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WIRELESS CONTROLLER AREA NETWORK IMPLEMENTATIONS AND APPLICATIONS: TECHNICAL DETAILS AND CASE STUDY

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ABSTRACT

This paper discusses the need and applications of the wireless version of the popular controller area network (CAN) introduced and standardized by Bosch as early as 1990. There are many practical applications where CAN messages need to be transmitted over short distances and where cable connections are either impossible or unwanted. Technical details and case study of the various possibilities of the wireless interface for the wireless transfer of CAN frames are discussed in this paper. Implementations of CAN over Bluetooth, CAN over ZigBee and CAN over UWB are presented. Among the various wireless possibilities, ZigBee based on IEEE 802.15.4 is recommended for the wireless and control applications of CAN.

KEYWORDS: wireless controller area network; applications of controller area network; implementations of wireless controller area network.

INTRODUCTION

The popularity of CAN due to its many advantages can be seen in its implementation in various automation applications. Researches uses CAN in home automation, robotics, medical, military, structural monitoring and many others.

CAN has gained wide acknowledgement due to its properties:

- distributed medium access control
- contention based & non destructive bus access
- content based addressing
- cyclic redundancy check
- error confinement

Credited to these properties, CAN has been implemented in many different application fields such as automotive, robotic, industrial automation, and etc. Recently, CAN has been proposed to be applied in home network protocol [1], [2], [3] [4].

POPULAR CAN APPLICATIONS

In [1], CAN was introduced in the application of direct load control programs for residential automation. This system was intended to allow users to monitor and control the heating and cooling individual loads of their homes offering flexibility in demand-side participation in deregulated electricity markets. The overall system is divided into three subsystems, each with their own function; subsystem of interaction, subsystem of measurement and subsystem of drive. In this case, transmissions of data are done using CANopen system.

Teoh et. al in [2], describes that most of the building automation technologies do not provide enough bandwidth for voluminous data. Besides that, robustness against harsh environment has yet to be addressed. Being a cost effective communication bus, CAN is resilient towards extreme heat and harsh environments. Its high signaling rates provide fast transmission of data from one node to another.

In [3], Kyung et. al proposed a fire detection system found in most home and offices which is designed utilizing CAN as its backbone network. By redefining the message identifier of Extended CAN, it has been determined that the enhanced system surpasses the conventional one. This is because conventional method perceives a fire based on the increase of current as the fire causes analog line to short-circuit. However, using CAN, the system can synthetically judge a fire occurrence by directly receiving fire detection data from multiple fire detectors.

Othman et. al in [4] proposed a stand-alone single chip embedded system that is equipped with five CAN ports to monitor and control home appliances locally. The five CAN ports are connected to different home appliances respectively. In their description, the CAN devices could send and receive data in contrast to previous works, where devices may only receive messages from a master. The proposed system is capable of communicating to the GPRS network with the usage of GPRS modem. This enables the system to communicate with user via the public wireless mobile network and the home internet.

CAN networks are used also in intensive care units including patient beds, in operating rooms, and in other healthcare equipment [5].

In VCAN [6] the idea of CAN-based vital signs monitoring system is presented. VCAN based system provides provision of monitoring vital sign including Electrocardiogram (EKG), heart rate (HR), blood oxidation (SPO2), Stolic Blood Pressure (SBP), diastolic blood pressure (DBP), temperature (temp). These vital signs were aggregated and transmitted to the CMS. This method of aggregation was adopted to efficiently utilize the bandwidth by decreasing the bus load. In this work the VCAN-based system for a network of interconnected ICUs is utilized. In this work, the data of four patients traveling in an ambulance, with medical equipment connected via CAN, is aggregated and sent to the hospital via CAN-UMTS gateway.

In the Design of WCAN-based home automation system [7], WCAN protocol is implemented in a Home Automation System. The proposed system consists of a controller server, several WCAN nodes that are placed around the house & home electrical appliances that are connected to these nodes. The function of the controller server is to send commands to all the nodes in the network and receive commands from the user itself. User may communicate with the predefined server using either multiple sensors that are placed in the home or a smart remote controller. In this example, a smart controller is used to communicate with the controller server using Bluetooth connection. The controller server receives the command & transmits messages across the network to all the nodes. Based on the message identifier that are embedded in the token, the sensor nodes reads the messages, and then either keep the message for further process or simply transmit the message back into the network. The former are used for performing tasks or actions to the connected household appliances. As an example, supposed the controller server transmit a command that turns on all the lights inside the house. The sensor nodes receive the message and perform task that are required by the controller server, based upon the message identifier, in this case turning on the lights.

TECHNOLOGIES USED FOR WIRELESS CAN IMPLEMENTATIONS

There are many practical applications where CAN messages need to be transmitted over short distances and where cable connections are either impossible or unwanted. An example is the moving arm of an industrial robot in a production line. Sensors and activators in this system need to communicate to their environment through CAN. A wireless CAN link removes the need for a cable connection between moving and fixed parts of this system.

