

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 ODVA 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). 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.

Keywords

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

Acronyms

CoAP: Constrained Application Protocol
IoT: Internet of Things
IIoT: Industrial Internet of Things
IT: Information Technology
OT: Operational Technology
PoDL: Power over Data Line

1. Background

The development and deployment of low cost sensing, computation, communication, and networking technologies are enabling smart things to be connected into IP network. It is predicted that 50 billion of things will be connected by 2020 year, and the things from the manufacturing sector will contribute a significant portion. Country-level initiatives, such as America's Advanced Manufacturing, Germany's Industrial 4.0, and China's China Manufacturing 2025, would drive investments, create programs, and execute modeling projects to retransform/evolve the manufacturing to the next level by using Information Technologies into the industrial automation space. To minimize operation risks, reduce the time to market and utilize assets better, the convergence of OT and IT is taking place. Connecting a machine, a working cell, or a factory to the enterprise network is becoming a demand to improve the data visibility and operation efficiency of devices, machines, and systems.

As a well-accepted, widely-deployed, standard-based industrial Ethernet technology, ODVA's CIP and EtherNet/IP is naturally becoming a fundamental network infrastructure for this convergence of OT and IT. 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 Industrial IoT system via EtherNet/IP. ODVA may not be able to drive EtherNet/IP exclusively for IIoT usage because this protocol is for real time automation applications, and is likely not fitted for other applications that will have their own open and vendor specific protocols. However, ODVA should ensure that IIoT vendors that want to expand their devices and solutions into the industrial automation area can easily get these devices implemented with, and then connected to an EtherNet/IP system.

Besides, the industrial IoT is pushing the field level industrial things, such as sensors, actuators, and process instruments, to have network capabilities. 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 as one example of IoT physical layer technologies likely to be selected by IIoT vendors. Detailed analysis shows that by taking advantage of these emerging physical layers, 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.

2. Resource-constrained IoT and IIoT Things

The IoT movement creates new resource-constrained IIoT things in the industrial space. These industrial things could be IoT devices^[1] which are originally not in the industrial space, but expanded into the

industrial space with new applications. These industrial things could also be industrial devices which do not have a communication interface or have a field-bus communication interface now, but will add or migrate to an IP-based communication interface.

These new resource-constrained Industrial things often have constraints in size, cost and power, and have limited resources of computation, memory, energy, and communication rate or bandwidth.

A resource-constrained industrial thing such as a proximity sensor usually has less than 10cm² area for the hardware circuit. The incremental cost of adding an IP-based communication interface to a resource-constrained industrial thing is usually limited to \$1-2. The power budget for a resource-constrained industrial thing is usually less than 100mA @24V otherwise it may cause a heating issue. For a wireless industrial thing powered by battery, there are more strict power management requirements.

A typical microcontroller for a resource-constrained industrial thing may have 100Mhz ARM Cortex-M3 or less capable core, and may only have 128 Kbyte flash and 32-64 Kbyte RAM.

A highly-integrated, low cost and small size hardware platform and a common firmware architecture that consumes less resources of computation, memory, and communication bandwidth have gradually evolved to adapt the above constrains in cost, size, and resources for the IIoT things. The hardware platform may have a MCU with the communication transceiver integrated such as IEEE802.15.4 microcontroller or Ethernet microcontroller. The hardware platform may also have the power and communication interfaces combined into one interface such as power over Ethernet and wireless power transmission over the antenna. The firmware architecture has a common IP network layer but most IIoT things only use UDP for transport and most IIoT things may need IPv6 for future expansion^{[2][3][4]}. Different physical layer technologies are used for different physical environments, and different application protocols are used for different domain applications.

