
# Extending EtherNet/IP™ to Resource-Constrained Industrial Things

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# Agenda

- IoT Opportunities for ODVA
- Constrains of IoT and IIoT Things
- Approaches to Connect IoT and IIoT Things to EtherNet/IP System
- Barriers in EtherNet/IP Hardware Interface
- Barriers in EtherNet/IP Protocol Firmware
- Single Pair Ethernet as a New PHY Layer
- UDP-capable Unconnected Explicit Message
- Scalable EtherNet/IP Stack
- Conclusion

# IoT and IIoT Things

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

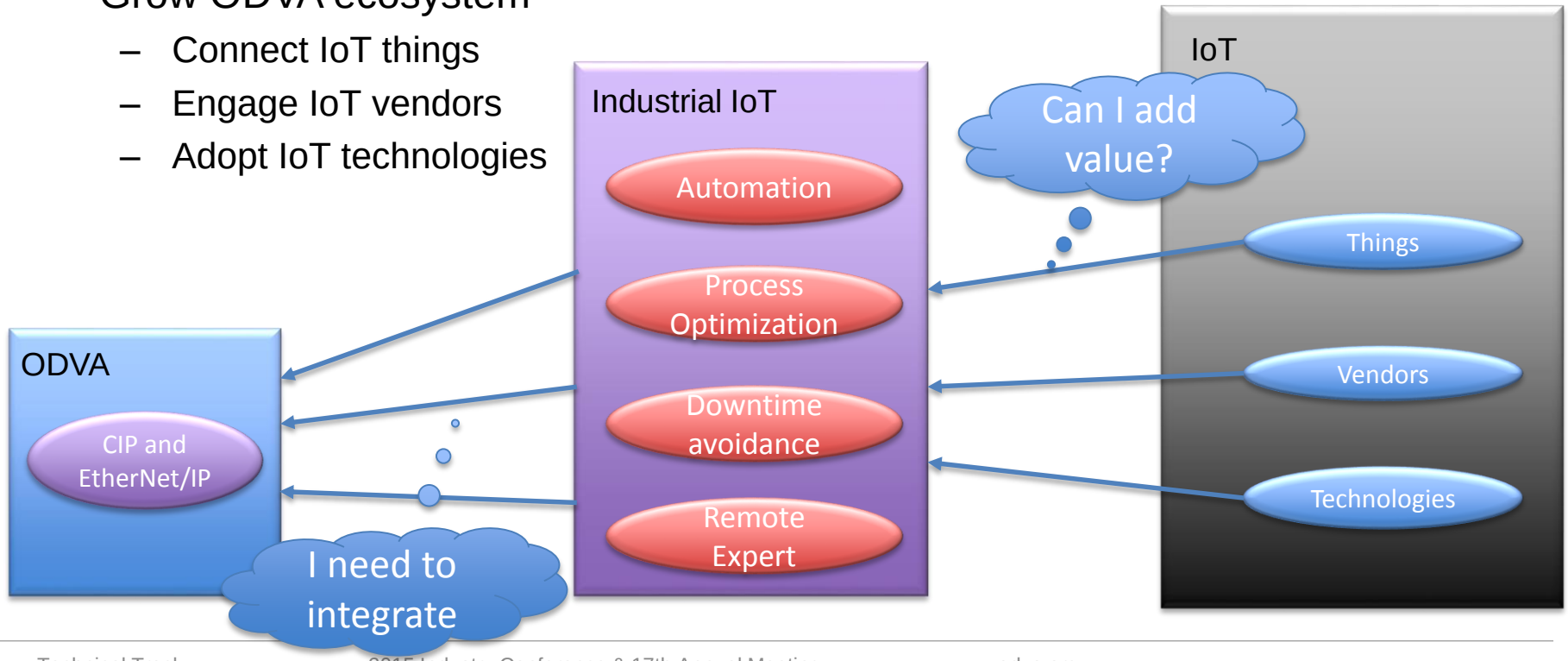



- IoT Things
  - Temperature sensor
  - Humidity sensor
  - Smoke detector
  - Light control


