Industrial Wireless Communication Protocol WIA-PA and Its Interoperation with Foundation Fieldbus

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***Abstract*—Wireless communication technologies can bring great benefits to industry plants. But because of the unreliability of wireless channel and wide use of wired Fieldbus, hybrid with Fieldbus is one of the main application manners of industrial wireless communication today. With different protocols, wireless devices can not communicate with wired Fieldbus devices directly and interoperation can not be implemented when they are hybrid. WIA-PA is the new Chinese industrial wireless communication standard. Its protocol is introduced and the interoperation mechanism between WIA-PA and Foundation Fieldbus is studied. The protocol conversion gateway translates device and automatic object information, process data and other messages to fulfill interoperation. The communication relations and services are also converted to guarantee real-time forwarding. The analysis shows the protocol conversion can provide interoperation between WIA-PA and Foundation Fieldbus devices and satisfy the performance requirements of automation systems.**

Keywords-WIA-PA; Foundation Fieldbus; interoperation; gateway; protocol conversion; communcation performance

I. INTRODUCTION

Wireless communication technologies have been identified as a very attractive option for industrial and factory automation systems. Compared with wired Fieldbus, the cost and time needed for the installation and maintenance of the large number of cables can be substantially reduced, thus making plant setup and reconfiguration easier. Wireless technologies can be used in harsh environments where chemicals, vibrations, or moving parts exist that could potentially damage any sort of cabling. They can also be used to couple to any mobile subsystems or mobile robots to get the flexibility. Furthermore, the tasks of temporarily accessing any of the machinery in the plant for diagnosis or programming purposes can be greatly simplified by the use of wireless technologies. And because of the low cost, low power consumption, self-organized and peer-to-peer features, wireless technologies can give new communication paradigms for industrial automation systems.

Since wireless channels are prone to possible transmission errors caused by either channel outages and/or interference, the real-time and reliability requirements are more likely to be jeopardized than they would be over a wired channel [1]. The industrial wireless communication cannot be implemented just by replacing the cables of Fieldbus with wireless channels. And the existing wireless communication standards, such as IEEE802.11, ZigBee and Bluetooth, cannot be used directly in factory automation systems [2]. So, new industrial wireless communication protocols are required for wireless technologies to go into the industrial plants. And considering the wide use and huge investments of Fieldbus technologies and the higher reliability of wired cables, industrial wireless communication couldn't replace wired Fieldbus completely. Hybrid with wired Fieldbus will be a main application manner of industrial wireless communication today.

Hybrid of industrial wireless communication and wired Fieldbus is to adopt wired and wireless communication devices in factory automation systems according to the application environments, conditions and communication features of different devices to implement production process monitoring and control tasks better. When industrial wireless communication and wired Fieldbus are hybrid, different devices exist simultaneously in a field network. Wired and wireless devices are not only interconnected simply, but also integrated into a unified network and automation system. Different field devices exchange information with each other to perform common automatic tasks. So, wired and wireless devices must be interoperable.

A lot of research work has been done on industrial wireless communication technologies and the interoperation with wired Fieldbus. In the R-Fieldbus wireless PROFIBUS, the MAC layer was still the PROFIBUS MAC layer, and the physical layer included PROFIBUS RS485 and IEEE802.11 DSSS. Repeaters were used to implement the information forwarding between the R-Fieldbus wireless devices and PROFIBUS devices to construct a single field network segment [3]. In [4] R-Fieldbus and PROFIBUS devices in a field network were divided into several network segments. Each segment had its own token passing ring and bridge/routers were used to connect different segments. Willig researched the influence of wireless channel and proposed a wireless PROFIBUS which used a polling protocol at the MAC layer and the Physical Layer was based on R-Fieldbus [5]. The base station/inter-working unit connected wired and wireless network segments at the MAC layer [6]. Morel used TDMA as the MAC protocol of wireless FIP. Gateways provided communication connection between wired and wireless devices at the Application Layer [7]. These researches just focused on the wired and wireless communication protocols with the different MAC layers and same upper layers. And they only studied the communication interconnection and forwarding, interoperability of the devices has not been considered yet. In the recently published industrial wireless communication standards, such as Wireless HART, WIA-PA, and those to be published, such as ISA SP100 and Wireless FF, interoperation with wired Fieldbus is put forward as one of the main contents.