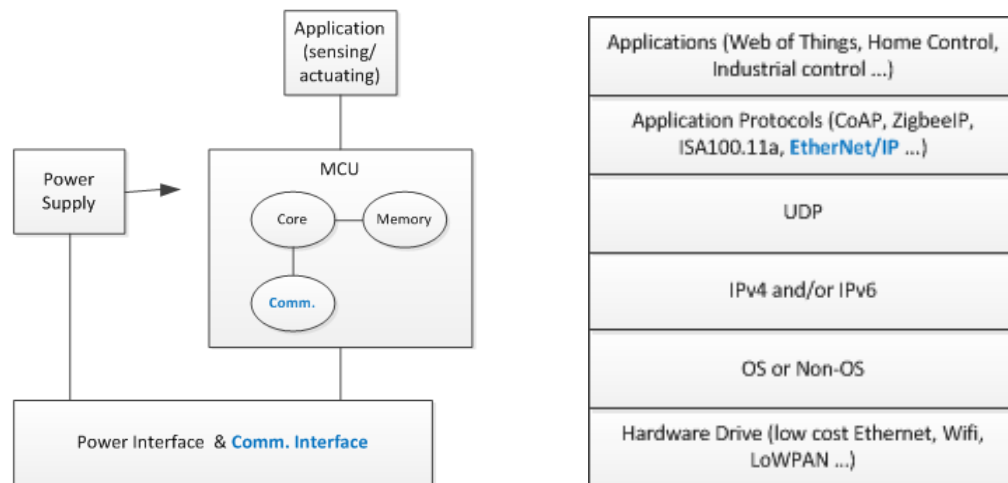


Figure 1 Potential Hardware and Firmware Architecture for IIoT things

3. Approaches to Connect Resource-constrained IIoT Things to an EtherNet/IP System

ODVA may not drive EtherNet/IP for IoT usage because this protocol is for the industrial automation, not for other industries that have their own protocols. However, ODVA should ensure that IoT vendors that want to expand their IoT devices and solutions into the industrial automation area can easily get these IoT devices implemented and then connected to an EtherNet/IP system. Most IoT companies are small venture companies. It is important for ODVA to ensure these companies can easily support EtherNet/IP with their hardware and with less investments so that they can become a part of an EtherNet/IP echo system. So EtherNet/IP needs to be based on the evolving IoT hardware platform and needs to have a protocol stack that is ready to be ported to the common IoT firmware platform without any change of IoT hardware and without any change of IoT lower layers network and communication protocols.

As mentioned, it is unlikely that EtherNet/IP can be driven to be an open IoT protocol. It is also unlikely to use an open IoT protocol to replace EtherNet/IP for the industrial control. When IoT things want to be in an EtherNet/IP system or an EtherNet/IP device want to be in an open IoT system, there are two approaches to make them connected.

3.1 Proxy Approach

Special gateways are required to connect the IIoT things into an open IoT system or connect the IoT things into an industrial automation system.

Putting a gateway in between to translate between the industrial protocols and the open IoT protocols is not a desired way but sometime is the most common way to get the industrial devices to participate in the IoT system today.

However this approach may present challenges to IoT vendors who want to connect their IoT devices to the industrial automation system. IoT vendors usually have no competence to develop the complex gateway. IoT vendors also have no skills to configure and program the gateway for operation in the industrial automation system even if the gateway is available from other companies. Technically the end-end connectivity between devices is lost. These challenges may become real burdens for IoT vendors to participate in the ODVA community.

3.2 Direct Connect Approach

The IoT movement is gradually evolving a highly-integrated hardware platform and a common firmware architecture as described in Section 2.

In this approach industrial protocols (e.g. EtherNet/IP) and open IoT protocols (e.g. CoAP) would both be implemented over this highly-integrated hardware platform and this common firmware architecture in the IIoT or IoT devices.

If the IoT devices' firmware can be changed to add an EtherNet/IP protocol implementation without any change of their hardware and without any change of their lower layers network and communication protocols and if the IP infrastructure devices (switch, router, not special gateway) can be used to connect these IoT devices to the EtherNet/IP system directly, it will make EtherNet/IP very attractive for IoT device vendors because only changing firmware to add an EtherNet/IP protocol implementation may not be a big concern for IoT device vendors. (You don't change the IoT device's hardware, you don't need a special complex gateway, you have end-end connectivity, and it is easy to deploy the system).

While outside the scope of this paper, it is also worth noting that an advantage EtherNet/IP device vendors have today is that their device hardware and stacks are likely ready to have open IoT protocol support (e.g. CoAP) added as a firmware upgrade

4. Barriers in Extending EtherNet/IP to Resource-constrained IIoT Things

The barriers in extending EtherNet/IP to resource-constrained industrial things are analyzed and the potential technical solutions to the barriers are discussed in this section. The analysis and discussion are made from the aspects of the communication interface hardware and the communication protocol firmware for the IoT or IIoT things.

