Enhancements to EtherNet/IP for Constrained Devices and Networks

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Purpose of Paper

This paper presents a set of proposed enhancements, many adopted from or inspired by IETF and IEEE, making it possible to use EtherNet/IP on constrained devices and networks, thus enabling the single-network vision - where all devices in an industrial plant can communicate with the same set of protocols.

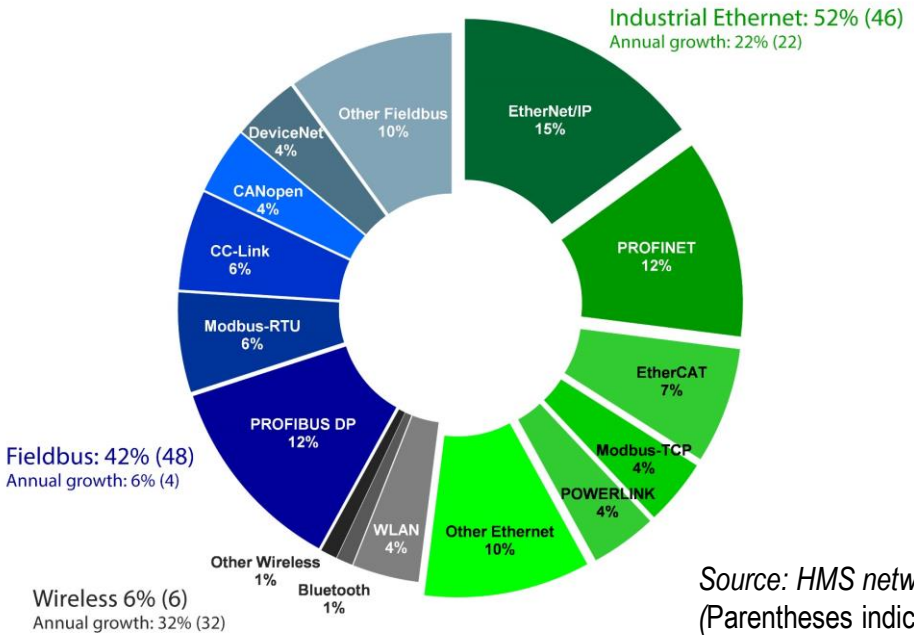
ODVA Community Interest

- ODVA Conference Papers have expressed interest in support for better addressing constrained devices
- 2014 – 2017
- Various applications:
  - Process Automation
  - In-Cabinet components
- Wired and wireless
- Considering usage of emerging technology
- See [1-6]

Industrial Network Convergence

Industrial Ethernet has exhibited rapid growth, with EtherNet/IP emerging as a leader.

Fieldbuses (and sensor networks) still retain a large position and many potential network nodes remain hardwired.

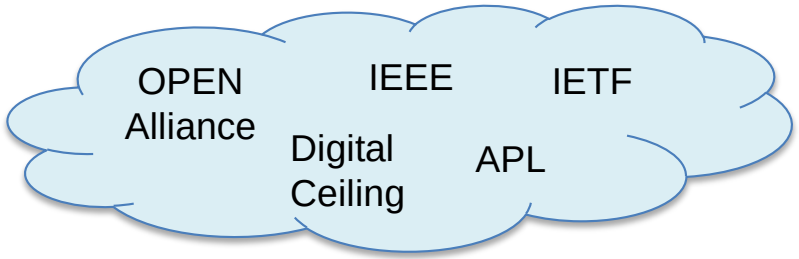


Source: HMS networks, Feb 2018
(Parentheses indicate 2017 numbers)

The Single Network Vision

End users understand and seek the advantages of a harmonized network - based on Ethernet, IP, and the related open ecosystem.

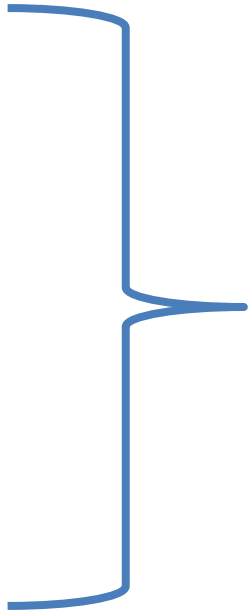
Organizations promoting Ethernet and IP to the edge
(See backup slide)



- Single network advantages include:
  - Higher performance for a similar cost
  - Elimination of costly application-specific gateways
  - Leverage of a large existing ecosystem (protocols, security, network switches, etc.)
  - Reduced installation, maintenance, and management complexity
  - Simplified integration with cloud applications
  - Reduced interoperability issues

Barriers to the “Single Network Vision”

- Cost adder
- Component footprint
- Power consumption
- System wiring complexity
- Cable distance
- Network power solution
- Intrinsic Safety compatibility
- Low power wireless solution
- Protocol complexity



The mix of Industrial Ethernet, fieldbuses, and hardwired nodes persists due to application constraints near the network edge.