WIA-PA (Wireless Networks for Industrial Automation/ Process Automation) is the Chinese standard of industrial wireless communication architecture and specification for process automation. It was accepted by IEC in 2008 and became the second industrial wireless communication standard in the world after Wireless HART. Foundation Fieldbus (FF) is a kind of typical Fieldbus technology, widely used in process automations. In this paper, we will introduce WIA-PA communication protocol and study the interoperation between WIA-PA and FF.

II. WIA-PA COMMUNICATION PROTOCOL

WIA-PA provides wireless communication services for automatic devices to perform monitoring, measuring and loop control for process industry. WIA-PA adopts 2-layered star-mesh network topology and supports field devices, handheld devices, routers and gateways. The field devices construct star networks and routers construct mesh networks.

The communication protocol model of WIA-PA includes the Application Layer (APL), network layer (NWL), Data link Layer (DLL) and Physical Layer (PHL) (Figure.1). The PHL is based on IEEE802.15.4 and consists of two separate frequency ranges: 868/915 MHz and 2.4 GHz.

The DLL includes the data link sublayer and MAC layer. The MAC layer is also based on IEEE802.15.4 and its superframe structure is shown as Figure 2. The Contention Access Period (CAP) of IEEE802.15.4 superframe is used for the joining of devices, intra-cluster managements and message retransmissions. Contention Free Period (CFP) is used for the communications between field devices and cluster heads. The inactive portion of the superframe can be used for sleeping and also be extended for inter-cluster and intra-cluster communications.

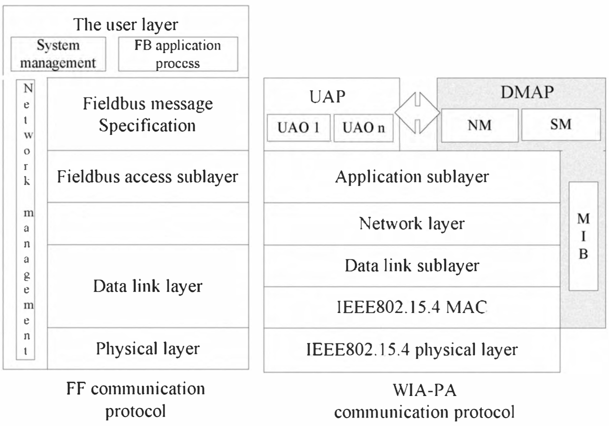

Figure 1. WIA-PA and FF communication protocol model

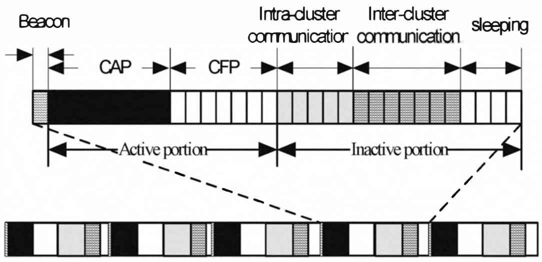

Figure 2. Structure of WIA-PA MAC layer superframe

The main functions of the NWL include network formation and address assignment, route discovery and maintenance, packets routing in multi-hop networks. WIA-PA NWL adopts static routing method to forward packets.

The APL includes User Application Process (UAP) and Application Sublayer (ASL). The UAP is made up of one or more standardized User Application Objects (UAOs) that interact with industrial processes, such as AI, AO and PID. These objects are used to construct distributed industrial automatic monitoring and control applications. Device Management Application Process (DMAP) is the UAP that carries out system management functions. ASL provides corresponding data communication and management services for UAP and DMAP. The communication services include client/server, publisher/subscriber and report/sink modes which use corresponding virtual communication relations (VCR) to define communication paths and resources for different automatic tasks [8].