4.1 Communication Interface hardware

There are a number of physical layer communication technologies (e.g. LoWPAN, WiFi, Ethernet, TSN and Bluetooth) that have been and are being adopted by resource-constrained IoT things. This paper analyzes the barriers of standard Ethernet used in EtherNet/IP and proposes single pair Ethernet as one example of IoT physical layer technologies for EtherNet/IP's extended usage for resource-constrained industrial things. This does not exclude the possibilities of using other physical layer technologies as EtherNet/IP physical layers for the resource-constrained industrial things.

4.1.1 Cable and Connector

Barrier: EtherNet/IP uses the RJ45 connector for the in-cabinet application and the M12-D connector for the on-machine application. The size of the RJ45 connector or M12-D connector is usually too large for the field level industrial sensors and actuators. The RJ45 connector or M12-D connector are also too expensive for the field level industrial sensors and actuators.

Potential Solution: A smaller, cheaper, and simpler 2-pin single pair Ethernet connector could potentially meet requirements of the field level industrial sensors and actuators. In addition, a lower cost single pair Ethernet cable (100BASE-T1's advanced signal processing function degrades the requirement of the communication channel, so potentially reduce the cost of the cable) and 24V power over the same single pair Ethernet cable would further reduce the cost and size of the EtherNet/IP system.

4.1.2 PHY and Its Accessories

Barrier: The hardware circuit of 100Mb/s Fast Ethernet usually contains a PHY chip, a Ethernet transformer, a connector, EMC protection components and other passive resistor and capacitor components. The cost and size of 100Mb/s Fast Ethernet hardware circuit are not acceptable for the field level industrial sensors and actuators. In addition, the height of the Ethernet transformer sometimes cannot meet the field level sensors or actuators' requirements.

Potential Solution: A single pair Ethernet hardware circuit only needs a half of components of 100Mb/s Fast Ethernet hardware circuit, this will obviously reduce the cost and size to a half in principle. In addition, the usage of capacitive coupling can further reduce the cost and size by removing the expensive and large Fast Ethernet transformer for applications that have no high voltage isolation requirement. The reduced MII between MAC and PHY is recommended to be used to reduce the size of the Ethernet hardware.

4.2 Communication Protocol Firmware

4.2.1 Network

Barrier: EtherNet/IP does not support IPv6 while IPv6 support is a common requirement for IoT things due to its large address space, high efficiency, simplicity, security and mobility.

Potential Solution: IP stack used in EtherNet/IP device should support IPv6, and should be able to be configured to IPv4 only, IPv4&IPv6, or IPv6 only working mode. EtherNet/IP stack should migrate to support IPv6. In addition, to minimize the usage of the memory resources, the IP stack should be able to be configured to run without Operating System for the resource-constrained industrial things.

4.2.2 Transport

Barrier: EtherNet/IP requires TCP for explicit messages while not supporting TCP is a common requirement for IoT things. TCP is connection-oriented, is more reliable but consumes much more resources than UDP. TCP is used to transfer large amount of data but with slow transaction rate while

UDP is used to transfer small packets with fast transaction rate. UDP is more suitable for resource-constrained industrial things.

Table 1 Comparison between TCP and UDP

	TCP	UDP
Connection-oriented	YES	NO
Reliable (ACK, stream control, sequence control)	YES	NO
Transaction rate	Slow	Fast
Resource (Computational capability, energy, storage, comm. bandwidth)	More	Less
Amount of data	Large	Small
Multicast support	NO	YES
Code size of protocol stack	Large	Small

Potential Solution: The TCP/UDP/IP stack used in an EtherNet/IP device should be able to be configured to the UDP-only operation mode. The EtherNet/IP stack should add the UDP transport for explicit messages. The EtherNet/IP stack should be able to be configured to the UDP-only operation mode too.

4.2.3 CIP Transport Protocol

Barrier: CIP explicit messages rely on TCP and EtherNet/IP Session while TCP is not suitable for resource-constrained industrial things. Connected explicit messages may consume too much resources for the resource-constrained industrial things.

Potential Solution: Extend EtherNet/IP to be able to transport explicit messages over UDP. Only use CIP unconnected explicit messages for the resource-constrained industrial things that have few parameters to be configured or monitored. The EtherNet/IP stack implementation should support the function of compiling Class 3 connection, EtherNet/IP session off for a UDP-only configuration.