IETF: Constrained-Node Networks

- *Constrained Node* characteristics:
  - Low cost
  - Small size
  - Limited memory [Flash, RAM], and processing resources
  - Limited power and energy [battery size or scavenging]
  - Limited upper layer services
  - Low weight

- *Constrained Network* characteristics:
  - Low bitrate or throughput
  - High packet loss
  - Variability delivery rate
  - Asymmetric traffic
  - Small packet size
  - Limited availability [device sleeps]
  - Limited upper layer services

"Terminology for Constrained-Node Networks" in https://tools.ietf.org/html/rfc7228

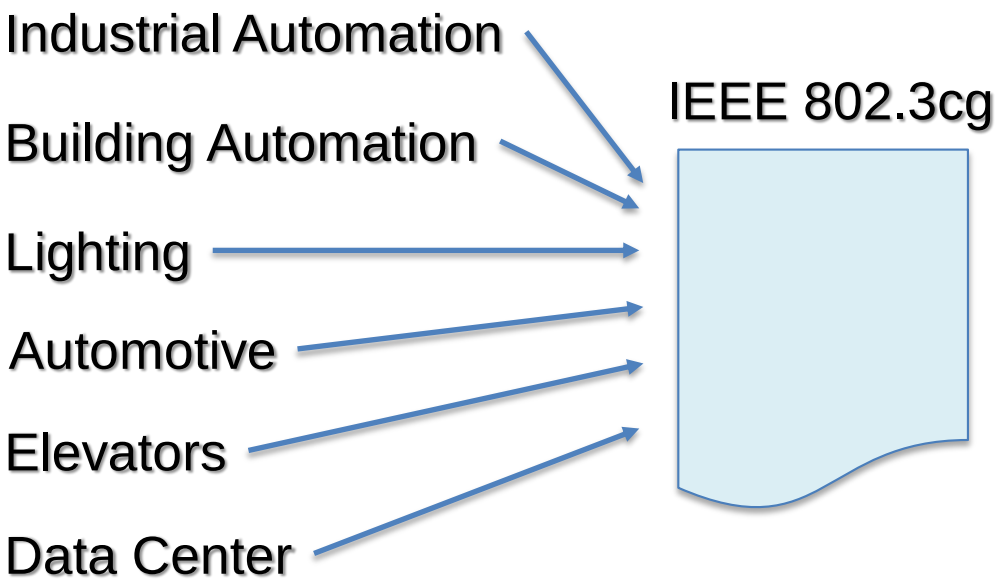
IETF: 6TiSCH Standards

- Enhancements for Constrained Nodes and Networks
- Applicable to both low power wireless and wired networks

- Features:
  - Eliminates TCP overhead (UDP-only)
  - Compresses messages
  - Expands the address space (IPv6)
  - Optimizes security (OSCORE)
  - Shrinks the Web server (CoAP)

IETF suite of IP standards solving IoT needs (similar to Fieldbus needs)

IEEE Single Pair Ethernet(s)



Numerous industries sought Ethernet enhancements to displace edge networks.

- **Communication and optional power over a single pair**
- **Reduction in wiring, node cost, size, and power consumption**

