ODVA 2017
Industry Conference
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Resource-constrained Industrial Things – Proposal for the Adaptation of CoAP to EtherNet/IP™

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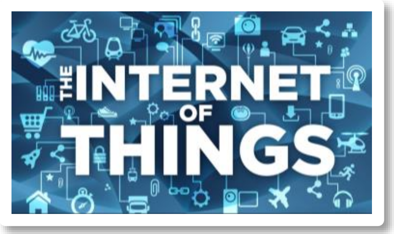
HMS Industrial Networks AB

February 22, 2017

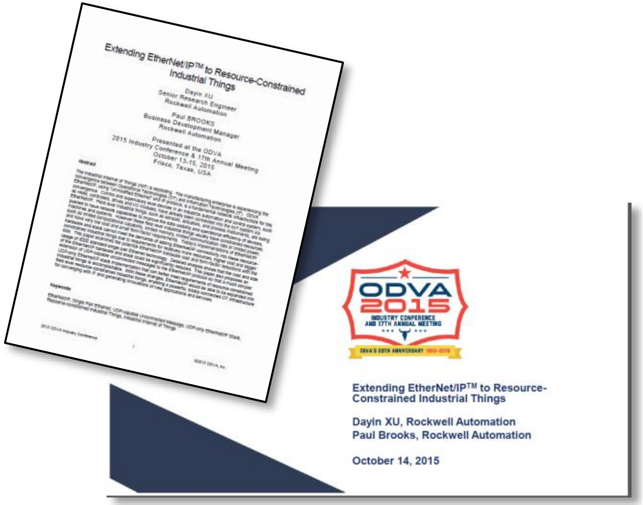
Why EtherNet/IP over CoAP?

- **Connect all devices in a factory to EtherNet/IP**
  - Even small and simple sensors and actuators
  - No need for routers
  - Enable more diagnostic data from the devices
- **Make EtherNet/IP cheaper and more simple to implement**
  - Remove TCP and the Encapsulation protocol and replace with CoAP
  - Less computing power and less memory required by the sensor system
- **Make the devices IoT Ready in a secure way**
  - Leverage on home automation to enable cloud connectivity for every sensor
  - Use the security features used by the home automation business



Introduction

- **Continuation on the work on Resource constrained EtherNet/IP device**
  - Presented 2015 by Paul Brooks and Dayin Xu



Extending EtherNet/IP™ to Resource-Constrained Industrial Things

Dayin XU
Senior Research Engineer
Rockwell Automation

Paul BROOKS
Business Development Manager
Rockwell Automation

Presented at the ODVA
2015 Industry Conference & 17th Annual Meeting
October 13-15, 2015
Frisco, Texas, USA

Abstract

The Industrial Internet of Things (IIoT) is exploding. The manufacturing enterprise is experiencing the convergence between Operational Technologies (OT) and Information Technologies (IT). [illegible]

Keywords

EtherNet/IP, Single Pair Ethernet, UDP-capable Unconnected Message, UDP-only EtherNet/IP Stack, Resource-constrained Industrial Things, Industrial Internet of Things

2015 ODVA Industry Conference

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ODVA 2015
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ODVA'S 20TH ANNIVERSARY 1995-2015

Extending EtherNet/IP™ to Resource-Constrained Industrial Things

Dayin XU, Rockwell Automation
Paul Brooks, Rockwell Automation

October 14, 2015

- **Quick recap:**
  - Widen the ODVA ecosystem with IIoT solutions
  - Cost and size reduction needed
  - EtherNet/IP over UDP reduces size/cost
  - Single Pair Ethernet reduces size/cost
  - CIP transport barrier – relies on TCP

Why do we need a resource constrained design?

- Introduce sensors and small actuators to the ODVA ecosystem via Ethernet connectivity
- Enable data and diagnostics to achieve smart operations from every thing on the factory floor
- Cheaper and smaller solution is necessary

IoT and IIoT Things

- Potential Industrial IoT Things
  - Industrial Sensors
  - Industrial Actuators
  - Process Instruments

- IoT Things
  - Temperature sensor
  - Humidity sensor
  - Smoke detector
  - Light control