5. Details on Potential Solutions to Barriers

5.1 Single Pair Ethernet Hardware

A variety of IEEE standard-based communication technologies, such as IEEE802.15.4 wireless personal area network technology, IEEE802.11 WiFi technology, and IEEE802.3 Ethernet technology, are being adopted in the Industrial IoT for different applications and environments. Although IEEE802.3 Ethernet was historically defined as EtherNet/IP's physical layer, other communication technologies like IEEE802.15.4, may need to be embraced in future for industrial IoT applications. Even for IEEE802.3 Ethernet, there are many types of Ethernet technologies for multiple types of media, multiple speeds and multiple distances. The scope of this paper is limited to discuss the new emerging single pair Ethernet technology in IEEE as an example of an emerging technology likely to be selected by IIoT devices. The key feature of single pair Ethernet is that it runs a full-duplex Ethernet communication over unshielded, balanced single pair twisted cable. This single pair Ethernet technology is promising to overcome the cost and size barriers in today's 100Mb/s Fast Ethernet hardware to extend EtherNet/IP to the emerging resource-constrained industrial things.

5.1.1 Introduction

The single pair Ethernet technology and standard development is driven by the automotive industry. It was predicted that the number of Ethernet nodes for the automotive industry would be 270M per year by 2020. It is also clear that the single pair Ethernet technology is gaining larger community supports from the whole automotive value chains (OPEN Alliance^[5] has more than 150 members). The potential huge

market space and the strong and wide community support would ensure/secure resources and investments on single pair Ethernet technologies of chips, cables, connectors, and tools.

Automotive applications have requirements of strict operational environment, high reliability (low bit error rate), and high performance (fast start-up time, low latency and jitter). Automotive applications will potentially drive high volume, low cost, and high performance Ethernet. The extended usage of single pair Ethernet into the industrial automation area is considered to be most likely feasible and desirable, similar to CAN that was first adopted in the automotive industry, then widely used in the industrial automation area.

Two types of single pair Ethernet 100BASE-T1 (802.3bw) and 1000BASE-T1 (802.3bp) are under development in IEEE from the year of 2013. 100BASE-T1 is more suitable for the IIoT things considering the cost and size. IEEE 100BASE-T1 standard is based on OPEN Alliance's one pair Ethernet specification which was first released in 2012 and now initially deployed in cars. IEEE 100BASE-T1 is targeted to be published in 2016. A 100Mb/s single pair Ethernet chip is now available from chip vendors.

5.1.2 Operation Principle

IEEE 100BASE-T1 PHY uses the standard MII/RMII interface but redefines the PHY and the physical media interface. The PHY utilizes 1000BASE-T Gigabit Ethernet technology to achieve full-duplex communication on a degraded communication channel of a single pair twisted cable. The simple Pulse Amplitude Modulation 3 (PAM-3) coding is used to achieve better EMI performance with a lower operation frequency bandwidth. The PHY works in a pre-managed MASTER or SLAVE mode for a communication link where one PHY is configured as MASTER and the other is configured as SLAVE. MASTER initiates the link-startup process. Fast link startup is supported and auto-negotiation is optionally supported. A two-pin connector or two pins of a multiple-pin connector are specified as Medium Dependent Interface (MDI). Rather than specifying the cable and connector, 100BASE-T1 defines the electric specification for the communication channel. Any type of cables and connectors could be used for the communication channel as long as they meet the electrical specification of the communication channel.

IEEE 100BASE-T1 standard only specifies 15 meters communication distance with the focus on automotive applications. The 15 meters distance is relatively short, but may be applicable for last hop industrial sensors and actuators in an automation machine or system. A longer distance in an automation application could be achieved by using a better communication channel (e.g. less inline connectors and shielded cable), or by increasing the TX power of the PHY chip, or by degrading the data rate (e.g. 10Mb/s).

A separate 1-pair Power over Data Line (PoDL) standard (802.3bu) is under development in IEEE. PoDL will enable the power delivery and Ethernet communication over a single pair twisted cable. With PoDL, only a two-pin connector is required for IIoT things' power and communication interfaces. This potentially save the cost and size of IIoT devices' hardware. Another key difference between PoDL and other Power over Ethernet technologies is that PoDL defines 24VDC as one voltage type.

5.1.3 Hardware Experimental Result

A hardware prototype was built for the proof of concept evaluation. Figure 2 shows the block diagram of single pair Ethernet PHY hardware circuit.

