Fundamental Guide to Industrial Networking

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A Connected World

- Buy a phone or tablet you expect connectivity
- Your phone can connect to a cell tower, the internet, GPS satellites, the audio system in your car, and your TV set
- If your car isn’t on the internet, your next one will be. Already devices within are on CAN bus
- By 2020 it is expected that 50 billion devices will be interconnected. My phone can talk to the thermostat in my home right now.

Connectivity in Automation

Devices in the automation world also need to talk

- To gather information from sensors
- And send control signal to actuators

Communication standards are essential

- Hardware & software defined protocols
- Get the data there
- Be sure it got there
- Know what it means to both ends

Connectivity in Automation

There are dozens of industrial networking standards

- If you're starting an application, how do you choose?
- If you are planning to build products, which networks will bring the most success?
- Let's compare and contrast the most popular industrial networks
- And hopefully learn enough to make an informed choice of which to use

Serial versus Ethernet

Most popular industrial networks started out on serial bus

- 1970’s and 1980’s
- RS-485 or CAN were available at the time to serve as the physical layer: the wires, connectors and IC’s the network is built on

Serial versus Ethernet

Rapid growth of Ethernet in office nets

- Drove Ethernet costs down, speed up
  - Serial bits rates: 9.6k to 12Mbits/sec
  - Ethernet: 100 – 1000 Mbits/sec
- 32 bit IP addressing allows practically unlimited number of nodes
- 16 bit ports allow multiple protocols to “share the wire”
- Most fieldbus standards were adapted to Ethernet in early 2000’s

Serial versus Ethernet

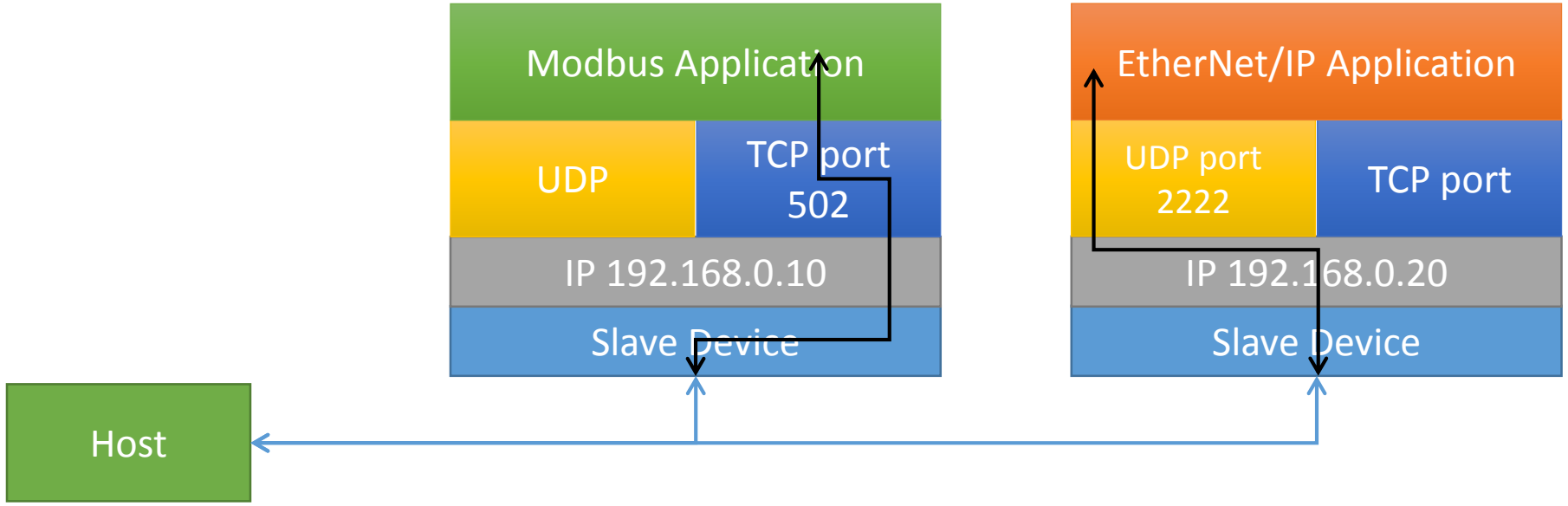
Many popular serial protocols have been updated to run on Ethernet

- Modbus/RTU → Modbus/TCP
- DeviceNet → EtherNet/IP
- CANopen → EtherCAT COE
- Profibus → Profinet
- CC-Link → CC-Link IE

Serial versus Ethernet

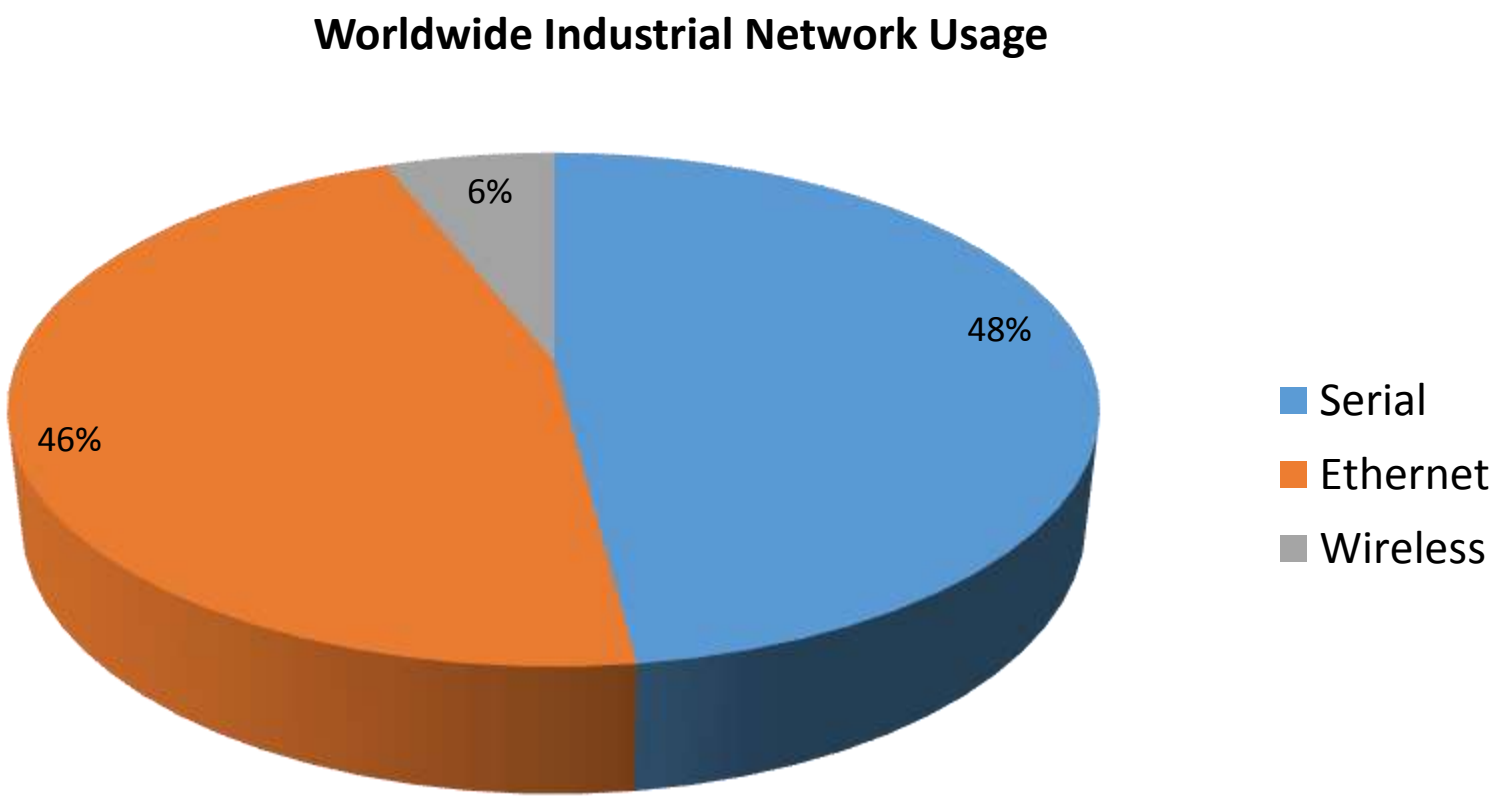
Why migrate to Ethernet?