Ref: http://www.ipso-alliance.org/

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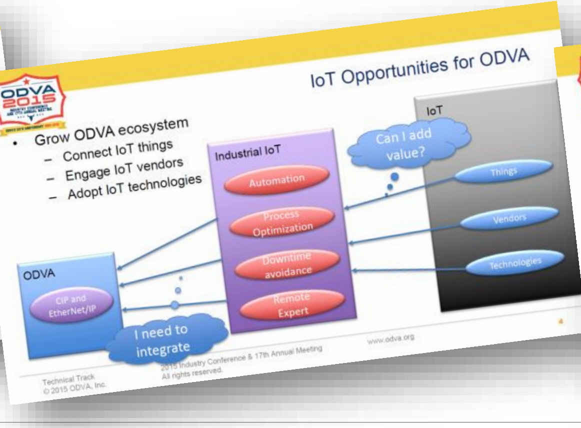

IoT Opportunities for ODVA

- Grow ODVA ecosystem
  - Connect IoT things
  - Engage IoT vendors
  - Adopt IoT technologies

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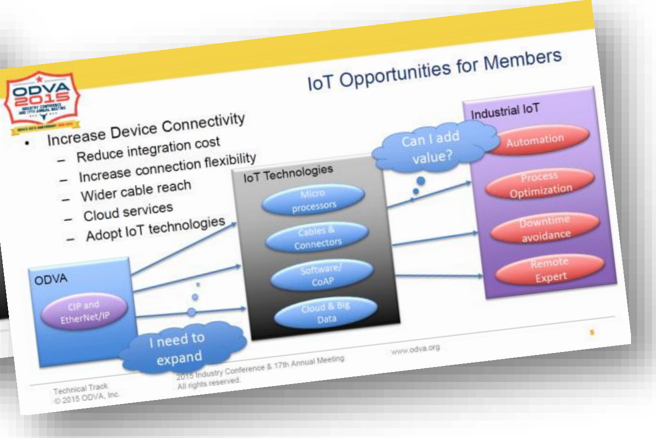

IoT Opportunities for Members

- Increase Device Connectivity
  - Reduce integration cost
  - Increase connection flexibility
  - Wider cable reach
  - Cloud services
  - Adopt IoT technologies

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Introduction

- **Bachelor thesis in collaboration with Halmstad University 2016**
  - Evaluated different IoT protocols to solve reliability for UDP based EtherNet/IP communication. *(CoAP, AMQP, MQTT and DDS were compared)*
  - CoAP is request/response oriented
  - Demo implementation

HÖGSKOLAN I HALMSTAD

Dataingenjör 180 hp

EXAMENSARBETE

Resource constrained Industrial IoT device

Henrik Wernersson, Yassin Atwa

Examensarbete 15hp

Halmstad 2016-06-18

CoAP

AMQP
Advanced Message Queuing Protocol

MQTT.ORG

Constrained Application Protocol

- Modern IoT protocol targeting IoT applications
- Use cases
  - OMA Lightweight M2M – Device management protocol
  - Supported by ARM mbed Device Server
  - Application-layer option to Thread

CoAP

ARM® mbed™

THREAD

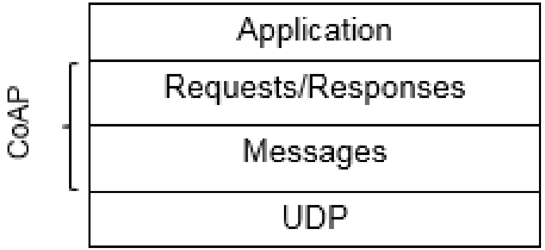
Constrained Application Protocol

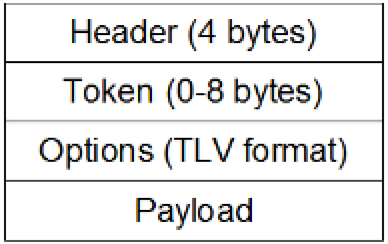
- Machine-2-machine protocol
- Targeting constrained devices

- Low overhead and complexity
  - Built upon UDP
  - 4-byte header

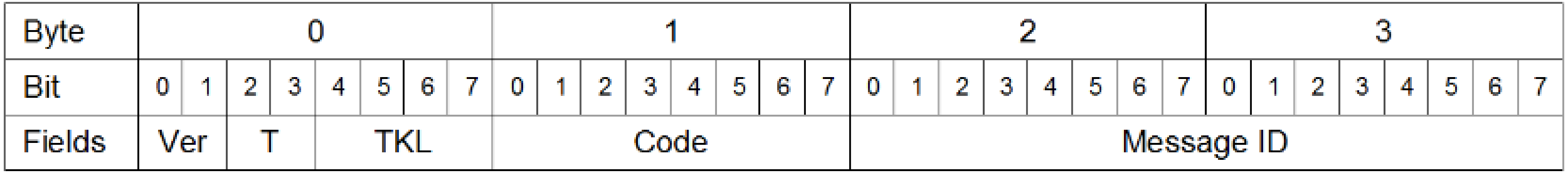
- Lightweight reliability
  - Re-transmissions
  - Duplicate message detection

