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Extending CAN bus with ISA100.11a wireless network

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A B S T R A C T

In this paper, we present a framework for building a hybrid network composed of Controller Area Network (CAN) bus and ISA100.11a industrial wireless network. The end-to-end delay of CAN-ISA100.11a hybrid network is evaluated. One scheme is proposed based on time slot configuration in ISA100.11a to ensure the prioritization hierarchy which is suitable for large packet size, namely priority assurance (PA). Moreover, a comparison between shared time slot and short time slot is evaluated to give insight on which one gives the best performance in CAN-ISA100.11a hybrid network. The delay of the proposed framework is further simulated under interference environment.

1. Introduction

The traditional wired control networks have been successfully implemented for industrial applications in decades. The ability of traditional wired control networks to provide high speed, high reliability, and bounded delay makes them a popular option to be implemented in industrial plants [1]. However, the wired control networks require infrastructure and space for installation. Adding the new machine to the existing plant using wired control networks often creates new problem of cable routing difficulties and sometimes requires system engineer to re-design the whole cable routing plan. Moreover, the installation and maintenance of cables and connectors are usually much more expensive than the cost of the sensors themselves [2]. Having a wireless network as an alternative in such environments would be exceptionally valuable.

Hybrid network of wired and wireless technology has become the hot topic research as a result of increasing demands in applying wireless network for industrial application. Hybrid network introduces different delay characteristics, depending on what technology composes the hybrid network. Bayilmis et al. proposed an interworking design to enable CAN nodes to communicate over IEEE 802.11b Wireless Local-Area Network (WLAN) using encapsulation method [3]. Similarly, in [4] Ren et al. proposed a design to integrate the CAN bus with Bluetooth. Those related works pointed out the necessity to extend wired control networks with the wireless one to satisfy industrial needs.

The work presented in this paper focuses on the integration of wired and wireless networks which can interconnect stationary and mobile devices. More specifically, this work deals with extending CAN bus using ISA100.11a to meet real-time control application requirements in both automotive and industrial control. CAN bus is a serial data communication protocol that provides high reliability and good real-time performance with very low cost. The CAN bus has gained popularity in the industry due to its wide usage in a wide range of applications [5]. For example, in industrial automation processes, robotic arms are connected to the controller (computer) using CAN bus [6].

On the other hand, ISA100.11a is an emerging open standard for process control dedicated for industrial automation and related applications [7]. This paper, to the best of our knowledge, is one of the first efforts in considering hybrid network of two popular communication protocols in the industry, CAN bus, and ISA100.11a. Given the critical nature and performance requirements of automation and control networks, both protocols' ability to support message priority and provide deterministic delay makes them suitable for most industrial environments.

The main contribution of this paper is to develop a hybrid network using both wired and wireless networks for industrial environment, where distributed control unit (DCU) is considered. CAN is used to connect among DCUs while ISA100.11a is used to connect sensor and/or actuator to DCUs.

The remainder of this paper is organized as follows. The following section presents a brief overview of CAN bus and ISA100.11a network. Section 3 highlights the network architecture that is used to describe the hybrid network, the proposed framework for interconnecting CAN bus and ISA100.11a, and our proposed schemes to ensure prioritization

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and reduce end-to-end delay in the hybrid network. Simulation model and presentation of results obtained from simulations are discussed in Sections 4 and 5, respectively. Finally, the conclusions are presented in Section 6.

2. Technical overview of CAN bus and ISA100.11a

2.1. CAN bus

CAN is a serial bus communication protocol developed by Bosch in the early 1980s [8]. In particular, the CAN standard only defines three layers namely the object layer, the transfer layer, and the physical layer while in the application layer could be CANopen, DeviceNet, CAL (CAN Application Layer), etc. CAN is essentially a broadcast network, where a message transmitted will be received by all nodes that are attached to the bus. In general, a CAN-compliant node consists of three parts: the host processor, the CAN controller, and the transceiver. The host processor decides which messages it wants to transmit, sees all the messages on the bus, and interprets received messages. The CAN controller is basically a buffer for both incoming and outgoing messages. Finally, CAN transceiver is the PHY (physical) layer of CAN, which converts the transmit bit received from the CAN controller into a signal that is sent onto the bus, and vice versa.

CAN bus uses CSMA/AMP (Carrier Sense Multiple Access with Collision Detection and Arbitration on Message Priority) mechanisms. In case of simultaneous transmission, arbitration is performed based on the priority level of the message identifier (ID), in which a logic zero is dominant over logic one, and enables the message whose ID has the highest priority to be delivered immediately. If two nodes start transmitting at the same time and one of them receives a dominant bit (0) when a recessive bit (1) has been transmitted, the node loses arbitration and stops transmitting as illustrated in Fig. 1.

The CAN bus specification has 2 versions, 2.0A (original version) and 2.0B (extended version). The difference between CAN 2.0A and CAN 2.0B standard is located in the format of the message header. CAN 2.0A allocates an 11-bit identifier while CAN2.0B contains a 29-bit identifier. CAN bus is optimized for short messages, with size of data field is between 0 and 8 bytes. The achievable data rate of CAN bus depends on the length of the bus. The maximum data rate supported by CAN bus is 1 Mbps, with bus length no more than 40 m. A data rate of 125 kbps would allow a network length up to 500 m. However, it is allowed to use bridge devices or repeaters to increase the allowed distance to more than 1 km.