- More speed
- More nodes
- Mixed protocols on same net

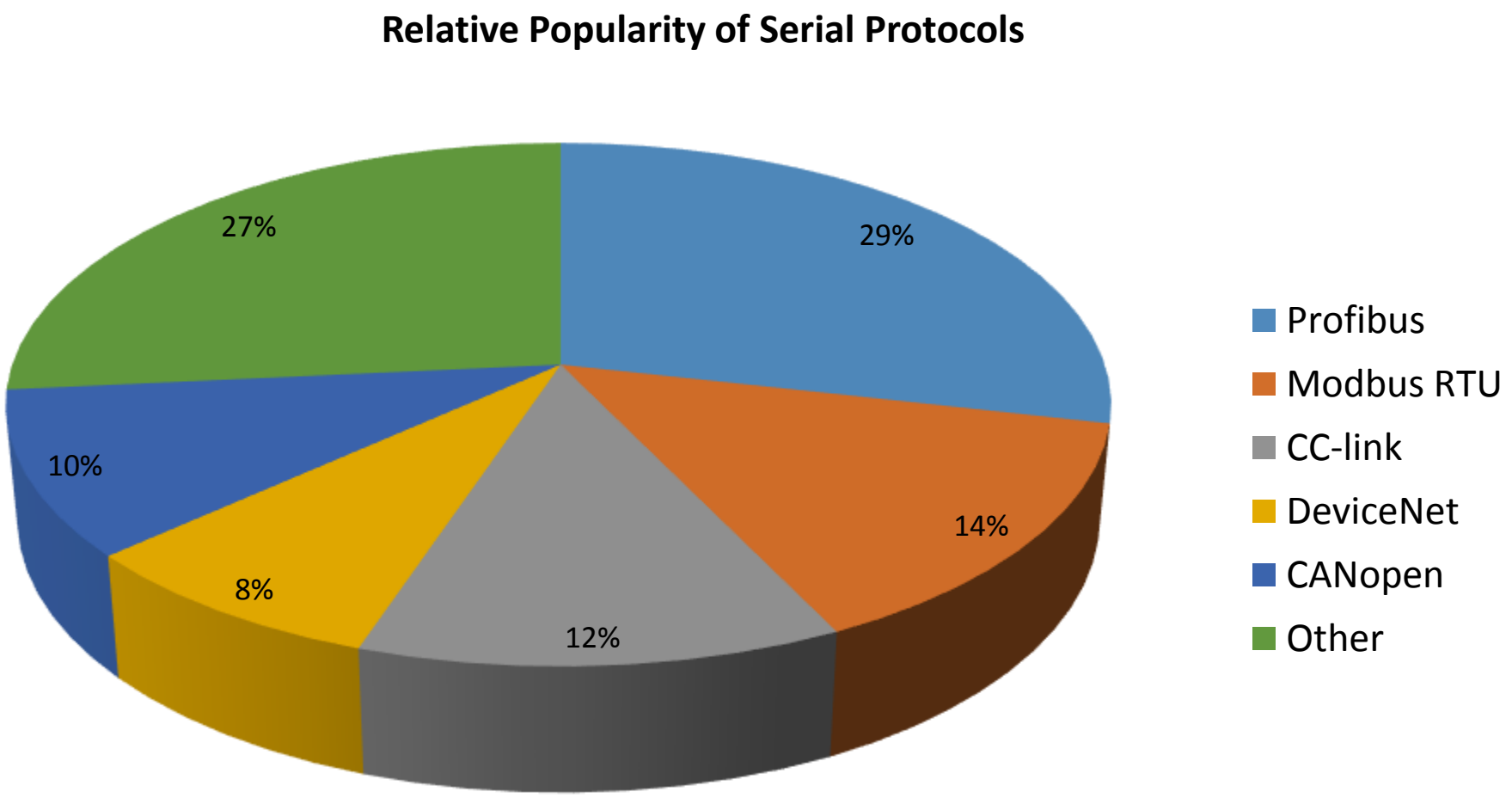


Serial versus Ethernet

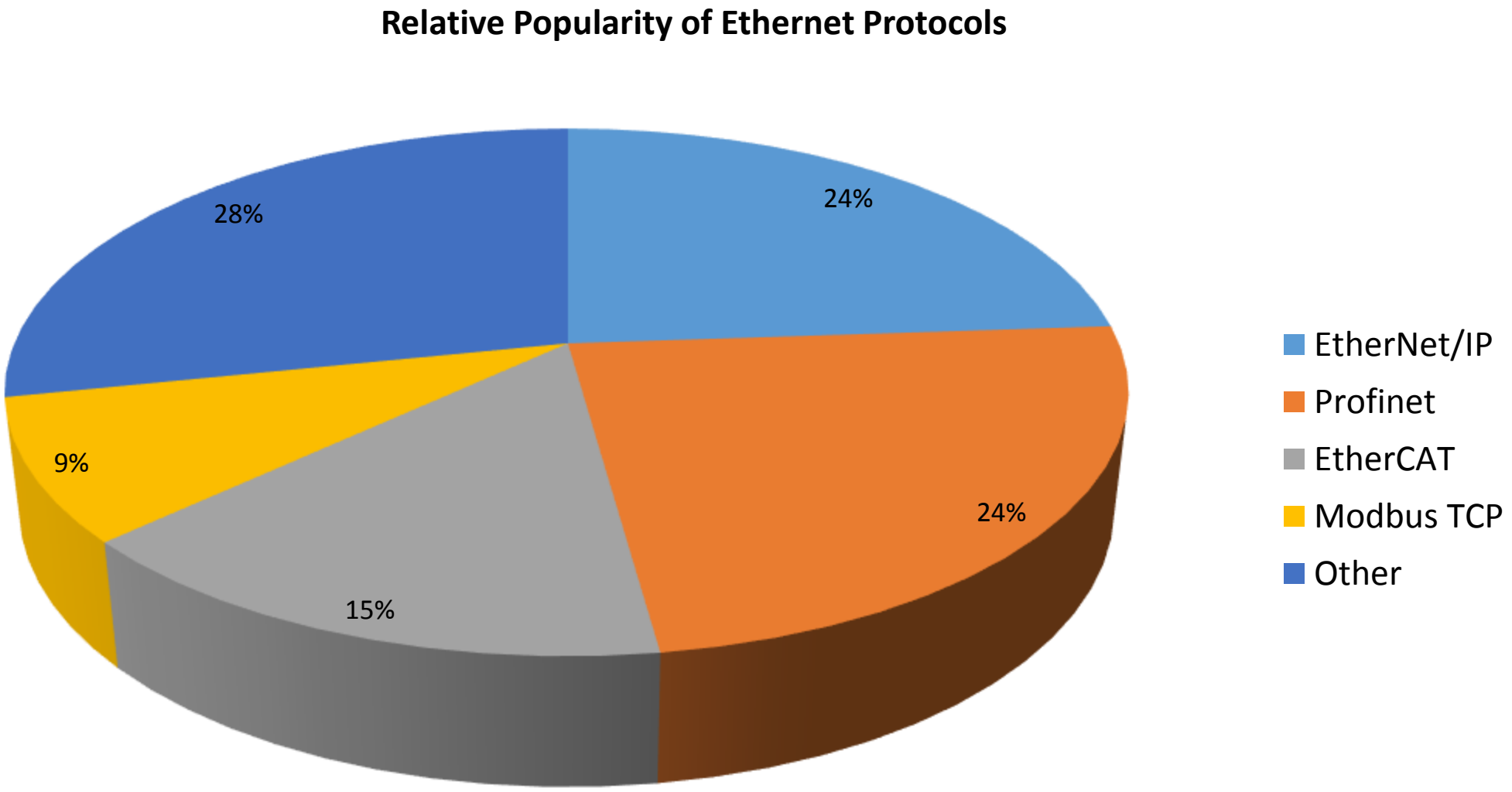
- The Industrial Ethernet market is growing by 22% annually
- Serial is growing just 4%