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

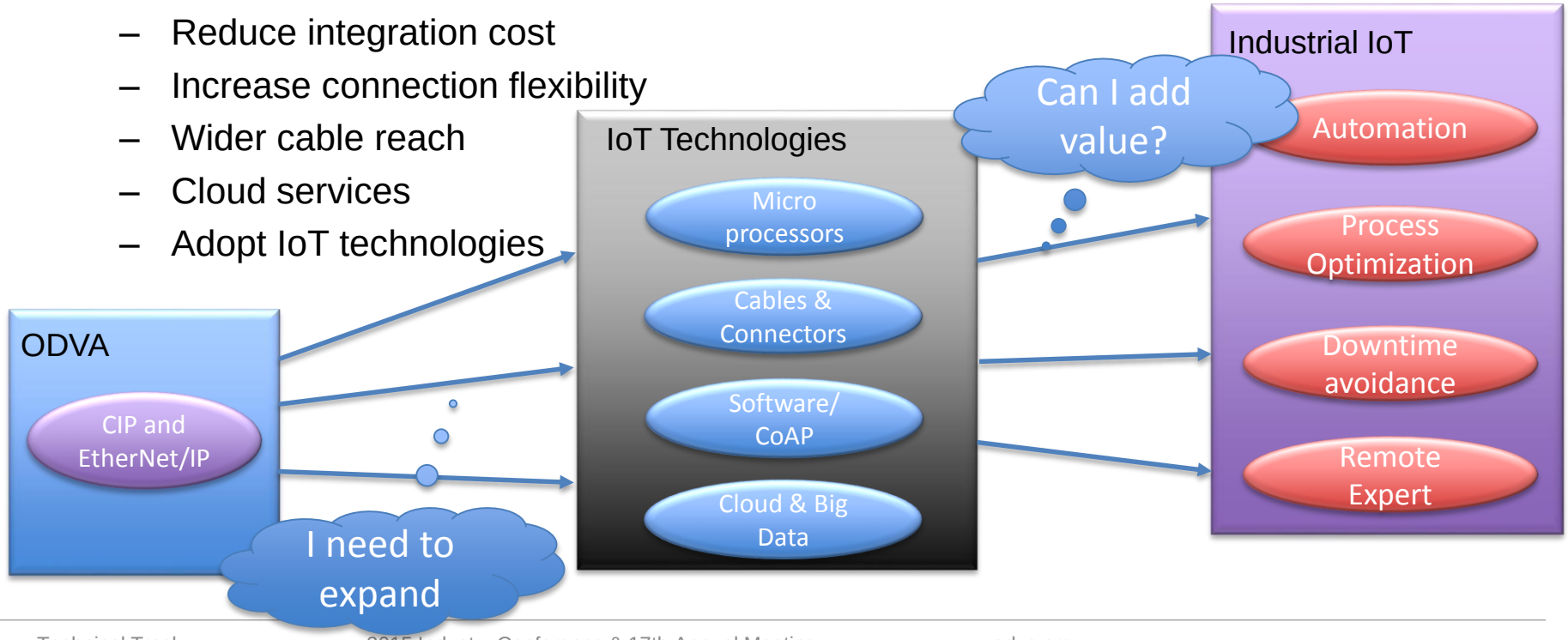
# IoT Opportunities for ODVA

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



# IoT Opportunities for Members

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

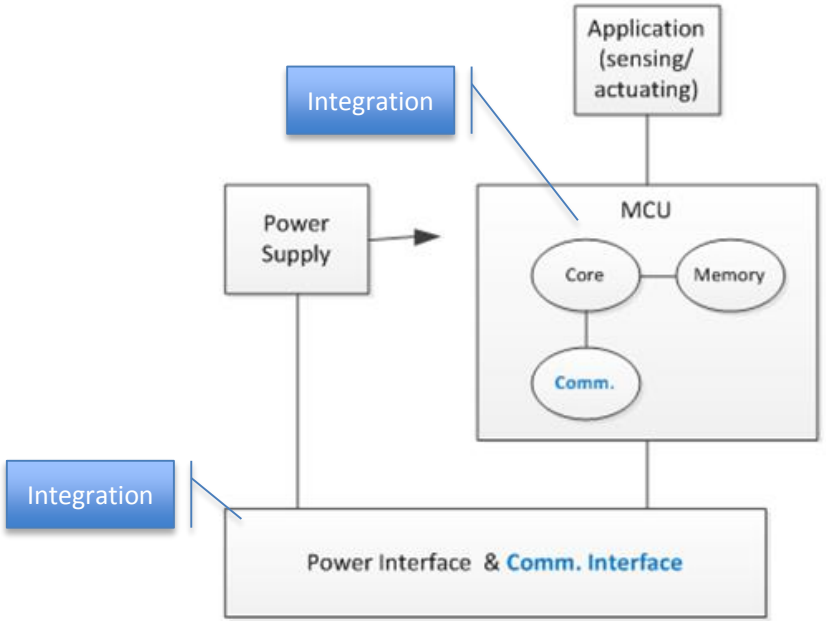


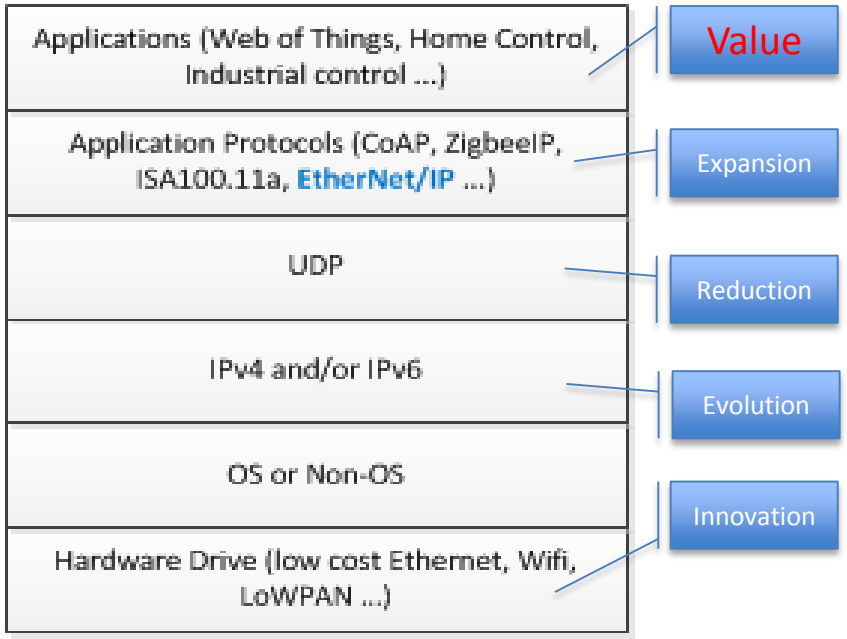
# Constraints of IoT and IIoT Things

- Hardware Constraints
  - Cost ($1-2 incremental cost)
  - Size (<10cm2, 5cm2 may be typical)
  - Power consumption (<2W, 1W may be typical – even lower in Ex areas)

- Resource Constraints
  - Computation power (Cortex-M3 100Mhz)
  - Memory (128Kbytes Flash, 32-64Kbytes RAM)
  - Energy (battery-powered)
  - Communication bandwidth (lower data rate 500Kbps)

# Evolution of IoT Hardware and Firmware




Ref: https://datatracker.ietf.org/wg/6lo/charter/
Ref: https://datatracker.ietf.org/wg/core/charter/
Ref: https://datatracker.ietf.org/wg/6lowpan/documents/