- Can be secured by DTLS





CoAP header

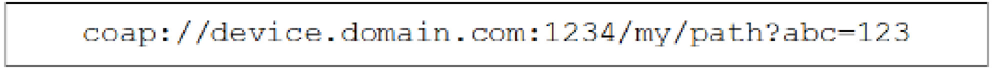


Byte	0								1								2								3							
Bit	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
Fields	Ver		T		TKL				Code								Message ID															

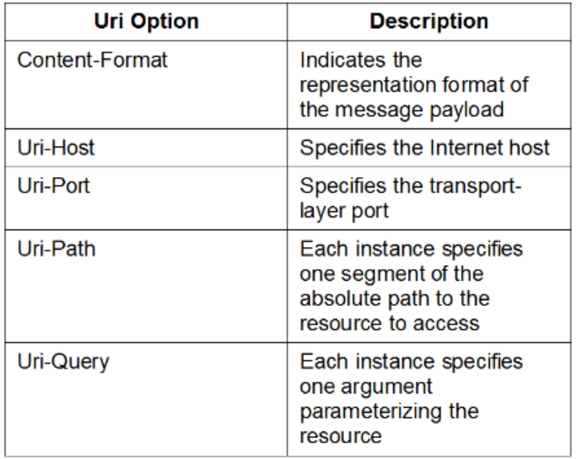
- Version
- Message type
  - Confirmable, Non-confirmable, Acknowledgement, Reset
- Token length
- Message code
  - Request, Success response, Client error or Server error response
- Message ID
  - Re-transmissions and duplicate message detection

CoAP options & payload

- Options
  - Present in both requests and responses
  - Type-Length-Value format
  - Multiple instances in single message
  - 15 options specified



```
coap://device.domain.com:1234/my/path?abc=123
```



Uri Option	Description
Content-Format	Indicates the representation format of the message payload
Uri-Host	Specifies the Internet host
Uri-Port	Specifies the transport-layer port
Uri-Path	Each instance specifies one segment of the absolute path to the resource to access
Uri-Query	Each instance specifies one argument parameterizing the resource

- Payload
  - Remaing part of the datagram size
  - Format determined by the Content-Format option

CIP adaptation on CoAP

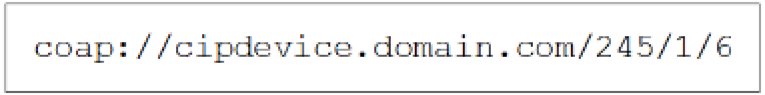
- Replace the Encapsulation layer

EtherNet/IP
CIP
Encapsulation protocol
TCP/UDP
Internet Protocol (v4)
Ethernet

EtherNet/IP over CoAP
CIP
CoAP
UDP
Internet Protocol (v4/v6)
Ethernet, 6LoWPAN etc.

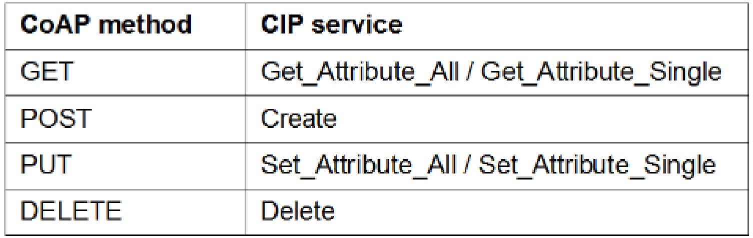
CIP adaptation on CoAP – Messaging

- Address resources with URIs
  - Objects, instances, attributes



```
coap://cipdevice.domain.com/245/1/6
```

- Translate CIP services to CoAP methods
  - Subset of all services
  - Enough to control a device?
  - CoAP option for CIP services



CoAP method	CIP service
GET	Get_Attribute_All / Get_Attribute_Single
POST	Create
PUT	Set_Attribute_All / Set_Attribute_Single
DELETE	Delete

- How to handle status codes?
  - Translate CIP status codes to CoAP response codes
  - Add CoAP options for general and additional status codes

CIP adaptation on CoAP – IO data

- CoAP is by design a messaging protocol
  - CoAP does not offer cyclic data exchange
  - Shall a resource contrained device handle cyclic data exchange?

