Drive Control via EtherNet/IP using CIP Motion and CIP Sync Profile Extensions

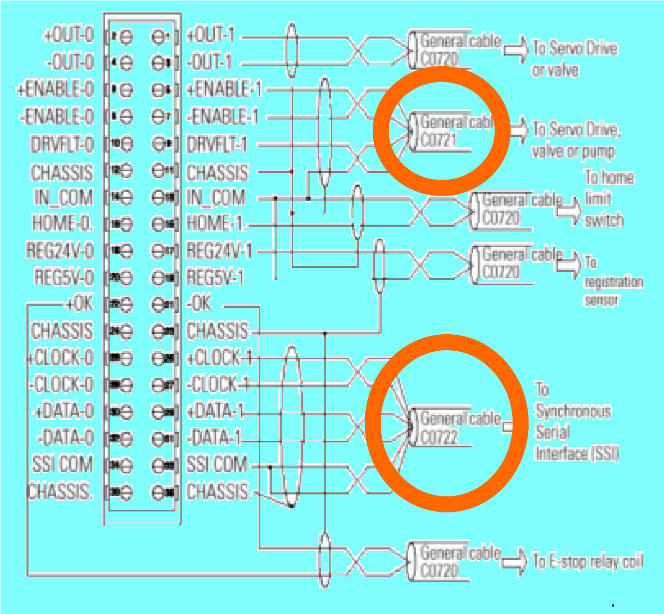
High-Performance Closed Loop Drive Control Using EtherNet/IP

- This session will discuss why Industrial Ethernet is emerging as the network technology of choice for control of high performance drives.
- EtherNet/IP with CIP Sync and CIP Motion will be presented as an example of an Ethernet solution which provides high performance drive control, and peer-to-peer motion synchronization.

1. Drive interface technology overview
2. Digital Motion Network Evolution
3. Emergence of EtherNet for Drive Control
4. EtherNet/IP with CIP Motion Overview

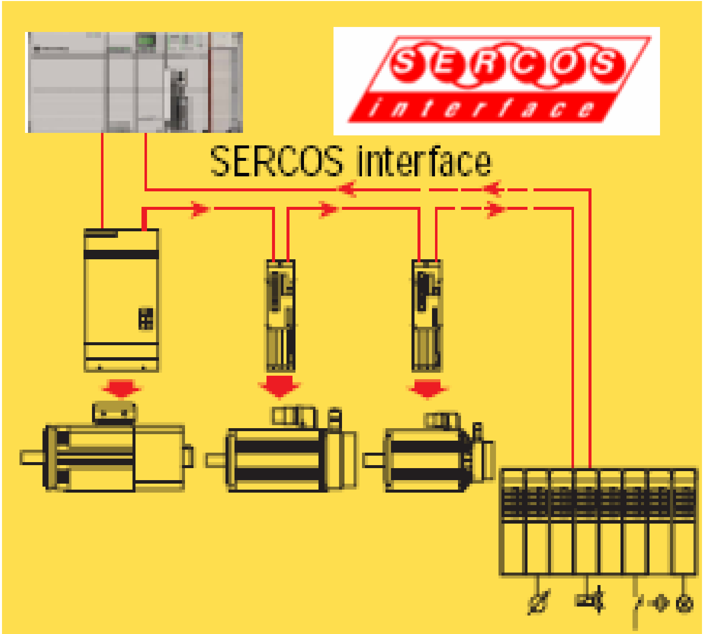
Closed Loop Drive Control Interface Options

- Analog
  - First motion interface, has a long history
  - Wide range of interoperable controls and drives from multiple vendors
  - Significant disadvantages
    - 12 discrete low level noise sensitive signals for drive command and feedback
    - Limited feedback resolution
    - Lack of drive/motor configuration and diagnostics communications
- Digital network
  - First generation introduced in the early 1990's
    - Optimized for closed loop drive control
  - Significant advantages
    - Replacement of discrete signals with a single network connection
    - Distributed control loops for higher performance
    - Support for distributed, high resolution, multi-turn absolute feedback
    - Drive/motor configuration and diagnostic communications
  - Disadvantages
    - Difficulty integrating products from multiple vendors – proprietary, many standards
    - A separate network is typically required for field bus device support



Digital Motion Network Evolution

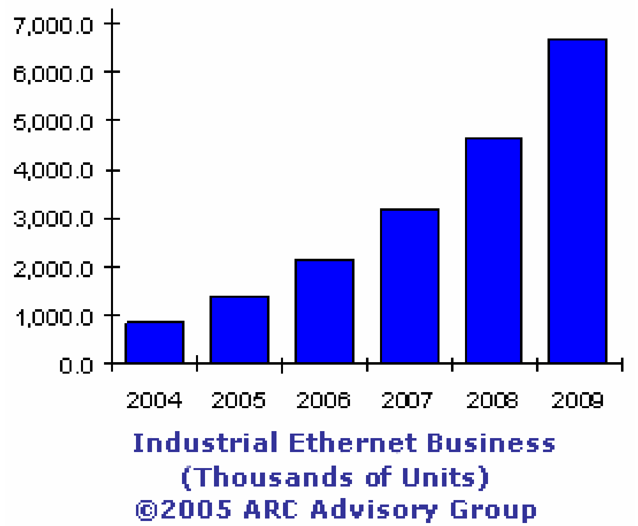
- There are a number of open and proprietary *"first generation"* motion network solutions
  - SERCOS interface was one of the earliest motion control network standards
    - Development started in 1985, introduced in 1992,
    - Defined by the IEC 61491 standard
    - Has the broad vendor community support with over 60 vendors
    - Optimized motion network



- Limitations of *"first generation"* motion networks have driven the introduction of *"second generation"* motion network standards
  - Early solutions were based on FireWire (IEEE 1394)
    - Adept
    - Nyquist
    - Ormec
  - Recent introductions are based on Ethernet technology
    - PowerLink
    - PROFInet
    - SERCOS III
    - EtherNet/IP with CIP Motion

Emergence of Ethernet for Closed Loop Drive Control

- Ethernet has always been attractive as a possible solution for high performance, closed loop drive control
  - Widely available, low cost standard hardware and software infrastructure components
  - Continuous improvements in capability and performance
  - Growing installed base in the industrial market
  - Support for a broad class of devices

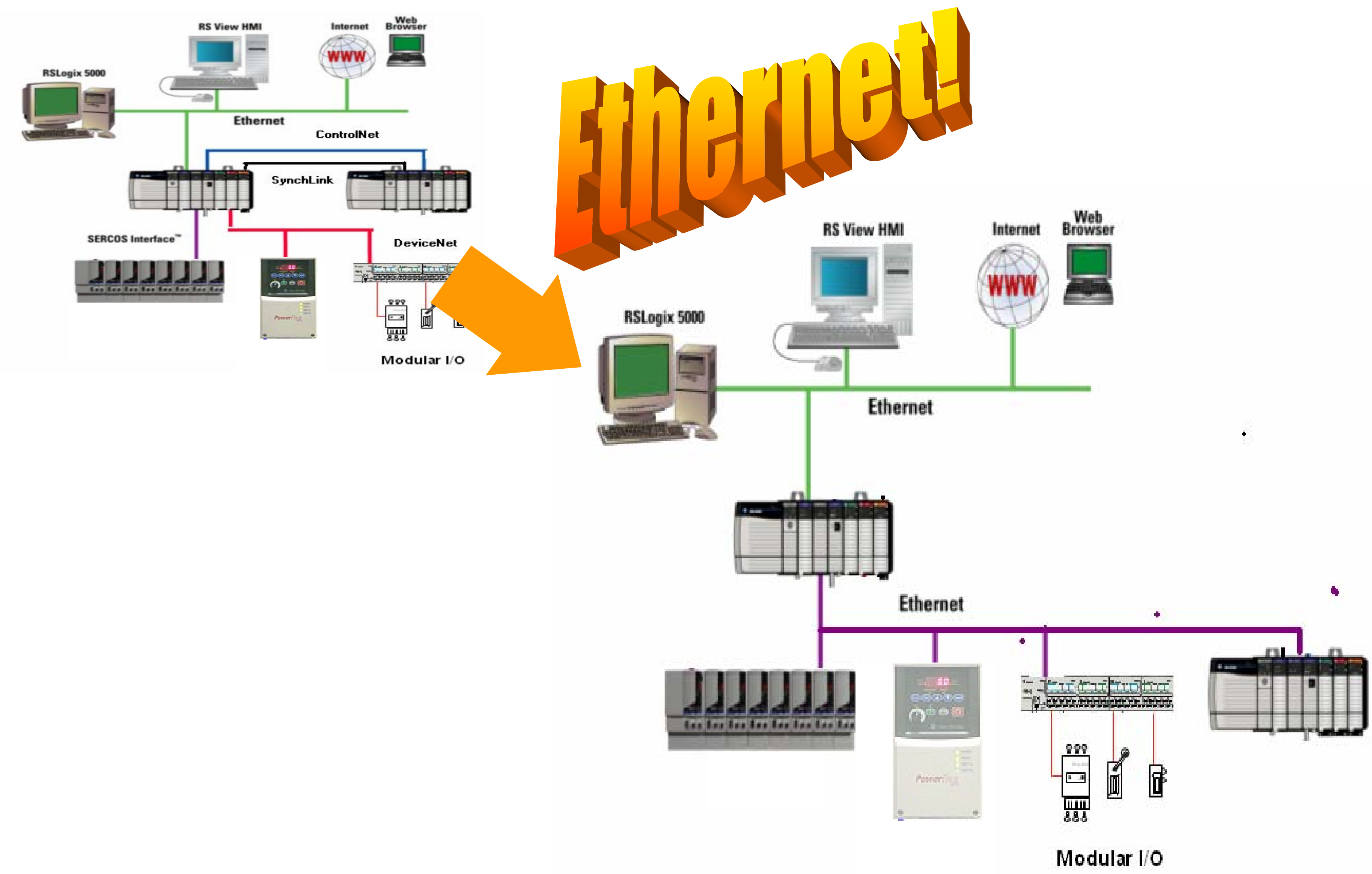


Recent advances make Ethernet suitable for Industrial, hard real-time control

- Early Ethernet
  - 10 mega baud
  - Half-duplex operation
  - Hub-based distribution
  - Transmission collisions
  - No frame prioritization
  - No time sync services
  - Low network reliability
  - High cost per node