# IIoT/CIP Device Integration Future State

CIP Device $$

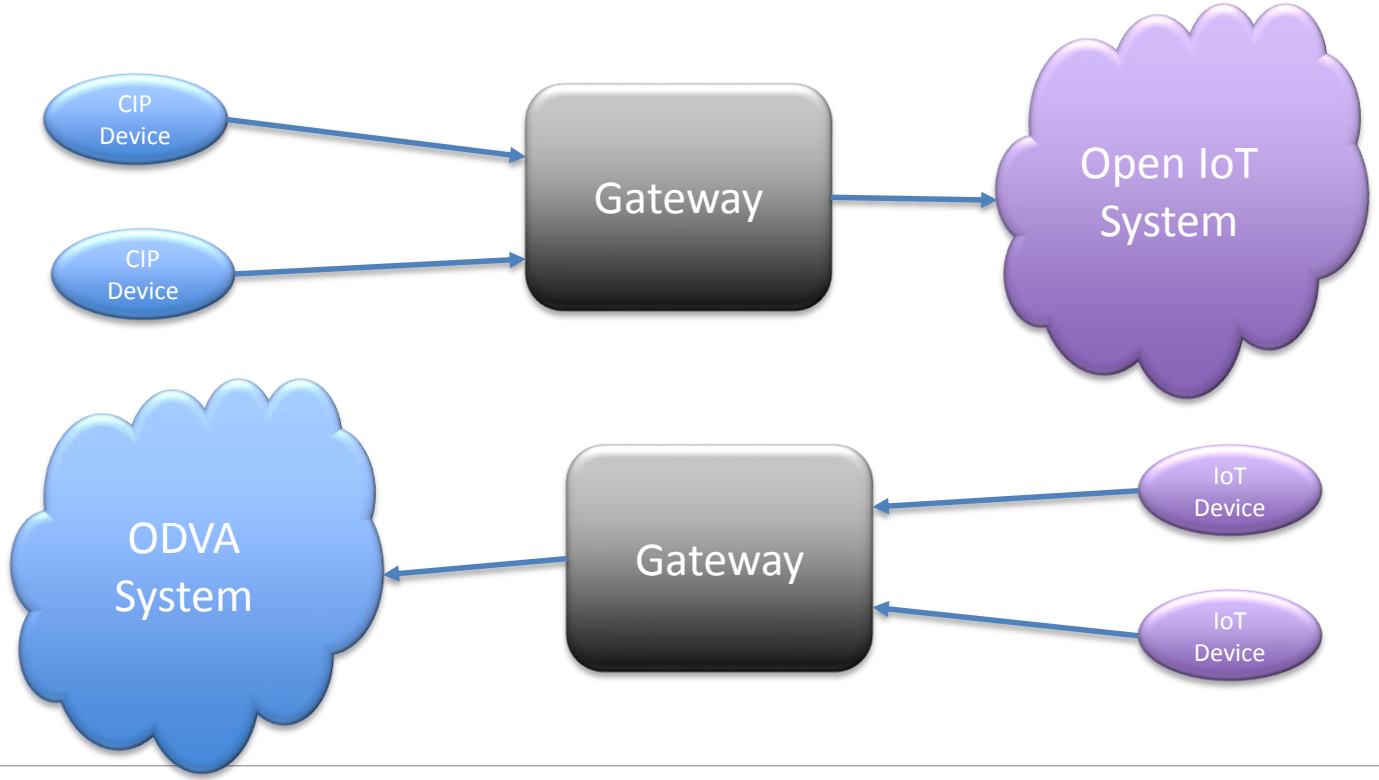
IoT Device $$

ODVA System

Open IoT System

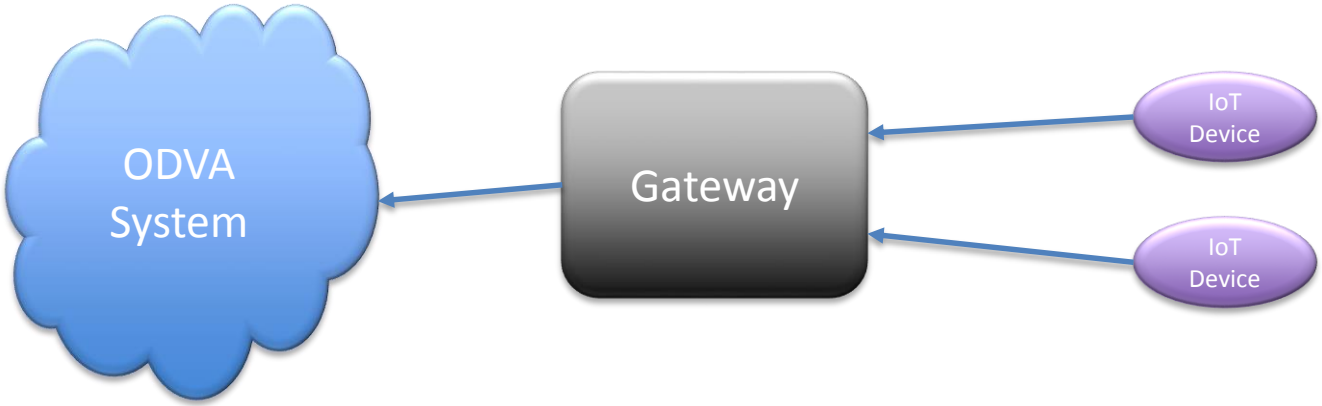
Metcalfe's Law

# Proxy Approach

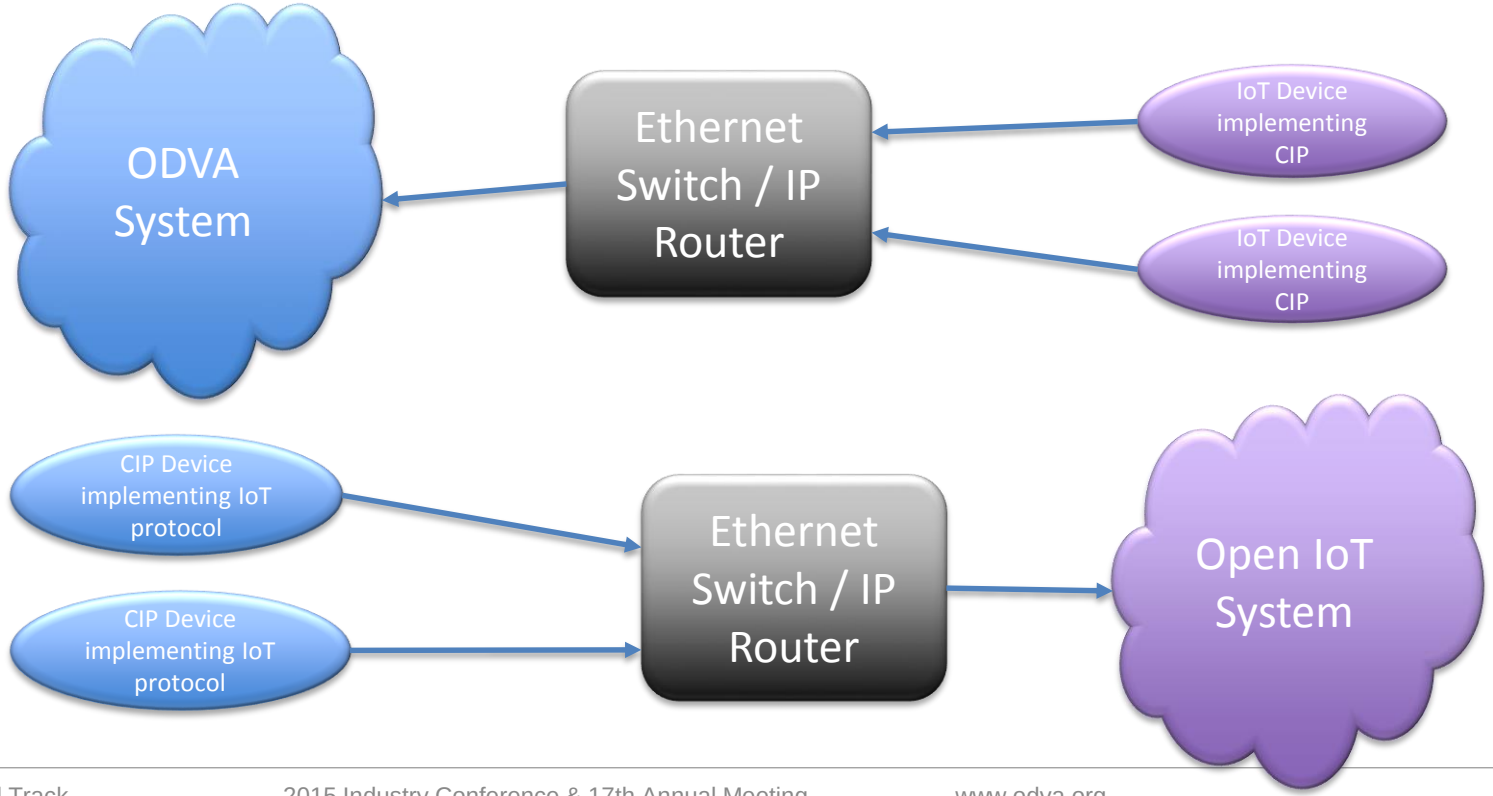


# Proxy Approach Challenges for IoT Vendors

- Lack of competence to develop gateway
- Lack of knowledge to program/configure gateway
- Loss of end-to-end connectivity



# Direct Connect Approach



# Can IoT Platform be addressed by CIP Device?

- Out of scope

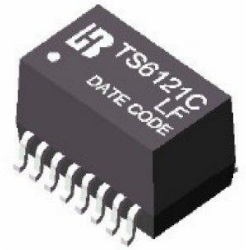
# Can EtherNet/IP be Implemented on IoT Platform?

- Multiple types of physical layers
- IPv4 and IPv6
- UDP-only capable, TCP optional
- Resource constraints
  - Limited computation, memory, bandwidth and energy
- Hardware constraints
  - Limited cost, size and power consumption

# Cost and Size Barriers in EtherNet/IP Hardware

- Cost and size barriers of Fast Ethernet

- Connector
  - RJ45 or M12-D
- Cable
  - Cat5e or above
- Ethernet Hardware
  - PHY chip
  - Transformer
  - EMC protection components
  - Product connector




# Barriers in EtherNet/IP Protocol Firmware

- Network
  - Barrier: IPv6 Support
