Designing a Deterministic Ethernet Network

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Introduction

Automation solutions have evolved considerably since the first Modicon PLC was released over four decades ago. Industrial solutions initially utilized proprietary networks – equipment from each major vendor communicated through a custom bus protocol and cable. Over time, the requirements placed on the network have grown. Communication speeds, transparency, and device connectivity requirements are driving customers away from traditional proprietary solutions. Ethernet based networks represent the next step in the evolution of industrial networking. It has taken over 10 years for Ethernet to reach this point in its evolutionary cycle since Schneider Electric introduced Modbus TCP in 1998.

Ethernet deployment was initially restricted to the plant and enterprise levels of the automation network. Over time it has penetrated into the process and field bus levels of the network.

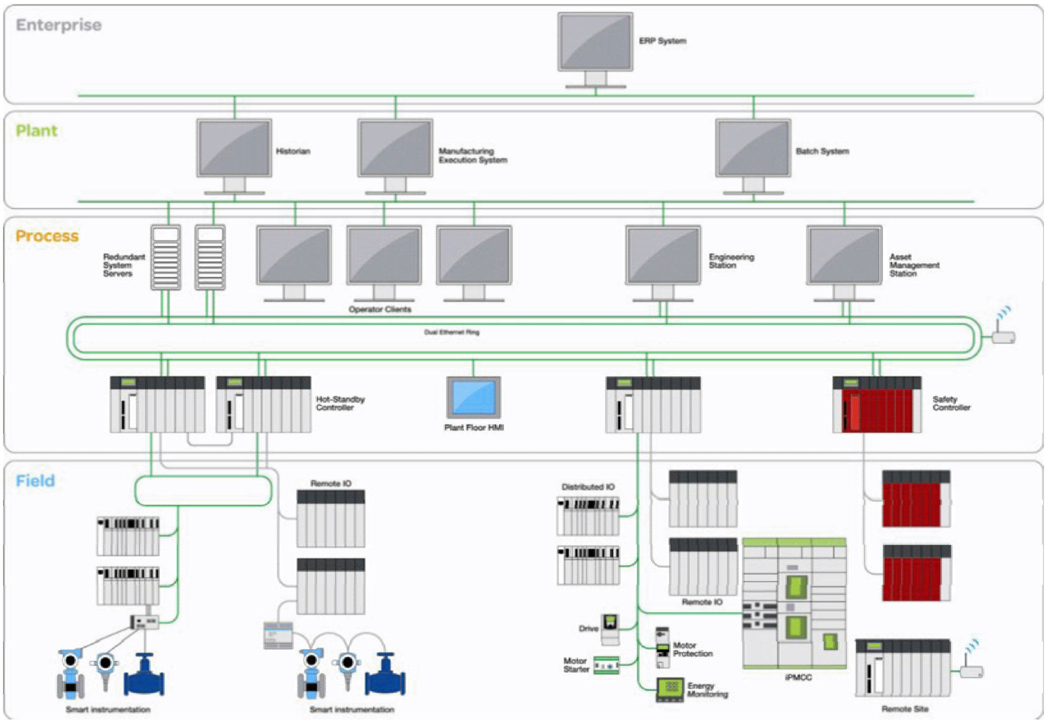


Figure 1: Industrial Automation Networking Sub Divisions

Figures 2 – 4 depict the present state of Ethernet penetration into the device level. Figure 2 shows the extent to which industrial Ethernet protocols are deployed at the device level. Note that in 2008 Modbus TCP and EtherNet/IP were converged in the CIP specification. The resulting converged EtherNet/IP specification dominates the market with over a 37% share of Ethernet devices. Figure 3 shows the leading suppliers of industrial Ethernet products at the device level. Figure 4 projects continued penetration of Ethernet into devices.