- Ethernet today
  - 100 Mega Baud "Fast Ethernet"
  - Full-Duplex → 200 Mega Baud
  - Switch-based Distribution
  - No Transmission Collisions
  - QoS Frame Prioritization
  - IEEE-1588 Time Sync Service
  - Proven Industrial Reliability
  - Low Cost per Node (Built-in)

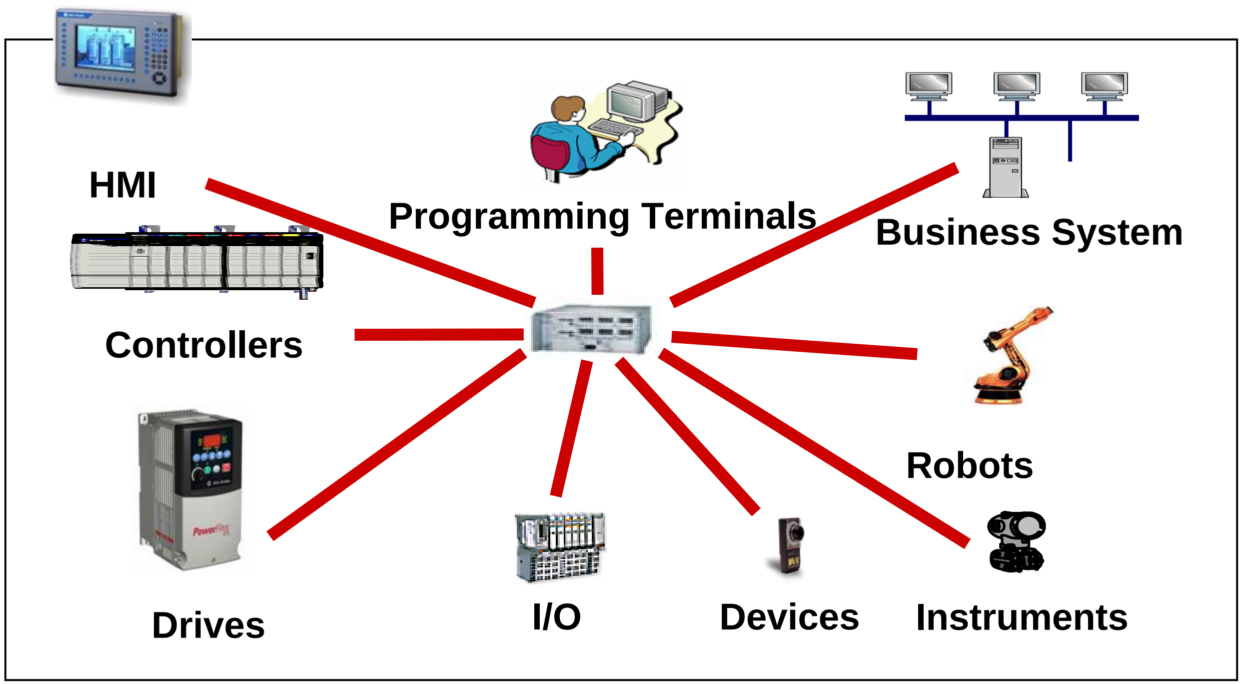
Eliminating Network Fragmentation - Key Driver



Ethernet Broad Technology Mix – Key Driver

Commercial Technologies

- Wireless
- Email
- Webpage
- FTP
- Remote Access
- Voice Over IP
- Video Over IP
- Other Commercial Technologies



Real-Time Plant Floor Control

Mix Industrial, Business and Commercial Technologies to Solve Applications – Plant-wide

Ethernet Based Solutions with Closed Loop Drive Support

	PowerLink	SERCOS III	SynqNet	EtherCat	PROFInet - IRT	EtherNet/IP CIP Motion
Nodes shipped	50,000	Not Shipping		3,500	Not Shipping	EtherNet/IP shipping CIP Motion not shipping
Managing Organization	EPSG	IGS	SynqNet Users Group	ETG	PNO	ODVA
Network Focus	Fieldbus with motion	Specialized motion bus	Specialized motion bus	Fieldbus with motion	Fieldbus with motion	Fieldbus with motion
Industry Focus	General	General	Electronics/Semi/Medical	General	General	General
Standard Enet Hardware	Yes	No FPGA or Comms Processor	No FPGA	No FMMU ASIC	No ERTEC 200/400 ASIC 2/4 port Switch/ARM 9	Yes
License Required	No	No	Yes - Master No-slave	No	No	No
"Standard" Ethernet	Open mode - Yes Protected mode -No Master polled transmissions	No Master/slave Scheduled ASIC required	No Master/slave Scheduled ASIC required	No Master/slave Polled ASIC required	No ERTEC ASIC switches normal and IRT traffic	Yes
UDP/TCP-IP Support	Yes Gateway required in protected mode	Yes Gateway required	No	Yes	Yes	Yes
Performance	<1us jitter 100 axes @ 1ms 200us min. cycle	<1us jitter 8 axes @ 32.5us (no IP messaging)	<1us jitter 4 axes @ 25us 10us min. cycle	<1us jitter 100 axes @ 100us	<1us jitter 100 axes @ 1ms 200us min. cycle	+/- 100 ns time synchronization 100 axes @ 1ms 200us min. cycle
Topology	Star Line Tree	Dasiy Chain Ring	Dasiy Chain Ring	Star Line Dasiy chain	Star Line Dasiy chain	Star Line Dasiy chain
Device Profile	CANopen	SERCOS	API	CANopen SERCOS other	Profi ProfiDrive	CIP with CIP Motion

EtherNet/IP with CIP Motion, CIP Sync

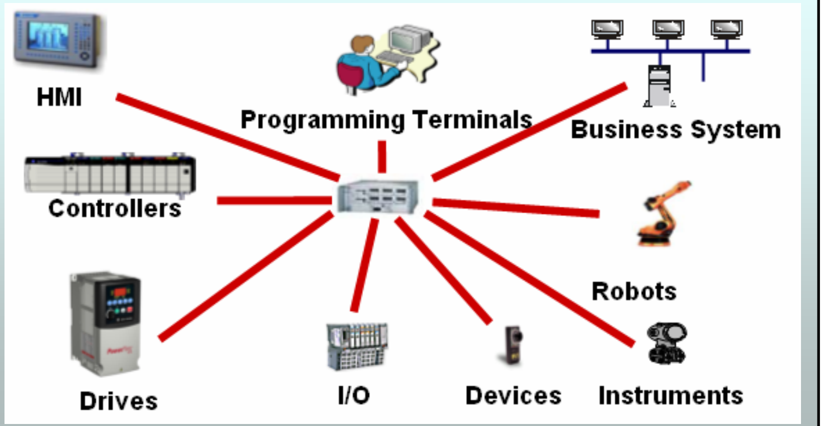
EtherNet/IP

- EtherNet/IP is a industrial Ethernet solution which provides information, configuration and diagnostics, control, and safety services
- Based on CIP – "Common Industrial Protocol"
  - ODVA is the managing organization for CIP and EtherNet/IP
- 1,000,000 node installed base, with over 230 products from a wide range of vendors

CIP Motion, CIP Sync

- CIP extensions which provide new real-time control services
  - Distributed node time synchronization
  - Closed loop drive control
  - Peer to peer control and drive synchronization
- Managed by ODVA Distributed Motion JSIG
- CIP April 2006 Specification Enhancement
  - CIP Motion Control Axis Object
  - CIP Motion Drive Axis Object
  - CIP Motion Drive Device Profile
- EtherNet/IP first implementation focus