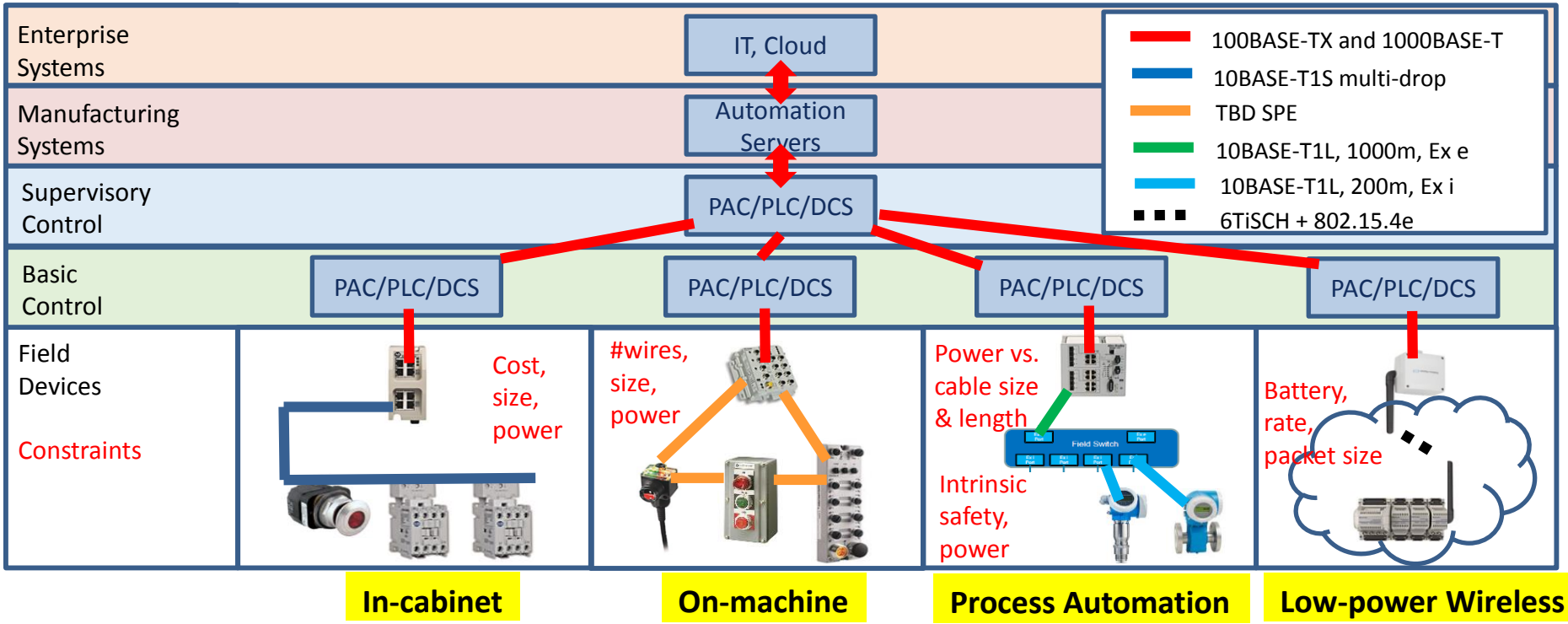
IEEE: Emerging SPE

- IEEE P802.3cg 10 Mbit/s SPE (Estimated 2019)
  - 10BASE-T1L
    - Targeted at process automation instruments
    - 1000 m, intrinsic safety compatible, legacy wiring
  - 10BASE-T1S
    - Targeted at replacing:
      - CAN, CAN FD, MOST and FlexRay in automotive
      - Hardwiring for in-cabinet components for industrial automation
      - I2C and SPI in data centers
    - 25 m multidrop option
    - Determinism by PHY-level Collision Avoidance (PLCA)

Addresses long distance

Addresses low cost control

Constrained EtherNet/IP application areas

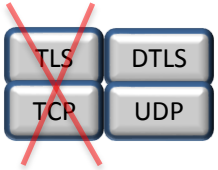


UDP-only option

UDP-only option

- Problem:
  - EtherNet/IP requires both TCP and UDP
  - TCP presents substantial overhead for constrained MCU limited Flash and RAM
  - “Chatty” TCP messaging reduces battery life in low power wireless devices
- Related Problem:
  - CIP Security requires both TLS and DTLS

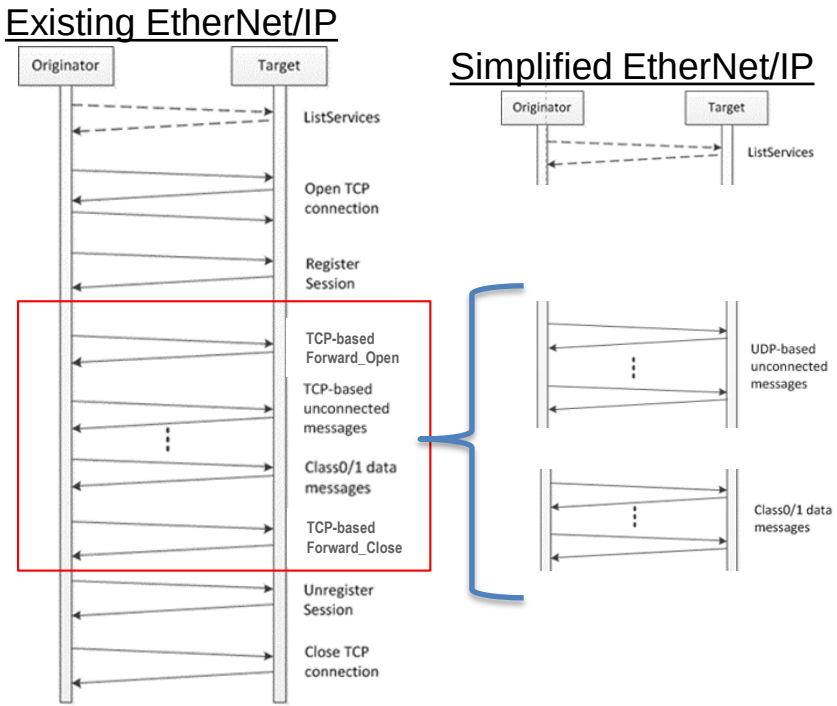
- Solution:
  - Add optional support for UDP-only and DTLS-only.