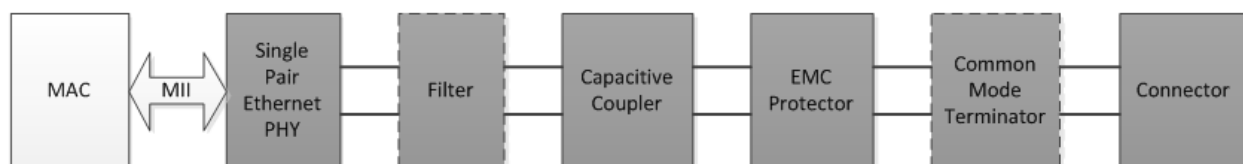


Figure 2 Single Pair Ethernet Hardware Block Diagram

From the size's perspective, the single pair Ethernet circuit may reduce the size by 50% compared to the 100BASE-TX Ethernet implementation in an industrial automation product. The major size reduction lies in the signal coupler, the connector, and the EMC protection components. The signal transformer would be replaced by a capacitor and a common mode choke. A smaller two-pin connector can save the size a lot too. Only 1/3 EMC protection components and a half of resistor and capacitor components are required.

From the cost's perspective, the experimental implementation shows that it is possible to reduce the cost by 40% compared to the 100BASE-TX Ethernet implementation. The cost reduction points are: a common mode choke is much cheaper than an Ethernet transformer, a number of component reductions reduces the cost, and a two-pin connector is cheaper than a RJ45 or M12-D connector.

5.2 UDP-only EtherNet/IP Stack

5.2.1 Concept Description

The idea of adding the UDP transport for EtherNet/IP unconnected messages is proposed so that a UDP-only EtherNet/IP stack could be implemented for the industrial IoT things. A UDP-only EtherNet/IP stack is more suitable for the IIoT things because it consumes less memory and has simplified transaction flow for the IIoT things.

Proposed Changes on EtherNet/IP Specification

Two changes are proposed to support UDP-capable CIP unconnected explicit messages. One change is to add a UDP transport way to transfer the CIP unconnected explicit messages. The other change is to add the "capability report information" in the ListService response data item to indicate the transport type of UDP or TCP or both for the CIP unconnected explicit messages. Based on this "capability report information", the client can know whether it chooses UDP or TCP for the CIP unconnected explicit messages to communicate with the server.

In particular, the SendRRCommand command will be able to be received or transmitted by using UDP socket with EtherNet/IP explicit port number(0xAF12) which has already been used by receiving or transmitting other EtherNet/IP encapsulation commands (e.g. ListIdentity).

Table 2 Comparison between TCP-based and UDP-based CIP Unconnected Explicit Message

	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 NULL Address Item (0x00) Unconnected Data Item (0xB2)	SendRRData command (0x6F) without an EtherNet/IP Session NULL Address Item (0x00) Unconnected Data Item (0xB2)
CIP Unconnected Message	Message Router Request/Response data	Message Router Request/Response data

The ListService response has a field named Capability Flags as defined in Table 3. Bit 8 has already been used to indicate the support of CIP transport class 0 or 1 UDP-based connections. Bit9 could be expanded to be used to indicate the support of UDP-based CIP unconnected explicit messages. Bit10 could be expanded to be used to indicate the support of TCP-based CIP unconnected explicit messages. This ListService response could be returned as a data item together with ListIdentity response data item to a ListIdentity request to save one ListService transaction.

Table 3 EtherNet/IP Encapsulation Capability Flag Definition

Flag Value	Description
Bits 0 - 4	Reserved for legacy usage ¹

Flag Value	Description
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.

There is no other change on the EtherNet/IP encapsulation protocol message format, there is also no change on the Class 0/1/3 connection. The function of sending and receiving CIP unconnected explicit messages via TCP connection and EtherNet/IP session is kept, but not intend to be used for the resource-constrained IIoT things.

One shortage of using UDP is lack of reliability that TCP has, but this is not an issue for CIP unconnected explicit message client/server applications. The failure of delivering a request or response will be detected by the CIP client via a timeout and will be notified to the application. The client will decide the further action based on applications (for example, may retry the packet or may stop the communication).

Simplified Transaction Flow

With UDP-cable CIP unconnected explicit messages, the transaction for reading or writing explicit parameters between the client and server is simplified as shown in Figure 3.

