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EVALUATING INDUSTRIAL ETHERNET

WHAT IS STANDARD?

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As industrial automation systems evolve, industrial Ethernet is becoming increasingly popular for networking. If you have been involved in the process of evaluating industrial networks, then you already understand the significance behind such a decision and the confusion that may often arise during the selection phase. Different claims and opinions about what is standard, what is not and what technology is suitable in an industrial application are plentiful. With so many automation network vendors claiming their Ethernet networks are "standard," the question arises as to what is fact and fiction, and why does it all matter?

This article will peel back the layers of marketing claims and analyze what constitutes standard Ethernet. In addition, it will overview the key advantages of an industrial network that uses standard, unmodified Ethernet over standards-based networks that deviate from one or more of these standards. Before proceeding, however, let us first carefully define what makes "standard Ethernet" standard.

I. Standard Ethernet defined

Ethernet, like other modern communication protocols, follows the OSI seven-layer communication model. The OSI model is an abstraction that describes how a communication protocol is designed.

While there are seven layers to the model, standard Ethernet is commonly discussed by talking about three distinct pieces: IEEE 802.3 at the bottom, the TCP/UDP/IP suite in the middle and an application layer that sits at the top of the stack. Typical uses of such unmodified Ethernet networks include the web pages and email you use over the Internet. Industrial protocols that use standard, unmodified Ethernet include EtherNet/IP, Modbus/TCP and PROFInet CBA (Version 1).

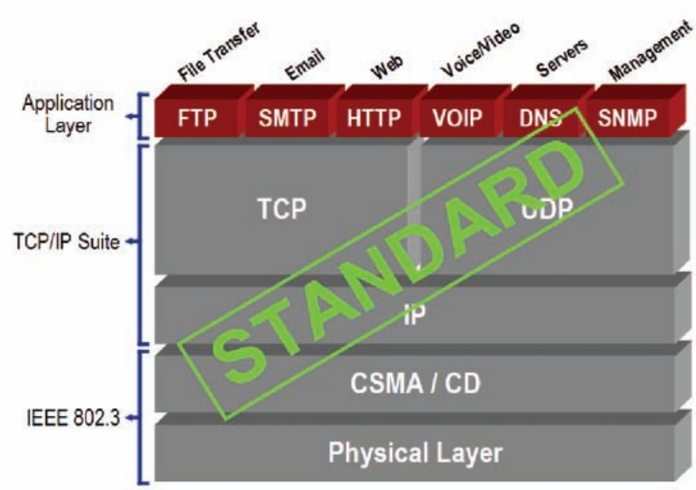

Figure 1- Standard, unmodified Ethernet stack

The first piece of a standard Ethernet industrial network is IEEE 802.3, which refers to a group of standards that collectively define the bottom two layers of the OSI model. Layer 1, also referred to as the physical layer, specifies the requirements for all compliant media, cabling and infrastructure devices (i.e. switches, routers, and hubs). The IEEE 802.3 standard also includes layer 2, which specifies a Media Access Control (MAC) protocol for the data link layer. This defines a simple frame format for moving data packets between Ethernet devices.

The second key piece that composes a standard Ethernet network is the TCP/UDP/IP suite, used in OSI layers 3 and 4. Transport layer protocols such as TCP and UDP allow two devices on the network to exchange data, and rest on top of the IP network layer protocol. The purpose of the IP protocol is to specify the format of Ethernet packets, along with the appropriate addressing scheme. Together, IEEE 802.3 and the TCP/UDP/IP layers form the powerful foundation that supports popular Internet features such as email (SMTP), web browsing (HTTP), file transfer (FTP), voice transfer (VOIP) and network management (SNMP). Over two billion people worldwide use these features, which are actually application layer (OSI layer 7) protocols that sit atop the IEEE 802.3 and the TCP/UDP/IP stack.

In order to meet the demands of industrial applications, a standard Ethernet network requires a third and final piece. This last piece consists of an additional application layer protocol that sits atop the IEEE 802.3 and TCP/UDP layers and rests alongside the various other application layer protocols described above. Typical industrial functions performed over this layer include device configuration, data collection, HMI messaging, operator control, I/O control and drive control. In order for Ethernet to serve as an effective industrial network, the application layer must also be able to handle the real-time requirements of additional functions such as machine safety, motion control and time synchronization. "Real-time capability" refers to the ability of a system to react to all possible events correctly under all operating conditions and within all expected time constraints. Many evaluators of networks also look for the entire industrial network protocol to be approved by organizations such as the IEC[1] and to meet the corresponding European standards[2]. These organizations and standards help ensure that the network can withstand the demands of industrial applications.