- Benefits:
  - *Use smallest MCUs*
    - UDP-only prototype shows 30% savings in Flash and RAM
  - *Draw enhancements from other sources*
    - Emerging IoT stacks like IETF CoAP rely on UDP exclusively

Simplified UDP-based Messaging

- ListServices identifies capability
  - UDP-only or TCP+UDP or Both
- No TCP connections
- No encapsulation sessions
- No bindings between TCP connections and EtherNet/IP sessions

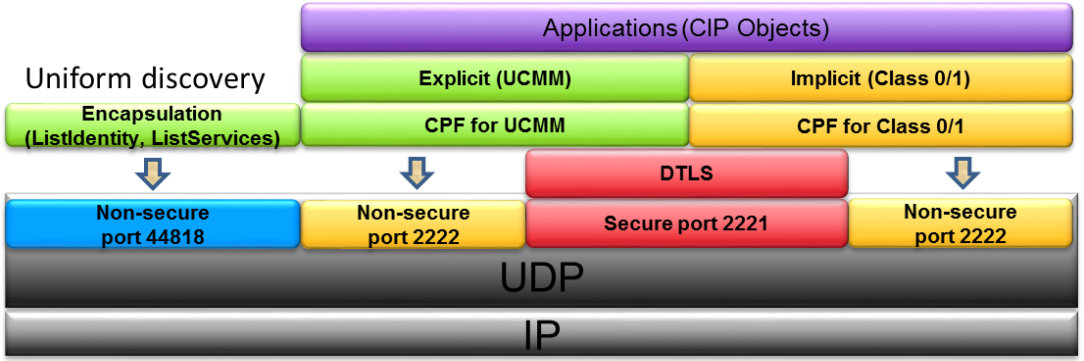


Message and stack complexity is reduced

Proposal

Existing Volume 8 Secure UDP-only

- Support both secure and standard UDP-only
- Extend for full set of services
- Develop a unified capability discovery method



Encapsulation and CPF Header Compression option

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Encapsulation and CPF header compression option

- Problem:
  - EtherNet/IP Encapsulation and CPF headers message overhead is significant for low power wireless networks
    - E.g., IETF 6TiSCH = 127B max.
    - Wireless constrains packet size to increase battery life
  - Large messages either cannot be sent or must be fragmented into multiple packets
    - Reduces battery life and increases latency
- Solution:
  - Compress EtherNet/IP encapsulation and CPF headers by well known (IETF 6TiSCH) techniques
    - Lossless “eliding” of header fields and options that rarely change
    - Added bits indicate the optional presence of byte or word fields (> 8:1 compression)
- Benefits:
  - *Increase battery life and reduce latency for low power wireless*

Proposal

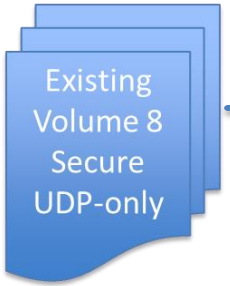
Evaluate Optional Compressions

- Encapsulation header
- CPF for Class 0/1
- CPF for UCMM
- CPFs used within CIP services

Prototype Examples

			ListIdentity	ListService	General UCMM	Class0/1
Header Compression and Command (HCC)		**Word Value**	0xB763	0xBF04	0xB76F	
	15	Header Comp. Flag	1	1	1	
	14	Reserved	0	0	0	
	13	Options	1	1	1	
	12,11	Sender Context	2	3	2	
	10	Status	1	1	1	
	9	Session Handle	1	1	1	
	8	Length	1	1	1	
	Bit7-0	Command	0x63	0x04	0x6F	
CPF Compression&Item Count (CCIC)		**Word Value**			0x8052	0x8092
	15	CPF Comp. Flag			1	1
	14	Message Type			0	0
	13,12	Reserved			0	0
	11,10	T->O Socketaddr			0	0
	9,8	O->T Socketaddr			0	0
	7,6	Data Item			1	2
	5,4,3	Address Item			2	2
	2,1,0	Item Count			2	2
Before compression (byte)			24	24	40	18
After compression (byte)			4	2	8	10