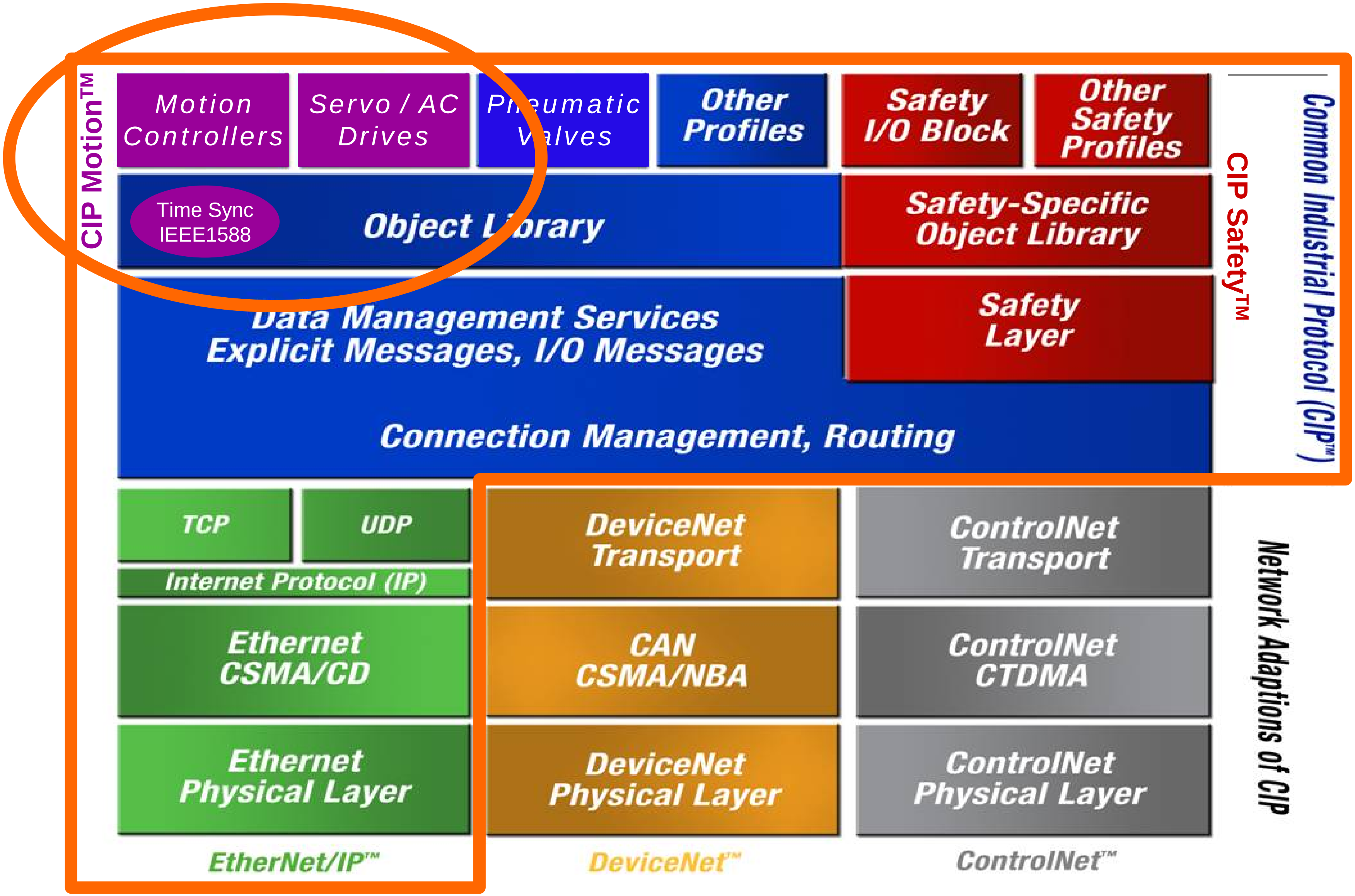
EtherNet/IP Capabilites and Devices



What is CIP Motion™?

- CIP Common Extensions to Support Motion Control
  - CIP Motion Axis Object
    - Defines Attributes, Services, and Behavior of Motion Axis Instances associated with a Motion Device, incl. drives, encoders, etc.
  - Motion Control Axis Object
    - Defines Attributes, Services, and Behavior of Motion Axis Instances associated with a Motion Controller.
  - CIP Motion Drive Device Profile
    - Defines Dynamic Connection Data Structures
    - Defines Motion Data Transfer Timing Model
    - Includes CIP Sync Time Sync Object
      - CIP Sync Time Sync Object defines the time synchronization services
- Capability Focus
  - Closed and open loop control of a broad class of drives/motors
    - From V/hz to closed loop vector to servos
    - Open loop, and closed loop position, velocity, and torque
    - Centralized and distributed planner (future) configurations
  - Control peer-to-peer motion synchronization
    - Gearing, camming, complex interpolation across distributed controllers

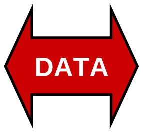
CIP Supported Technologies



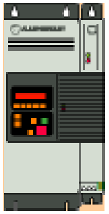
Motion Network Requirements

- Synchronization Services
  - Need a mechanism to synchronize all controller and drive nodes in the system to a common time-base with sub-microsecond accuracy, node-to-node.

- Timely Data Transfer - determinism
  - Need enough network bandwidth and packet-processing power to guarantee timely exchange of cyclic data between multiple controller and drive nodes at sub-millisecond update rates.

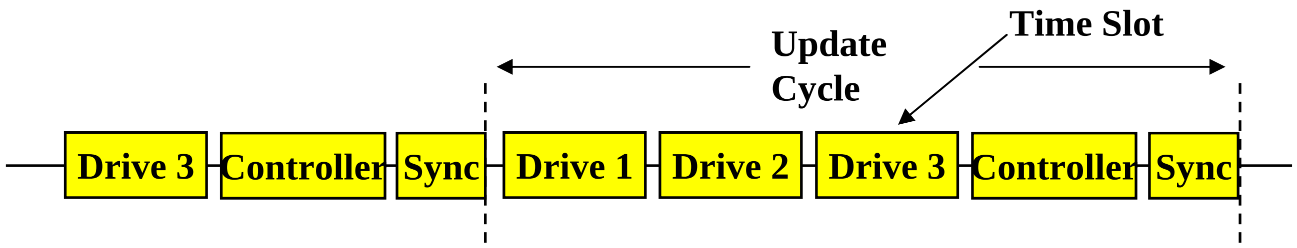


- Motion Control Device Profiles
  - Need well-defined device profiles to provide a common interface to a wide variety of contemporary motion control devices including drive profiles that span from simple volts/hertz drives to vector controlled servo drives.



Traditional Design Approach - Determinism

- Many solutions employ proprietary mechanisms to provide data delivery determinism
  - Use of Proprietary Media Access Hardware/Software to Control Device Network Access.
  - Use of Special EtherType or UDP Port Packet Format
  - Use of Proprietary Gateways to Re-schedule non-Motion Packet Transmission
  - Schedule Update Cycle into Transmission Time-slots for each Device on the Network.



- Implications
  - Non-standard Ethernet Infrastructure
    - Switches, Gateways, & Routers
  - Proprietary Silicon in Device Nodes
  - Compromised Interoperability with Standard Ethernet Devices, Tools, and Services.
  - Complex Time Slot Schedule Configuration
    - Scheduled Network is Incompatible with Standard Ethernet Devices