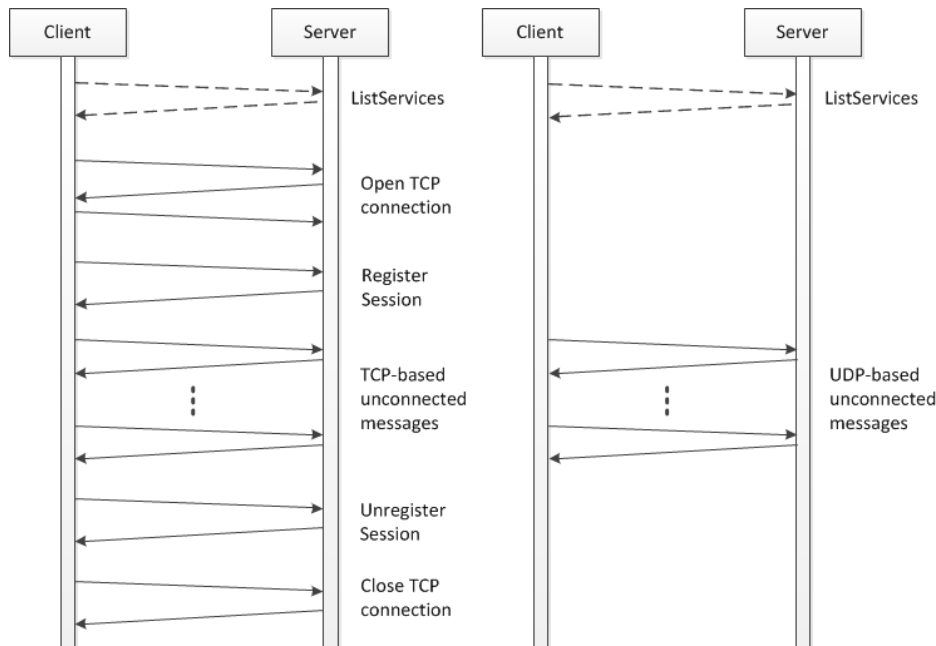


Figure 3 Comparison between TCP-based and UDP-based CIP Unconnected Explicit Message Sequence

Compared to the transaction using TCP-based CIP unconnected explicit messages, the transaction using UDP-based CIP unconnected explicit messages does not need the processing of opening or closing TCP

connection and registering or unregistering EtherNet/IP sessions. The client directly communicates with the server without pre-established communication channel bindings.

As shown in Figure 4, for opening or closing I/O connections, the originator directly sends a UDP-based ForwardOpen or ForwardClose request to the target without establishing TCP connection and EtherNet/IP session.