Multiple Items



- Replaces and shrinks Encapsulation header
- Could be reduced further

Constrained EtherNet/IP Physical Layers

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Constrained EtherNet/IP Physical Layers

- Problem:
  - EtherNet/IP does not support appropriate physical layers for several constrained application areas:
    1. Process Automation wired instruments for APL
    2. Process Automation companion wireless instruments
    3. In-cabinet components

- Solution:
  - Reference and extend 3 new PHYs:
    1. IEEE P802.3cg 10BASE-T1L PHY
    2. IEEE Std 802.15.4-2015 PHY
    3. IEEE P802.3cg 10BASE-T1S PHY

- Benefits:
  - *Support important constrained EtherNet/IP application areas*

Constrained EtherNet/IP Communication Profile

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Constrained EtherNet/IP Communication Profile

- Problem:
  - EtherNet/IP does not support constrained device and network requirements
- Solution:
  - Develop a constrained EtherNet/IP *communication* profile

Communication Profile

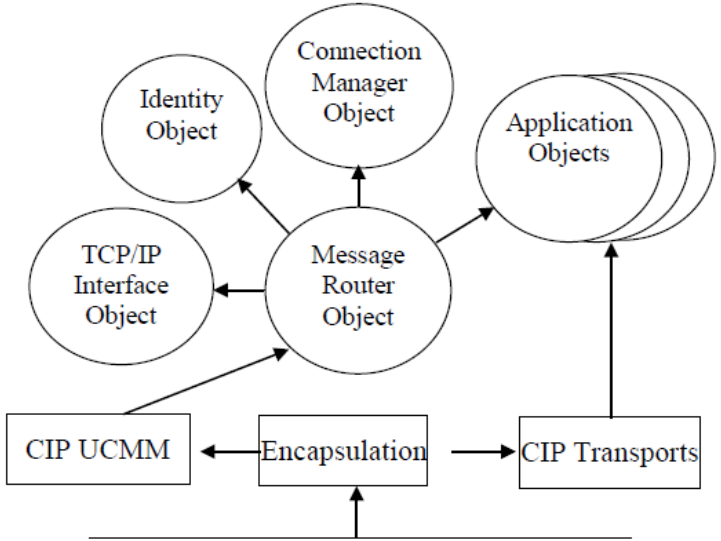
Required:
- UDP-only
- Minimum objects
- UCMM and Class 1 only
- Simplified Connection Manager object

Optional:
- DTLS-only security
- Encapsulation header compression
- IPv6 mapping

Minimum device object model

- Same base objects for constrained EtherNet/IP, but minimize implementation of base objects
- Optional compression of Encapsulation and CPF headers
- Minimized CIP transports over UDP
  - UCMM + Class 1 only

Figure 6-2.1 Base Device Object Model



Object minimization example - **Connection Manager**

Original Definition in EtherNet/IP Specification	Simplified Implementation for Constrained Devices
Object level simplifications	
20 optional attributes	Zero attributes
4 common services	Zero common services
8 object specific services	2 object specific services (Forward_Open and Forward_Close)
Service level simplifications	
Class 0 and 1 I/O connection	Class 1 I/O connection
Unicast and multicast	Unicast
Class 2 and 3 explicit connection	No explicit connection, UCMM only
CIP Routing	No CIP Routing
Listen-only or redundant owner	No redundancy

Constrained EtherNet/IP Capability CPF Item

- New “Constrained EtherNet/IP Capability” CPF item
  - Discover constrained device’s EtherNet/IP capability using ListIdentity
- New EDS entry [Constrained EtherNet/IP Capability]
  - Describe constrained device’s EtherNet/IP Capability

Field	
Type ID	Constrained EtherNet/IP Capability
Length	
Link Type	0 = Ethernet 1 = 802.15.4e
TCP/IP Type	TBD (future compression or feature reduction capabilities)
Encapsulation & CPF Compression	WORD1: ENCAP Header Compression Profile WORD2: CPF Compression Profile
CIP Transport Type	Bit 0 = UCMM Bit 1 = Class 1
CIP Application Type	Bit 0 = Active Report Manager

Constrained EtherNet/IP over 6TiSCH Network

9-2 Data Link Layers

Though this specification is called “EtherNet/IP”, Ethernet is technically not required. The EtherNet/IP protocol may be used on any media that supports the transmission of the Internet Protocol.