- Let clients register for data updates
  - Observe resources
  - Publish/subscribe to topics linked to resources

CIP adaptation on CoAP – IO data

- Observing Resources in the Constrained Application Protocol
  - Extension to the CoAP specification (RFC7641)

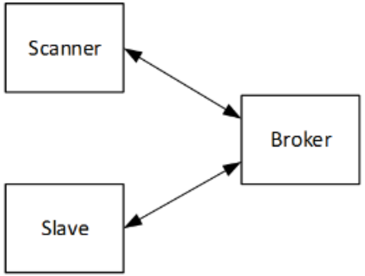
- Using the CoAP GET request but adds a Observe option

- Clients register to observe a resource
  - In GET request the Observe option tells the server to register an observer
  - Register and deregister is supported

- Servers send notifications when resources are updated
  - Subsequent responses to previous request
  - Sequence number for reordering detection

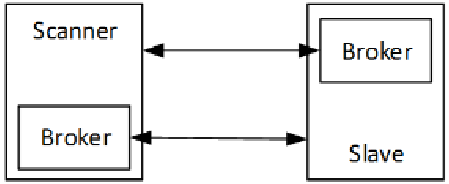
CIP adaptation on CoAP – IO data

- CoAP publish/subscribe
  - Register topics
  - Publish data on topics
  - Subscribe to topics to get data updates (change-of-state)



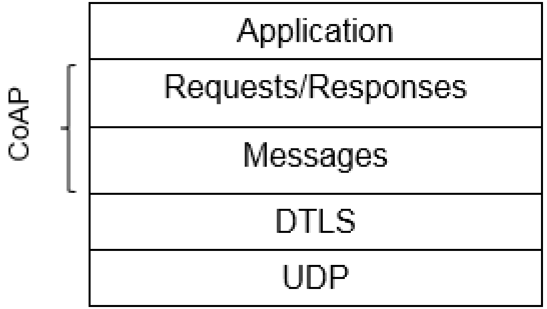
- Separate broker device

- ”Brokerless” setup
  - Pre-configured topics in the devices



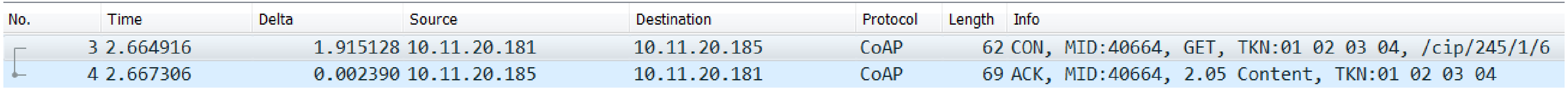
CIP adaptation on CoAP – Security

- CoAP has built in support for DTLS
  - URI: coaps://
  - Port 5684
- For key-exchange CoAP has support for
  - Pre-shared keys
  - X.509 certificates
  - Raw public key
- Uses AES128 for encryption
- Adds an extra burden on the host system
  - Cipher suites must be carefully chosen, Standardized on Elliptic-Curve DH (*secp256r1)*
  - Hardware acceleration
  - Use raw public keys instead of X.509 certificates (RFC7250)