  - Solution: Migrate EtherNet/IP stack to support IPv6; Choose IP stack that can be configured to IPv4 only, IPv4 and IPv6, or IPv6 only and support non-OS operation

- Transport
  - Barrier: EtherNet/IP requires TCP while IoT firmware does not require TCP
  - Solution: Choose TCP/UDP/IP stack that can be configured to UDP-only and Non-OS operation

- CIP Transport
  - Barrier: CIP Explicit messages rely on TCP and EtherNet/IP Sessions
  - Solution: Extend the EtherNet/IP protocol to transport explicit messages over UDP; The implementation of an EtherNet/IP stack should be scalable for resource-constrained IoT things

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- Barriers in EtherNet/IP Hardware Interface
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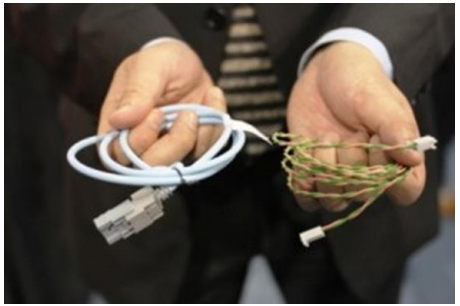
- **Single Pair Ethernet as a New PHY Layer**
- **UDP-capable Unconnected Explicit Message**
- **Scalable EtherNet/IP Stack**
- **Conclusion**

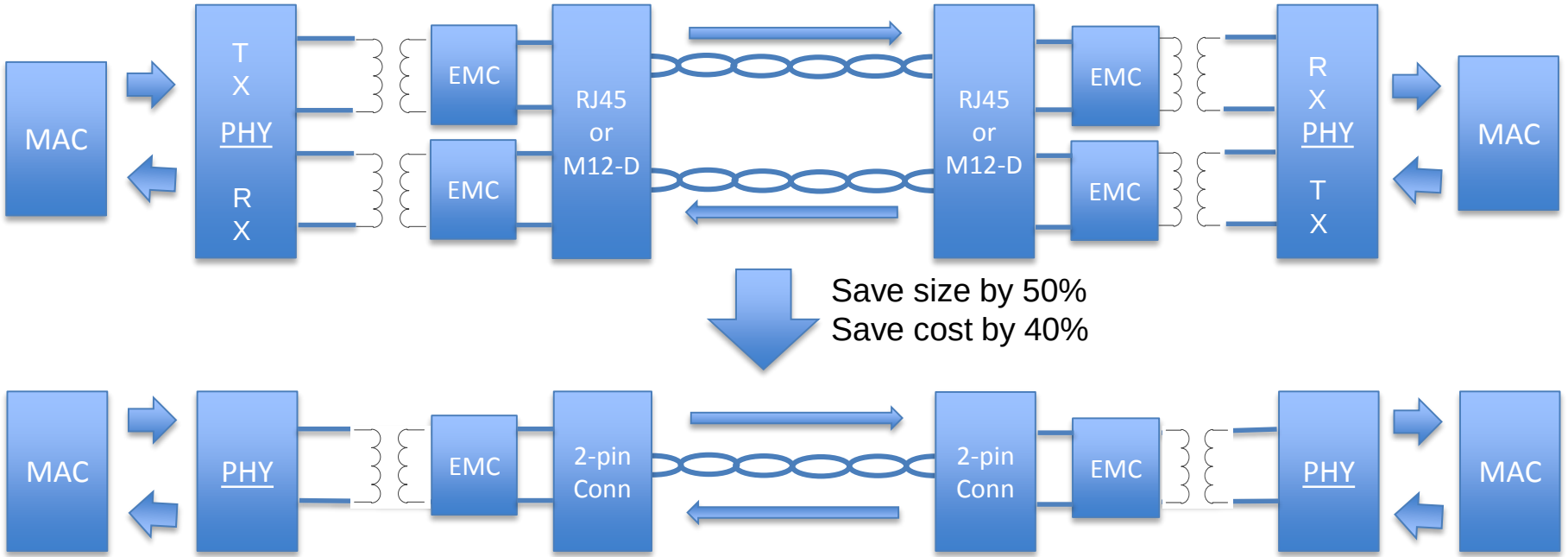
# Introduction of Single Pair Ethernet

- Two versions: 100Mbps and 1Gbps, this paper focus on 100Mbps
- Driven by the automotive industry for on-vehicle, then used by multiple industries?
  - High volume, low cost, good performance
- 100Mbps standard target to be published in Aug. 2016
- Chips already available in market