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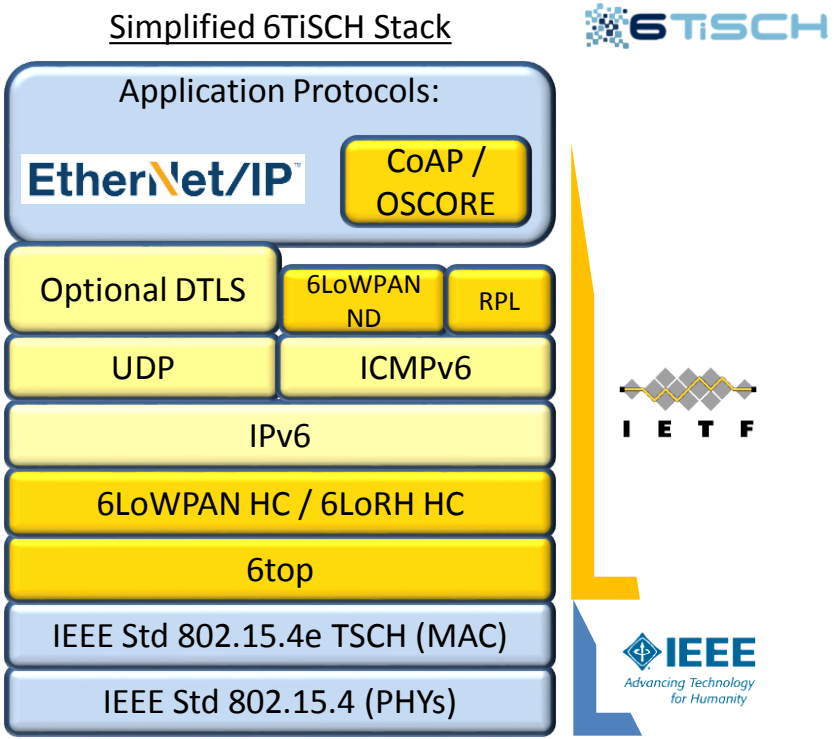
Constrained EtherNet/IP over 6TiSCH Network

- Problem:
  - EtherNet/IP does not have a low power wireless option
- Proposed Solution:
  - Specify necessary enhancements for EtherNet/IP over 6TiSCH:
    - Leverage proposed constrained EtherNet/IP enhancements
    - Add 802.15.4 MAC and PHY
    - Add 6TiSCH router and network management objects
    - IPv4/6 mapping to integrate 6TiSCH devices into IPv4
- Benefits:
  - *Complements wired Process Automation (under APL)*

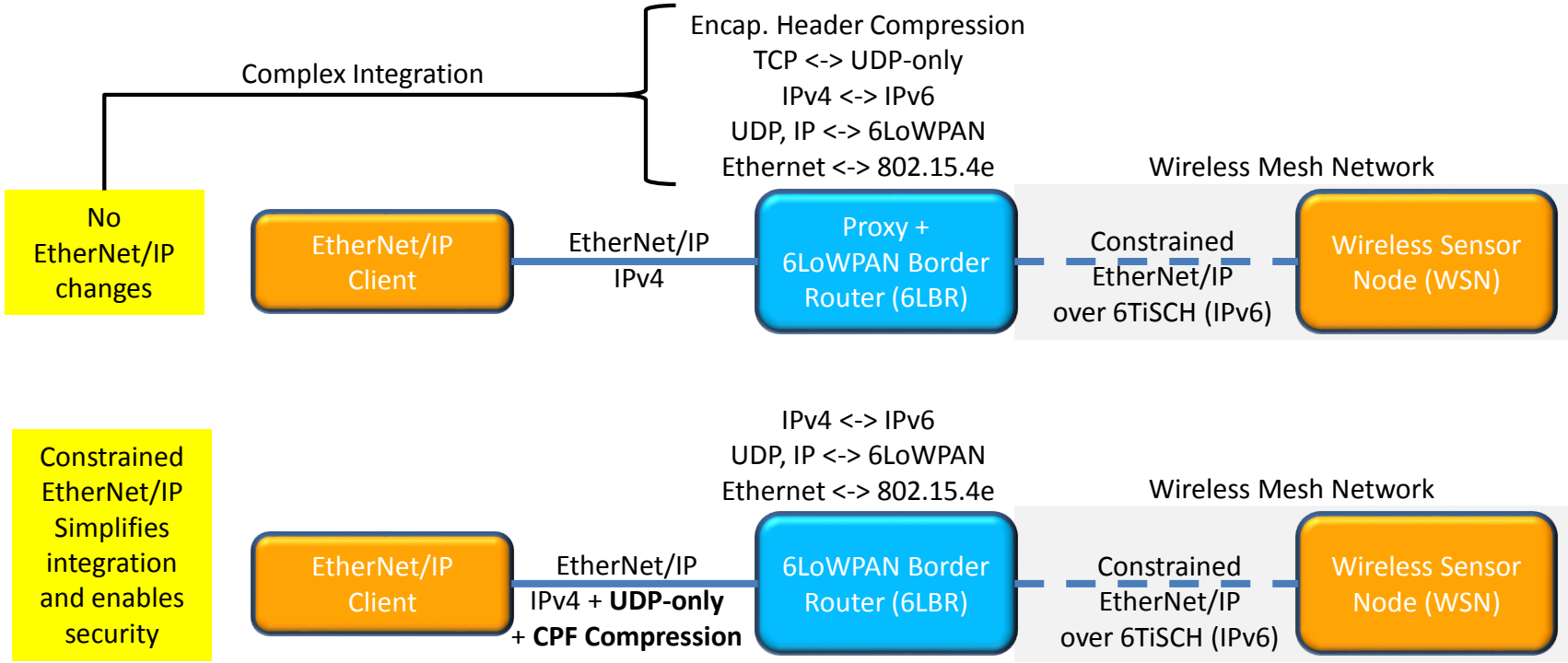
A full IPv6 solution would be beneficial, but is not proposed