Example of network traffic

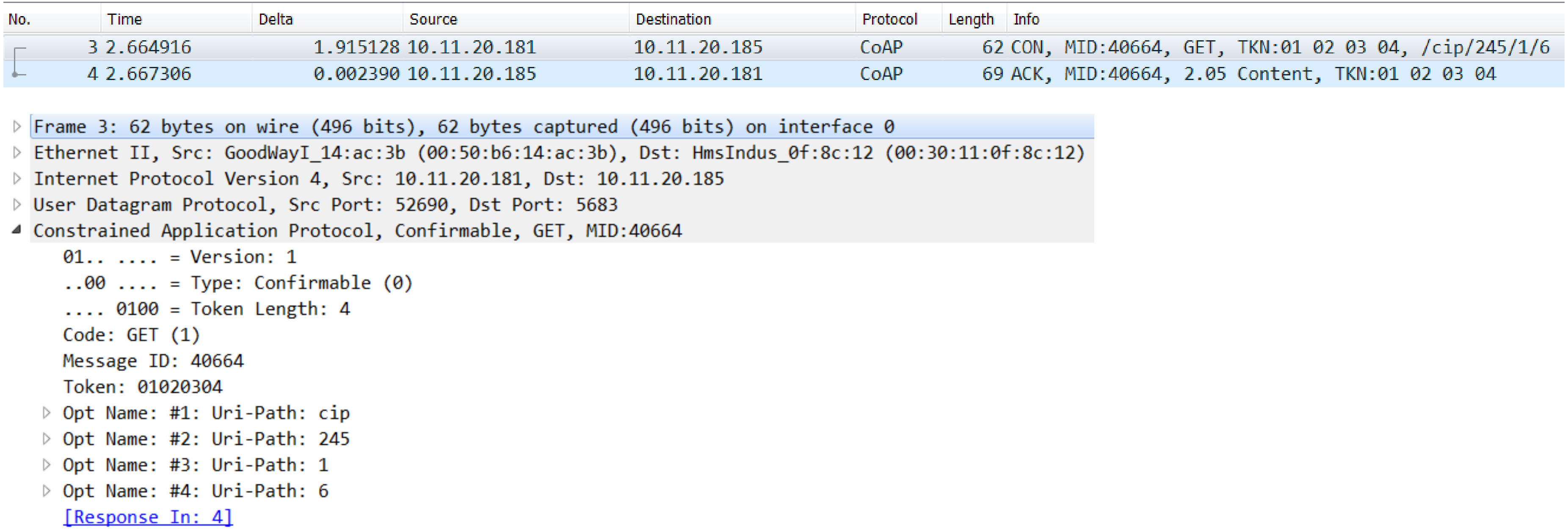
- Get_Attr_Single TCP/IP Interface object, instance 1, attribute 6 (host name)



No.	Time	Delta	Source	Destination	Protocol	Length	Info
3	2.664916	1.915128	10.11.20.181	10.11.20.185	CoAP	62	CON, MID:40664, GET, TKN:01 02 03 04, /cip/245/1/6
4	2.667306	0.002390	10.11.20.185	10.11.20.181	CoAP	69	ACK, MID:40664, 2.05 Content, TKN:01 02 03 04

Example of network traffic

- Get_Attr_Single TCP/IP Interface object, instance 1, attribute 6 (host name)

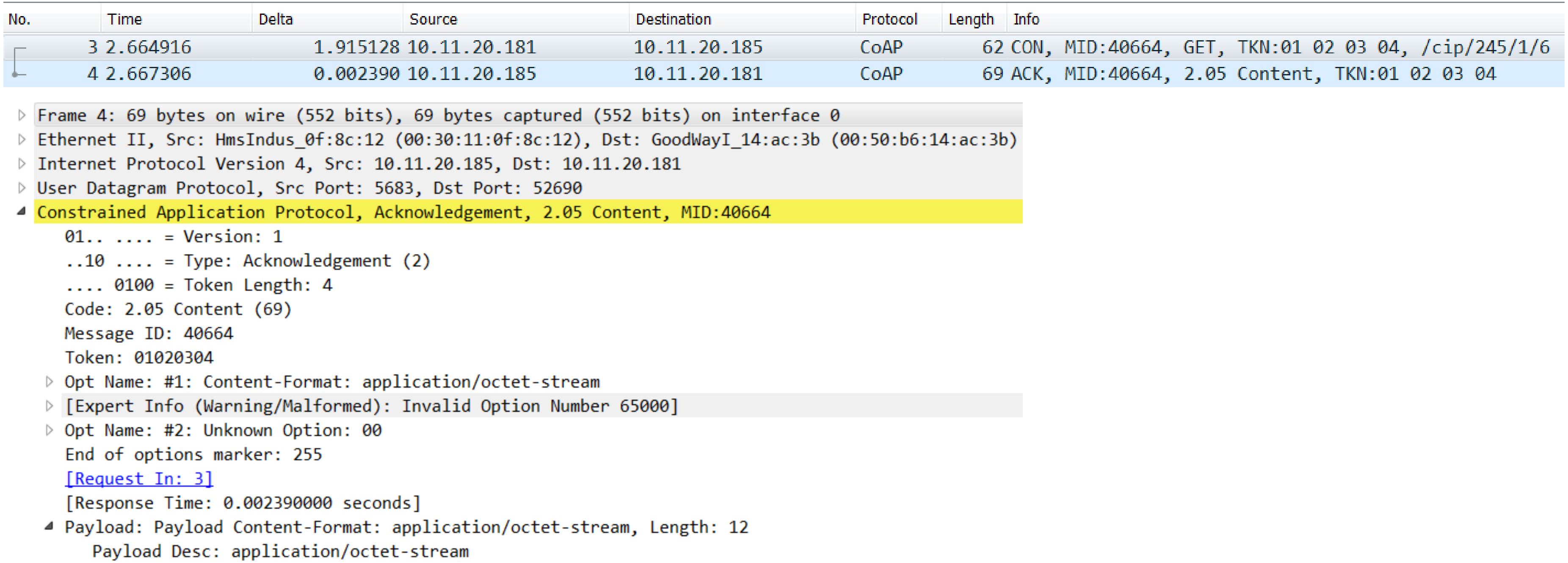


```
No.    Time      Delta     Source        Destination   Protocol Length Info
     3 2.664916  1.915128  10.11.20.181  10.11.20.185  CoAP         62 CON, MID:40664, GET, TKN:01 02 03 04, /cip/245/1/6
     4 2.667306  0.002390  10.11.20.185  10.11.20.181  CoAP         69 ACK, MID:40664, 2.05 Content, TKN:01 02 03 04
```

```
▷ Frame 3: 62 bytes on wire (496 bits), 62 bytes captured (496 bits) on interface 0
▷ Ethernet II, Src: GoodWayI_14:ac:3b (00:50:b6:14:ac:3b), Dst: HmsIndus_0f:8c:12 (00:30:11:0f:8c:12)
▷ Internet Protocol Version 4, Src: 10.11.20.181, Dst: 10.11.20.185
▷ User Datagram Protocol, Src Port: 52690, Dst Port: 5683
◢ Constrained Application Protocol, Confirmable, GET, MID:40664
     01.. .... = Version: 1
     ..00 .... = Type: Confirmable (0)
     .... 0100 = Token Length: 4
     Code: GET (1)
     Message ID: 40664
     Token: 01020304
   ▷ Opt Name: #1: Uri-Path: cip
   ▷ Opt Name: #2: Uri-Path: 245
   ▷ Opt Name: #3: Uri-Path: 1
   ▷ Opt Name: #4: Uri-Path: 6
     [Response In: 4]
```