Serial Based Networks



Ethernet Based Networks



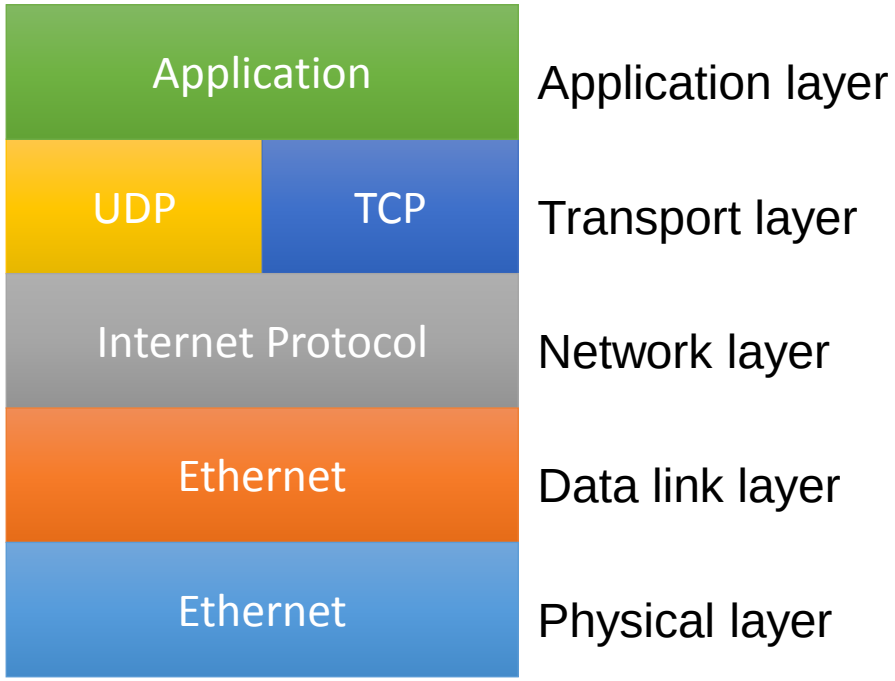
Geography

- North America
  - Rockwell: DeviceNet, EtherNet/IP
  - Galil, Trio, National Instruments, CTC: EtherCAT
- Europe
  - Siemens: Profibus, Profinet
  - Beckhoff: EtherCAT
- Asia
  - Mitsubishi: CC Link
- Modbus is used everywhere

There is much fragmentation: Choose wisely or choose all

Typical Ethernet Model

- 5 Layers:

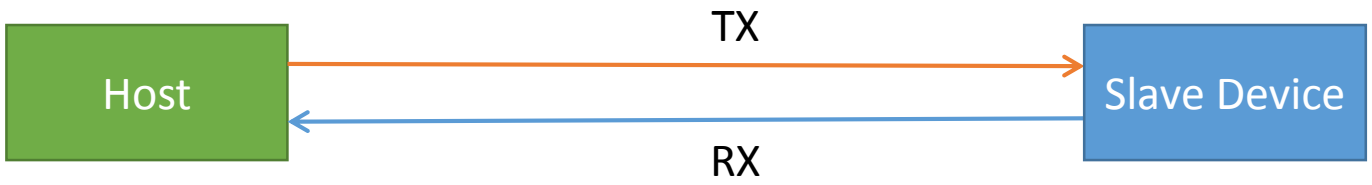


Modbus RTU

- Introduced by Modicon, a PLC maker, in 1979.
- First popular industrial network.
- Ubiquitous, easy to use, cheap.
- Reliable but not fast: 9.6k to 115k bits/sec.
- Tames RS-485 which is otherwise a less than reliable medium
- Good communication standard but not specialized for applications
- Standard organization: The Modbus Organization

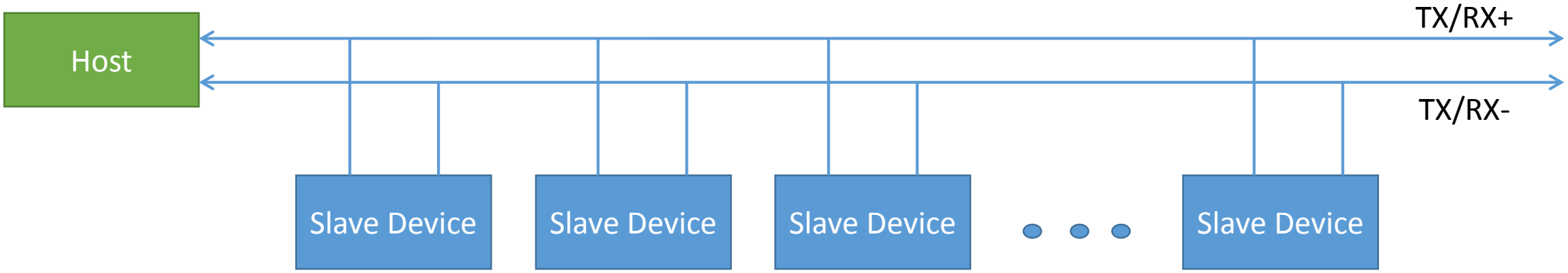
Modbus RTU Typical Network

- **RS-232** is point to point so only one slave device can connect



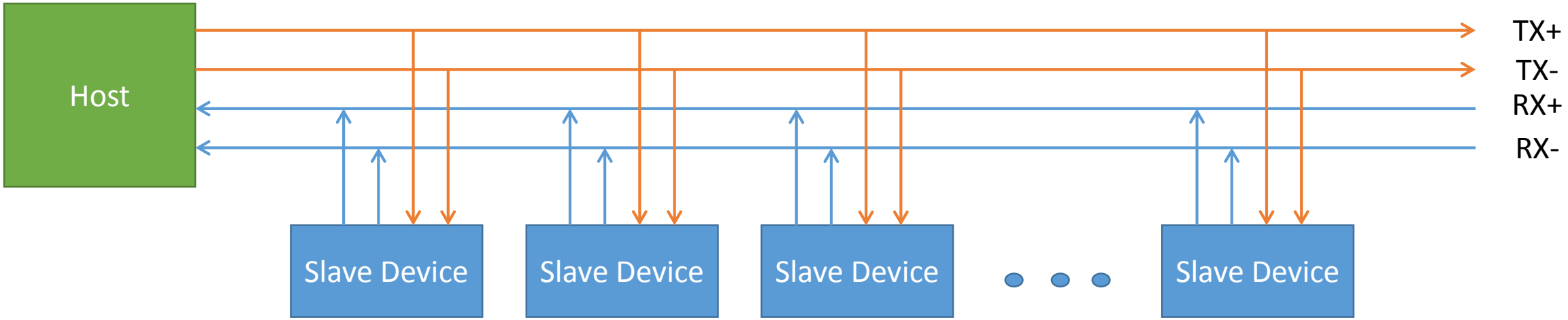
Modbus RTU Typical Network

- RS-485 allows multiple devices to share the network.
- All devices share a parallel, **two wire bidirectional bus**
- Up to 247 devices, depending on manufacturer
- Most RS-485 transceivers limit the number of nodes to 32



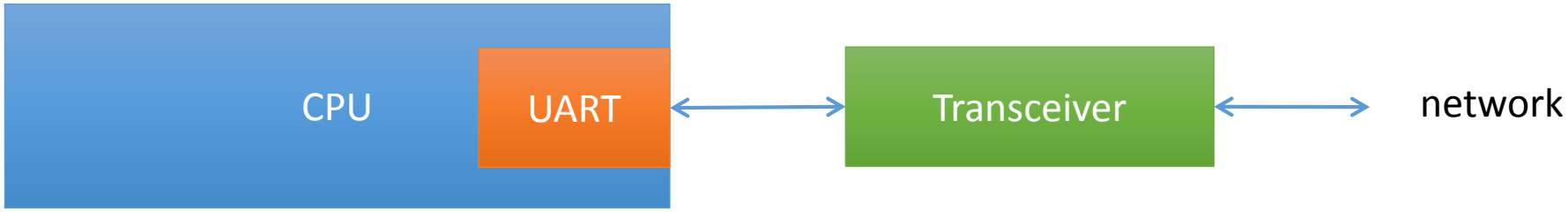
Modbus RTU Typical Network

- RS-485 can also be implemented as a four wire network.
- Modbus is inherently half duplex so using four wires does not increase network bandwidth
- Modbus masters always wait for a response (or a time out) before sending another message



Modbus RTU Physical Layer

- Simple and low cost
- Most DSP and MCU have built-in UARTs, making Modbus designs incredibly simple and affordable

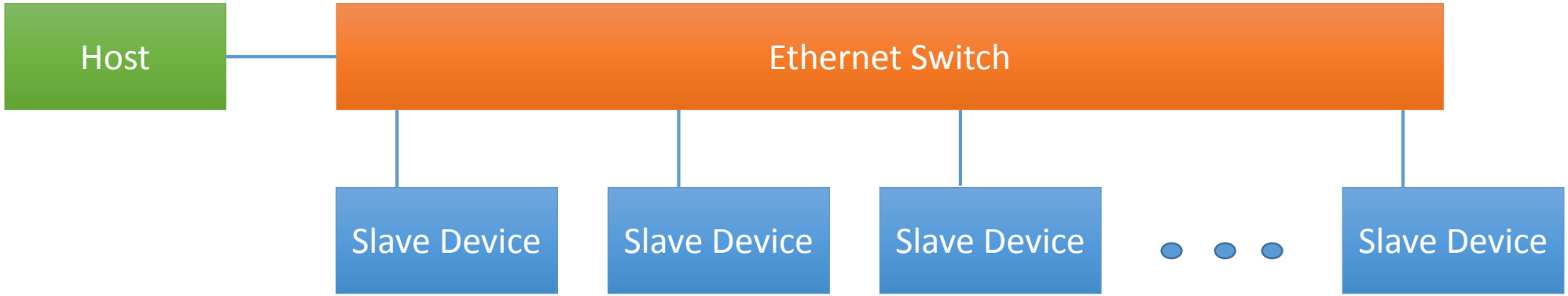


Modbus TCP

- Introduced in 1999 by Schneider Electric
- Runs on standard Ethernet TCP/IP
- more speed (1000x), more devices on the wire
- Can share the network with other protocols and standard TCP/IP traffic

