td>Low (0)</td>
<td>39 (‘100111’)</td>
<td>Open</td>
</tr>
<tr>
<td>CIP UCMM CIP Class 3</td>
<td>All</td>
<td>35 (‘100011’)</td>
<td>CIP Messaging</td>
</tr>
</tbody>
</table>
Network Traffic Segregation

Non-Time Critical Traffic

Time Critical Traffic
Line and Ring Topologies

A

B

C

D
Summary & Conclusion

- Importance of Holistic System Analysis
- Introduced 6 System Performance Metrics
  1. Cycle Utilization Metrics - Timing Model Constraints
  2. AC and NIC Data Processing Utilization Metrics
  3. Ethernet Media Utilization Metric
- System Performance Optimization
  1. Multi-Cycle Timing Models
  2. Faster Automation Controllers
  3. Faster Communications Controllers
  4. Multi-Core Processors
  5. Gigabit Ethernet - Future
  6. Distributed Motion Control - Future
- Performance Impact of Non-Motion Traffic
  - Deterministic Data Delivery using End-to-End QoS
  - Switch Support for IEEE-1588 Boundary/Transparent Clocks.
  - Network Topology Recommendations