Example of network traffic

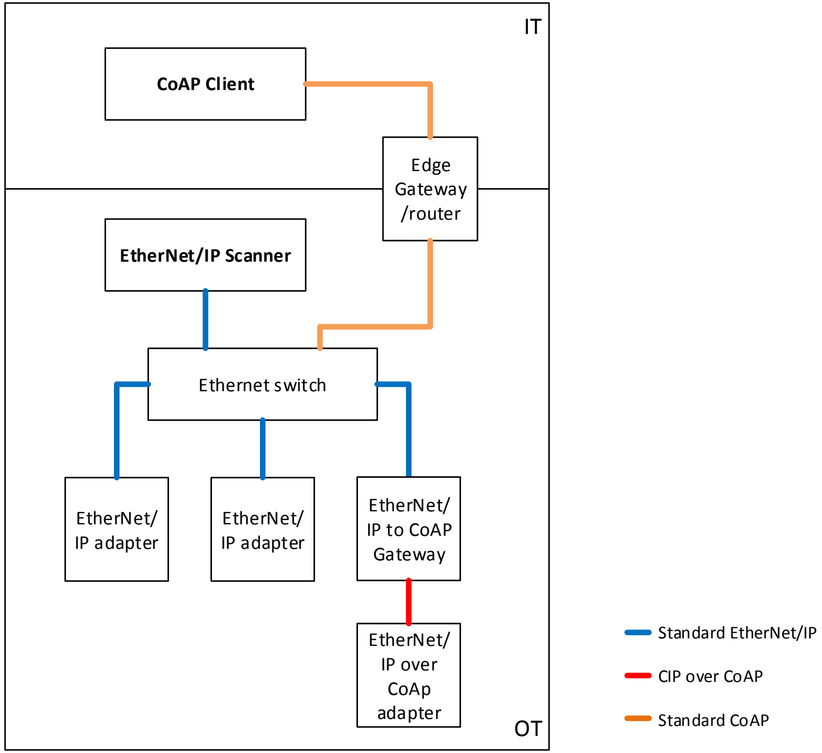
- Get_Attr_Single TCP/IP Interface object, instance 1, attribute 6 (host name)