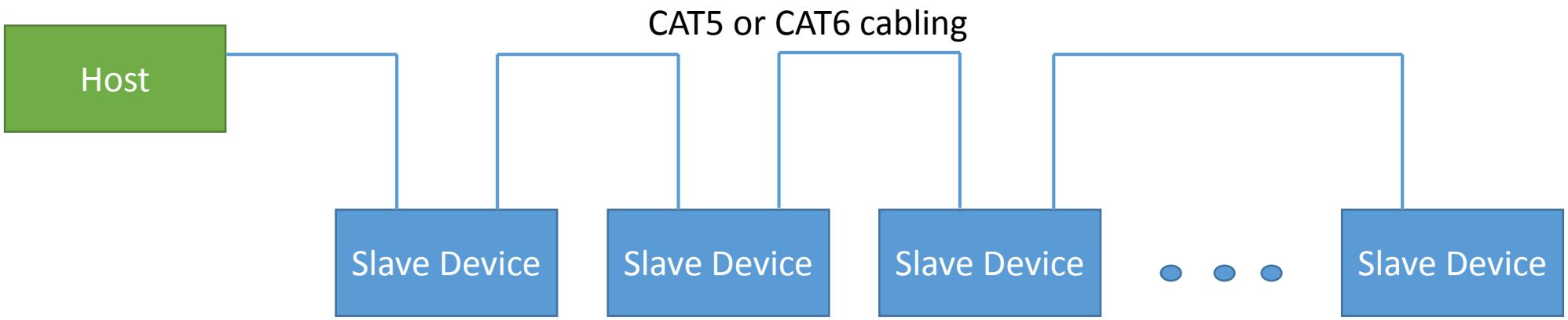
Typical Modbus TCP Network

- IPv4 allows nearly unlimited addressing (2^{32} devices)
- A typical subnet would be limited to 2^{8} or 2^{16} devices



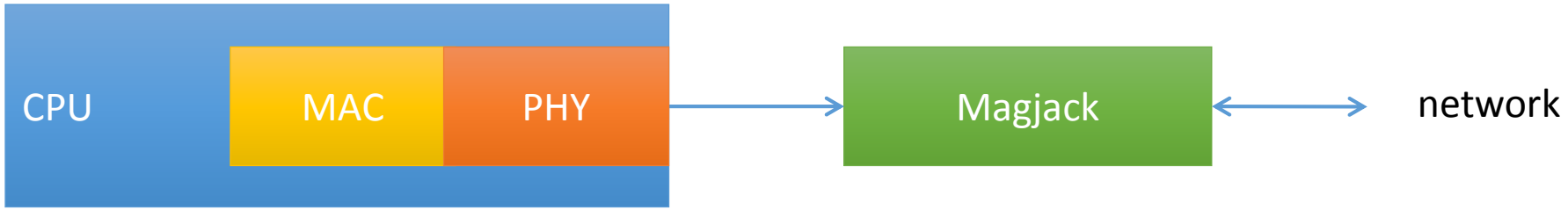
Modbus TCP Dual Port Network

- IPv4 allows nearly unlimited addressing (2^{32} devices)
- A typical subnet would be limited to 2^{8} or 2^{16} devices



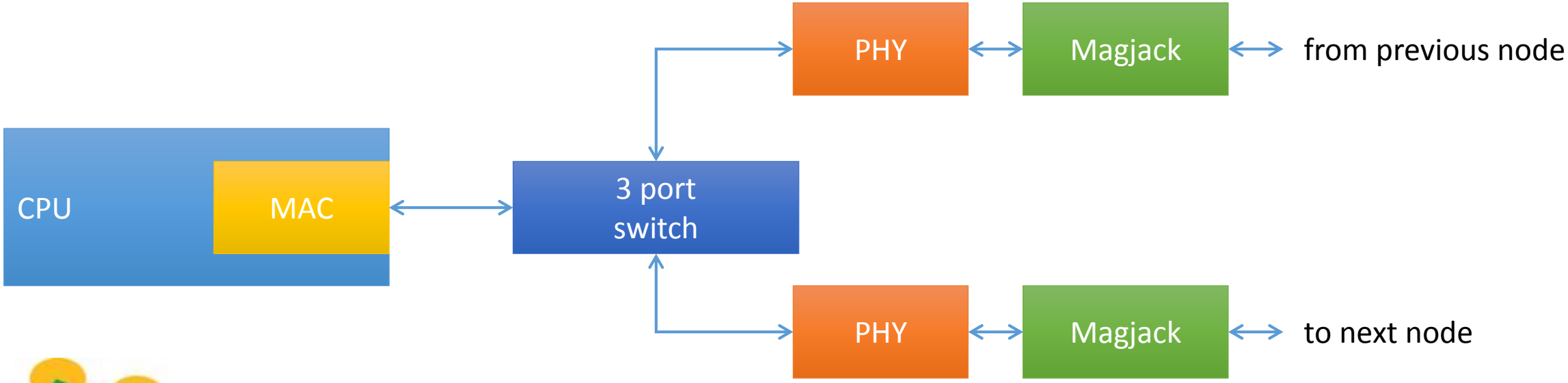
Modbus TCP Physical Layer

- MAC/PHY can be built into CPU – very common in ARM processors – simple, low cost
- Magjack includes transformers and RJ-45 jack
- For harsh environments, M12 connectors can be used with separate magnetics



Modbus TCP Physical Layer (Dual Port)

- Dual port Ethernet provides a “daisy chain” network
- Eliminates Ethernet switches
- Useful where a star topology is inconvenient

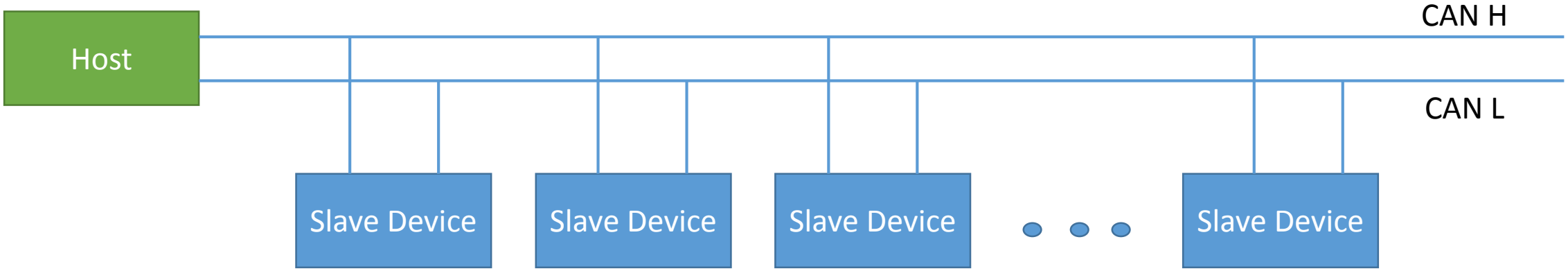


CANopen

- Introduced in 1995
- Standards body: CAN in Automation (CiA)
- Many things defined by standards
  - CIA301 – communication
  - CIA402 – motion
- Standards improve but do not guarantee interoperability.
  - Example: CIA402 object 606C is motor actual velocity
  - But scaling is not defined. Could be RPM, steps/sec, etc.