CIP Motion EtherNet/IP - Standard Technologies

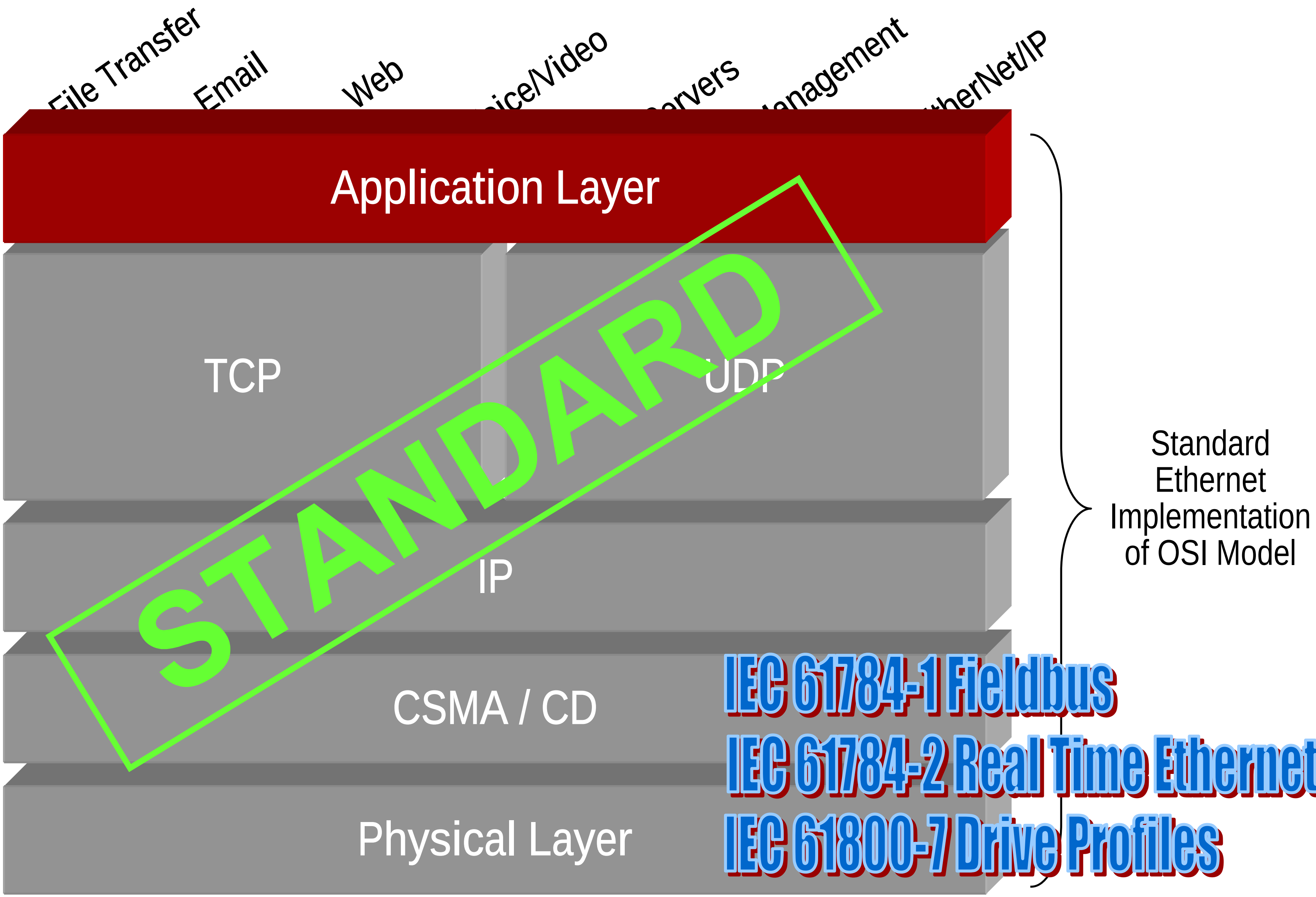
CIP Motion EtherNet/IP Technologies

- Employ Standard Mechanisms to Insure Timely Data Transfer
  - Use Full-Duplex 100-BaseT or 100BaseF “Fast” Ethernet.
  - Use Ethernet Switches to Eliminate Collisions.
  - Use QoS Frame Prioritization to Eliminate Queuing Delays
- Employ Standard Mechanism to Synchronize Devices.
  - Use IEEE-1588-based CIP Sync to Synchronize Device Nodes.
- Employ Simple Data Transfer Timing Models.
  - Do Not Constrain Device Node Transmission.
- Employ Time-stamped Data to Relax Data Delivery Requirements.
  - Time stamp data at the end nodes
  - Provide “Ride-thru” Mechanism to Extrapolate through any Unexpected Late or Lost Ethernet Packets.

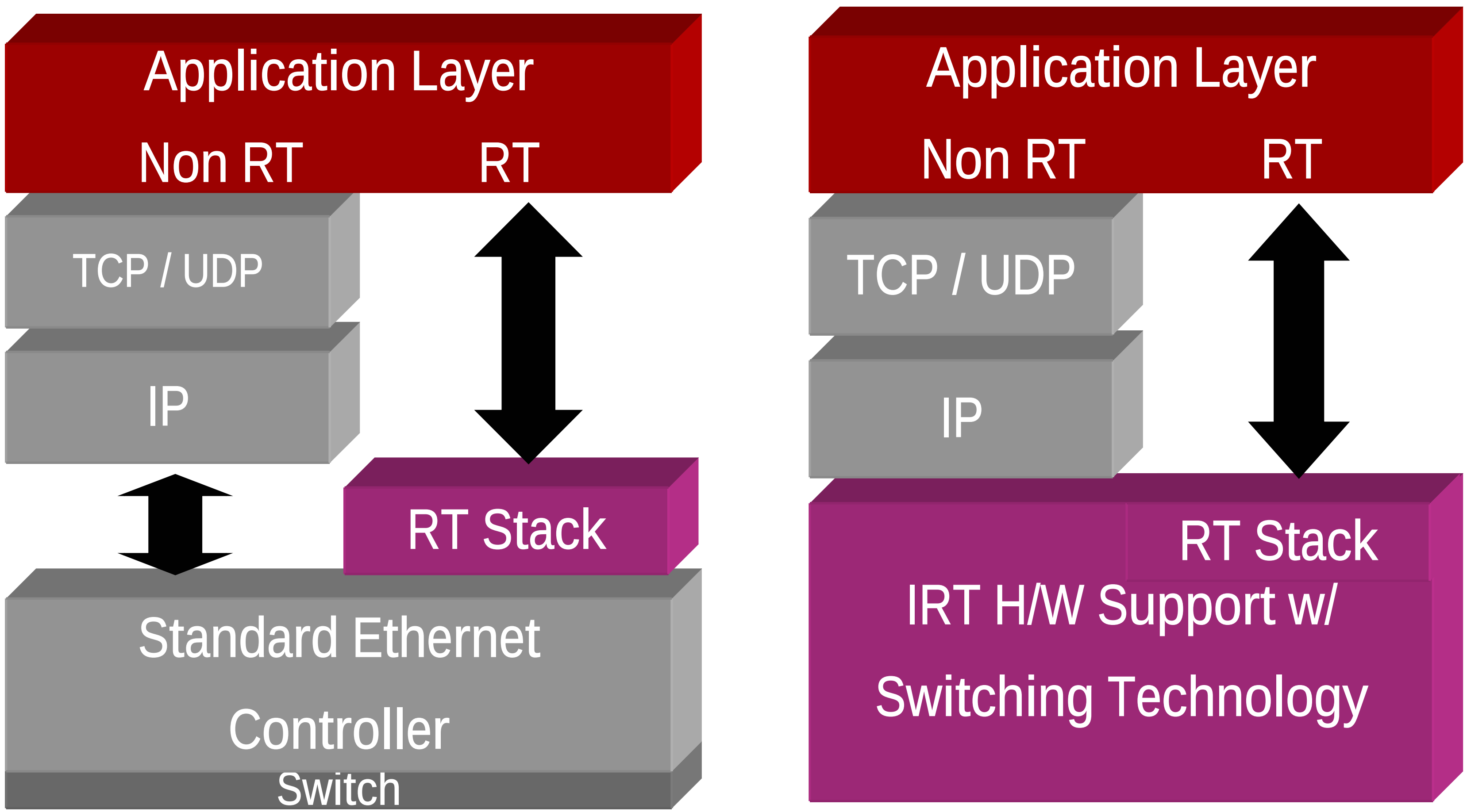
CIP Motion on EtherNet/IP

- Standard 802.3 Ethernet Components
  - Standard Phy, CPU MAC Ports, Switches, Routers
- Standard EtherNet Protocols
  - Standard TCP/UDP/IP
  - Standard 802.1Q QoS frame prioritization
  - Standard IEEE-1588 Time synchronization
  - Standard Ethernet network diagnostic tools
- Standard 802.3 CSMA/CD data link layer
  - Does not require proprietary algorithms like scheduling the network