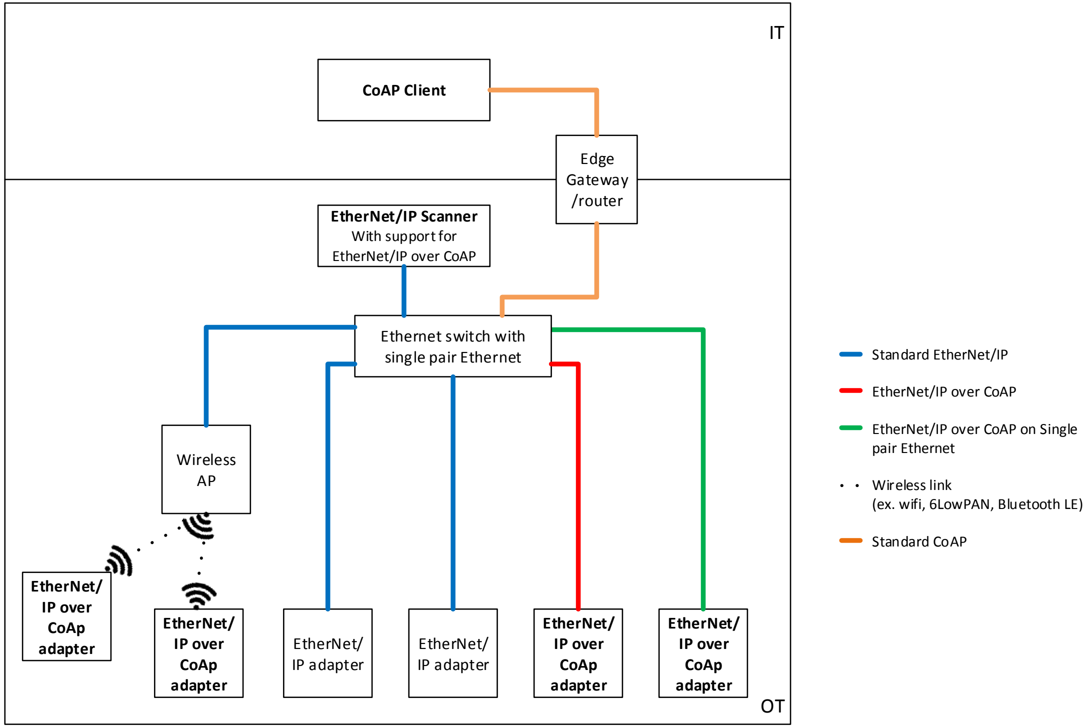
```
No.   Time      Delta     Source        Destination   Protocol Length Info
    3 2.664916  1.915128  10.11.20.181  10.11.20.185  CoAP          62 CON, MID:40664, GET, TKN:01 02 03 04, /cip/245/1/6
    4 2.667306  0.002390  10.11.20.185  10.11.20.181  CoAP          69 ACK, MID:40664, 2.05 Content, TKN:01 02 03 04
```

```
▷ Frame 4: 69 bytes on wire (552 bits), 69 bytes captured (552 bits) on interface 0
▷ Ethernet II, Src: HmsIndus_0f:8c:12 (00:30:11:0f:8c:12), Dst: GoodWayI_14:ac:3b (00:50:b6:14:ac:3b)
▷ Internet Protocol Version 4, Src: 10.11.20.185, Dst: 10.11.20.181
▷ User Datagram Protocol, Src Port: 5683, Dst Port: 52690
◢ Constrained Application Protocol, Acknowledgement, 2.05 Content, MID:40664
    01.. .... = Version: 1
    ..10 .... = Type: Acknowledgement (2)
    .... 0100 = Token Length: 4
    Code: 2.05 Content (69)
    Message ID: 40664
    Token: 01020304
  ▷ Opt Name: #1: Content-Format: application/octet-stream
  ▷ [Expert Info (Warning/Malformed): Invalid Option Number 65000]
  ▷ Opt Name: #2: Unknown Option: 00
    End of options marker: 255
    [Request In: 3]
    [Response Time: 0.002390000 seconds]
  ◢ Payload: Payload Content-Format: application/octet-stream, Length: 12
      Payload Desc: application/octet-stream
```

How to connect to the network



How to connect to the network



IT

CoAP Client

Edge Gateway /router

EtherNet/IP Scanner
With support for EtherNet/IP over CoAP

Ethernet switch with single pair Ethernet

Wireless AP

EtherNet/ IP over CoAp adapter

EtherNet/ IP over CoAp adapter

EtherNet/ IP adapter

EtherNet/ IP adapter

EtherNet/ IP over CoAp adapter

EtherNet/ IP over CoAp adapter

OT

🟦 Standard EtherNet/IP

🟥 EtherNet/IP over CoAP

🟩 EtherNet/IP over CoAP on Single pair Ethernet

· · Wireless link (ex. wifi, 6LowPAN, Bluetooth LE)