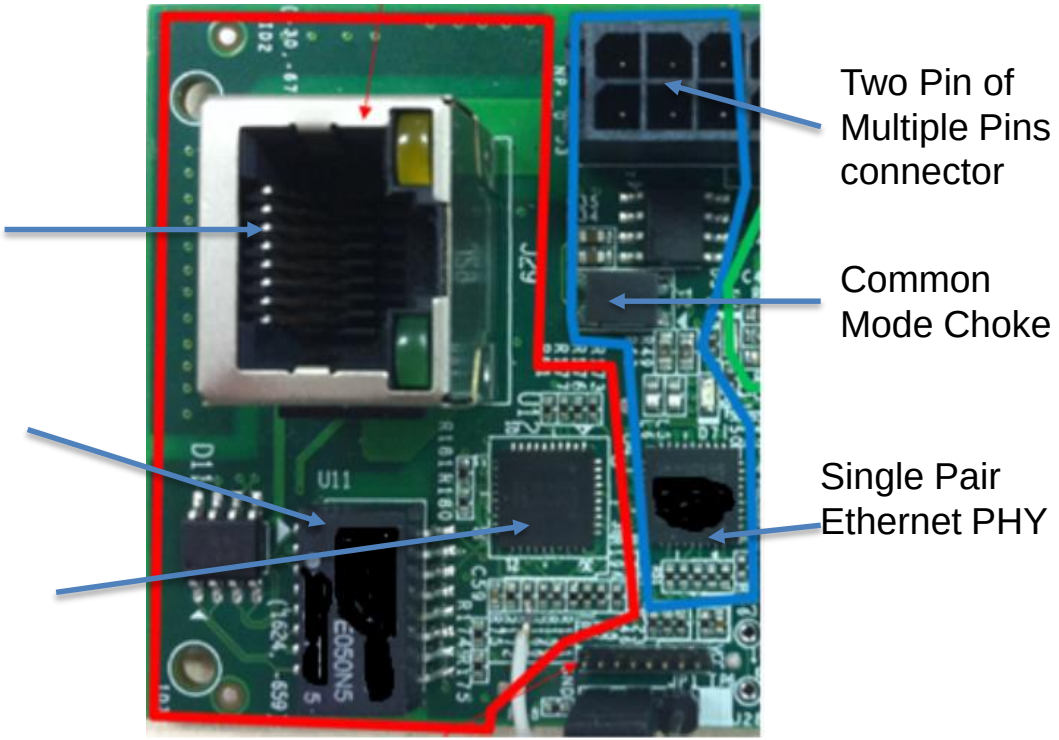
- 15 meters twisted single pair cable with 4 inline connectors
  - Specify electronic characteristics, rather than cable and connector
- Full-duplex
- MASTER/SLAVE
- Optional Auto-negotiation of Master/Slave and Speed
- Pulse Amplitude Modulation 3 (PAM3) Coding
- Lower frequency bandwidth requirement to the communication channel

# Potential Cost and Size Reduction



# Potential Cost and Size Reduction

- Save size by 50%
- Save cost by 40%

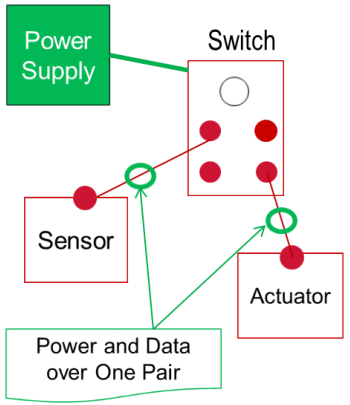


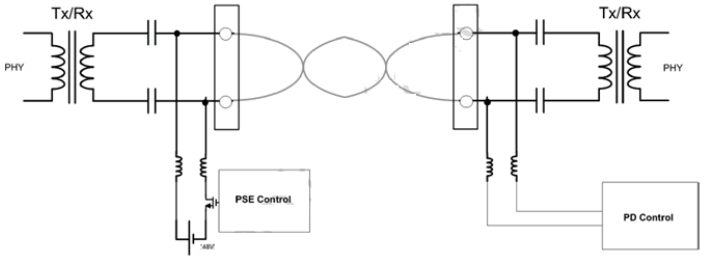

Note: 5 surge protector for Fast Ethernet in back not shown

# 1Pair Power over Data Line (PoDL)

- Standard State
  - Call for Interests in July2013
  - Task Force approved in Nov2013
  - D1.2 in review, D2.0 in Nov2015 for WG ballot

- Key Features
  - 12V for automotive, **24V for industrial**; 48V for standard PoE
  - Up to 10W for 24VDC
  - <100ms startup time
  - No limits on cable and connector



# UDP-capable CIP Unconnected Message

- Extend EtherNet/IP to transport unconnected explicit messages over UDP
  - TCP/UDP/IP stack that can compile TCP off
  - EtherNet/IP stack that can compile TCP Encapsulation and EtherNet/IP Session and Class 3 messages off

| | **TCP-based CIP unconnected explicit message** | **UDP-based CIP unconnected explicit message** |
|---|---|---|
| Transport | **TCP**, EtherNet/IP Explicit Port (0xAF12) | **UDP**, EtherNet/IP Explicit Port (0xAF12) |
| EtherNet/IP Encapsulation | SendRRData command (0x6F) over an **EtherNet/IP Session**<br>NULL Address Item (0x00)<br>Unconnected Data Item (0xB2) | SendRRData command (0x6F) without an EtherNet/IP Session<br>NULL Address Item (0x00)<br>Unconnected Data Item (0xB2) |
| CIP Unconnected Message | Message Router Request/Response data | Message Router Request/Response data |

# UDP-capable CIP Unconnected Message

- Add definition in Capability Flag of ListServices Response
  - Client chooses UDP/TCP based on this Capability information