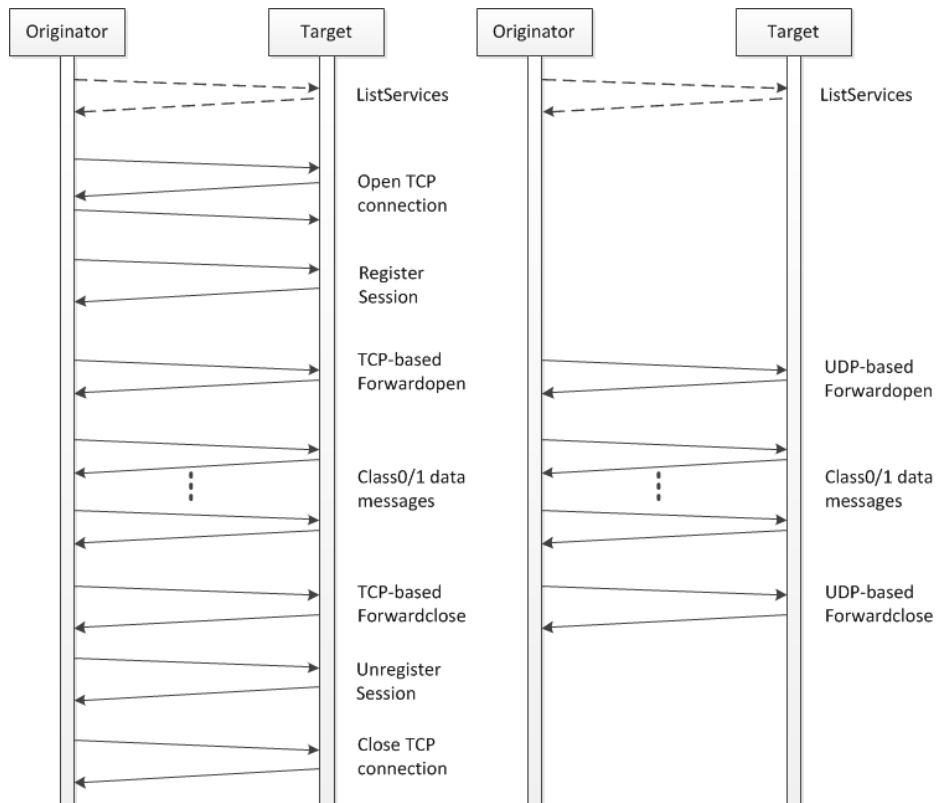


Figure 4 Comparison between TCP-based and UDP-based CIP Unconnected Message Sequence for Creating I/O Connections

For those IIoT things that do not need real-time communication, UDP-based CIP unconnected explicit communication pattern is the only communication pattern that needs to be implemented.

The simplified message sequence makes differences for the IIoT things. It makes the CIP unconnected explicit communication stateless, which is much easier and simpler to be implemented by the IIoT things.

Scalable EtherNet/IP Stack

By adding UDP-capable CIP unconnected explicit messages, a scalable firmware stack including both EtherNet/IP and TCP/IP stack could be developed for more wide applications as shown in the left diagram of Figure 5. The firmware stack with the TCP function could be used for the relatively complex EtherNet/IP devices. The firmware stack could be configured to the UDP-only stack for the resource-constrained IIoT things as shown in the right diagram of Figure 5. If the firmware stack is configured as the UDP-only stack, the code and data memory size will be reduced significantly by compiling off the TCP in the TCP/IP stack, the session and TCP encapsulation server in the EtherNet/IP stack, and the class 3 connection function in the EtherNet/IP stack. In addition the UDP-only EtherNet/IP stack still have the capability of opening I/O connections for the real-time I/O data communication.

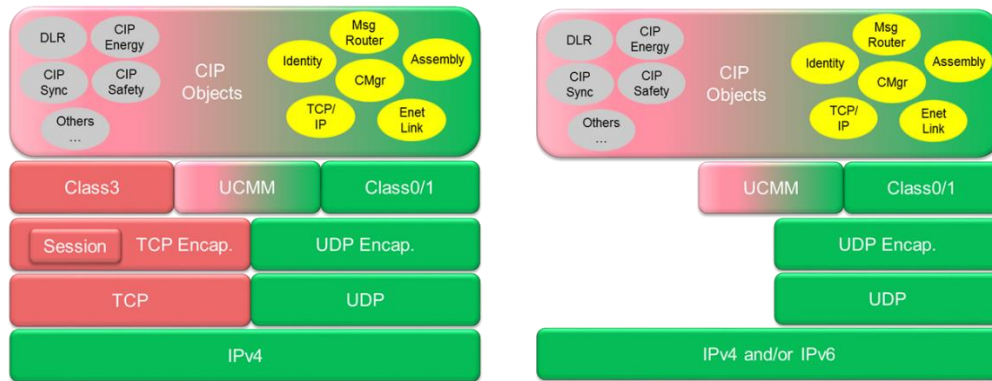


Figure 5 Firmware Structure of a Scalable EtherNet/IP Stack

5.2.2 Impacts on EtherNet/IP Products

A new implemented client MUST support both UDP and TCP methods to send or receive CIP unconnected explicit messages. A legacy client needs to be upgraded to have the UDP-cable CIP unconnected explicit message function to communicate with the new resource-constrained IIoT things.

A new implemented server MUST support at least one of UDP and TCP methods to send or receive CIP unconnected explicit messages. A new implemented resource-constrained industrial thing may only support the UDP method. A new complex system level device may support the TCP method, and may optionally support the UDP method. A legacy server will operate in a hybrid system with no modifications.

The client retrieves the server's capability by using the ListService or ListIdentity command, and then chooses the UDP or TCP method to communicate with the server. If the server supports both UDP and TCP methods, the client will pick either way based on the user's implementation (TCP preferred). If the client cannot get the server's capability with all above methods, then it may first try the TCP method and then try the UDP method.