III. INTEROPERATION PROBLEMS WHEN HYBIRD WITH FF

A. FF Comunication Protocol

FF consists of FF HSE and H1, and FF H1 is used for digital communications between sensors, controllers and actuators in production field. FF H1 communication protocol includes the APL, DLL, PHL and the additional User Layer (USL) as shown in Figure.1.

The USL is above the APL. It defines standardized user application object Function Block (FB), Device Description (DD), and network and system management which are used to form distributed application processes needed by the users and to implement interoperation. The device management and FBs construct Virtual Field Devices (VFDs). The APL is divided into Fieldbus Access Sublayer (FAS) and Fieldbus Message Specification (FMS). FMS specifies the data, commands and events and the packet formats exchanged between the devices. FAS provides communication relations for the User Application Processes, which are described as virtual communication relations. The VCRs include Client/Server, Publisher/Subscriber and Report/Distribution VCRs. FAS and VCRs also provide different communication services for UAPs.

The DLL supports data transferring between the devices in the link and provides the share of network medium and the schedule of communications. The medium access and communication schedule of the field network segment are implemented by the Link Active Scheduler (LAS) through communication tokens. The predefined periodic communication is initiated by the Compel Data (CD) token, which is sent periodically by the LAS to field devices according to the system schedule table. The non-predefined communication is initiated by the pass token (PT), which is sent between the predefined communication periods according to the active device list of the network segment.

The PHL provides the mechanical and electrical interfaces and specifies the physical signal sending and receiving processes [9].

B. Interoperation Problems

Interoperation means the abilities that two or more systems or their components exchange messages and utilize them. In industrial automation systems, the field devices are connected together to construct and carry out automatic applications. The automatic applications are established by connecting the automatic objects in the field devices through configuration tools. When being hybrid, wired FF and wireless WIA-PA field devices must be able to report their device and automatic object information to the same configuration tool. The configuration tool then could connect the objects in different devices to construct automatic tasks. When the automation system runs, the wired and wireless devices must be able to exchange messages with each other to complete common monitoring and control tasks.

But WIA-PA and FF devices have different communication protocols and there are some substantial facts that would influence the interoperation between them. They are: different physical communication medium, different transmitting data rates, different formats of message packets and different services in each communication protocol layer. When WIA-PA and FF field devices are hybrid in a field network, they can not communicate with each other directly and therefore they can not implement interoperation. So, wired FF devices and wireless WIA-PA devices can not support common configuration tools to establish automatic applications and work together to carry out monitoring and control tasks.

IV. IMPLMENTATION OF INTEROPERATION

A. Interoperation Method

The current interoperation methods in industrial communication include the User Layer interoperation specifications, such as the open communication standards, object dictionary, device description and function block definitions. But they are just used for the field devices with the same standard and from different manufactories. As for devices with different communication standards, OPC can be used to implement the integration and interoperation at plant management level. But it can not guarantee the real-time performance required by automatic tasks.

To implement interoperation between WIA-PA and FF, first the WIA-PA and FF field devices must be able to exchange device, automatic object information and setting commands to support automation system configuration and management. Then they must be able to exchange field monitoring and control messages to perform automatic tasks and satisfy the performance requirements.

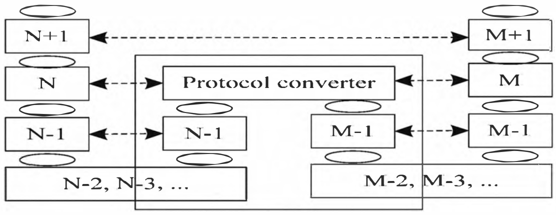

Figure 3. Protocol-level protocol conversion

Because WIA-PA and FF communication protocols are different, protocol and communication conversion is the way to implement interoperation. The network interconnecting devices translate the communication packets between the WIA-PA and FF field devices and convert the communication services to forward the messages and to guarantee the required performance.

B. Protocol converter

According to the characteristics of WIA-PA and FF communication protocol models and the conversion rules defined in [10], we adopt protocol-level protocol conversion for the interoperation. Protocol-level conversion means when two protocols are compatible above layer N (M), the protocol converter converts the PDUs between the peer entities at layer N (M) (Figure.3).