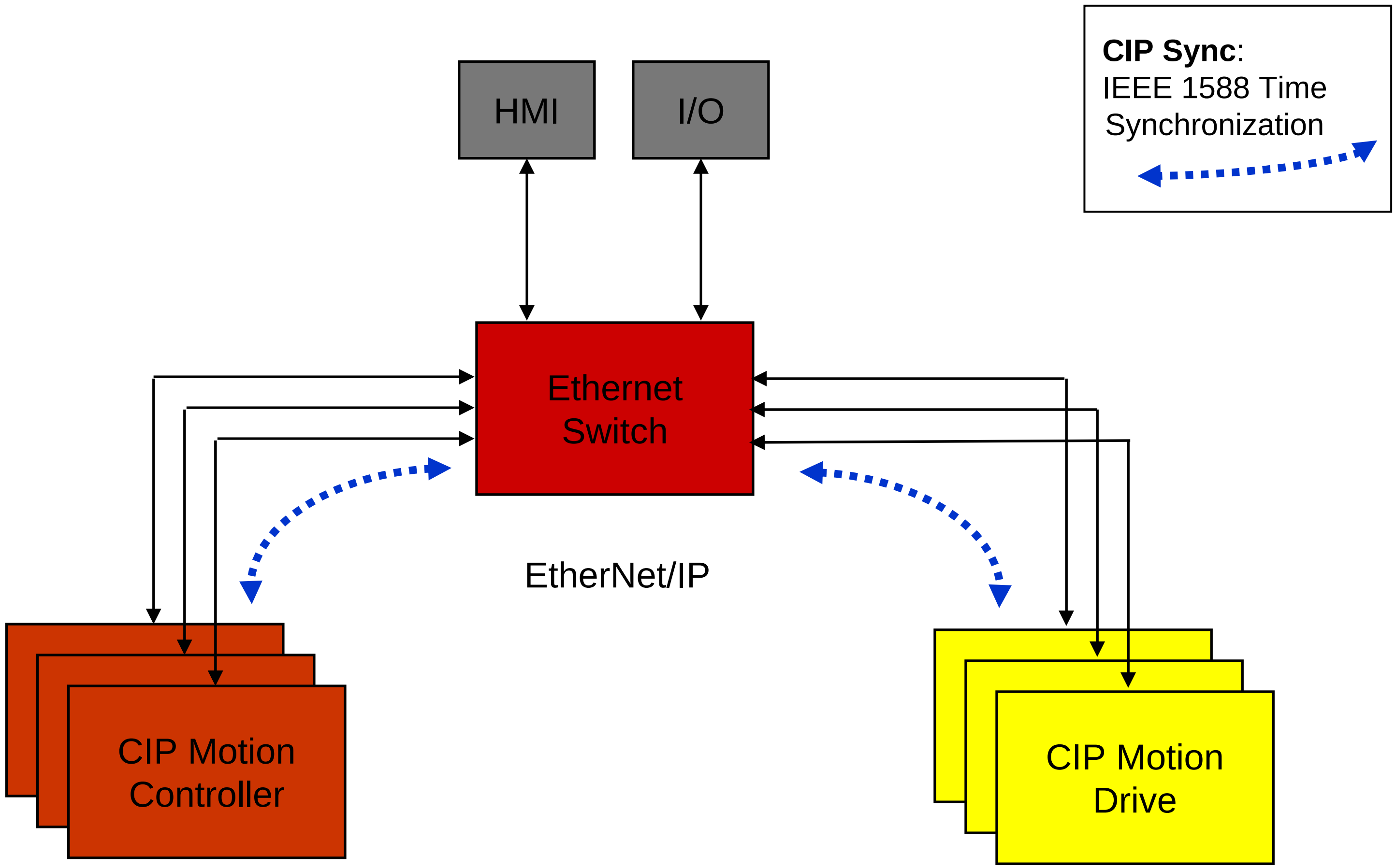
EtherNet/IP - Standard Protocol Model



Standard vs. Standards-Based Networking

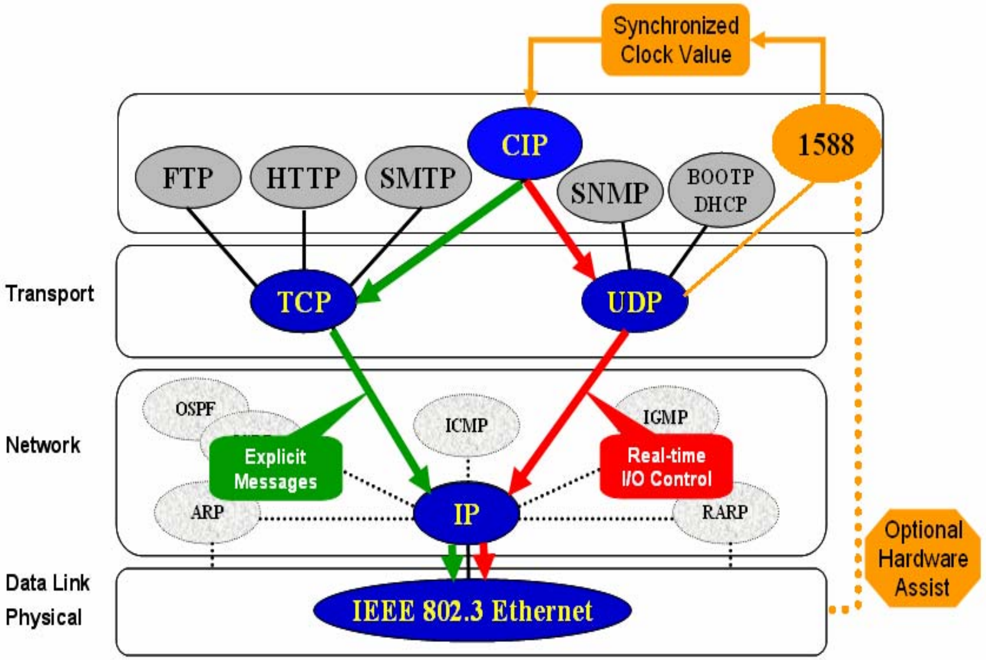


EtherNet/IP with CIP Motion



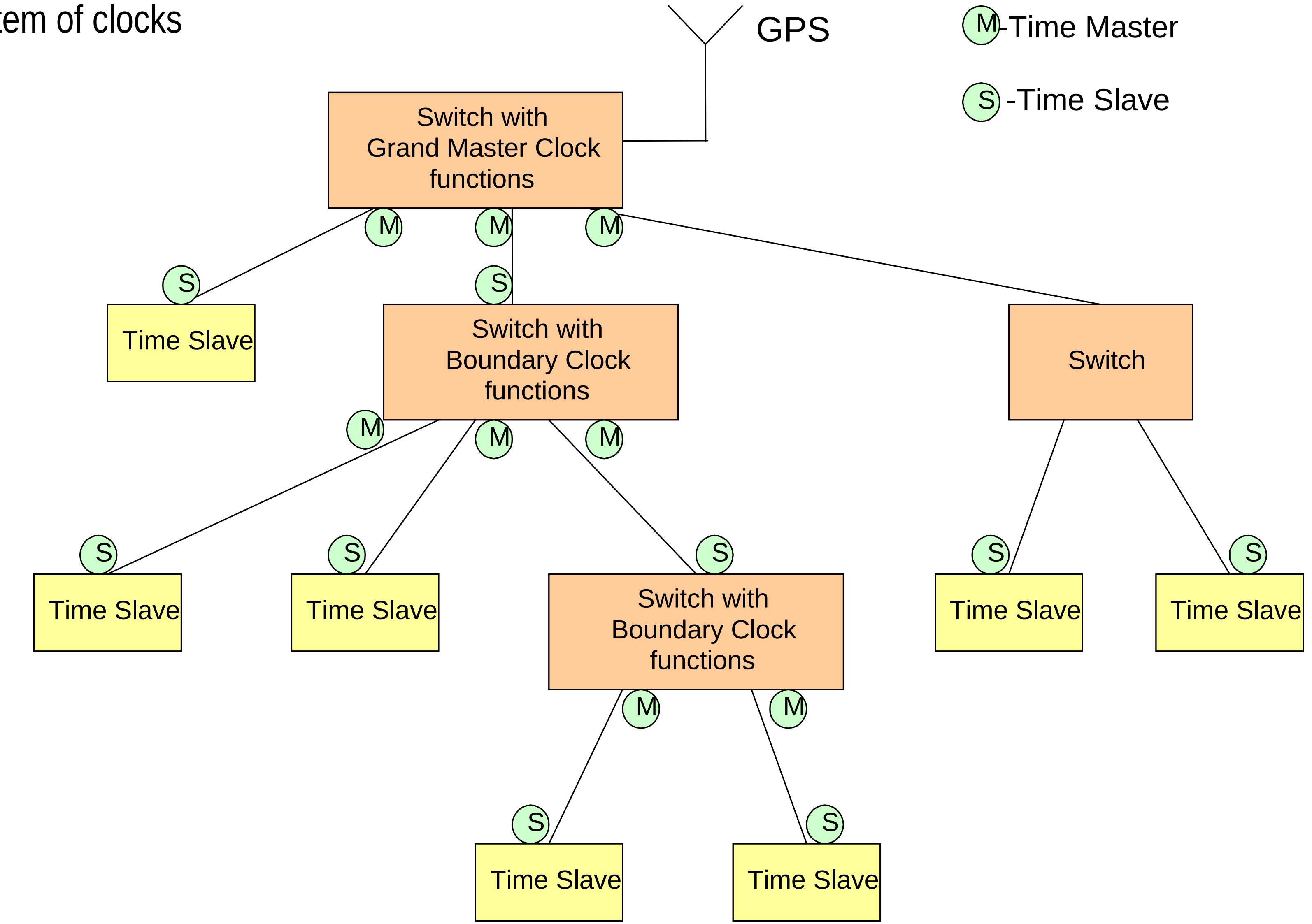
CIP Sync Time Synchronization Services

- System-wide synchronization for CIP-based Networks
  - CIP Sync ™ = CIP Network + IEEE-1588
- IEEE 1588
  - "Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems"
  - "Precision Time Protocol" (PTP) definec by standard.
  - Nanosecond resolution
  - +/- 100 nanosecond synchronization (Hardware-assisted clock)
  - +/- 100 microsecond synchronization (Software clock)
- Defines
  - System Time data representation
  - Clock Model for each node
  - Timestamp Step Compensation Algorithm
  - Time Sync Object for CIP

