NEW I/O ARCHITECTURE OPTIONS

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Abstract- *Fieldbus based I/O systems are continuing to evolve in response to the accelerating trend toward modular manufacturing techniques. New form factors have been introduced that provide the right balance of configuration flexibility and installed costs. This paper will review how to evaluate the different I/O form factors in light of the modular manufacturing driven requirements for main control panels, distributed panels and enclosure-less control. Industrial Ethernet applications are rapidly expanding to include direct I/O connections. However, many do not realize the differences between Ethernet and Fieldbus based I/O systems. This paper will address the applications considerations for Ethernet based I/O systems including system layout, infrastructure requirements, installation, and performance influencing factors.*

I.   INTRODUCTION

The increasing number of distributed I/O options available today is steadily increasing to meet industry's changing needs. Ethernet in industrial applications are growing rapidly. As Ethernet expands into high speed direct I/O control, the performance of the network infrastructure and I/O devices has been increased. The following will describe the some of benefits and application factors of this new technology.

II.   GENERAL CONSIDERATIONS WHEN SELECTING AN I/O SYSTEM

Openness to Multiple Networks

Selecting an I/O system that is open to multiple networks enables you to standardize on an I/O structure with the flexibility to choose the best network for each individual application. This can lower design (common prints), training (same technology) and maintenance costs (same hardware troubleshooting approach). Different users see different benefits from this, for example an OEM will appreciate the design time savings where an end user will see savings in training and maintenance.

Types of Signals and Functions

Applications can include many different signal types in varying quantities. An I/O system that offers a broad range of I/O enables you to build I/O stations that meet the exact application requirements without need for intermediate signal conditioning. Modular I/O solutions offer the highest flexibility of any I/O form factor, combining individual modules for the network interface and field device connections to form an I/O station.

The Number of Signals and Locations

The concentration of signals and distance between signals will determine the form factor of I/O that will be best solution for each application. With the network interface and a fixed I/O configuration integrated into one module, Block style I/O offers lower installed costs and are optimized for highly distributed digital signals. Modular I/O structures allow higher concentrations of signals at any one location, but have a higher installed cost.

Diagnostics

Distributed I/O devices often communicate that they are malfunctioning or if there is a problem with a connected field device. This information is locally indicated on the device for maintenance personnel and remotely transmitted over the network for control decisions and display at the PLC/HMI levels. Selecting a distributed I/O system that displays this information clearly and commonly across the product family will reduce training, installation and down times.
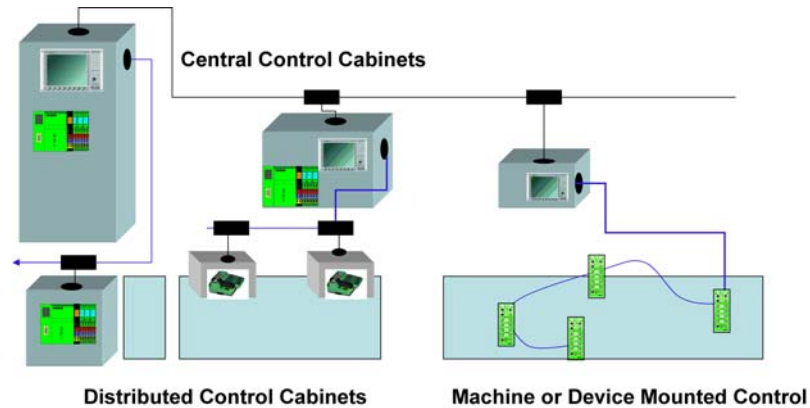
III. DISTRIBUTED I/O ARCHITECTURES

Figure # 1, Distributed Control Architecture

Central Control Cabinets

The central control cabinet normally controls the entire process and utilizes a PLC or PC based controller. Typically there will be high I/O counts routed directly to the cabinet. The I/O will be a mix of signal types, digital, analog, as well as higher function signals. Modular I/O with high density modules (32 points digital or 8 channels analog) have the capacity of landing large concentrations of I/O onto one network interface, reducing the need for multiple network drops in the cabinet and fewer total modules. A modular I/O system that supports sub-network branching has the ability easily integrate networks like AS-i for discrete manufacturing and HART for process control into the control cabinet.

Distributed Control Cabinets

Distributed control cabinets provide connection for a mix of I/O signals as well as control of the local process. A modular I/O system with an embedded PLC to handle the local process control is a common solution for these applications. The complexity of control and process time requirements can be different for the individual distributed cabinets. Choosing an I/O system with scalable processor performance options will allow you to standardize on the I/O as well as the programming software for the entire process. This will reduce engineering time, training of maintenance personnel and need for multiple "experts" for one job. Although there are still the same types of signals the I/O counts in the distributed cabinets will not be as high as the central control cabinet, so lower density modules may be used to better meet the exact I/O counts.

Distributed I/O cabinets with some type of user interface (push buttons, and lamps) or another networked control element such as a drive or inverter will require the lowest counts of I/O. Block style modules with integrated network interface and I/O are designed to be placed in these distributed I/O cabinets. The compact fixed configuration design requires less space that a modular solution at a lower cost for I/O counts of typically 32 points of less.