CANopen Typical Network

- All devices share a parallel, **two wire bidirectional bus**
- Up to 127 devices



CANopen®

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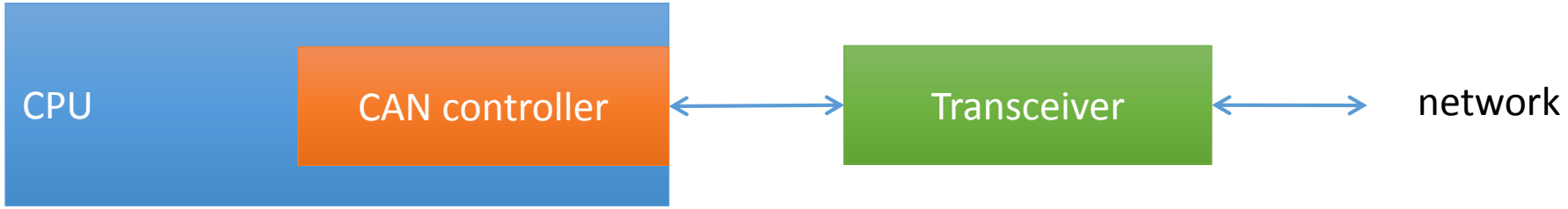
CANopen Physical Layer

- Simple and low cost
- Many DSP and MCU have built-in CAN controllers, making CANopen hardware designs inexpensive

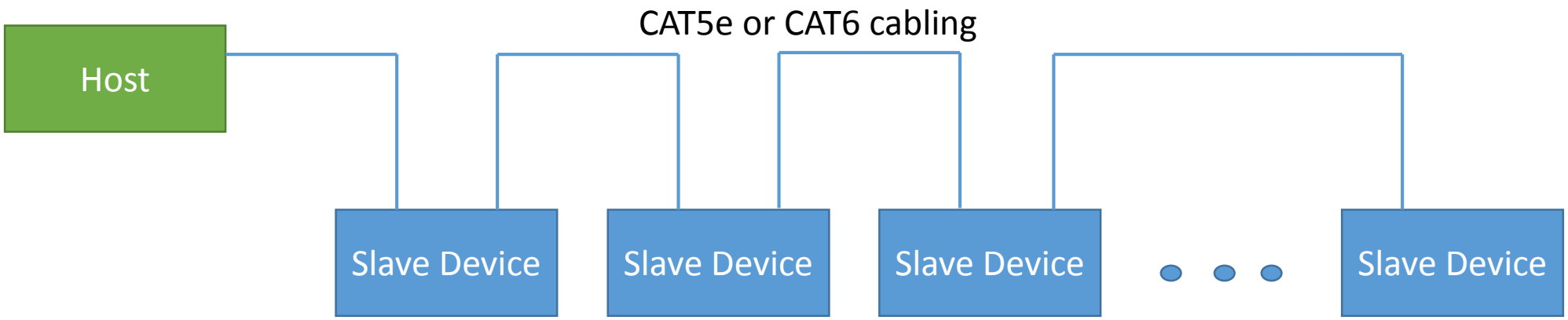


EtherCAT COE

- Introduced in 2003 by Beckhoff
- Same issue as CANopen but very real time, intelligent.
- To make up for loose standards definition, devices get “baked in”. Partnering, pay to play
- EtherCAT is opening up.
  - Not long ago, the only solution was strapping a Beckhoff ASIC to a processor.
  - Now you can get alternate EtherCAT slave controllers
  - Or ARM processors with built-in EtherCAT hardware

Typical EtherCAT Network

- Up to 65,535 nodes



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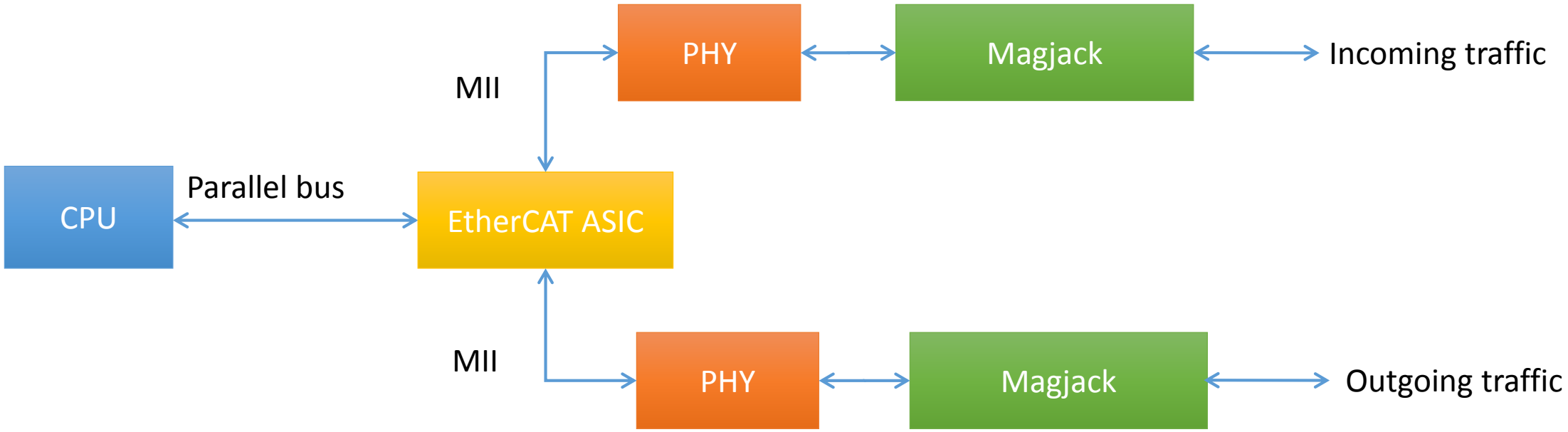
EtherCAT Physical Layer

- Always dual port, no external switches
- Slave node: large footprint design, relatively expensive



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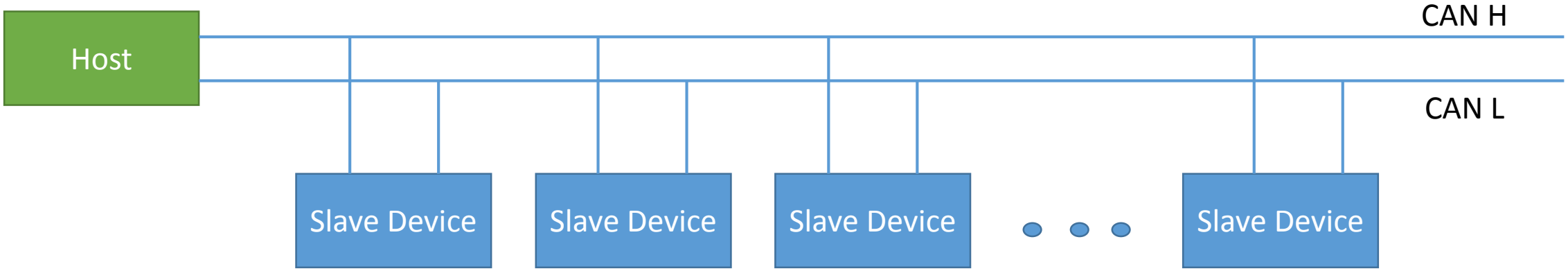
DeviceNet

- Developed by Allen-Bradley (now Rockwell)
- Introduced in 1994
- Uses CIP protocol on CAN physical and data link layers
- Low cost to implement
  - Many DSP’s and MCU’s have built-in CAN controllers
  - Can transceivers are widely available and inexpensive

DeviceNet Typical Network

- All devices share a parallel, **two wire bidirectional bus**
- Up to 127 devices



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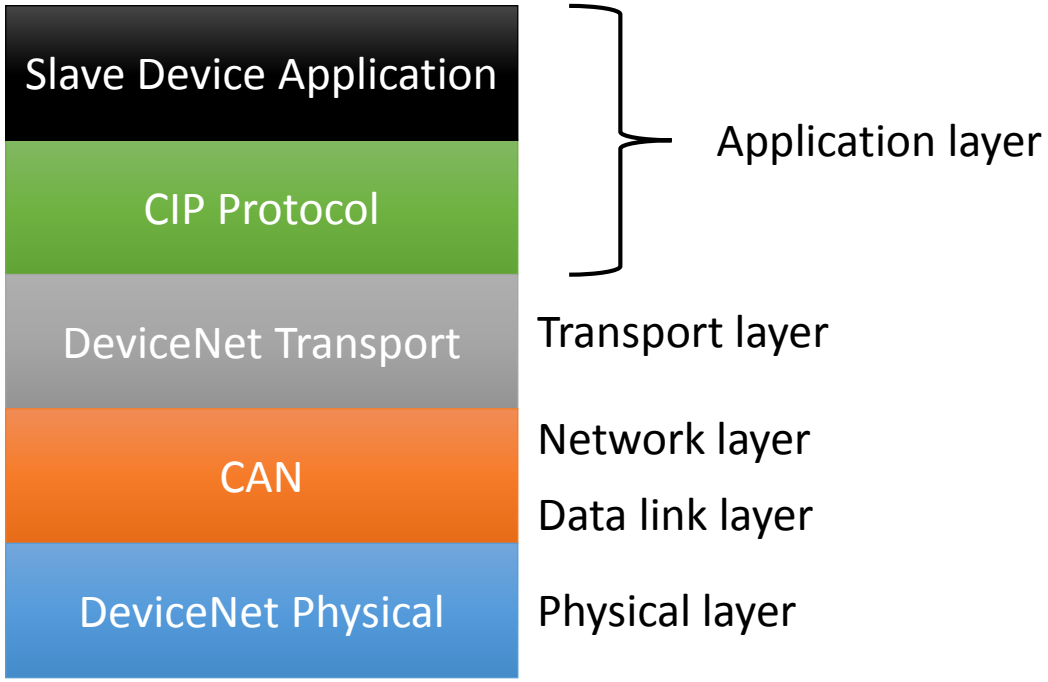
DeviceNet Model