The communication protocols of WIA-PA and FF are different from the PHL to the highest layer. The protocol-level protocol converter works at WIA-PA APL and FF USL as a communication gateway. It converts PDUs exchanged between the highest protocol layers of WIA-PA and FF.

Although WIA-PA and FF protocols are different, they are both designed for process automation. The protocol function, device structure, automatic objects, communication data and services are just the same or similar. There are corresponding mapping relations between WIA-PA ASL and FF USL communication packets and services. So, the gateway can convert the PDUs according to the mapping of the messages and forward them through corresponding communication services and relations to fulfill interoperation.

C. WIA-PA and FF Communication Gateway

The interoperation gateway converts and forwards the device, automatic object and other communication messages between WIA-PA APL and FF USL according to the corresponding relations. The main components of the gateway includes: WIA-PA communication interface, FF communication interface, protocol converter, logic devices and buffer. WIA-PA and FF communication interfaces include full WIA-PA and FF protocol layers and are used to communicate with WIA-PA and FF devices respectively. The protocol converter converts the communication PDUs and services between WIA-PA and FF devices, including device, automatic object information, process data and management messages and their services. Logic devices are constructed according to system configuration results and used for forwarding predefined periodic communications between WIA-PA and FF devices. The basic device and automatic object information of the source devices is converted and stored in the gateway as logic devices.

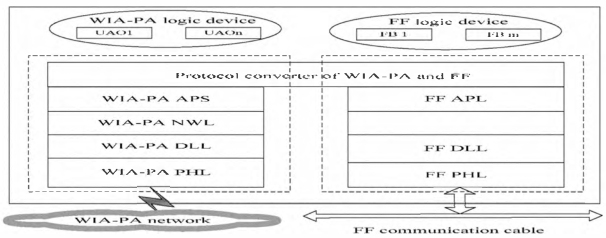

Figure 4. Architechture of WIA-PA and FF interoperation gateway

D. Protocol Conversion between WIA-PA and FF

The protocol conversion in the WIA-PA and FF gateway mainly includes device information conversion, automatic object conversion, process data, alarming and command conversion and management information conversion.

The device information conversion means the gateway converts the device information in WIA-PA DMAP and FF VFD and then reports them to upper level systems. The common configuration tool could then identify the wired and wireless field devices transparently and get the device information to construct automation systems.

The automatic object conversion means the gateway converts between WIA-PA UAOs and FF FBs. The converted automatic object information is also reported to upper level systems. The configuration tool can connect the automatic objects in different devices to establish distributed automation applications. When predefined periodic communications are defined between WIA-PA and FF devices, the gateway establishes logic devices for the sending devices according to the converted device and object information and configuration result. The logic device does not contain the entire device and object information converted, but the basic information needed to forward the field monitoring values and control commands of the objects.

The process data conversion means the gateway converts WIA-PA and FF field monitoring, control and alarming information from one to the other. The predefined periodic communication data between WIA-PA and FF devices are stored in logic device for forwarding. The non-predefined messages are just converted according to the mapping relations and then forwarded to the other devices.

Management information conversion translates configuration, maintenance, diagnosis and download information. They are converted and forwarded without logic devices just as non-predefined messages.

Besides the PDU conversion, the converter also translates the communication relations and services to guarantee the forwarding communication performance. That is, the gateway converts the VCRs and their communication services between WIA-PA and FF to forward messages.

V. An Example of Hybrid WIA-PA and FF Field Network and Interoperation Analysis

A. Hybrid WIA-PA and FF Field Network

Figure.5 is a simple example of hybrid WIA-PA and FF field network.