Machine Mount I/O

Initially small junction boxes were used to supply power to and terminate highly distributed sensors and actuators. Machine mount modules with integrated network interface and I/O were designed to replace the junction box. Reducing the number of enclosures and eliminating wiring errors with pre-terminated field connections machine mounted I/O provide the benefits of less floor space, speed of design, construction, and commissioning of the control system.   As modular manufacturing techniques are realized, there is a growing need to for higher concentrations of signals and mixed signal types to be placed on the machine mount I/O. To meet this need new modular machine mount I/O solutions are being introduced. Modular machine mount I/O systems with flexible cable interconnection of I/O modules and network interface module offer the advantage the single network interface for many I/O points while still keeping the ability of placing the I/O modules around mechanical restrictions.

IV.   NETWORK CONSIDERATIONS

Why Industrial Ethernet?

The demand for industrial Ethernet is rapidly growing due to business and technical reasons. From a commercial viewpoint, the costs of Ethernet technology has greatly decreased, embedding Ethernet in highly distributed basic plant floor devices is now more affordable. The introduction of industrial Ethernet infrastructure products provides the size, reliability, and maintainability needed for installing and supporting large networks Ethernet control devices in a plant.

High Data Capacity and Performance with Growing Capabilities

The Ethernet specification continues to evolve and expand and now includes new media types such as wireless, and increasing performance such as expanding data rates from 10Mbps up to 10Gbps. Most fieldbus networks have data rates of 128Kbps to 512K or, in some cases, 12mbps. Industrial Ethernet applications operate in the range of 10Mbps to 100Mps, providing a faster throughput for large amounts of data. It has also been expanding in functional areas such as "auto-negotiation", redundancy, message filtering protocols that reduce network traffic and increase throughput.

Ethernet Flexibility Simplifies Data Transfers

Moving information through or between the control systems, manufacturing cells, manufacturing lines requires significantly lower effort with Ethernet vs. the traditional array of individual fieldbus networks. An Ethernet network allows many 1000's of devices to be inter-connected on the same network. Major Fieldbus networks have a limited range of connected devices: 32, 64, 128, or 256 maximum devices based on the network type. Control systems overcome this by creating individual PLC controlled networks. Then the PLC's are networked using the same fieldbus or a higher level network.   To transfer

data through the individual networks requires separate communication programming and in some cases different network cabling solutions. With Ethernet's large device capacity and data capacity all the devices can be connected on one network. Compared with fieldbus networks, different communication protocols can be simultaneously transmitted on the same Ethernet network. This allows different vendor devices, talking different protocols to be connected to the same wire, which eliminates running multiple different network cables.

Universal NW Design, Layout and Maintenance Rules

Today, plants may have a variety of networks to maintain. In addition to proprietary legacy remote I/O and data networks, different fieldbus networks may be used on different lines or manufacturing areas of the plants. Each fieldbus network has different installation, layout guidelines and different diagnostics. This can results in increased training for maintenance personnel and can lead to longer down times if the network "expert" is gone. With Ethernet, all the network diagnostic LED indicators and layout / wiring guidelines are the same regardless of which vendors and which protocols are used.

## V.   MAJOR DIFFERENCES BETWEEN ETHERNET AND FIELDBUS NETWORKS

Network Layout and Device connections

Fieldbus systems are typically laid out in a trunk and drop manner where there is one main network cable and the devices connect to it via "T" or daisy chain connections. Industrial Ethernet systems are laid out point-to-point configuration. Each Ethernet device connects to the network with a single cable through an infrastructure component such as an Ethernet switch. With this approach, multiple infrastructure components are interconnected creating star layout of individual control devices. While this provides much greater cabling layout flexibility vs. trunk and drop systems, it requires Ethernet switches or hubs instead of only the connectors used in fieldbus systems. Ethernet also has the advantage of allowing devices with different data rates to be mixed in the same system and even connected to the same Ethernet Switch. This allows existing installations or systems with a 10Mbs Ethernet devices to be easily expanded to use faster 100Mbs products. This is an advantage over fieldbus systems where the slowest device determines the data rate setting of the whole network.
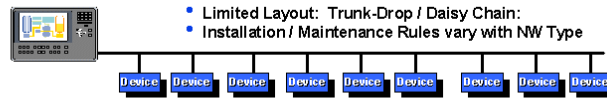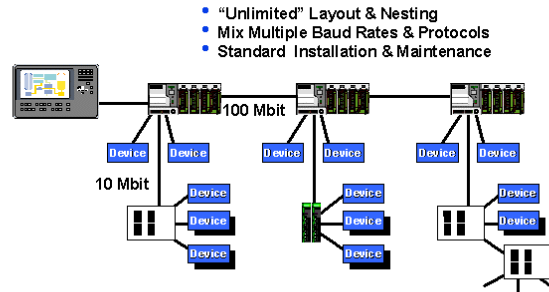
Figure#2, Network Structures

Addressing of Devices

   To communicate with controllers such as PLC's or PC's, networked devices require an address on the network. In both proprietary networks and in fieldbus systems, this has normally been done using rotary or dip switches on the device. Industrial Ethernet device addresses can be set over the network using standard network addressing protocols.

