Middleware for Wireless Process Control Systems

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Abstract

A process control system manages fluid processes in a factory plant. It typically reads temperatures, speeds, etc. from the plant via smart sensors and adjusts the process via smart actuators like valves and motors. In many cases the control system and the smart devices are from different vendors. Fortunately, industry standards have been established for the communications among them. These standards are based on wireline networks; they are no longer suitable for wireless networks. In this paper we discuss the interoperability issues related to wireless communication among process control system components.

1. Introduction

A process control system controls an industry process. Its core involves some sensors measuring the process, actuators adjusting the process, and the controller controlling both types of devices. The controller and devices form a control unit wired together by a control network. The control network has high real-time requirement. The sensor and control data should be delivered at pre-determined times. A loss of scheduled data normally triggers big costs such as the shut down of the process. Industry fieldbus network standards are usually employed in the control networks. Such standards are Foundation Fieldbus, ProfiBus, DeviceNet, etc. In this paper we look at the ways and challenges to apply wireless to the control network.

In a modern process control systems such control units are further connected in a wider network, the control area network. Usually workstations are also on this network serving as the gateway from the controller to the users and outside world. A user could configure and monitor the control unit from the workstation. The control area network has less stringent real-time requirement than the control network. [5] talked about applying wireless in control area network.

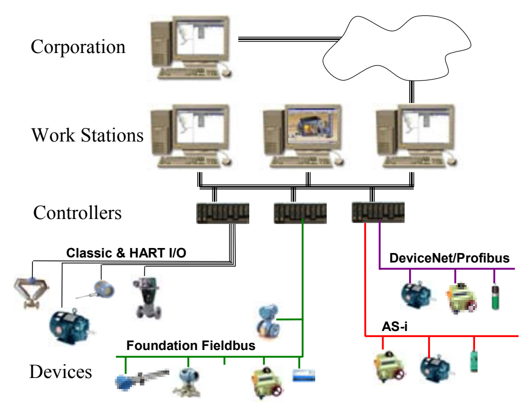

Figure 1: A Process Control System

The workstations in the control area network could also be connected to the office network, or the Internet. The networks involved here are regular ones with no special control requirements; applying wireless to them is beyond our concern.

In the next section we shall briefly describe an exemplary wireline control network standard, the Foundation Fieldbus. Section 3 looks at the issues of a wireless version of Foundation Fieldbus. In Section 4 we address sensor network, which is much talked about in the automation industry. Section 5 is the conclusion.

2. The Foundation Fieldbus Standard

Foundation Fieldbus standard (FF) [6], in Figure 2, is developed from the OSI 7 layer standard. It adopts the physical and data link layers of the OSI standard; it strips network, transport, and session layer; it breaks the application layer into fieldbus access sublayer and fieldbus message specification layer; it also defines system management, network management, and user layer.

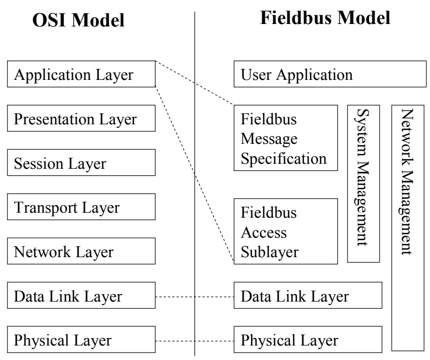

Figure 2: Foundation Fieldbus Standard

Before a system runs the control over the fieldbus, the network has to be configured. This includes the system and network parameters in all the layers. Those parameters will be different among different control networks. Being able to adjust network parameters for individual process under control is an important feature of a fieldbus. The Link Active Schedule (LAS) that defines scheduled (synchronous) traffic is also preconfigured. LAS resides within the data link layer and will be executed periodically. At run time, a link master device manages the network. It guarantees the execution of LAS and controls other devices' access time to send unscheduled (asynchronous) traffic.

3. Wireless as a replacement

We first look at how a wireless network could achieve the same level of support as FF wireline control network.

If we ignore the cost and spectrum restriction, the same level of functionality could be achieved by replacing the physical layer in FF with wireless antennas that has enough power to achieve a reliable 31.25k bps (bits per second) data rate, FF's official bandwidth. This approach is prohibitive but not impossible if such an industry standard comes along.

We shall, however, look at using current wireless standards and proliferating wireless transmission hardware.

