Application and System Diagnostic Framework on CIP

Joakim Wiberg
HMS Industrial Networks

Technical Track
Agenda

- Introduction
- System overview
- Device heartbeat
- Aggregators
- Diagnostic object
- Summary
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- Device heartbeat
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Introduction

- Longstanding topic at the EtherNet/IP Workshops
  - Troubleshooting
  - Diagnose Ethernet and TCP

- The European series looked at a different type of diagnostics
  - Application
  - Device diagnostics
  - A working group was started
Introduction

- Diagnostics and event logging as an integrated part of the functionality of devices
- Minimize the overall downtime
- Increase flexibility of the manufacturing system
- Maximize investment turnover
Introduction

- Detect misaligned photo-eye
  - Log an high priority event
    - Service technician gets notified
  - Production stopped or run at a lower speed

- A motor has been used under a certain load for a certain number of hours
  - A low priority event is logged
    - Service for the motor gets scheduled to the next downtime period
Agenda

- Introduction
- **System overview**
- Device heartbeat
- Aggregators
- Diagnostic object
- Summary
System overview

- HMI
- PLC/Controller
- Supervisor Station
- Handheld Network Monitor
- IO Devices
- AC Drives
- EtherNet/IP
System overview

Diagram showing a network with a supervisor station, aggregators, and IO devices.
Agenda

- Introduction
- System overview
- **Device heartbeat**
- Aggregators
- Diagnostic object
- Summary
Device heartbeat

Device Heartbeat Consumers

Device Heartbeat Producers

= Device Heartbeat
Device heartbeat

Diagnostic Heartbeat delivery method
- Unicast
- Broadcast
- Multicast

All have their pros and cons

Preferable method
- Multicast
  - Can be filtered
- Using IGMP Snooping
  - Already used on EtherNet/IP
### Device heartbeat

<table>
<thead>
<tr>
<th>Structure</th>
<th>Field Name</th>
<th>Data Type</th>
<th>Field Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encapsulation</td>
<td>Command</td>
<td>UINT</td>
<td>Device Heartbeat</td>
</tr>
<tr>
<td></td>
<td>Length</td>
<td>UINT</td>
<td>Length of the command specific data</td>
</tr>
<tr>
<td></td>
<td>Session handle</td>
<td>UDINT</td>
<td>Any value (ignored by receiver).</td>
</tr>
<tr>
<td></td>
<td>Status</td>
<td>UDINT</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sender Context</td>
<td>ARRAY of octet</td>
<td>Value from request. Length of 8.</td>
</tr>
<tr>
<td></td>
<td>Options</td>
<td>UDINT</td>
<td>0</td>
</tr>
<tr>
<td>Command specific data</td>
<td>Item Count</td>
<td>UINT</td>
<td>Number of target items to follow</td>
</tr>
<tr>
<td></td>
<td>Target Items</td>
<td>STRUCT of</td>
<td>Device Heartbeat Information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UINT</td>
<td>Item ID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UINT</td>
<td>Item Length</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ARRAY of octet</td>
<td>Item Data</td>
</tr>
</tbody>
</table>
Device heartbeat

- **Time To Live (TTL)**
  - Part of the IP header
  - Defines how “far” an IP datagram can “travel”
- By default set to one
  - Limits Device Heartbeats to the local network
- Would have to be configurable
  - A new attribute in the TCP/IP Interface Object
Device heartbeat

- **IP Multicast Address**
  - Can not use the same address as for Class 0 and Class 1
    - Different IP Multicast Addresses per device
- A new IP multicast address needs to be allocated from the IPv4 Organizational Local Scope
- Would have to be configurable
  - A new attribute in the TCP/IP Interface Object
Device heartbeat

Sent as Change-of-State

- Speed up the delivery
- The cyclic production interval is in seconds
- An inhibit time is required
  - Defaults to $\frac{1}{4}$ of the heartbeat interval
# Device heartbeat