Motivation for IETF 6TiSCH

- Open (not industry specific) wireless standard
- IP-based communication
- Self-organizing mesh network
  - Robust, reliable, less engineering
- The market leader:
  - "By 2023, there will be **4.5 billion** 802.15.4 mesh devices sold worldwide."
    - https://onworld.com/research/zigbee/vip/

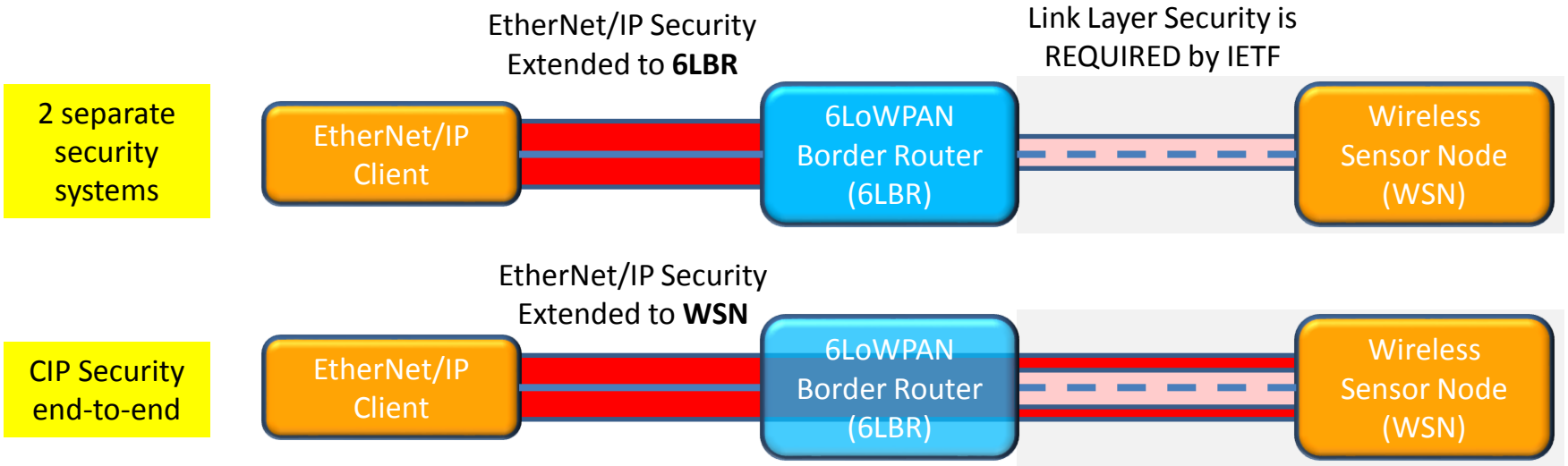


Prototype: Important Enhancements for Integration of Constrained EtherNet/IP over 6TiSCH



Security for Constrained EtherNet/IP over 6TiSCH

- CIP end-to-end security is precluded by any 6LBR processing of the application layer (Encapsulation Layer compression)
- 6TiSCH requires IETF OSCORE security for network join, DTLS has some increase in overhead



New objects for 6TiSCH Network

- 804.15.4 link object
  - In both 6LBR and WSNs
  - Similar to Ethernet: Interface Speed, Flags, Counters, State, Label, Capabilities, Physical Address…
  - New: RF characteristics

- 6TiSCH wireless network management object
  - In 6LBR
  - Network status information
  - Network topology information
  - Network routing information
  - Device join and leave