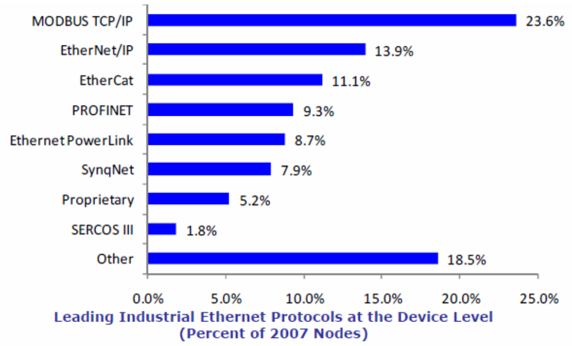


Figure 2[1]

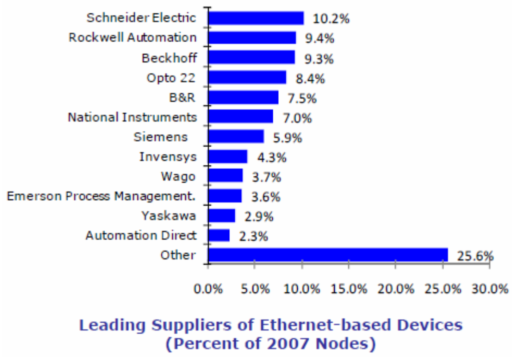


Figure 3[1]

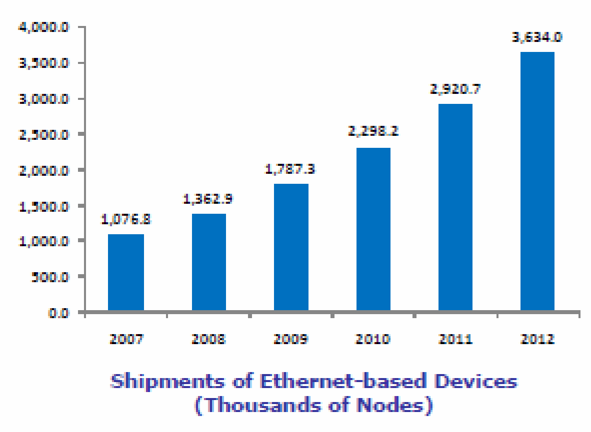


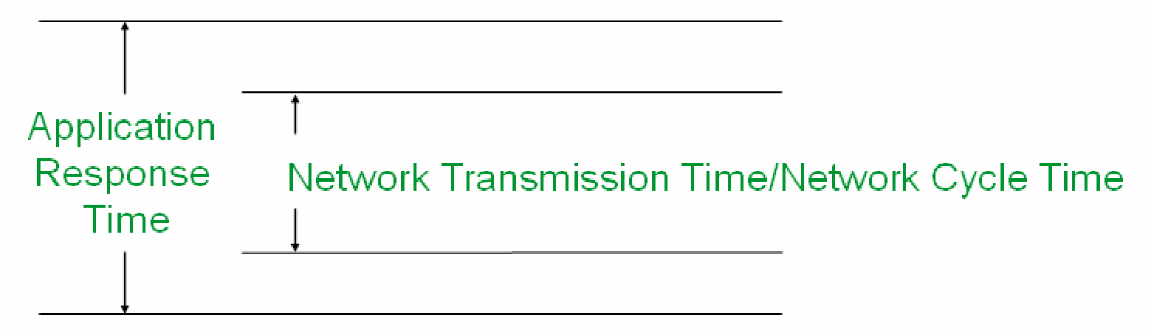
Figure 4[1]

[1] Source: "Ethernet-Based Device Networks Worldwide Outlook", ARC Advisory Group, 2008.

Movement from the plant/control network to the device level represents an important milestone in the evolution of industrial Ethernet. The device level has different requirements than the plant/control network. One of the key parameters in the device network is determinism. This white paper will discuss determinism in Ethernet networks. The paper will differentiate between industrial Ethernet protocols and categorize relative performance.

Ethernet Determinism

A deterministic system is regarded as predictable, producing a calculable, consistent, response time between two end devices. Ethernet determinism is impacted by two elements: system determinism and network determinism. System determinism can be thought of as application response time, or the amount of time it takes for an input on an I/O device to turn on, for the change of state to be detected by the PLC, and for the PLC logic to solve the change of state and write the logical output of the I/O device. Network determinism refers to ability of the network to consistently propagate data between end points within a guaranteed timeframe. Determinism can be a key requirement for industrial automation solutions. It is important to note that the network represents one link in the chain of application activity. In a traditional IO scanning application, the PLC CPU processes logic and forwards data to a network interface module in the PLC, which sends data through the network to the IO point, which in turn processes the data. Data is then returned over the same path from the IO point to the PLC. The network represents a portion of the application processing time and contributes to overall system determinism.