<table>
<thead>
<tr>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Heartbeat Sequence Count</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Identity Object Instance ID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Device State</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Severity Level</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>AH</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>VS3</td>
<td>VS2</td>
<td>VS1</td>
</tr>
<tr>
<td>5</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>MA</td>
<td>EV</td>
<td>SF</td>
<td>UF</td>
</tr>
<tr>
<td>6</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Configuration Consistency Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Device Heartbeat Instance ID (included if AH flag is set)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Path Size (included if AH flag is set)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Padded EPATH (included if AH flag is set)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Agenda

- Introduction
- System overview
- Device heartbeat
- Aggregators
- Diagnostic object
- Summary
Aggregators

- EtherNet/IP Device Heartbeat
- DeviceNet Device Heartbeat
- I/O Connection with diagnostic status
Aggregators
Aggregators

Aggregator Object

- The Aggregator collects and store Device Heartbeat messages here in
- One instance per Device Heartbeat
  - Only new Device Heartbeat messages is stored
- The object either add or prepend the EPATH to the original producer with the address of the previous producer and the entry port
- Once the Device Heartbeat messages is stored it’s produced “upstream”
Aggregators

- Upper layer tools making use of the Device Heartbeat messages are responsible for deleting consumed Device Heartbeat messages from the Aggregator Object.

- The upper layer tools use the Original Device Heartbeat Producer Path to drill down through the network hierarchy.
Aggregators

- **Path in A1**
  - Path Size: 01 00
  - Path: 03 0B

- **Path in A2**
  - Path Size: 08 00
  - Path: 14 0B 31 39 32 2E 31 36 38 2E 30 2E 34 00 03 0B
Aggregators

Filtering options in Aggregator Object

- An acceptance mask of the Flags in the Diagnostic Heartbeat message
  - Applies as a logical AND
  - Defaults to all ones

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implem</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>Diagnostic Flag Mask</td>
<td>WORD</td>
<td>Filter mask applied to Diagnostic Flags on received Device Heartbeat messages</td>
<td>See semantics section</td>
</tr>
</tbody>
</table>
### Filtering options in Aggregator Object

- **Severity level acceptance**
  - Only events with a severity level equal to or higher than the configured will be accepted

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implem</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>Severity Level Filter</td>
<td>USINT</td>
<td>Sets the minimum Severity Level of events that shall be accepted</td>
<td>See semantics section</td>
</tr>
</tbody>
</table>
Aggregators

Filtering options in Aggregator Object

- Device Heartbeat IP Address Mask
  - Filters on the destination IP Address
  - Default the defined IP Multicast address used for Device Heartbeat messages

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implem</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>Device Heartbeat IP Address Mask</td>
<td>STRUCT of: List of IP addresses that shall be masked</td>
<td>See semantics section</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UINT</td>
<td>Number of filtered addresses</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UDINT</td>
<td>Device Heartbeat IP Address</td>
<td></td>
</tr>
</tbody>
</table>
Aggregators

Storage policy in Aggregator Object

- It’s possible to define when new instances are created
  - One instance per Device Heartbeat producer
  - Keep creating new and overwrite old instances
  - Keep creating new until out of memory

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implem</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>Device Heartbeat Storage Policy</td>
<td>USINT</td>
<td>Defines how instances will be used to store Device Heartbeat</td>
<td>See semantics section</td>
</tr>
</tbody>
</table>
Agenda

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Diagnostic object

Event Log Object

- Already exists and is defined
  - Seems logical to use because of the above
- Contain some issues
  - Loosely defined
  - Defined in a generic way to support any kind of logging
- Suggests defining a new object
  - The Diagnostic Object
Diagnostic object

- Device implementing the Device Heartbeat shall also implement the Diagnostic Object.
- A small and lightweight object
  - Yet flexible enough
  - Can be implemented in devices with limited resources
Diagnostic object

One instance per bit in the Flag field of the Device Heartbeat

- Bit 15 excluded
- Bit 0 corresponds to 1
- Bit 1 corresponds to 2
- And so on...
Diagnostic object

Event list attribute

- Where all information about the logged events are stored
- Comprise of a size member and an array of logged events
- Grow as new events are logged
- New events are added to the end of the list
## Diagnostic object