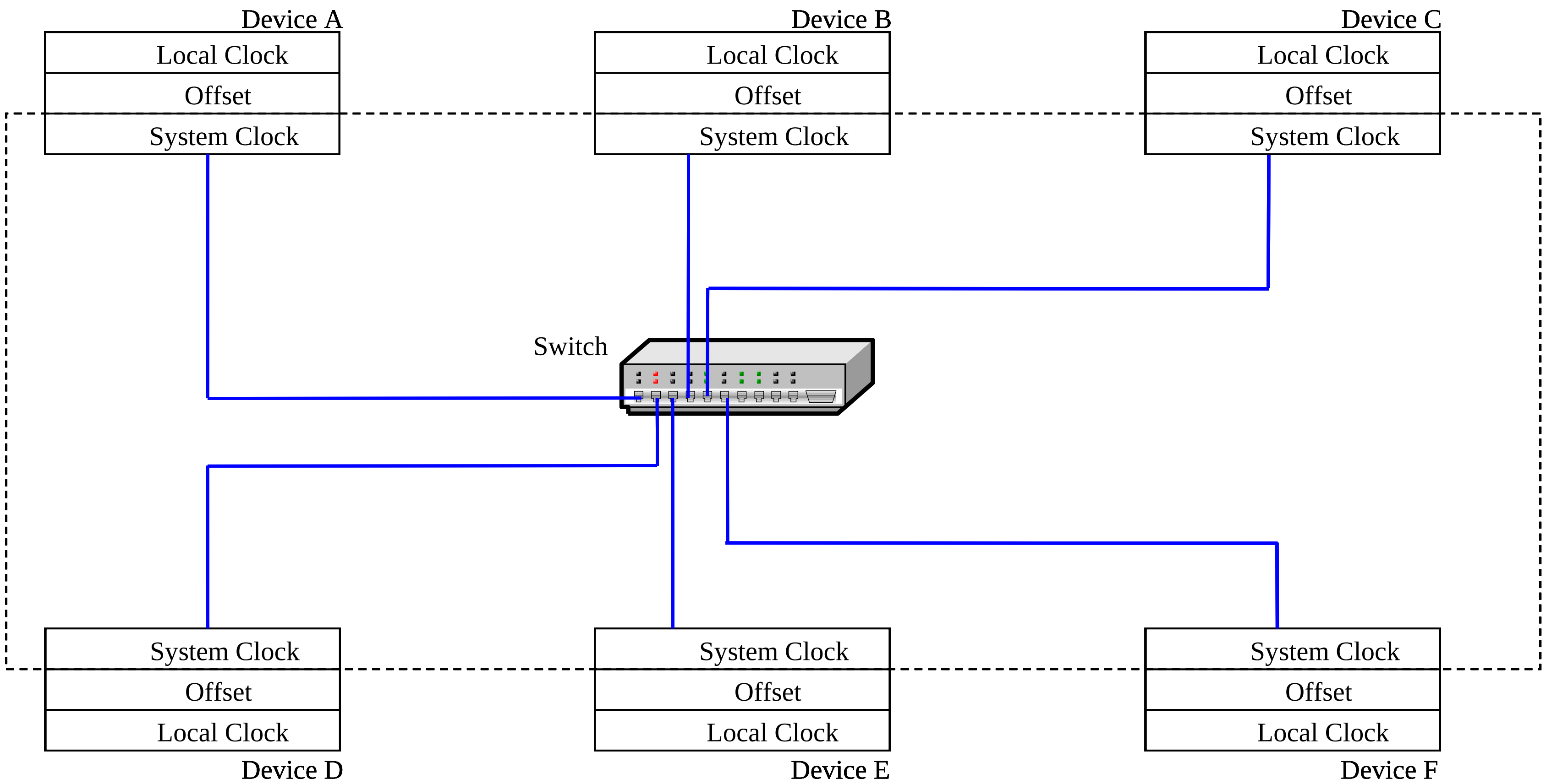


IEEE 1588 System Configuration

- System of clocks

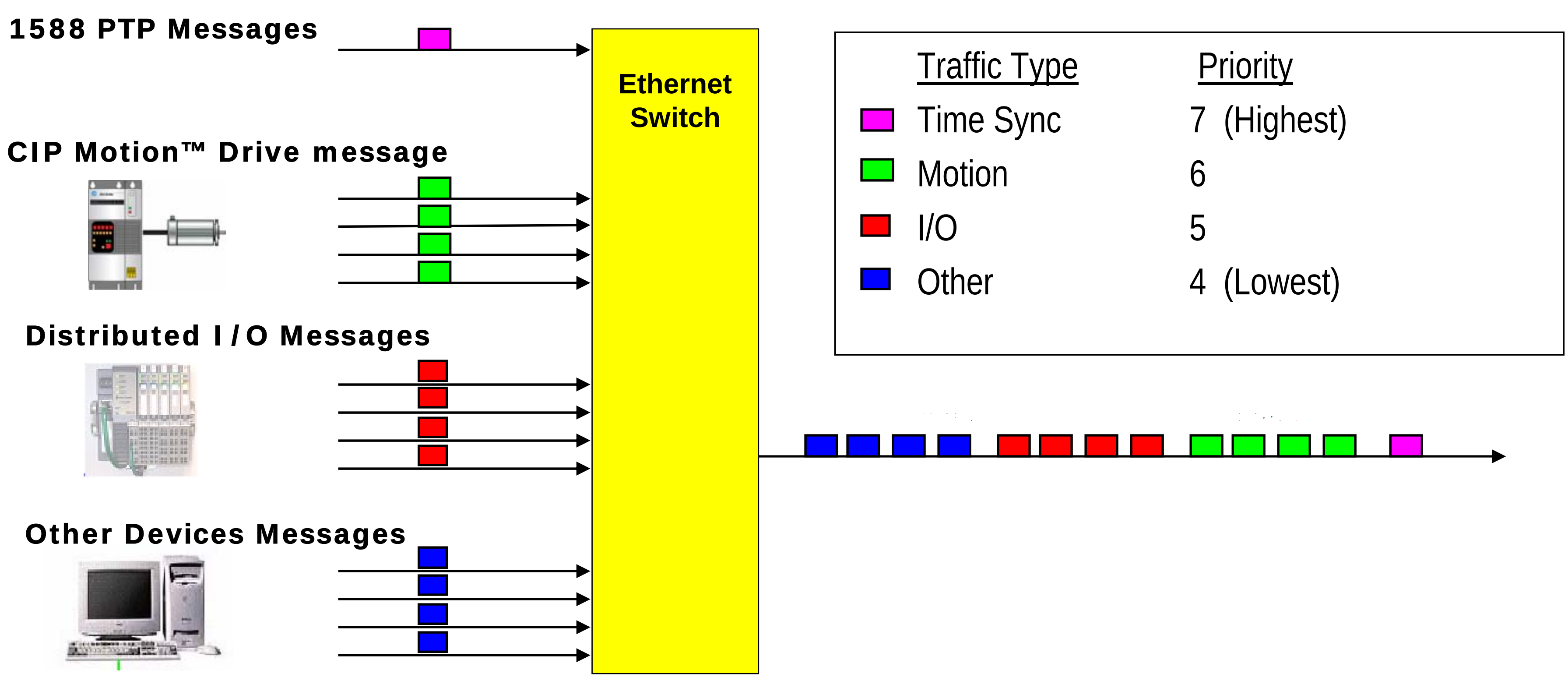


CIP Sync System of Clocks

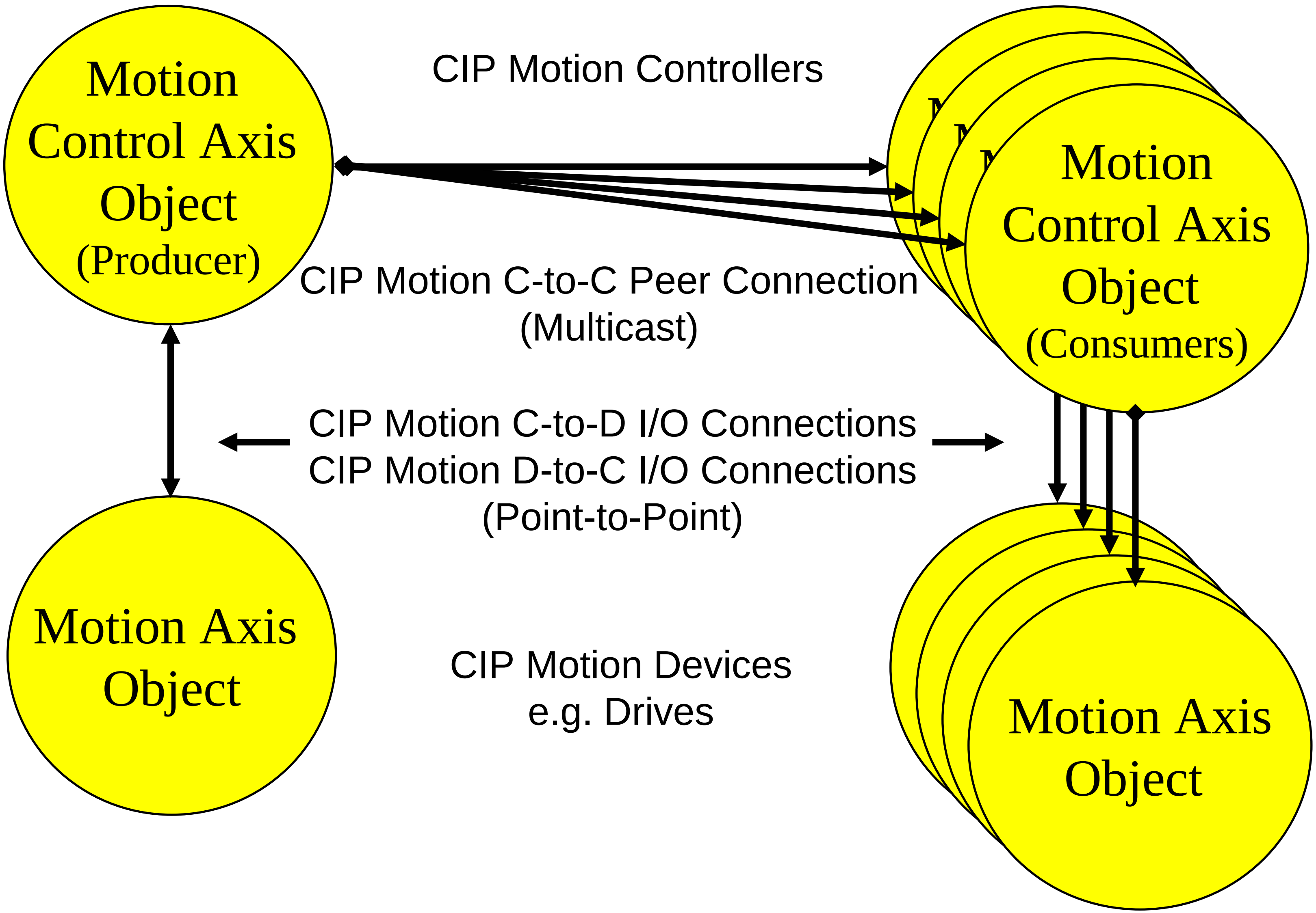


Quality of Service (QoS)

- CIP Sync implements Quality of Service
  - 802.1Q tagged frames on Ethernet
- Insures timely delivery of high priority traffic