A process unit in a plant ranges in tens to hundreds of meters. The controller could be mounted close to the devices, or remotely in a control room, which is normally not far away from the process. Depending on the type of cables, the maximum length of FF ranges from 200 meters to 1900 meters. As devices are mounted within the process equipments, there is normally no line of sight among them and the controller. Also most of the process is outdoor. Among the many wireless standards, those defined for personal area network and local area network could be candidates. Personal area network standards such as Bluetooth and IEEE 802.15.4 have work range of 10 meter distance but could be up to 100 meters. Local area networks such as Wi-Fi have work range of 100 meters. The standards normally define the physical and data link layers, but industry consortia such as ZigBee also define upper layers. Wide area networks such as WiMax have higher power consumption and serves distance up to tens of kilo meters. They are better suited for the control area networks that cover a whole process plant.

Figure 3 displays a middleware between the wireless standard layers and a process control strategy. To achieve the same level of control as wireline FF network, many challenges should be worked out. But first of all, some problems associated with wireless are less problematic.

Mobility. The devices are mounted in fixed locations in a process; the controllers are also mounted in fixed locations. The wireless communication among them does not suffer the problem related to mobility. In a wireless network, the signal strength and bandwidth change as the distance changes.

Connection Establishment. Dynamic connection establishment needs not to be part of a running process. The configuration stage sets it up before hand.

Connection Reestablishment. As the components are fixed, we do not need to worry about losing communication caused by distance variation. There may be signal noise. But noise just causes transmission retries.

Scalability. Scalability is an issue in wireless as devices can join and leave the network randomly. Again this is not a concern here.

Battery life. The controller has wireline power, devices mounted in the process normally have readily power supply close by. A new type of device could even draw power from the process itself. Unless we used battery powered devices, or use wireless repeaters to relay traffic, battery problem is easier to solve in a process environment.

Bandwidth. Although it is a relative term, bandwidth could be considered sufficient. Process control targets fluid material, whose change rate is limited by physical laws. With more data transmission rate we could have better control, but as replacement for FF's 31.25k bps, the bandwidth proposed by current wireless standards is abundant, for which 1M bps is common. High bandwidth could also help resolve other challenges we shall discuss in the following. For example, redundant transmission could prevent data losses introduced with wireless.

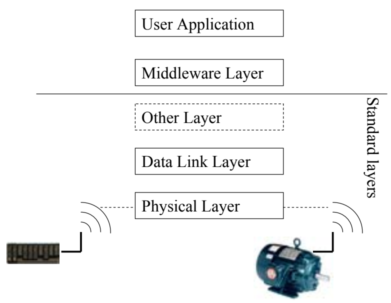

Figure 3: Wireless Network

Transparency. The place and type of the controller and devices are part of the configuration procedure. The middleware does not need to hide the location and object type of the remote components.

Of course, there are always more challenges. And above points could easily become challenges if we venture beyond just replacing FF. There is no need to repeat the common issues associated with wireless in this paper. We shall list here those specific to replacing FF.

The fact that so many wireless standards exist poses the challenge for a middleware. The user layer should not change for different standards. This implies that the same set of APIs offered by the middleware will be implemented differently for different standard layers beneath it. The process control industry may settle down on one wireless standard. But we could not rule out the change to apply process control technology to other industries, which happen to adopt a different wireless standard.

Network Configuration. The middleware should support the application to set network parameters. This may be a problem if a network layer can only access the immediate layer below and the lower layers are already standardized.

The standardized lower layers are specified without fully considering the strict real-time requirements of process control. FF was created because the OSI model does not suit well. The exact situation happens now. The question is if we will see a wireless version for FF, or some new middleware comes about on top of the existing wireless standard. It will be difficult for such middleware to translate process control requirements into supports from such standards.

Another reason for FF is to reduce the layers of OSI to reduce delays. One question is if the advancement of processor power could alleviate such limitation in using existing wireless standards.

LAS is the key component in FF. It is the foundation for periodic execution of loop controls. How do we simulate this in wireless is a big challenge. The underlying network should provide deterministic transmission delays. IEEE 802.15.4 seems promising in this perspective. It designates time slots to devices on the network.

While the wireless standards try to make the protocol stack small to save power, the upper layers of the process control stack needs more sophistication to handle its more demanding requirements.