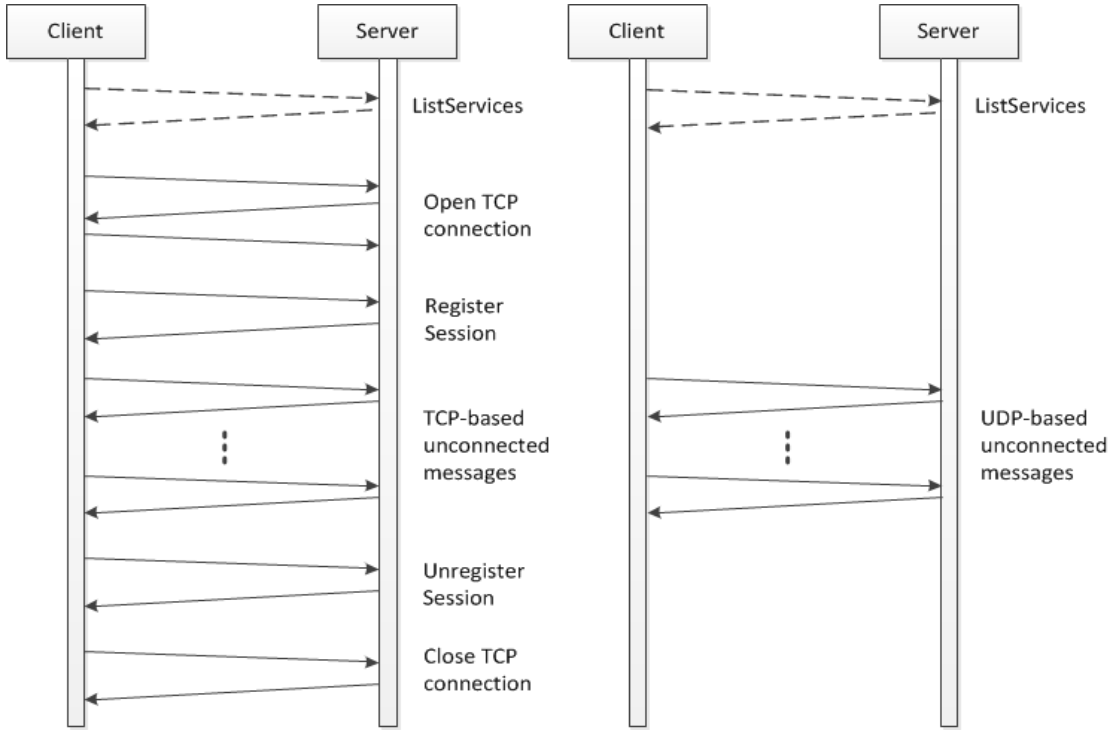
| Flag Value | Description |
|---|---|
| Bits 0 - 4 | Reserved for legacy usage [1] |
| Bit 5 | If the device supports EtherNet/IP encapsulation of CIP this bit shall be set (=1); otherwise, it shall be clear (=0) |
| Bits 6 - 7 | Reserved for legacy usage [1] |
| Bit 8 | Supports CIP transport class 0 or 1 UDP-based connections |
| **Bit 9** | **If the device supports UDP-based CIP unconnected explicit message this bit shall be set (=1); otherwise, it shall be clear (=0)** |
| **Bit 10** | **If the device supports TCP-based CIP unconnected explicit message this bit shall be clear (=0); otherwise, it shall be set (=1)** |
| Bit 11 - 15 | Reserved for future expansion |

Table Footnotes

1. Flags marked as “Reserved for legacy usage” indicate flags that were defined prior to the publication of this specification. Their usage is undefined in this specification. Devices should not use these flags without prior knowledge of the legacy usage. If a device receives a reserved flag that it does not understand, the reply shall be processed and the flag ignored.

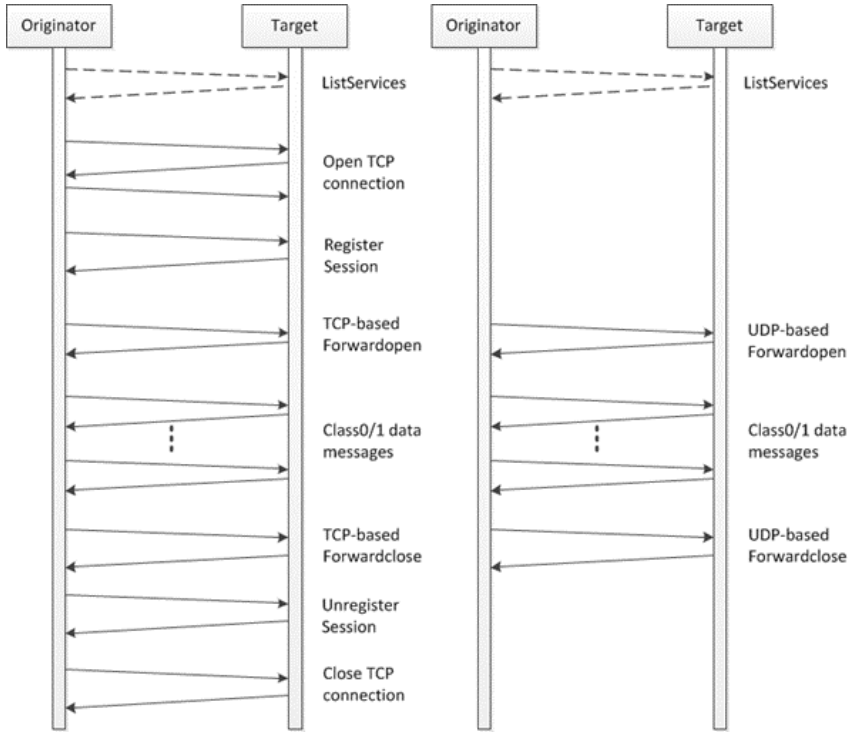
# UDP-based CIP Unconnected Explicit Message Sequence

- ListServices to get Servers' capability
  - UDP or TCP or Both
- No open/close TCP connection
- No register/unregister session
- No communication bindings, simple for servers



# UDP-based CIP Unconnected Message Sequence for Creating I/O Connections

- ForwardOpen/ ForwardClose as special unconnected messages
- No impact on I/O connection operation



# Backward Compatibility

- Clients
  - New clients must support both TCP and UDP methods
  - A legacy client needs to be updated to support the UDP method

- Servers
  - New servers MUST support at least UDP or TCP method
    - New resource-constrained servers ONLY support UDP method
    - New complex servers may support TCP method, and may support UDP method
  - A legacy server can operate in a hybrid system without any modifications

- Behaviors
  - Client first retrieves servers' capability (TCP or UDP) by ListServices
  - Client chooses the method according to the capability
    - Client choose TCP if both TCP and UDP are supported
  - Client may first try TCP and then try UDP without knowing the servers' capability