There are a variety of industrial Ethernet protocols available on the market today. To evaluate determinism, protocols can be subdivided into two major subcategories:

Solutions Utilizing Commercial off the Shelf (COTS) Products

Industrial Ethernet protocols fitting into this category are designed to interoperate with products supporting layers 1-4 (physical through transport layers) of the standard OSI stack. The application layer of these protocols are different, but support of layers 1-4 enables plug and play interoperability with most Ethernet equipment. Solutions using COTS equipment can be capable of meeting the determinism requirements of most automation applications. Examples of COTS protocols are EtherNet/IP, ProfiNet RT, and Modbus TCP.

Solutions Designed to Improve Network Transmission Time

There are a variety of automation applications which require determinism with exceptional timing. Motion applications for example have stringent application determinism requirements. Traditional COTS based solutions are not able to deliver the performance needed to support these applications. So vendors have customized Ethernet based protocols to address these markets. Implementations typically require equipment supporting the protocol to utilize a custom chip. These implementations support the physical layer of the Ethernet protocol stack (layer 1 only) enabling customers to use Ethernet cabling and connectors, but the protocol running above the physical layer will not work with COTS equipment. For example, customers could not use a generic Ethernet switch in these architectures. Examples of these protocols include SERCOS, ProfiNet IRT, and EtherCat.

Each of the solutions detailed above have advantages and disadvantages - customers should choose the network protocol best suited to support their application. COTS solutions offer a variety of advantages, including:

- ***Ability to work with equipment from a variety of vendors -*** One of the key advantages of moving towards a standards based solution is to remove a customer's reliance on a single vendor. Products from multiple vendors results in increased competition which equates to cost savings. A second advantage lies in the removal of a customer's dependency on the roadmaps of a single vendor, enabling customers to access new features and technologies more quickly.
- ***Lower solution cost -*** Solutions using custom chips may be more expensive than COTS solutions. COTS solutions utilize standard components with greater volumes than custom components, potentially lowering product costs.
- ***Large catalog of devices -*** COTS solutions offer an endless array of options to expand the systems architecture. For example, switches with a variety of port counts, wireless devices, fiber links, remote access, and security solutions can be incorporated into networks.
- ***Network scalability (devices per network and bytes per device)*** – Systems based on customized Ethernet implementations put restrictions on the number of devices as well as the amount of data that can be processed on a single network in order to achieve tighter performance. COTs solutions generally allow for increased device counts and data per device
- ***Ability to easily add and remove devices from a configuration -*** It can be difficult to add or remove devices from custom solutions. For example, a solution using a time slot paradigm assigns each device specific timeframes when it can communicate. In such a scenario, adding or removing a device may temporarily affect the system, as the solution must recalculate how time slots are assigned to devices.

It is important to note that solutions utilizing COTS technology can not satisfy all applications. Industry estimates indicate that COTS solutions can meet approximately 85% of applications and another 10% using proper network design rules.

Deterministic Network Design Rules

Solutions using COTS protocols do not possess the same rigid control over timing as solutions with custom chips. But COTS solutions can be made deterministic if implemented properly. Three techniques to enable deterministic behavior in COTS solutions are presented below.

Utilize Full Duplex Switched Infrastructure

Early Ethernet implementations utilized hubs. Networks utilizing hubs experience data collisions which impact determinism. Ethernet switches enable deterministic behavior. Ethernet switches utilize a full duplex store and forward paradigm. Full duplex communication insures that there are no collisions or delays for packets going in opposite directions on the same cable. Store and forward switches wait until they have fully received each packet before sending it out to the destination address. Store and forward behavior adds delay time (ranges from 20-110 micro seconds depending on packet size). Store and forward enables the quality of service feature described in the next section.

Other features available in switches that impact network determinism are broadcast rate limiting and multicast filtering. Excessive broadcast traffic can affect determinism by congesting the buffers of end devices. Broadcast rate limiting protects end devices from excessive broadcast by restricting any broadcast traffic above a configured level. Multicasting is a useful real time message distribution method but can be disruptive if flooded to all end devices on a subnet. With multicast filtering, the switch distributes multicast messages to end devices registered to receive them (not to all switches in the subnet).