🟧 Standard CoAP

Not a finished concept

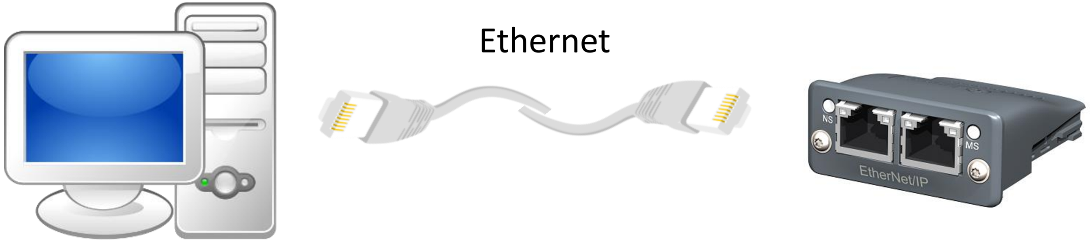
- CoAP works very well with explicit messaging of CIP
  - Examine how to support all CIP services and CIP Status codes
- No support for exchange cyclic data
  - Examine proposed techniques to replace cyclic data connections
  - How to map these techniques to the Connection Manager and Connection object?
- Investigate how to handle device commissioning
  - Discovery of new devices

Summary

- Low resource protocols for IoT devices exists
- Take advantage of already developed IoT protocols
  - Use as is or use ideas of it when adapting EtherNet/IP
- Possible to use CoAP
  - Support for explicit messaging
  - Cyclic data exchange needs a new approach
- Security of CoAP is well investigated and conforms well with CIP Security
- More to investigate for a final solution

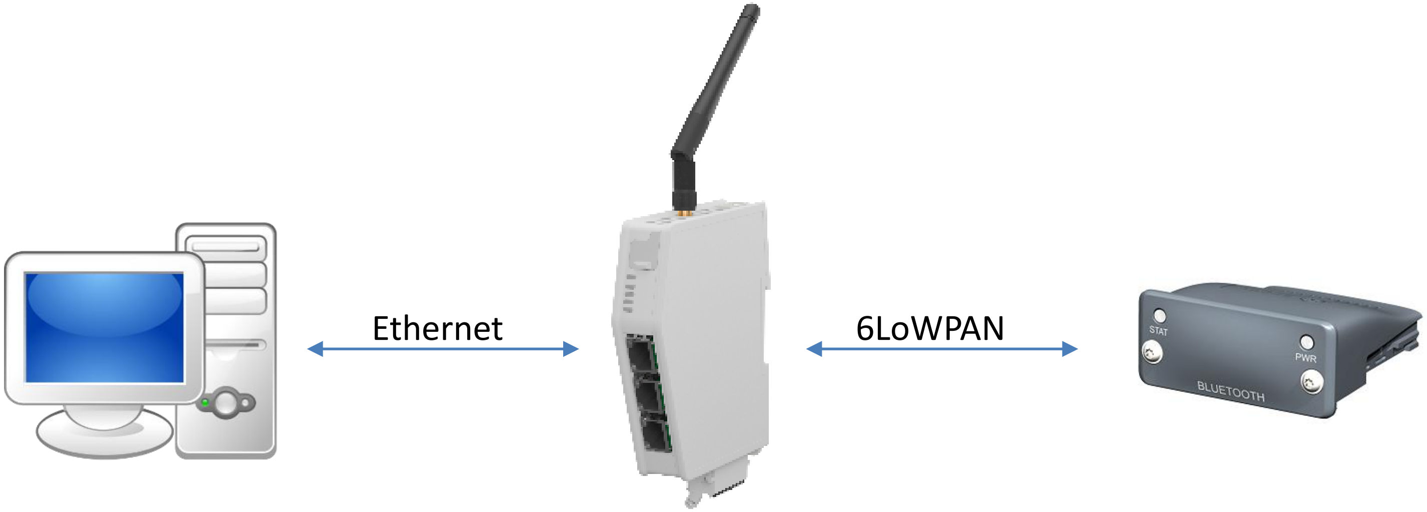
Demo of EtherNet/IP CoAP network adapter

- HMS Anybus CompactCom 40 EtherNet/IP™ adapter
- Open source CoAP stack ”libcoap”
- PC with CoAP browser used as originator



Coming up

- **Next step:** New work in collaboration with Halmstad University, moving technology to a wireless mesh network (6LoWPAN)



Questions and discussion

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THANK YOU