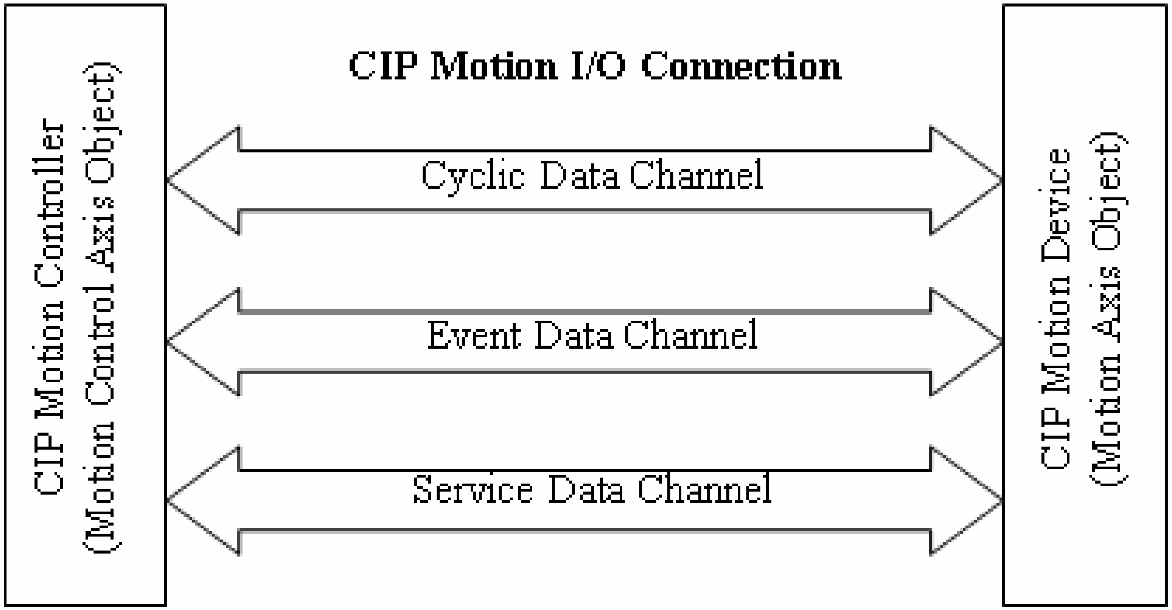


CIP Motion Connections



CIP Motion I/O Connection

- Based on Standard CIP Bi-directional Class 1 Implicit Point-to-Point Connection.
- Innovative Drive Connection Data Structure Supports 3 Prioritized Data Channels.



Flexible Connection Data Structures

- CIP Motion Connection Data Structure and Data Blocks can Change in both Size and Content.
- Data Format described in Connection Headers.
- Single Structure supports Multiple Axis Instances.
- Event Channel supports Multiple Events per Axis.
- Flexible Service Channel per Axis.

← 32-bit Word →

Controller-to-Drive Connection Format			
Connection Format	Format Revision	Update ID	Node Control
Instance Count	-	-	Time Config
Timing Data			
Instance Data Blocks			

Instance Data Block
Instance Data Header
Cyclic Data Block
Cyclic Write Data Block
Event Data Block
Service Data Block

Controller Update Period
Controller Time Offset
Controller Time Stamp

Flexible Connection Data Structures

0 = (Reserved)
1 = (Reserved)
2 = Fixed Controller-to-Device Connection
3 = Fixed Device-to-Controller Connection
4 = (Reserved)
5 = (Reserved)
6 = Variable Controller-to-Device Connection
7 = Variable Device-to-Controller Connection
8-15 = Reserved.

Controls the state of the associated drive communications node.

- Remote Control
  - ➢ 0 – under control of local drive interface
  - ➢ 1 - CIP Motion Controller
- Sync Control
  - ➢ 0 - Asynchronous Operation
  - ➢ 1 – Synchronous Operation
- Controller Data Valid
  - ➢ Allows the drive to check for valid data during initialization
- Node Fault Reset
  - ➢ Request for CIP Motion drive to perform a reset of the communications

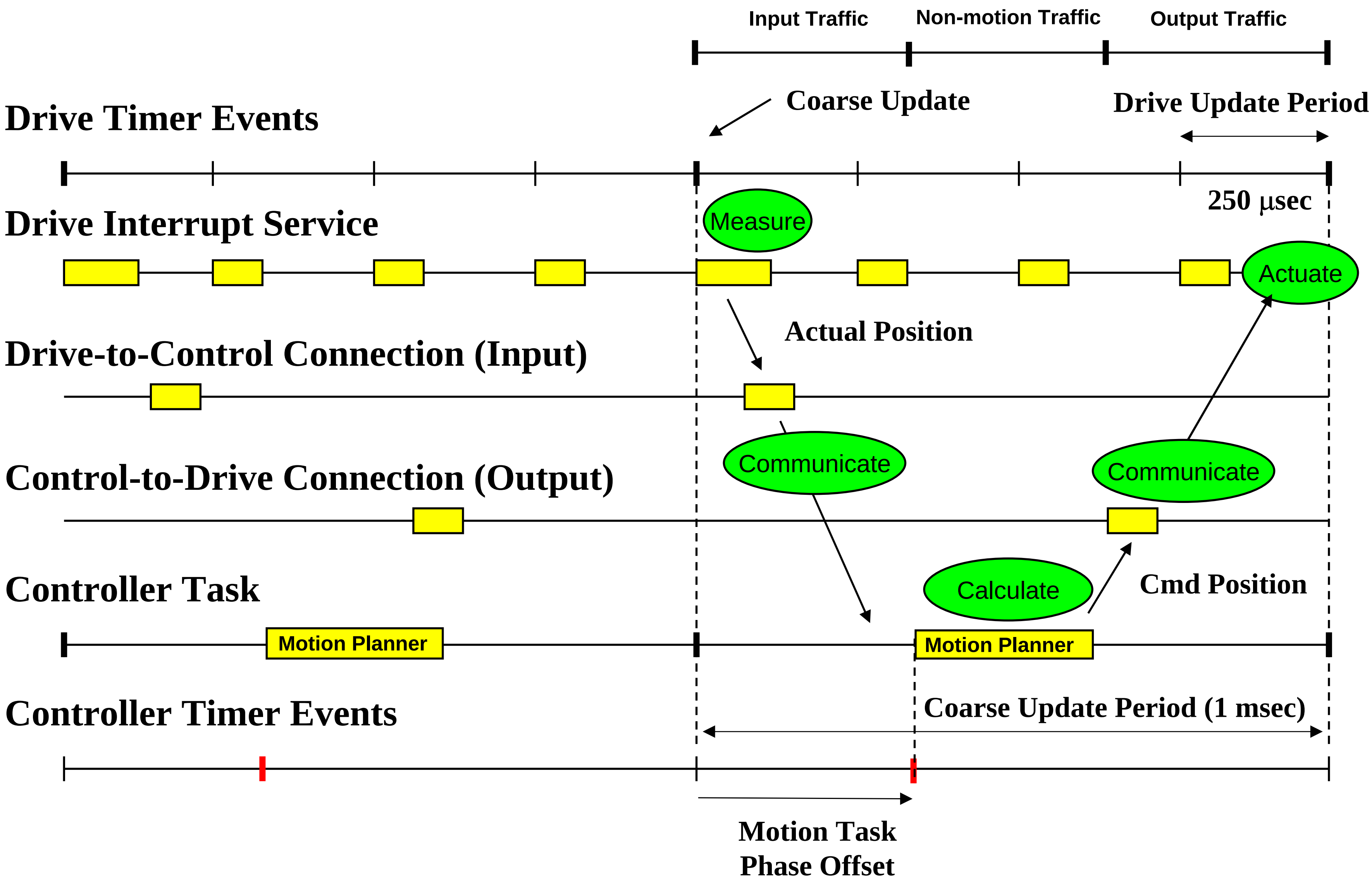
← 32-bit Word →

Controller-to-Drive Connection Format			
Connection Format	Format Revision	Update ID	Node Control
Instance Count	-	-	Time Config
Timing Data			
Instance Data Blocks			

Time Data Set

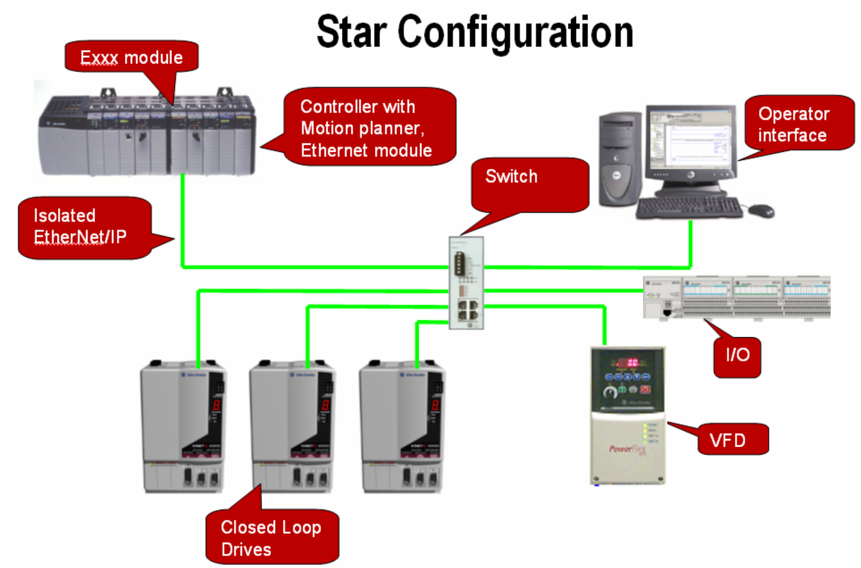
Instance Data Block
Instance Data Header
Cyclic Data Block
Cyclic Write Data Block
Event Data Block
Service Data Block