5.2.3 Impacts on Advanced CIP Applications

Advanced CIP applications, such as CIP Safety™, CIP Sync™ and CIP Motion™, are usually not resource-constrained, so these applications should work with the TCP-based firmware stack.

Even with UDP-only firmware stack, these advanced applications are still achievable. All safety I/O packets, time-sync packets, and motion I/O packets are UDP packets. Creating safety connections and motion connections could be done via UDP-based unconnected messages just as creating standard I/O connections.

5.2.4 Firmware Experimental Result

Experiments are done on two EtherNet/IP stacks from two companies, one of which is Adapter only for an embedded device, the other one is SCANNER for a PC-based software application. Only 2-days have been spent on adding UDP transport for unconnected messages into the Adapter-only EtherNet/IP stack, and also making the Stack scalable to be configured as a UDP-only EtherNet/IP stack. Only 3-days have been spent on adding UDP transport for unconnected messages in the SCANNER EtherNet/IP stack. The changes on the code itself are very minor and easy for an EtherNet/IP stack developer. The changed EtherNet/IP SCANNER is able to communicate with the changed EtherNet/IP Adapter with UDP-only explicit messages. The changed EtherNet/IP SCANNER can also open/close class0/1 I/O connections through UDP-based ForwardOpen or ForwardClose messages. All UDP-based messages including ForwardOpen and ForwardClose are able to be well interpreted by the traffic analyzer tool WireShark.

Further analysis was made on the memory consumption of the whole experimental firmware including hardware drives, OS, TCP/UDP/IP stack, EtherNet/IP adapter stack, and an example application. The firmware is compiled in the release version with a medium optimization level. The EtherNet/IP sample application supports 3 explicit message clients with maximum 446 bytes explicit message size and 4 I/O connections with maximum 18 bytes I/O data size. The results are compared under the combination of firmware configuration of “with OS and with TCP” and “without OS and without TCP”. The analysis shows that 30.54% code (38.8Kbytes) and 51.99% RAM (39.3Kbyte) could be saved from the configuration of “with OS and with TCP” to the configuration of 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.

Table 4 Memory Consumption Analysis for EtherNet/IP Firmware

	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%

6. Conclusion

Industrial IoT will create new eco-systems of devices and suppliers to the industrial space. This paper identifies the likely attributes and constrains of these new devices, the enhancements to the EtherNet/IP adaptation of CIP required to allow these devices to integrate with a control system and these suppliers to participate in the ODVA community. The introduction of single pair Ethernet to EtherNet/IP is proposed to potentially and partially resolve the cost and size barrier in the Ethernet hardware for IIoT things, and the implementation of UDP-only EtherNet/IP stack is proposed to potentially and partially resolve the resource constrains in the communication protocol firmware. With these enhancements, EtherNet/IP would be able to be expanded into the 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.

References

1. IPSO Alliance: <http://www.ipso-alliance.org/>
2. IETF IPv6 over Networks of Resource-constrained Nodes (6lo): <https://datatracker.ietf.org/wg/6lo/charter/>
3. IETF Constrained RESTful Environments (core): <https://datatracker.ietf.org/wg/core/charter/>
4. IETF IPv6 over Low power WPAN (6lowpan) : <https://datatracker.ietf.org/wg/6lowpan/documents/>
5. OPEN Alliance link: <http://www.opensig.org/>

 The ideas, opinions, and recommendations expressed herein are intended to describe concepts of the author(s) for the possible use of ODVA technologies and do not reflect the ideas, opinions, and recommendation of ODVA per se. Because ODVA technologies may be applied in many diverse situations and in conjunction with products and systems from multiple vendors, the reader and those responsible for specifying ODVA networks must determine for themselves the suitability and the suitability of ideas, opinions, and recommendations expressed herein for intended use. Copyright ©2015 ODVA, Inc. All rights reserved. For permission to reproduce excerpts of this material, with appropriate attribution to the author(s), please contact ODVA on: TEL +1 734-975-8840 FAX +1 734-922-0027 EMAIL odva@odva.org WEB www.odva.org. CIP, Common Industrial Protocol, CIP Energy, CIP Motion, CIP Safety, CIP Sync, CompoNet, ControlNet, DeviceNet, and EtherNet/IP are trademarks of ODVA, Inc. All other trademarks are property of their respective owners.