Stack Summary

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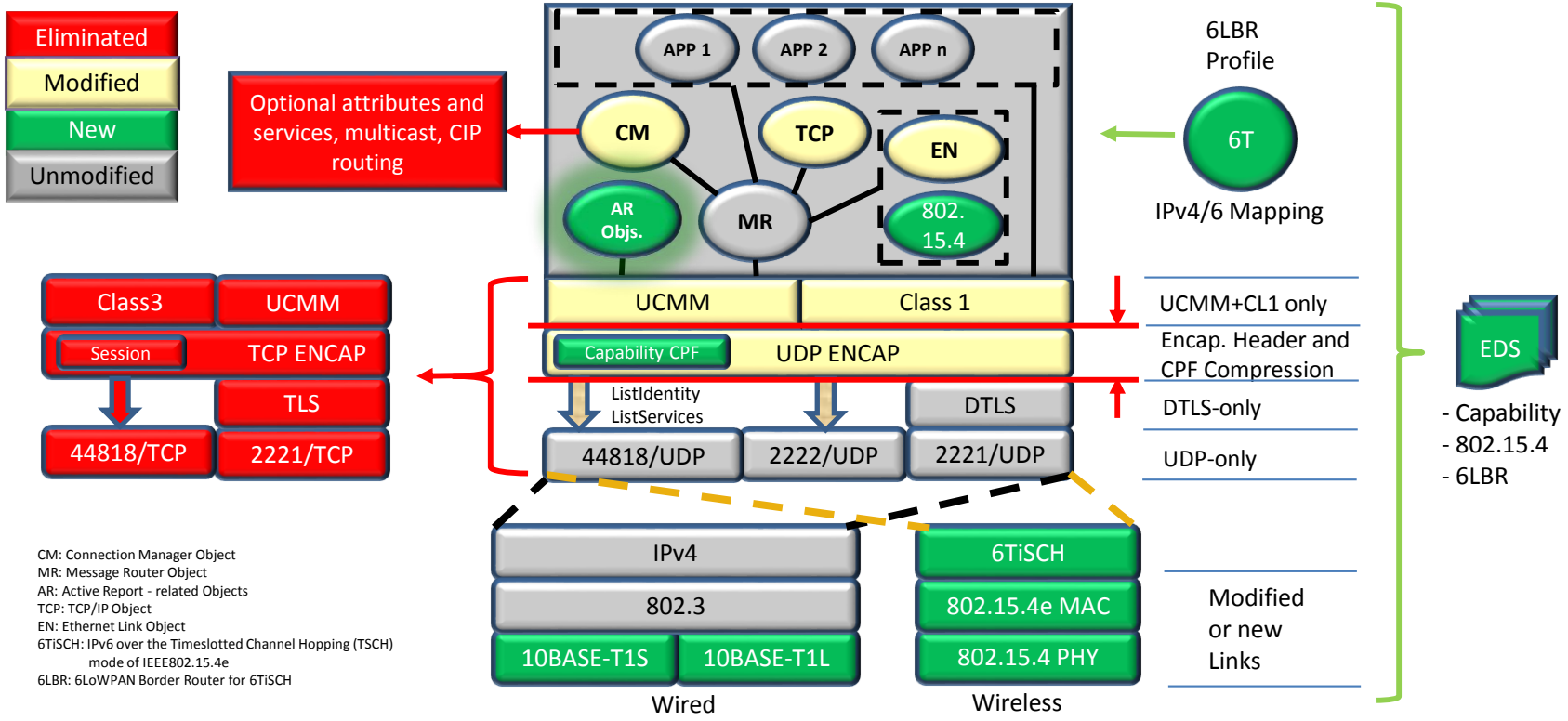
Constrained EtherNet/IP Stack



CM: Connection Manager Object
MR: Message Router Object
AR: Active Report - related Objects
TCP: TCP/IP Object
EN: Ethernet Link Object
6TiSCH: IPv6 over the Timeslotted Channel Hopping (TSCH) mode of IEEE802.15.4e
6LBR: 6LoWPAN Border Router for 6TiSCH

THANK YOU

References

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Outside efforts related to expanding Ethernet and IP to edge devices

- OPEN Alliance: One Pair EtherNet Alliance, Automotive industry organization focused on the all-Ethernet car
- Digital Ceiling: LED lighting connected and powered by Ethernet with PoE, augmented by sensors and wireless communication
- IEEE: Standard for Single Pair Ethernet for Automotive, Industrial, Lighting, Building, Elevator, Data Center, etc., reducing cost/size/weight
- IETF: Standards for IP protocol enhancements for constrained devices
- APL: Advanced Physical Layer, Process Automation effort to bring Ethernet to instruments and other field devices