Together, the three pieces outlined above compose an industrial solution that uses standard, unmodified Ethernet. Next, we will see how modified Ethernet networks stray from standard Ethernet and how these deviations affect end users.

II. What is NOT standard?

Today, many automation network vendors violate one or more of the criteria above that constitutes standard Ethernet, with the hope of providing faster performance, greater priority for industrial traffic and products that better withstand harsh industrial environments. However, to appeal to customers, they claim that their networks are "standards-based." These assertions have generated a great deal of confusion for those who are looking to deploy Ethernet networks, and have warped the true definition of standard Ethernet. Below we will analyze the technical differences between a truly standard industrial Ethernet network and "standards-based" or "standards-compatible" industrial Ethernet technologies.

The terms "standards-based" and "standards-compatible" alone do NOT guarantee a network's compliance with all Ethernet standards. So what exactly constitutes a "standards-based" or "standards-compatible" industrial Ethernet network? The answer is simple: any standards-based solution that alters IEEE 802.3, bypasses or modifies the TCP/IP suite, and/or or lacks an appropriate application layer is not standard. In many cases, a network vendor starts with the unmodified layers of an Ethernet stack and modifies or adds to them, injecting proprietary software, protocols, hardware or a combination of all three into the stack.

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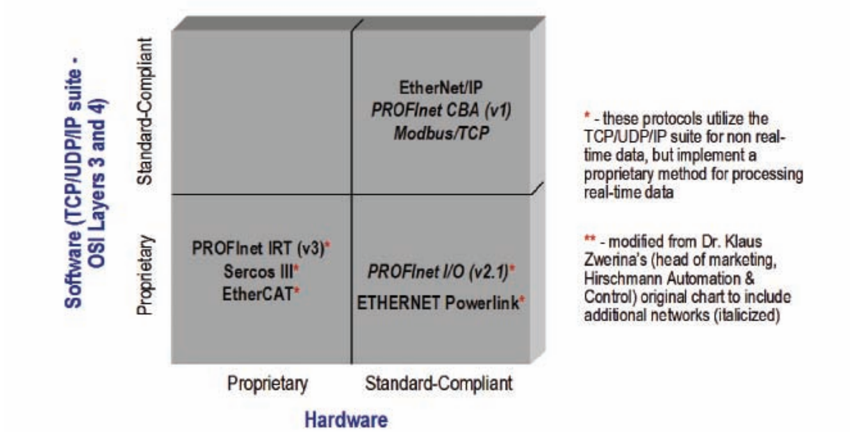

Classification of Ethernet real-time methods**

Modifications to IEEE 802.3 (physical and data link layers)

Almost all Ethernet solutions claim compatibility with standard, ubiquitous Ethernet hardware, including switches, cables and connectors; however, this assertion can be misleading to customers. Networks such as PROFInet IRT (Version 3) and EtherCAT, for example, utilize proprietary (non IEEE 802.3-compliant) hardware in end devices with built-in custom switches. These devices require designers to apply additional rules, adding complexity to standard Ethernet networks, and may not be able to use standard network management and troubleshooting utilities.

Another aspect of the standard Ethernet model that standards-based networks often modify is the data link layer. IEEE 802.3 defines the data link layer in standard Ethernet to use Carrier Sense Multiple Access with Collision Detection (CSMA/CD), a network control protocol that defines a simple frame format for transferring packets of data across the network and between devices. Some network vendors bypass this protocol, claiming it is not deterministic because of data packet collisions. However, this view is archaic and misleading, since standard switches eliminate the possibility of collisions to provide excellent determinism. Other vendors claim that switches add variability, or “jitter” to the network timing; however, the amount of jitter introduced is negligible (on the order of 100 nanoseconds) in all but the most demanding automation applications.

Typically, the modifications to the data link layer used by non-standard Ethernet networks include “slicing” the network update cycle into discrete transmission time slots, implementing non-standard media access hardware to control devices on the network and/or using special polling schedules to communicate between master and slaves. Although these mechanisms improve network determinism, they may introduce additional problems to customers, such as the inability to use COTS Ethernet devices, requirement of proprietary hardware, limited support of network topologies, and added complexity as a result of modified schedules. Furthermore, COTS Ethernet devices do NOT have knowledge of any proprietary transmission schedules or special polling schemes in the data link layer, which may dramatically reduce the amount of bandwidth available for normal TCP/UDP/IP traffic.