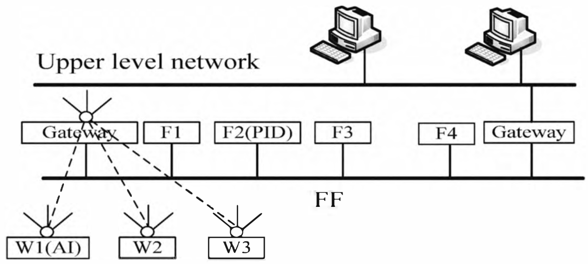

Figure 5. A simple example of hybrid WIA-PA and FF field network

In the network, W1-W3 are WIA-PA field devices. They can communicate with each other and construct a simple star wireless WIA-PA subnet. F1-F4 are FF field devices connected by FF cables. There is an AI UAO in WIA-PA field sensor device W1 and PID FB in FF controller F2. They are connected together to construct a PID closed loop control. The field measuring values are transmitted from WIA-PA W1 to FF F2 to perform the PID control. The gateway converts the communications between them.

B. Protocol Conversion and Interoperation Process

During configuration process, the WIA-PA and FF devices should report their device and automatic object information to the common configuration tool. The information from WIA-PA devices are converted and forwarded by the gateway. The WIA-PA DMAP is converted to FF DD and device information (VFD) and WIA-PA UAO to FF FB. The configuration tool gets the information transparently and then connects the AI UAO in W1 to PID FB in F2 to establish the control loop. The converted WIA-PA device and AI UAO information are stored in the gateway as its FF logic device.

The communication relation between W1 AI and F2 PID is divided into two independent connections, which are W1 to gateway and logic device AI to F2 PID. The communication service is also converted for the AI FB in the logic device to forward the message. That is, WIA-PA W1 device uses publisher/subscriber mode and VCR to transmit the AI values and the gateway translates them into FF publisher/subscriber service and VCR for the logic device.

When automatic system runs, WIA-PA W1 device transmits field measuring values of AI UAO periodically. The data are delivered to the gateway through WIA-PA publisher/subscriber mode and VCR. The gateway receives the message, converts it and stores it in the logic device AI FB. The logic device AI forwards the converted message to the FF F2 PID through FF publisher/subscriber service and VCR. Then the field measuring value is received by the PID FB in F2 device and the control process is completed.

Other non-predefined communications between WIA-PA and FF devices are just converted and forwarded by corresponding VCR and services without logic device.

C. Performance Analysis

When WIA-PA and FF devices are interoperable, they not only exchange messages with each other, but also support the running of automatic applications and satisfy the performance requirements as well.

- Predefined Periodic Communication

Predefined periodic communications, such as W1 AI UAO communication, are forwarded by the logic device through corresponding publisher/subscriber relation and service. When a WIA-PA device sends predefined periodic messages to a FF device, the gateway receives the messages, converts and stores them in the logic device. The logic device then forwards the messages through corresponding FF publisher/subscriber service and VCR. The gateway logic device will forward WIA-PA sensor data to FF controller through the DLL CD tokens. Suppose WIA-PA and FF adopt the same communication cycle T. The WIA-PA and FF devices are time synchronization. T_S is the time WIA-PA sensor sends the message, T_C is the time the gateway gains the CD token to forward the message in the logic device. D_{WT} is the message transmitting time along the wireless channel, D_{GR} is the message receiving delay in the gateway, D_{GC} is the message conversion delay, D_{GS} is the message processing and forwarding delay of the gateway, D_{GT} is the transmitting time of the forwarded message in FF cable.

If WIA-PA sensor data have been received, converted and ready for forwarding before the logic device gains the CD token in the cycle, namely $T_S + D_{WT} + D_{GR} + D_{GC} + D_{GS} \le T_C$, the additional forwarding communication delay is:

$$D_P = T_C - T_S + D_{GT} \quad (1)$$

If WIA-PA sensor data reach the gateway after the CD token in the cycle, namely $T_S + D_{WT} + D_{GR} + D_{GC} + D_{GS} > T_C$, the message has to wait until next communication cycle and the additional forwarding delay is:

$$D_P = T + T_C - T_S + D_{GT} \quad (2)$$

D_{GC}, D_{GR} and D_{GS} are relative to the CPU processing speed, which are usually constants of microsecond level. D_{WT} and D_{GT} are relative to network transmitting speed and usually constants of millisecond level. So, the forwarding delay for predefined periodic communication is deterministic and smaller than the cycle, which is $D_P < T$ and the real-time requirement can be satisfied.