Drive Connection Timing Model

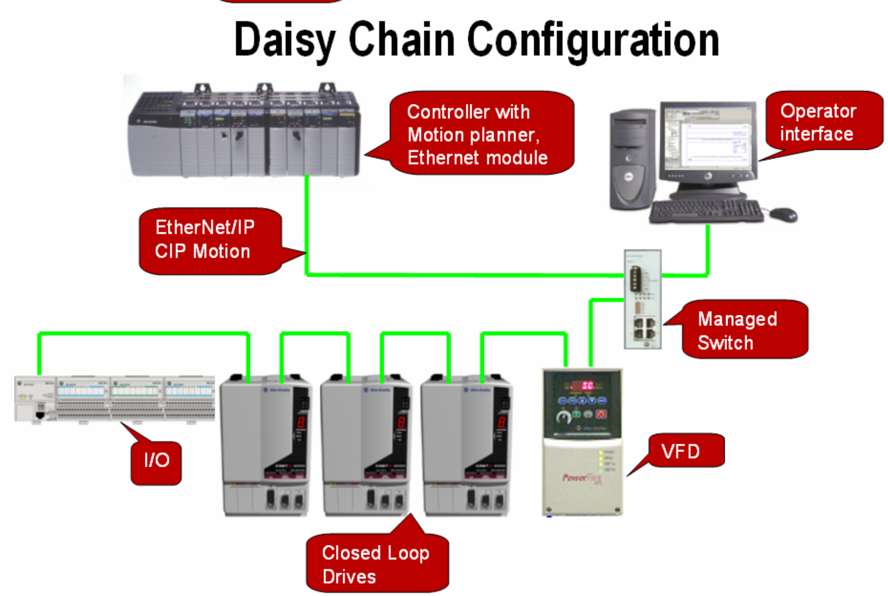


Topology support

- Star topology
  - Supports removal/insertion of drives without impacting the operation of other drives on the network
  - Supports on-line addition of new drives
    - Complements dynamic telegram configuration
  - Effective when drives are centrally located near the switch



- Daisy chain topology
  - Simplifies interconnect wiring between distributed devices
  - Effective when devices are not located near the switch

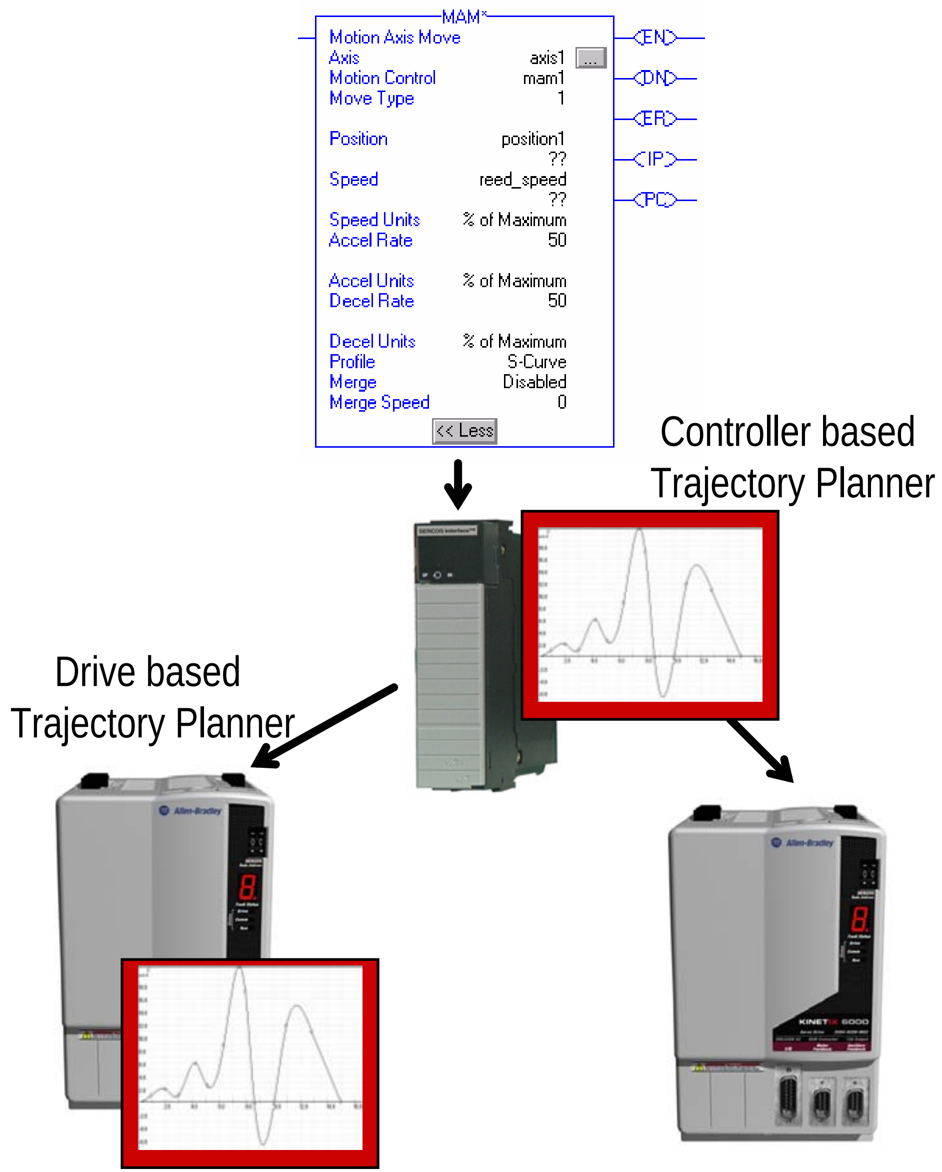


IP Addressing Options – ADR Support

- Isolated network configuration
  - 3 digit thumbwheel switch on the drive can be used to set the last octet of the drive's IP address (192.168.xxx)
  - Facilitates easy setup and identification of the drive IP address
    - No need for a DHCP/BOOTP server
  - Can use a unmanaged switch
  - Facilitates easy replacement and reconfiguration of a failed drive
    - Set new drive switch setting to match the setting of the drive being replaced
    - Automatic detection and reconfiguration of the drive (ADR support)
- Integrated network configuration
  - 3 digit thumbwheel switch on the drive is set from 255-999, which initiates use of a DHCP/BOOTP server for IP address assignment
  - Facilitates easy replacement and reconfiguration of a failed drive (requires use of a DHCP server/switch with option 82 support)

Centralized and Distributed Architectures

- Centralized trajectory planner
  - Centralized control with trajectory planner support for a group of drives
  - Servo loop closure typically located in the drive but can be located in the centralized control
- Distributed trajectory planner
  - Trajectory planner located in the drive
  - Servo loop closure located in the drive
- Control of simple of non-synchronized axes
  - Control of simple process axes or machine configuration axes
  - Reduces controller and network overhead while retaining all the configuration and programming advantages of a centralized planner
  - Enables drive support on networks that do not support time synchronization services
- High performance gearing and PCAMing
  - Local gearing and PCAMing trajectory control for fast updates and ultra-high performance



Integrated Drive Safety

- Single network connection for drive command, configuration, status, and safety support
- EtherNet/IP safety channel supports drive safety configuration and interlocking
  - Eliminates the need for a discrete safety interface
  - Eliminates the need for a separate network or local connection for drive safety configuration
  - Simplifies integration and commissioning
- Integration with other EtherNet/IP safety devices

Integral dual channel monitoring
Safe operational stop (cat0,1,2)
Zero speed monitoring
Safe reduced speed
Safe maximum speed
Enabling switch control
Door monitoring and control
Safe direction monitoring
Safe jog
Safe homing
Safe position monitoring

EtherNet/IP Safety™

CIP Motion – Comprehensive Technology

- Wide Range of Drive Types and configurations
- Control-to-controller connectivity
- Multi-vendor Drive/Motor/Feedback Interoperability
- Simple Network Connection Startup
- Modern, comprehensive Drive Profile

	EtherNet/IP with CIP Motion	Other Motion Networks
Standard [illegible] link and physical layer	✓	☐
Uses standard TCP/IP and UDP transport and network	✓	✓ (Not All)
Use of standard, commercially available Ethernet hardware, switches, routers	✓	☐
Integration of non-automation devices on the same network segment	✓	☐
Integration of field devices, I/O, drives, and motion on same network	✓	✓ (Not All)
Simple, scalable network configuration - no schedule required	✓	☐
Compatible with all standard Ethernet topologies	✓	✓ (Not All)
Run time configuration changes	✓	☐
Support for real time (<1ms), multi-axis synchronized motion control	✓	✓

100 Axes with 1 ms Update – 200nS Clock Synchronization

CIP Motion Demonstration Attributes

- Controller – Controller
  - 2 Nodes
- Controller – Servo Drive
  - 16 Nodes
- Controller – VFD
  - 4 Nodes
- Controller Driven Strobe
- Switches from Hirschmann
- Vision system
- Mix of Commercial & Industrial Technologies

Thanks