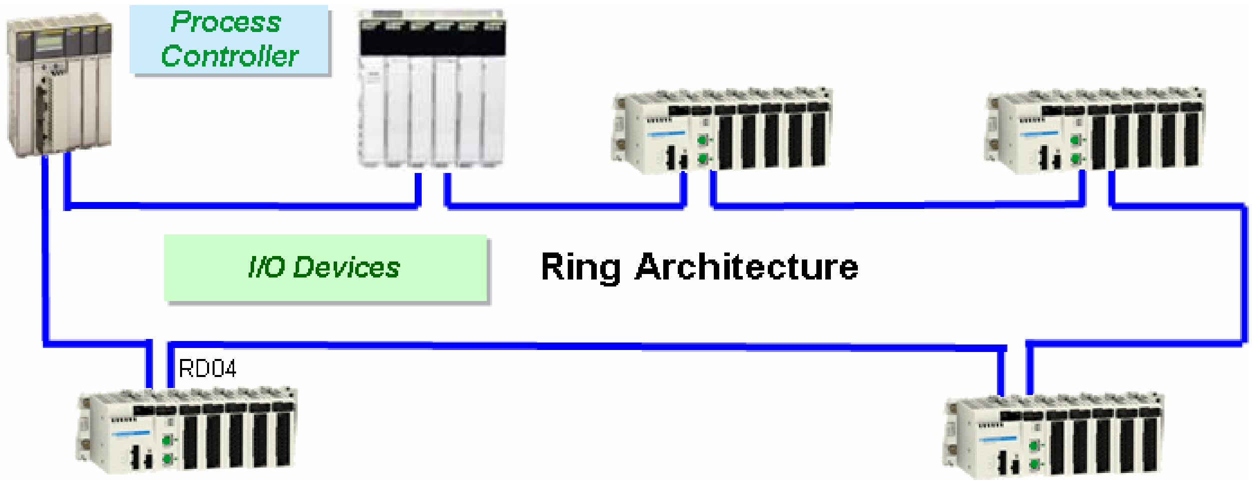
Configure Quality of Service

Quality of Service (QoS) is a technique used to prioritize traffic on an Ethernet network. Traffic can be prioritized based on application or port. Implementation of QoS helps to tighten the delay/jitter times. Implementations typically feature multiple configured priority classes. For example, an administrator could set IO scanning traffic at the end node as higher priority than other application traffic (HMI, SNMP, etc.). When the switch receives traffic from the end node, IO scanning traffic will be sent out ahead of other traffic (even if it has been received after the other traffic) due to prioritization applied by the end node.

Elements with QoS can still contribute to network latency/jitter. The switch could be in the process of sending out a lower priority packet when it receives a prioritized packet. Thus, each switch can introduce a potential delay associated with the max time to send out a single packet before the prioritized traffic can be sent. The delay will depend on the size of the lower priority packet being sent by the switch. Note that the switch can be waiting to send multiple higher priority packets as well.

Controlled Network Design

Perhaps the best way to guarantee determinism in networks using commercial off the shelf products is by controlling the size and configuration of the network. Each node in the network introduces some degree of latency and jitter. If the network configuration and size are restricted, the maximum latency/jitter for the network can be calculated, enabling guaranteed deterministic behavior. For example, a vendor could specify deterministic behavior for a ring architecture with 32 hops. A second parameter affecting determinism lies in controlling the amount and type of traffic in the network. Network transmission time can be decreased by designing the network so that each slave device will generate a single packet every 5 ms or more destined for the master. The network can also be designed to prevent the generation of high priority packets between slave devices.



The best way to illustrate potential COTS solution determinism is through some examples. Performance will vary based on application and protocol used, but the examples should provide an approximate level of magnitude for deterministic performance.

Example 1 - Network delay to send data from PLC to IO and back again
Assumptions:

- Ring architecture
- PLC with 31 IO drops,
- 800 bytes in / 400 bytes out

Network Determinism: 5.5 ms.

Example 2 - Network delay to send data from PLC to IO and back again
Assumptions:

- Ring architecture
- PLC with 3 IO drops,
- 64 bytes in / 64 bytes out

Network Determinism: 0.25 ms.

Note that the times provided in examples 1 and 2 assume a single scanner with multiple adapters with no high priority traffic between adapters.

Conclusion

Protocols created to work with commercial off the shelf equipment provide a cost effective, scalable solution

Ethernet will continue to aggressively penetrate industrial automation solutions in the coming decades. The most dramatic growth will occur at the device level. There are a variety of industrial Ethernet protocols available in the market today. Customers should choose the protocol best suited to meet the needs of their specific applications. Protocols created to work with commercial off the shelf equipment provide a cost effective, scalable solution that will satisfy the determinism requirements for the majority of automation applications.

Make the most of your energy

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