- Non-predefined communication

Non-predefined communications between WIA-PA and FF are converted according to the mapping of protocols and forwarded through corresponding communication relations and services. The converted messages are sent at the DLL with relative priorities. When a WIA-PA device sends non-predefined messages to FF devices, the gateway receives the messages, converts them and forwards them through corresponding FF VCRs. The FF DLL sends the messages through PT tokens with different priorities. When the gateway gets PT token, it first sends high priority messages. When all of the high priority messages are sent, messages with lower priority are sent through the PT token. Thus high priority real-time communication can be guaranteed.

The delay of non-predefined communication is related to the number of the messages in the gateway. Because the time the gateway gains PT token and communicates is undetermined, the delay is also undetermined. When the network traffic is light and the non-predefined messages in the gateway can be sent in one PT token, the communication delay is just similar with the predefined periodic communication. Otherwise the messages must wait for the PT token in the queue. In the best case, the message may be forwarded immediately. In the worst case, it could be the last one transmitted in the queue and deferred several cycles later according to the number of the messages in the gateway.

VI. CONCLUSION

Hybrid with wired Fieldbus is one of the main application manners of industrial wireless communication technologies now. And interoperation between Fieldbus and industrial wireless communication is the key issue to hybrid. In this paper, the interoperation between WIA-PA and FF is implemented through protocol conversion. Protocol-level protocol conversion gateway translates device and automatic object information, process data and other communication messages at the highest layers of WIA-PA and FF protocols to fulfill interoperation. Communication services and relations mapping guarantee the required real-time performance of message forwarding. This makes WIA-PA and FF field devices support common automation systems and carry out automatic tasks as required when being hybrid.

The realization of interoperation between WIA-PA and FF will facilitate WIA-PA entering actual applications in industrial plants and bring great benefits to them.

REFERENCES

[1] A. Willig, K. Matheus, and A. Wolisz, “Wireless Technology in Industrial Networks,” Proceeding of the IEEE, vol. 93, no. 6, June 2005, pp. 1130-1151.

[2] A. Willig, “Recent and Emerging Topics in Wireless Industrial Communications: A Selection,” IEEE Transactions on industrial informatics, vol. 4, no. 2, 2008, pp.102-124.

[3] L. Rauchhaupt, “System and device architecture of a radio-based fieldbus-The RFieldbus system,” in the 4th IEEE Workshop Factory Communication Systems (WFCS), 2002, pp. 185-192.

[4] L. Ferreira, M. Alves, and E. Tovar, “Hybrid wired/wireless profibus networks supported by bridges/routers,” in Proc. 2002 IEEE Workshop Factory Communication Systems (WFCS), 2002, pp. 193-202.

[5] A. Willig, “Polling-Based MAC Protocols for Improving Real-Time Performance in a Wireless Profibus,” IEEE Transactions on Industrial Electronics, vol. 50, no. 4, August 2003, pp. 806-817.

[6] A.Willig, “An architecture for wireless extension of PROFIBUS,” in Proc. 29th Annu. Conf. IEEE Industrial Electronics Society, vol. 3, 2003, pp. 2369-2375.

[7] P. Morel, A. Croisier, and J. D. Decotignie, “Requirements for wireless extensions of a FIP fieldbus,” in Proc. IEEE Int. Conf. Emerging Technologies and Factory Automation (ETFA ’96), 1996, pp. 116-122.

[8] Industrial wireless networks WIA Specification. Part Ⅰ: WIA System Architecture and Communication Specification for Process Automation （WIA-PA）, 2008.

[9] Fieldbus Foundation, Foundation specification: fieldbus technical overview. Revision 1.0, 1996.

[10] G Bochmann, and P. Mondain-Monval, “Design Principles for Communication Gateways,” IEEE Journal on Selected Areas in Communications, vol. 8, no. 1, 1990, pp. 12-21.