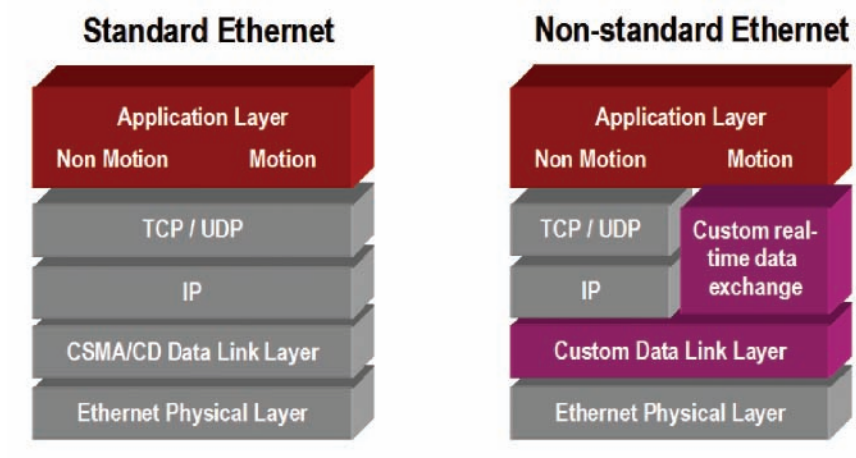

Figure 3- Standard and non-standard Ethernet stacks

Modifications to or bypassing of TCP/UDP/IP (transport and network layers)

Standard Ethernet communication utilizes TCP/IP, which is inherently non-deterministic and has a reaction time in the hundreds of milliseconds. However, applications such as remote I/O and motion control applications demand millisecond response times in the single digits or less. In an effort to boost determinism, many standards-based networks modify or bypass the TCP/UDP/IP suite of protocols altogether. Instead, these networks utilize alternative, often custom technologies in the transport and network layers of the Ethernet stack. Some standards-based networks claim to be "compatible" with TCP/IP; in reality, these networks merely use TCP/IP as a supplemental channel to provide non real-time data transfers. Actual real-time data is transmitted using proprietary time-slicing or polling schemes. In addition, these schemes often require the addition of more specialized hardware in the form of gateway devices.

By bypassing the TCP/IP protocols, such proprietary networks limit the end user's ability to use standard, off-the-shelf Ethernet products such as routers, switches, firewalls, etc. This limitation destroys one of the fundamental advantages of standard Ethernet – the availability of low-cost, ubiquitous COTS Ethernet hardware.

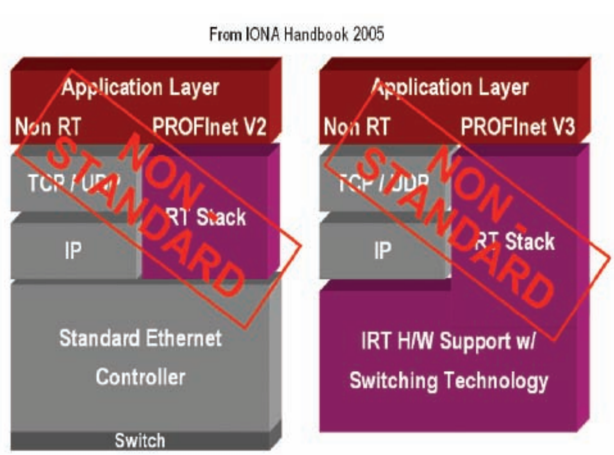

Figure 4 – Examples of non-standard OSI stacks

Another significant disadvantage to modifying standard Ethernet protocols is the resulting inaccessibility of the network to IT traffic that may arise. For example, what happens when a plant's IT department requires large amounts of data to be communicated? Time slicing techniques and polling schemes often modify the behavior of network timing; as a result, the network's ability to process high levels of TCP/UDP/IP traffic may suffer. Since these networks prioritize time-sliced data over other data, how much delay will be experienced by TCP/UDP/IP traffic? Again, this performance is unknown to the IT department.

When the layers of standard Ethernet are modified, the training of IT staff on these new, proprietary technologies can present significant challenges as well as additional costs. IT personnel are typically experts on standard Ethernet technologies and protocols such as IEEE 802.3 and TCP/UDP/IP; however, when specialized technologies such as polled scheduling, time-slicing and custom hardware are inserted into the Ethernet stack, there is often a steep learning curve that requires much time and effort from the entire IT department. In addition, traditional Ethernet tools and infrastructure devices preferred by IT such as standard network management tools (e.g., network analyzers) and features (e.g., VLANs and standard security protocols) may no longer be compatible with the new network.

Proprietary Ethernet networks generate conflict between a plant's engineering staff and its IT staff; as a result, both groups must make significant compromises, such as sacrificing the use of some of IT's favorite standard Ethernet tools and devices and accepting a level of uncertainty in terms of network performance. In addition, the IT staff must also spend considerable time to learn both the hardware and software aspects of the new network.