# Experimental Results and Wireshark Traffic

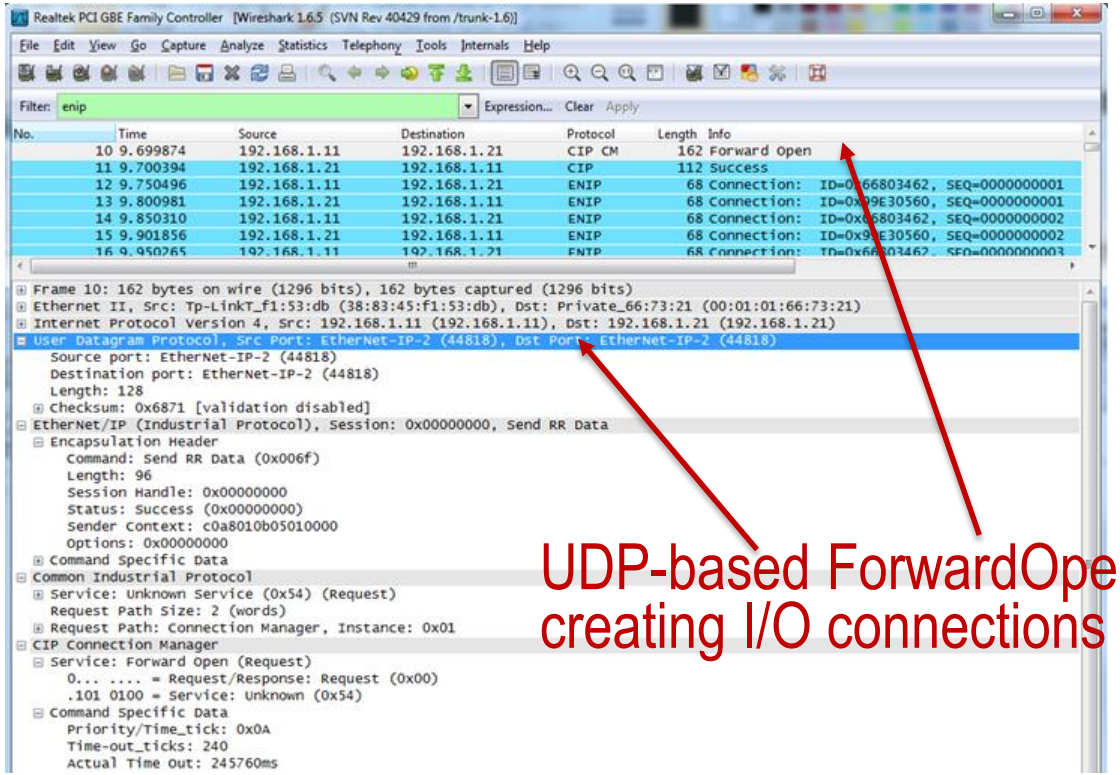
- EtherNet/IP Adapter Stack for an embedded device
  - **2 days** to add the feature of UDP-capable unconnected messages for an EtherNet/IP adapter stack (CIP Server and Target)
  -
- EtherNet/IP Scanner Stack for a PC software
  - **3 days** to add the feature of UDP-capable unconnected messages for an scanner stack (CIP Client and Originator)

- Scanner devices can create I/O connections to Adapter devices
  - Messages are well interpreted by Wireshark

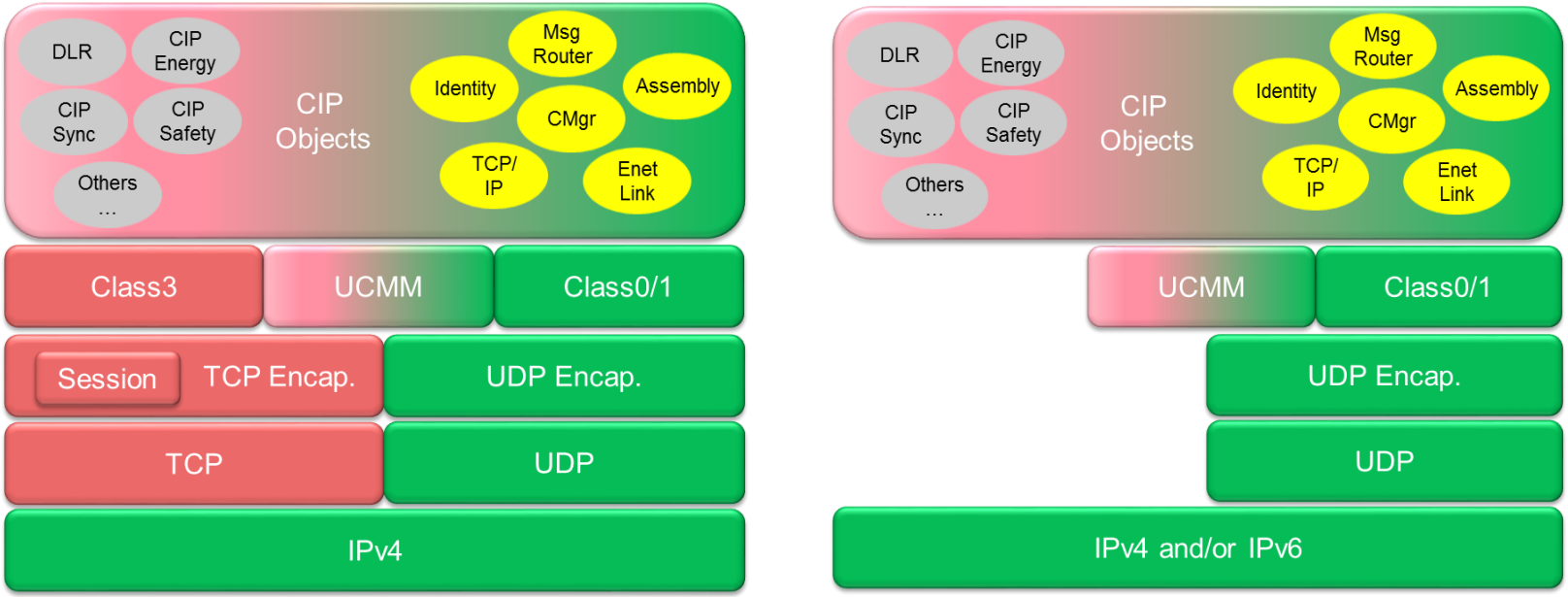
- Focus on UDP-capable concept, not IPv6
  - Refer to previous papers for IPv6 discussions

https://www.odva.org/Portals/0/Library/Annual-Meeting-2012/2012_ODVA_Conference_XuYuBrooksBatke_FINAL.pdf
http://www.odva.org/Portals/0/Library/Annual_Meeting_2014/2014_ODVA_Conference_Xu_Brooks_Yu_Brandt_CIP_over_6LoWPAN_FINAL.pdf