   Greater use of fiber optic cabling

   With Ethernet's high data rates, the maximum copper cable point to point length is 100meters. This is fixed regardless of the data rate. In the IEEE Ethernet specifications, it was decided to maintain the fixed 100m length, but require increasingly higher frequency carrying cables (at increasing costs) as the data rates increase. Because of this, fiber optic cables are required (not optional) for most long distance applications. The first step is in selecting the right fiber cable based on differences in distance, cost, and termination ease. Plastic fiber cables are available that are optimized for creating short (50m-100m)-noise immune custom cable lengths using standard wire tools. Glass fiber cables cover greater distances (typically 2000 m), and have become much easier to terminate than early connector generations.

   Troubleshooting and Fault Response with Ethernet Connections

   With fieldbus networks, the physical connection between the devices and the protocol messaging are integrally tied together. If one breaks a cable, the connection LEDs on the various devices signal an error, the I/O devices recognize the network is "down" and they go into their fault response modes. In Ethernet, there are 2 different types of "connections". Physical cabling connections are indicated with "Link" LED's. Communications messaging connections are the software link between the controller (ie a PC/PLC) and

the I/O. This is analogous to a phone system. One has to first plug the phones into the network (physical connection) and then one must dial up and have the other person answer (establish a communications connection), before anyone can speak (transmit/receive messages). Because there can be many Ethernet switches in between the controller and it's I/O, the I/O can have a good physical connection to the switch it is connected to, yet the cable is cut 3 switches upstream that shutdown Ethernet communication connections. Unlike fieldbus networks, the communications cable can be OK (Link LED on), but have no communications. To properly diagnose a system, the communications activity, transmit/receive LED's should be used. In addition, communications connection diagnostics are available on some products.

 In addition to troubleshooting, the fault response aspects need to be considered. Industrial protocols such as PROFINET and EtherNet/IP have built in "heart beat" checks. If the communications connection is lost, the loss of heartbeat is detected by the I/O module at it goes into the user programmed fault response mode. Other protocols do not have a built in heartbeat mechanism. This requires that the user check to insure that the particular vendor's I/O product have a watchdog function that checks for active communications. Without a watchdog, a wire can be disconnected 3 switches up, and the I/O outputs will stay on waiting for new I/O commands that will not be forthcoming. When designing Ethernet I/O based systems one needs to confirm that either the application protocol or I/O device contains proper connection checking and fault response mechanisms.

VI.   APPLICATION OF INDUSTRIAL ETHERNET

Industrial Protocol Impact on Switch Features:
    There are a number of standardized industrial Ethernet control protocols that can be applied to control I/O with response times in the low 2 digit to single digit ms range. Popular protocols include Modbus TCP, EtherNet/IP, and PROFINET. Message filtering functions in managed switches are typically needed to obtain the highest performance levels. The filtering functions needed vary based on which I/O control protocol is used. ODVA recommends the IGMP Snooping (filters out unwanted multicast messages) feature be used for the best EtherNet/IP performance. The Quality of Service function (allows priorities to be placed on the communications from the different devices) is recommended for the highest performance PROFINET applications. New protocol extensions are emerging that allow coordinated motion over Ethernet. While these provide ms level response times and jitter (variance in update times) of less than 1ms, they require added switch functions such as IEEE 1588 for EtherNet/IP CIP Sync motion control. PROFINET IRT (Isynchronous Real Time) requires that the switches contain IRT ASIC chips. In less time critical applications more unmanaged switches may be used. Many quality monitoring systems use unmanaged switches to connect I/O to monitoring PCs. Many OEM machines use unmanaged switches to connect the machine to a supervisory PC, or interlock sections of a manufacturing process.

Managed switches can also be used in combination with unmanaged switches to allow a balance between system performance and the total installed cost. In general, the faster the required I/O performance, the greater the need for managed switches.

Redundant Communications

PLC systems have had cable redundancy for decades where a cable breaks, but control communications continue on a separate wire. Managed Ethernet switches not only compensate for broken cables but they can re-route communications around one or more powered down or failed switches. To accomplish this is not as easy as connecting all the switches together into a ring or loop. Connecting unmanaged switches in a loop configuration will create conflicts in the switches. The switches compensate by broadcasting messages to all the other switches, which create more conflicts. This whole process accelerates into a "broadcast storm" which can completely shut down the network. Special redundancy protocols like spanning tree or rapid spanning tree allow the switches to communicate redundancy status between them. The control of redundancy related communications prevents network stopping broadcast storms.

VII.   CONCLUSIONS

I/O products now include a full range of IP20, IP65, Block and Modular options. Within an application, combinations of these form factors allow functionality, installation cost and product cost to be balanced for each I/O node. Ethernet options for these form factors are rapidly increasing, driven by the need for communications connectivity, increased layout flexibility, and standardized maintenance approaches. The costs of industrial Ethernet infrastructure components have been rapidly dropping, further increasing demand. While demand for Industrial Ethernet based I/O applications is increasing, users need to consider the changes in addressing, installation, layout, and troubleshooting that is required to have successful Ethernet I/O applications.