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implem</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Required</td>
<td>Get</td>
<td>V</td>
<td>Event List</td>
<td>STRUCT of:</td>
<td>List of all logged events</td>
<td>See semantics section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>List Size</td>
<td>UINT</td>
<td>Number of entries diagnostic entries</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Event Information</td>
<td>ARRAY of STRUCT of:</td>
<td>Array of diagnostic entries</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Event Code</td>
<td>UINT</td>
<td>Identifier uniquely identifying this diagnostic event</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Severity Type</td>
<td>USINT</td>
<td>The severity of the event</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Event Code Description</td>
<td>SHORT_STRING</td>
<td>Textual representation of the diagnostic event</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>DATE_AND_TIME</td>
<td>Data and time when the event was logged</td>
<td></td>
</tr>
</tbody>
</table>
Diagnostic object

Severity levels

- Discrete levels identifying the importance
- Loosely based on the Syslog severity levels

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Emergency</td>
</tr>
<tr>
<td>1</td>
<td>Alert</td>
</tr>
<tr>
<td>2</td>
<td>Critical</td>
</tr>
<tr>
<td>3</td>
<td>Error</td>
</tr>
<tr>
<td>4</td>
<td>Warning</td>
</tr>
<tr>
<td>5</td>
<td>Information</td>
</tr>
</tbody>
</table>
### Diagnostic object

The behavior of new events can be controlled
- What to do with a full list
- How duplicates are handled

<table>
<thead>
<tr>
<th>Attr ID</th>
<th>Need In Implement</th>
<th>Access Rule</th>
<th>NV</th>
<th>Name</th>
<th>Data Type</th>
<th>Description of Attribute</th>
<th>Semantics of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>List Full Action</td>
<td>USINT</td>
<td>Configures the action to take when a new event is detected and the log is full.</td>
<td>See semantics section</td>
</tr>
<tr>
<td>4</td>
<td>Required</td>
<td>Set</td>
<td>NV</td>
<td>Duplicate Action</td>
<td>USINT</td>
<td>Configures the action to take when a duplicate event is detected.</td>
<td>See semantics section</td>
</tr>
</tbody>
</table>

*<snip>*
## Diagnostic object

A new object specific service
- Used to read logged events
- Return the last unread event logged

<table>
<thead>
<tr>
<th>Service Code</th>
<th>Need in Implementation</th>
<th>Service name</th>
<th>Description of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>4Bhex</td>
<td>n/a</td>
<td>Get_Next_Unread_Member</td>
<td>Returns the next member in the Event List Attribute that has not been read yet.</td>
</tr>
</tbody>
</table>
Diagnostic object

EDS construct

- Make it possible to provide textual strings for the events in the EDS file

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Number</th>
<th>Data Type</th>
<th>Required/Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Event Code</td>
<td>1</td>
<td>UINT</td>
<td>Required</td>
</tr>
<tr>
<td>First Event Code String</td>
<td>2</td>
<td>STRING</td>
<td>Required</td>
</tr>
<tr>
<td>Nth Event Code</td>
<td>3, 5, 7, ...</td>
<td>UINT</td>
<td>Optional</td>
</tr>
<tr>
<td>Nth Event Code String</td>
<td>4, 6, 8, ...</td>
<td>STRING</td>
<td>Conditional¹</td>
</tr>
</tbody>
</table>

Table Footnotes
1  Required if preceding field is specified, not allowed if preceding field is not specified.

[Diags]
```objectivec
Diag =
  0x3000, "Over temperature",
  0x3001, "Under temperature",
  0x3002, "Delta temperature error",
  0x4000, "Sensor misaligned",
  0x4001, "Sensor disconnected";
```
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Summary

A generic framework for diagnostic reporting and event logging

- Can be used for almost any type of application and device diagnostics and events
- Functionality to report diagnostics
- Store and publish diagnostics
- Aggregate diagnostics through a network hierarchy
- All based on standardized CIP functionality
Thank you for your attention!