DeviceNet™

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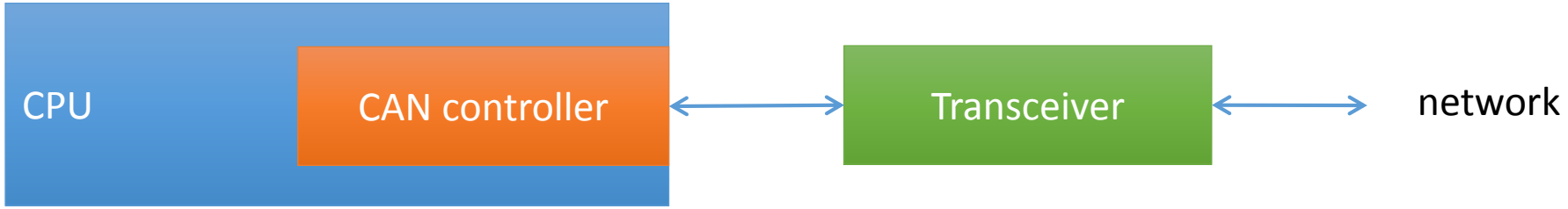
DeviceNet Physical Layer

- Simple and low cost
- Many DSP and MCU have built-in CAN controllers, making DeviceNet hardware designs inexpensive

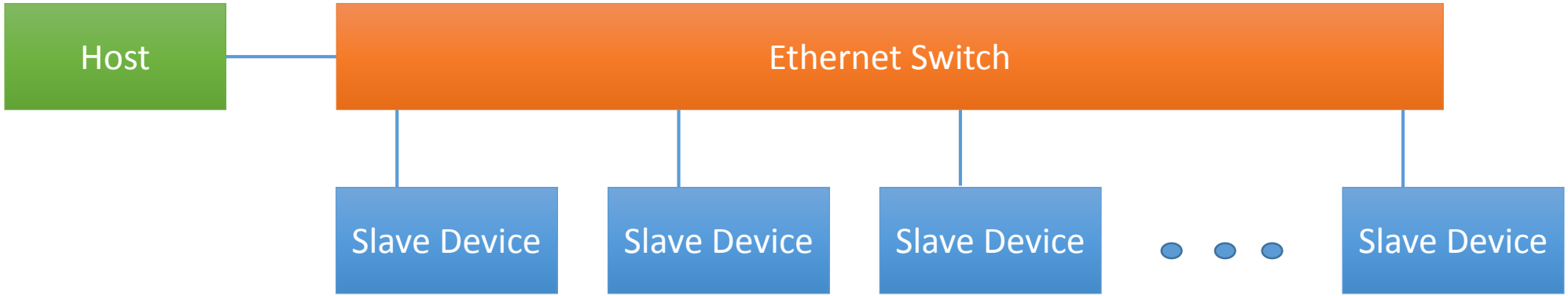


EtherNet/IP

- Developed by Allen-Bradley (now Rockwell)
- Introduced in 2001
- Standards organization: ODVA
- Runs on standard Ethernet
- Uses Common Industrial Protocol (CIP)
- Uses TCP transport for explicit messages
- UDP for fast, cyclical implicit messaging

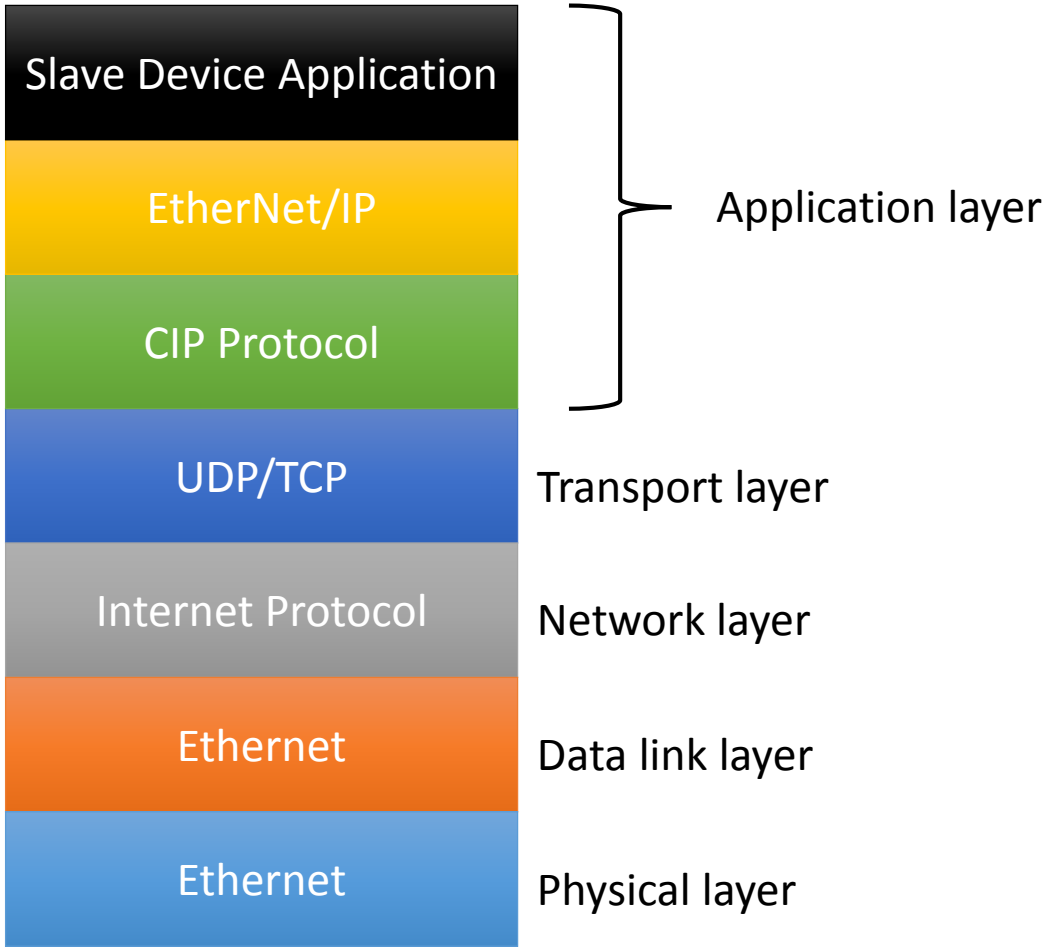
Typical EtherNet/IP Network

- IPv4 allows nearly unlimited addressing (2^{32} devices)
- A typical subnet would be limited to 2^{8} or 2^{16} devices



Dual port solutions are also popular

EtherNet/IP Network Model



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EtherNet/IP Physical Layer

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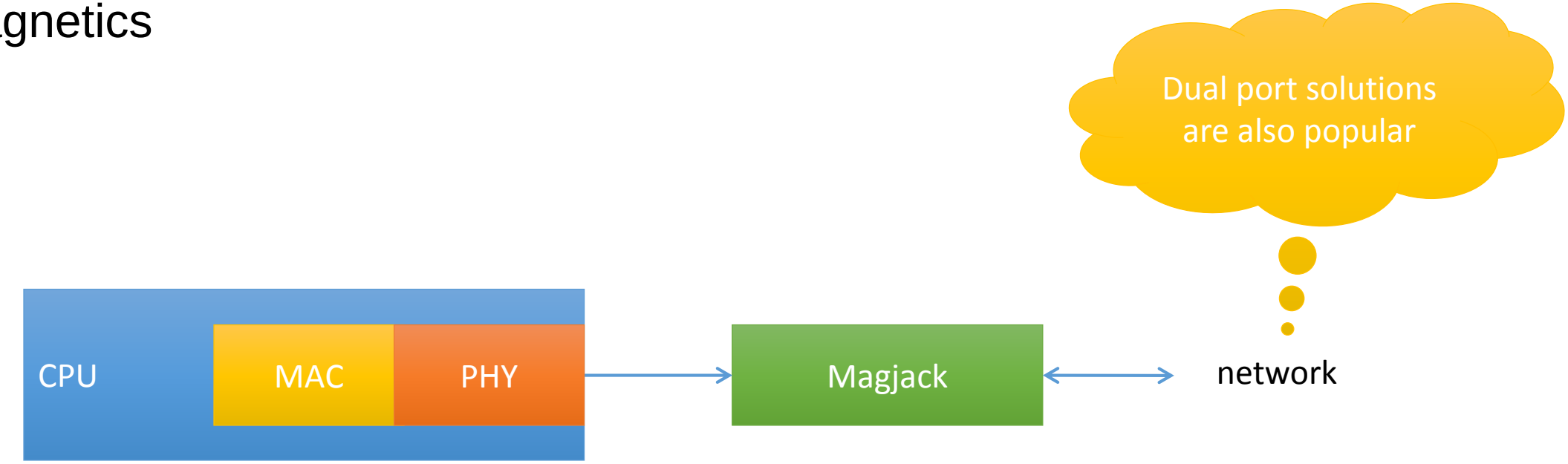
- For harsh environments, M12 connectors can be used with separate magnetics