2.2. ISA100.11a

The ISA100.11a standard is intended to provide reliable and secure wireless operation for non-critical monitoring, alerting, supervisory control, open loop control, and closed loop control applications [7,9,10]. The components of an ISA100.11a network consist of the security manager, system manager, gateway, backbone routers, and field devices as depicted in Fig. 2. The system manager performs policy-based control of the network runtime configuration, monitors, and reports on communication configuration, performance, and operational status. The security manager provides security services while gateway provides an interface between ISA100.11a field network and plant network. Backbone router enables external networks to carry ISA100.11a-compliant packet by encapsulating the PDUs (Protocol Data Units) for transport, allowing ISA100.11a network to use other networks. However, ISA100.11a standard is not specified particularly the data network for backbone. In that case, the backbone could be an IEEE 802.11, an industrial Ethernet, or any other network which has an interfacing feature to the plan network [7]. Furthermore, the backbone routers are employed to extend the routing capability via the backbone. By using a backbone router device, it allows the ISA100.11a network to communicate with other networks.

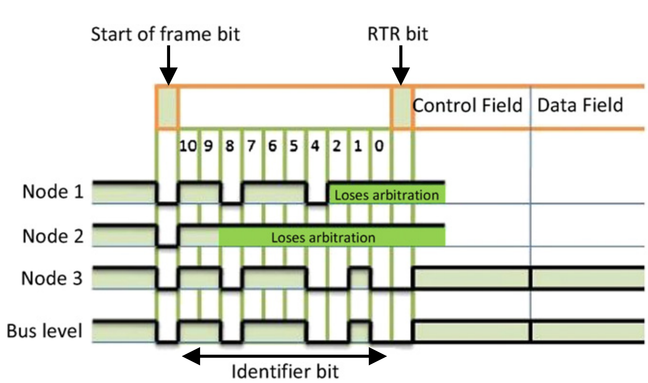

Fig. 1. CAN bus arbitration example.

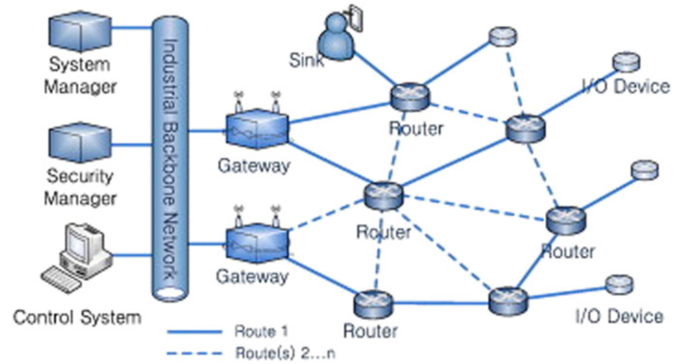

Fig. 2. ISA100.11a mesh network.

ISA100.11a protocol supports star, mesh, and the combination of both topologies. The physical layer of ISA100.11a devices is constructed based on IEEE 802.15.4 PHY standard that uses Direct-Sequence Spectrum Spreading and O-QPSK (Offset-Quadrature Phase-Shift Keying) modulation [11]. ISA100.11a only operates in a 2.4-GHz band, using IEEE 802.15.4 channels 11–25. Channel 26 is defined as optional in ISA100.11a. Each channel is spaced 5-MHz apart and has a bandwidth of 2 MHz.

The MAC (Media Access Control) of ISA100.11a implements both TDMA (Time Division Multiple Access) and CSMA/CA (Carrier Sense Multiple Access with Collision Detection and Collision Avoidance) mechanisms. The usage of TDMA allows ISA100.11a to provide a contention free period which is known as dedicated time slot. The main advantage of dedicated time slot guarantees one node to transfer data in a particular slot without colliding with other data from another node. However, dedicated time slot requires time slot reservation in other to attempt the slot. Also, time slot can be wasted if node failed to transfer the data in those reservation slots. Due to that reason, the dedicated time slot is designed for predictable and regular traffic to achieve QoS (Quality of Service), which is desired for industrial applications. In comparison, the shared time slot is adopted using CSMA/CA algorithm. The advantage of the shared time slot provided a chance for every node to occupy the slot. Nevertheless, in shared time slot, each node competed in getting the slot in transmitting the data. It is recommended that shared time slot is used for high priority and fewer predictable data such as alarm and retry. The timing axis of each device is divided into configurable fixed time slot duration, with the typical value of 10–12 ms. A collection of time slots repeating in one cyclic schedule forms is called superframe. The length of the superframe is configurable and can vary from one device to another. In general, longer-period superframes result in higher data latency and lower bandwidth, but with reduced energy consumption and less concentrated allocation of digital bandwidth [7]. Unlike the IEEE 802.15.4, in ISA100.11a the number of retries depends on the packet living time determined by *MaxLifeTime*.