Bandwidth versus delay. We claim that the wireless bandwidth may be enough, but the transmission delay will be a problem. The long delay and the variation of delays, especially in the multi path case, will make precise periodic control difficult.

Bandwidth variation. Although there is no mobility, the interference in the open air still exists. This introduces new fault-tolerance considerations. We have to expect that messages may not be transmitted in time, or not transmitted at all. In FF, messages may be retried due to device response problem; in wireline, message may be retried due to network problem.

No matter how good the middleware is, there is going to be changes in the user application layer to handle wireless idiosyncrasies that the middleware could not mask. A wireless fieldbus standard could also standardize the user layer to handle this like in FF.

We have said that the advancement of wireless speed may solve some of the challenges. On the other hand, higher speed leads to more features people want to jam into the system.

The next generation of FF is called H2. H2 has bandwidth up to 1M bps. It uses dedicated Ethernet. It is interesting to see if it is easier to adapt wireless Ethernet for H2.

4. Sensor network

Of all the wireless hype, sensor network is the closest to industry automation. We cannot end this paper without looking at its implication in process automation.

Figure 4 is a ZigBee sensor network. IEEE 802.15.4 defines a low data rate, long battery life, and low complexity protocol. It has the speed of 20k bps and 250k bps. Data transmission is controlled by the router; sensors can sleep most of the time except its transmission time. ZigBee Alliance [9] pushes its adoption in industry automation. In a sensor network [2] many sensors scattered around an area. They collect environment data and transmit data to the base station. A mesh is a typical sensor network in which a sensor also forwards data from another sensor. This essentially increases the transmission distance. It also increases the robustness with multiple data paths.

ZigBee is considered the best candidate for process control. It is also suggested [3] that FF like standard should be built on top of ZigBee. Some of the additional challenges with sensor network, especially mesh network are as follows.

The data rate is comparable with that of wireline standards, but given the possible deteriorating of wireless transmission, will it achieve the same level of control?

Sensor network emphasizes on collection data, and is optimized for it. Another half of process automation is sending control data to actuators. Timely delivering of control data in a mesh would be difficult.

Multi path increases robustness, but results in delays that are not deterministic. This is bad for scheduled data. However, IEEE 802.15.4 does provide good support for direct communication between two nodes.

Mesh network could be an auxiliary to an existing process control unit. As a replacement, several issues have to be resolved. The architecture of mesh network does not match exactly that of a control unit with wireline replaced by wireless. Devices have fixed location; sensors in a mesh are normally randomly scattered. Devices could be considered a sensor in the mesh. Do we deploy other sensors other than the devices? If so, what do they do in the mesh? How do we manage if scheduled data is relayed by other sensors in the mesh?

5. Conclusions

Wireless will be pervasive in the future. Its penetration in the process control industry is just a matter of time. We looked at the role of wireless in the process control unit, the low level network of a process control system. We looked at wireless as a replacement of wireline. We also looked at the sensor network. It should be pointed out that, besides as a fieldbus replacement, wireless as a new technology could open up many new opportunities. Although we only described FF in this paper, the basic idea applies to other fieldbus standards.

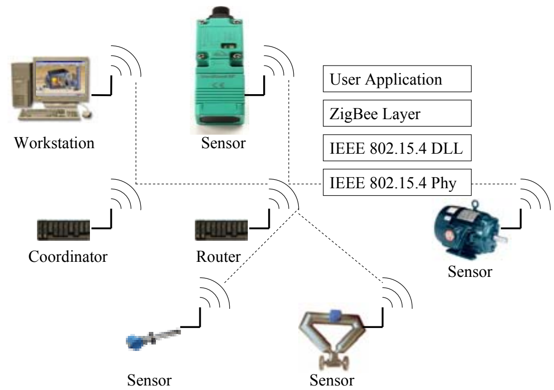

Figure 4: Sensor Network

We skipped the topics of wireless that is common in many application areas. The thinking is that the challenges there are well known and tackled from every aspect. The process control industry could benefit directly from those breakthroughs. Such topics are security, privacy, noise, interference, battery life, fault tolerance, routing, etc. Hopefully the problem of too many wireless standards could be sorted out as well.

The success of the middleware depends on the support from all players, including device vendors, system vendors, and wireless vendors. The success of wireless in process control depends on the success of wireless technology, process automation standard, software infrastructure, and vender support. Technology aside, social engineering challenge could be even more difficult.

6. References

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