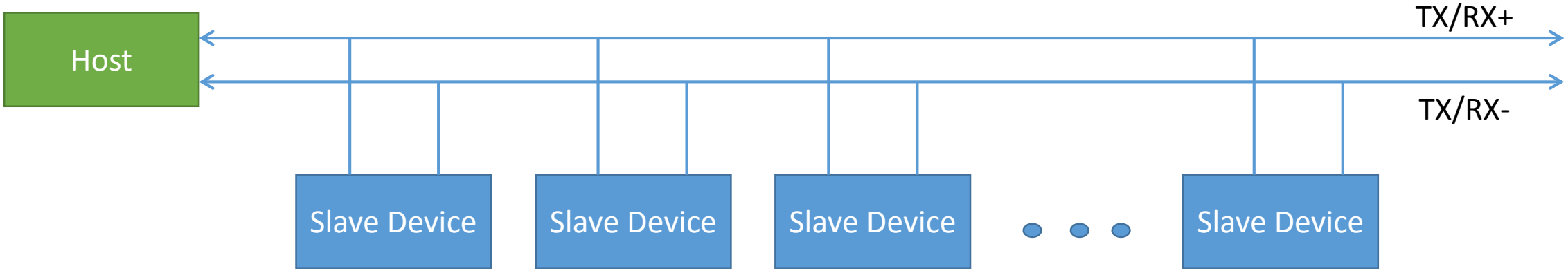


Profibus DP

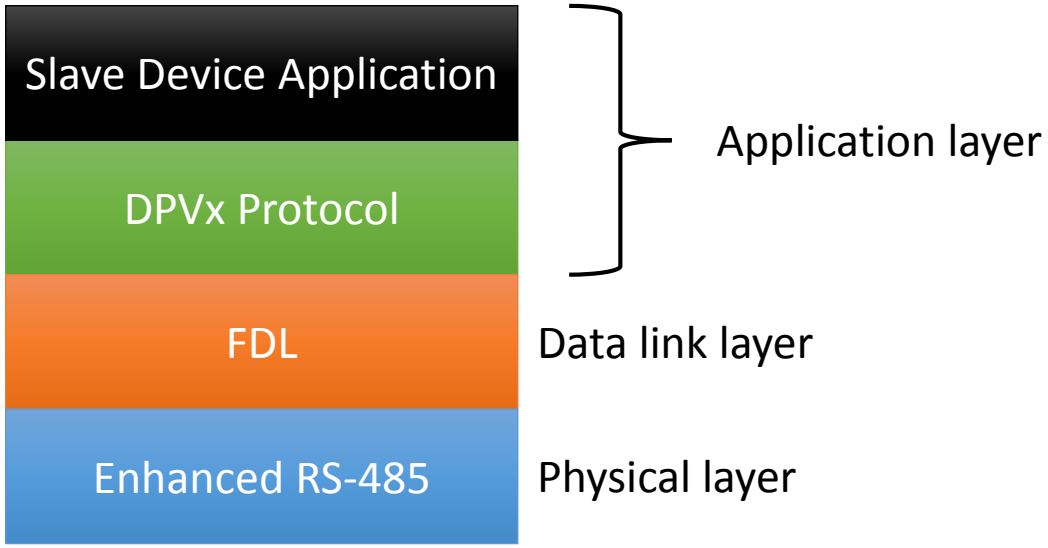
- Devised in Germany in 1987
- Primary controller: Siemens
- Popular in Europe
- Enhanced RS-485 physical layer
- Speeds to 12 Mbits
- Requires ASIC for data link layer

Profibus DP Typical Network

- Enhanced RS-485 allows multiple devices to share the network at high speeds
- All devices share a parallel, **two wire bidirectional bus**
- Up to 32 devices per segment

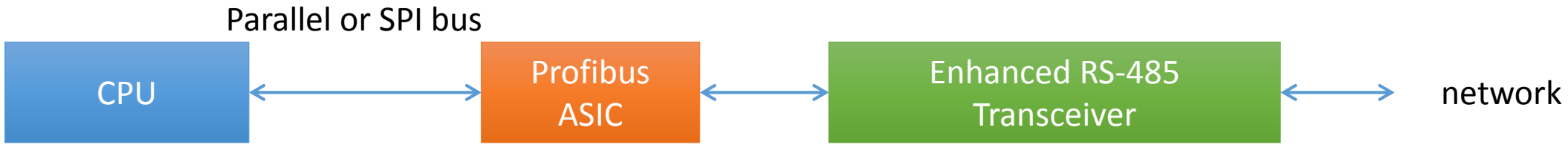


Profibus DP Network Model



Profibus DP Physical Layer

- At least one ARM CPU is available with a built-in Profibus subsystem,
  - eliminates need for ASIC
  - eliminates potential need for parallel bus