# Experimental Results and Wireshark Traffic

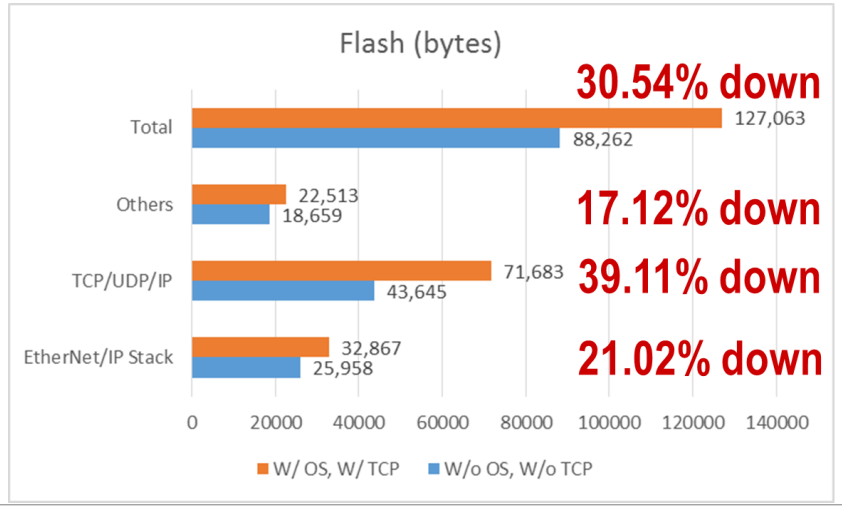


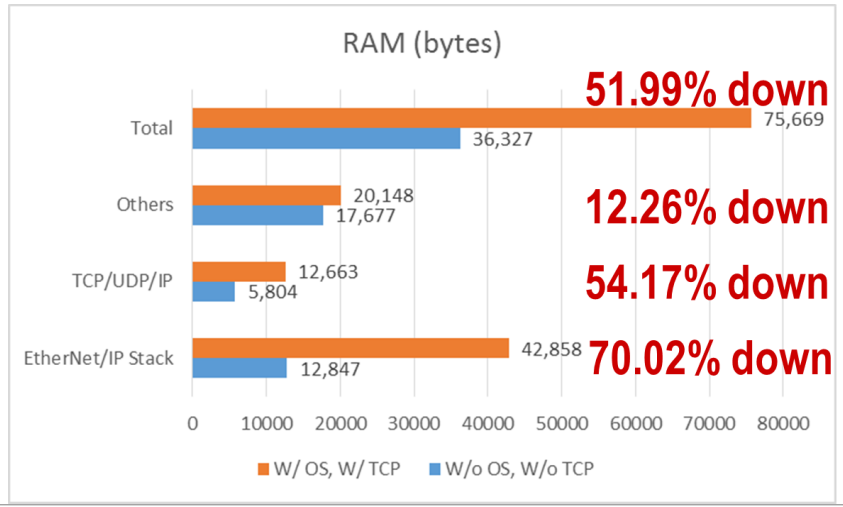
# Scalable EtherNet/IP Stack



# Experimental Results for Scalable EtherNet/IP Stack

- 30.54% code (38.8Kbytes) and 51.99% RAM (39.3Kbytes) could be saved from “with OS and with TCP” to “without OS and without TCP”
- The total UDP-only, Non-OS firmware consumes around 88Kbytes Flash and 36Kbytes RAM providing 40Kbytes Flash and 28Kbytes RAM for the application firmware for a MCU with 128Kbytes flash and 64Kbytes RAM.



# Experimental Results for Scalable EtherNet/IP Stack

- Conditions
  - Experimental firmware including EtherNet/IP adapter stack, TCP/UDP/IP stack, OS/Scheduler, HW drivers and an example application
  - Compiled in release version with medium optimization level
  - Firmware configuration of “with OS and with TCP” and “without OS and without OS
  - 3 explicit clients with a maximum 446 bytes explicit message
  - 4 I/O connections with 18 bytes I/O data
  - CIP objects: Identity, Connection Manager, Message Router, Assembly, TCP/IP Interface, Ethernet Link

| | Flash (Kbytes) | | | RAM (Kbytes) | | |
|---|---|---|---|---|---|---|
| | W/ OS, W/ TCP | W/o OS, W/o TCP | Reduction | W/ OS, W/ TCP | W/o OS, W/o TCP | Reduction |
| EtherNet/IP | 25,958 | 32,867 | 21.02% | 12,847 | 42,858 | 70.02% |
| TCP/UDP/IP | 43,645 | 71,683 | 39.11% | 5,804 | 12,663 | 54.17% |
| Others | 18,659 | 22,513 | 17.12% | 17,677 | 20,148 | 12.26% |
| Total | 88,262 | 127,063 | 30.54% | 36,327 | 75,669 | 51.99% |

# Conclusion

- IoT brings opportunities to ODVA to grow its ecosystem
- Barriers exist for EtherNet/IP and CIP to connect IoT and IIoT things
- Solutions proposed to Barriers
  - The introduction of Single Pair Ethernet to EtherNet/IP
  - The introduction of UDP-capable unconnected explicit message to EtherNet/IP
  - The implementation of scalable EtherNet/IP stack that can be configured to UDP-only for IIoT things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AND 17TH ANNUAL MEETING
ODVA'S 20TH ANNIVERSARY 1995–2015

# THANK YOU

# Abstract

The Industrial Internet of Things (IIoT) is exploding. The manufacturing enterprise is experiencing the convergence between Operational Technologies (OT) and Information Technologies (IT). ODVA EtherNet/IP, using “Unmodified Ethernet” and IP protocol, is a fundamental network infrastructure for this convergence. Control and supervisory level devices in an industrial automation and control system, such as HMIs, controllers, drives and I/O modules, have already been connected into the IIoT system via EtherNet/IP. Field level industrial things, such as sensors, actuators, and process instruments, are being pushed to have network capabilities to improve the data visibility and operational efficiency of devices, machines and systems. However these field level industrial things usually have constrained resources, such as limited computational capability, limited memory, limited communication rate or limited power, and have very low cost and small form-factor requirements. Today’s implementations of EtherNet/IP hardware and stack cannot meet the demands of adding EtherNet/IP connectivity into these resource-constrained industrial things due to requirements for relatively more resources, higher cost and bigger size. This paper examines the potential EtherNet/IP hardware cost and form-factor reductions with the usage of IEEE standard single pair Ethernet technology. Detailed analysis shows that the cost and size of the EtherNet/IP hardware and stack could be significantly reduced. This paper also proposes an extension of UDP-capable unconnected messages to the EtherNet/IP protocol so that a much simpler UDP-only Ethernet/IP stack implementation that can better meet requirements of resource-constrained industrial things is accomplishable. With these changes, EtherNet/IP would be able to be expanded into field level resource-constrained industrial things, enabling a powerful, totally-connected OT infrastructure for converging with IT and generating innovations of new applications and services.