III. Benefits of standard, unmodified Ethernet over proprietary, "standards-based" networks

Standard, unmodified IEEE 802.3

Compliance with the lowest two layers of the standard Ethernet stack yields significant advantages over networks that are "compatible with" or "based on" IEEE 802.3. An IEEE 802.3-compliant network guarantees hardware interoperability in its end nodes; as a result, any standard, COTS device that complies with IEEE 802.3 can reside on the network without the use of custom switches, gateways or custom ASICs and without considering special design rules. An abundance of standard devices with industrial characteristics are currently available and cost effective.

Standard TCP/UDP/IP protocol suite

In the past, standard Ethernet technology limited the performance of networks to half-duplex communications, restricted the speed of networks to 10 Mbps and required the use of hubs and repeaters. Today, standard Ethernet offers 100+ Mbps performance, full-duplex communications and intelligent switches that manage network traffic – all while yielding levels of determinism exceeding that of most industrial networks in use today, and far exceeding the requirements of all but the most demanding applications.

Standard Ethernet networks achieve determinism and performance using UDP, which yields faster transmission rates than TCP. In addition, standard switches employ a feature called Quality of Service (QoS), which allows for prioritization of critical time data.

Standard application layer

The primary benefit of a standard industrial application layer is its unquestioned compatibility with commercial applications such as email, web browsers, file transfer programs, voice transfer programs and network management tools.

Integration with IT

Another advantage stemming from a standard network is the fact that the plant floor is able to integrate much more seamlessly with the rest of the enterprise. Because such networks utilize existing technologies and practices, little or no additional hardware/software training is required. As an added benefit, the IT department is able to continue using its favorite standard network tools, including:

- Traffic analyzers such as Ethereal to capture network data over Ethernet networks and isolate traffic by traffic types, IP address, packet content, error types and physical address, etc.
- Tools that use Simple Network Management Protocol (SNMP) to monitor and control network devices in TCP/IP networks and manage configurations, performance, data collection and security.
- Standard, COTS switches with a robust set of features to manage network traffic.

Migration

Finally, because standard Ethernet networks use widely-adopted standards, migration to future versions of Ethernet promises to be easy and widely supported. As Ethernet technologies evolve, end users are able to leverage standard, well-established tools and features such as IGMP snooping[3], port mirroring[4] and Gigabit Ethernet[5] to improve network maintainability and performance.

Conclusion

Currently, numerous industrial Ethernet solutions exist, each backed by a particular group of vendors and/or organizations who claim their solution as "standard." As a result, end users and system integrators often experience a great deal of confusion and uncertainty when selecting an appropriate Ethernet network. However, determining whether a network is truly compliant with standard Ethernet does not have to be an overly complex ordeal, and the benefits of doing so can be substantial.

Use the following questionnaire to help you identify whether the network is standard:

Questions to ask when determining whether an industrial Ethernet network is standard:

1. Is the network compliant with unmodified IEEE 802.3? (answer should be "yes")
2. Does the network use the unmodified TCP/UDP/IP protocol suite without any other protocols that may time slice or bypass it? (answer should be "yes")
3. Does the network have an appropriate application layer protocol that meets my application needs and is approved by organizations such as IEC, EN and/or IEEE? (answer should be "yes")

Additional network selection criteria to consider:

1. Can COTS components be used?
2. Can popular Internet features such as email, web browsing, file transfer, etc. be used on the network?
3. Is proprietary hardware (e.g. ASICs/FPGAs, switches and linking devices) needed?
4. Can IT use standard Ethernet hardware (e.g. switches) and software (e.g. traffic analyzers and SNMP) tools?
5. How much additional training is required for IT to learn the new network?
6. Is TCP/IP traffic limited on the network? What is the time delay introduced?
7. What level of determinism or real-time capability does my application require, and what capabilities do the networks I am considering provide?
8. How easy will it be for the network to migrate to future versions of Ethernet?
9. What additional design considerations are required?

1) Examples include IEC 61158 ("Digital data communications for measurement and control – Fieldbus for use in industrial control systems") and IEC 61784 ("Digital data communications for measurement and control – Part 1: Profile sets for continuous and discrete manufacturing relative to fieldbus use in industrial control systems")

2) Examples include EN 61158 and EN 61784-1

3) A feature of managed switches that protects networks against multicast traffic flooding

4) Another managed switch feature that forwards all network packets seen on one switch port to another port for monitoring and analysis

5) The IEEE 802.3-defined standard for transmitting Ethernet data at one billion bits per second

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