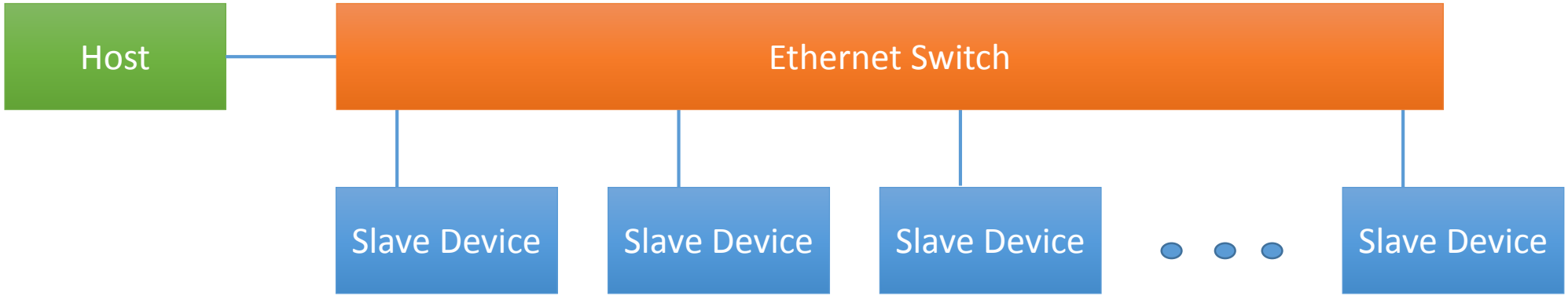


Profinet IO

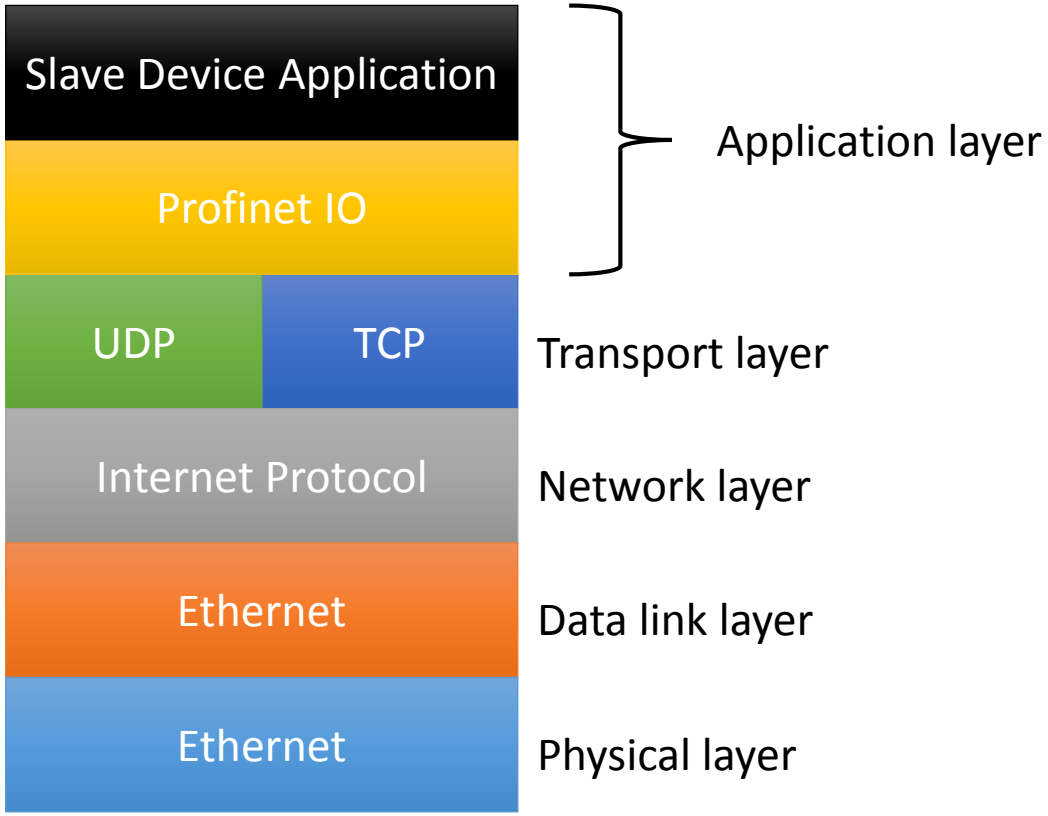
- Introduced in 2003 by PI working group
- PI North America is standards organization
- Built on standard Ethernet
- Uses UDP and TCP transport
- Can “share the wire” with other protocols

Profinet IO Typical Network

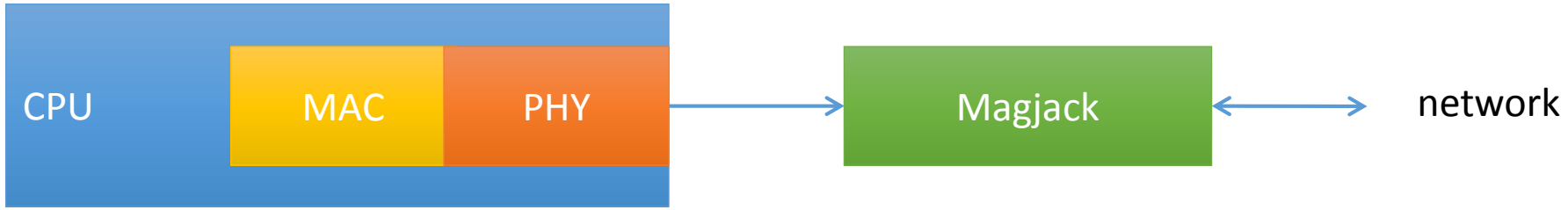
- Thousands of nodes are possible



Profinet IO Network Model



Profinet IO Physical Layer



Summary

	serial bus				Ethernet			
	Modbus RTU	DeviceNet	Profibus DP	CANopen	Modbus TCP	EtherNet/IP	ProfiNet IO	EtherCAT COE
year introduced	1979	1994	1987	1995	1999	2001	2003	2003
max physical layer speed (Mbits/sec)	0.1	0.5	12	1	1000	1000	1000	100
max nodes	32 typ 254 max	64	32/segment, 126 max	127				
share wire?					✓	✓	✓	
cyclic			✓	✓		✓	✓	✓
motion specific option			ProfiDrive	CIA402		CIPsync, CIPmotion		CIA402
standards body	Modbus Org	ODVA	PNO, PI	CiA	Modbus Org	ODVA	PI	ETG
controllers	many			many	many	mainly Rockwell	Beckhoff, Siemens	Beckhoff, Trio, Galil, National Instruments, others
Relative cost of slave node	1	3	7	3	5	7	6	10

Implementation Options

How do I go about designing a fieldbus node?

- If the device already has a fieldbus option, consider using an external gateway to convert the protocol
- Use HMS Anybus module to device can be adapted to many popular protocols
- Buy a commercial software stack (RTA)
  - Design your own physical layer

Implementation Options

Pay to Play

- Some standards require you to pay an annual fee
  - For access to written standards
  - For test tool subscriptions
  - For a vendor ID
- Additional fees apply for
  - Conformance testing
  - Plug fests

Other Considerations

Distributed Intelligence

- A stored program in each node can reduce needed bandwidth for non-tightly coordinated axes
- Individual nodes can read I/O, make decisions, execute motion
- Can be cost effective because stored programming in an already needed CPU costs little (beyond software development)
- Still has benefit of real time connectivity, streaming set up, feedback, data logging

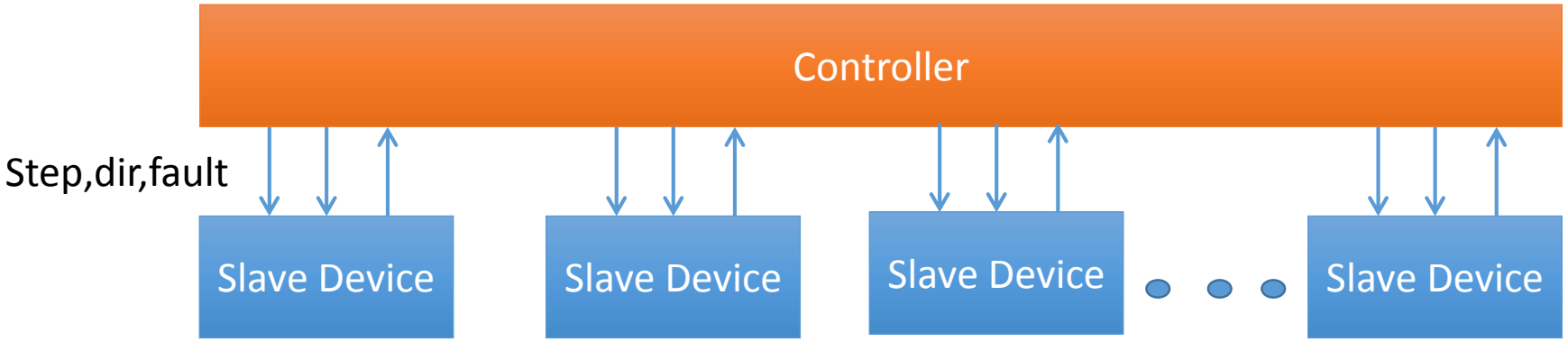
Other Considerations

Step & Direction

- Controller sends step pulses and a direction signal to each motion node

Advantages

- Motion can be tightly coordinated
- Very low slave cost

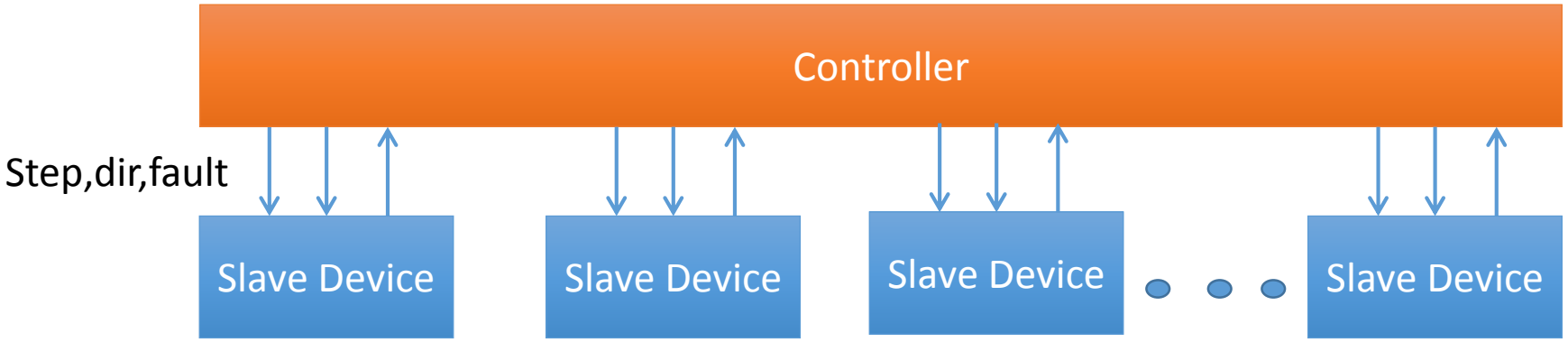


Other Considerations

Step & Direction

Disadvantages

- No certainty if signals reached the node
- Only feedback is fault signal.
- No status monitoring or data logging



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