To access mobile and moving CAN fieldbus systems a wireless approach is often a good solution. For short-range wireless communications using RF links the Bluetooth Wireless Technology has been introduced. When the data rate requirements are not so high, radio techniques such as ZigBee, Wibree [10] can be used. From the localization accuracy point of view, an ultra wideband (UWB) technology is superior due to the high time domain resolution achieved with its sub-nanosecond pulses [8]. UWB can be used also when the amount of data is high, very fast links need to be established or transmission power needs to be limited [9].

CAN-OVER-BLUETOOTH IMPLEMENTATION

This section describes the use of the Bluetooth Wireless Technology [11] beyond its primary mission, Bluetooth links as a transport media for CAN data. The use of Bluetooth technology in industrial applications is very new and will be highlighted in this paper. After an introduction to Bluetooth technology an overview of CAN-over-Bluetooth scenarios will be given. Furthermore, a practical implementation of a Bluetooth CAN interface is presented [12].

In 1998 the Bluetooth Wireless Technology was introduced as a standard for short-range wireless communication. The main goal of this technology was to allow instant networking and voice communication between small mobile devices such as cellular phones, PDAs and notebooks. Bluetooth allows short distance radio links over approximately 10 meters with an option to extend the distance up to 100 meters. It operates in the free ISM frequency band from 2.402 to 2.480GHz and uses a Frequency Hopping Spread Spectrum (FHSS) technology in order to achieve some immunity against electronic eavesdropping and interference. Frequency Hopping means that the transmitting frequency is changed 1600 times per second with the result that the data traffic is divided into time slots of 625s. The signalling speed is always 1 Mbit/s. Bluetooth devices are capable of setting up small wireless networks so-called *piconets* with other devices that are in range.

Each piconet consists of one master and up to seven slaves as shown in Figure 1. The simplest form of a piconet is a point-to-point connection between a master and a single slave. The master of a piconet controls the joining slaves and specifies the hopping sequence. All communication only takes place between the master and a single slave at a time since there is no broadcast mechanism for application data available inside a piconet. Moreover, inter-slave communication is not possible. The master-slave communication follows a TDD scheme. Bluetooth also defines a topology of overlapping piconets this is called *scatternet* as shown in Figure 1. Some devices in a scatternet scenario participate in more than one piconet.

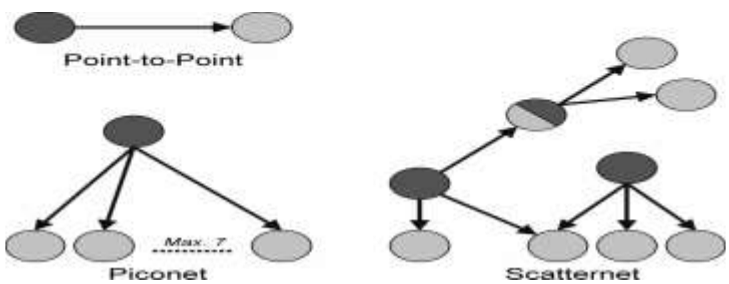

Figure 1 Bluetooth Topologies

A special advantage of the Bluetooth Wireless Technology can be seen in the way Bluetooth devices can start to communicate. Bluetooth nodes only need to get in range. The devices will discover each other and connections can be setup automatically, without any user interaction. This behavior can be used for autonomous systems in CAN-controlled environments as shown in Figure 2.

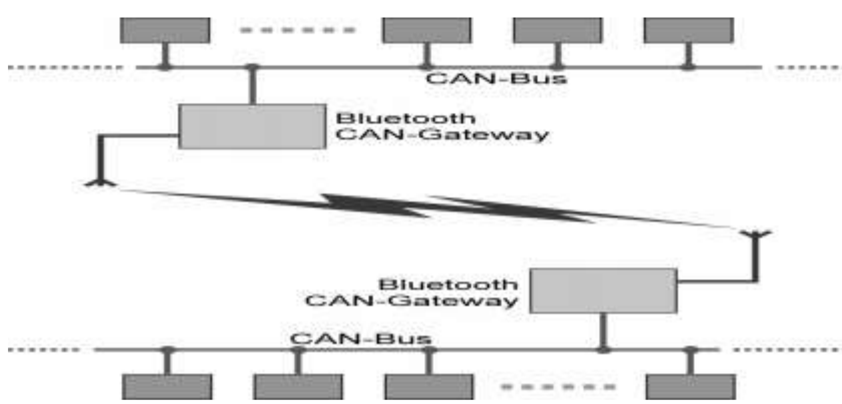

Figure 2 Bluetooth in CAN controller Environments

CAN-OVER-ZIGBEE IMPLEMENTATION

ZigBee is based on IEEE 802.15.4 it is targeted toward low-rate, low-power consumption and low-cost. IEEE 802.15.4 defines three network topologies: star, peer-to-peer, and the cluster tree. Its Physical Layer management services include the following: activation and deactivation of the radio transceiver, Energy Detection (ED), Link Quality Indicator (LQI), and Clear Channel Assessment (CCA). The MAC layer provided by IEEE 802.15.4 provides services such as beacon management, channel access, GTS management, frame validation, acknowledged frame delivery, association and disassociation, and security mechanisms. IEEE 802.15.4 can operate in two modes: beacon-enabled and non-beacon-enabled [14].

When relaying, CAN messages over wireless using 802.15.4, addressing changes are required, hence Messages being relayed from CAN-to-Wireless require packet restructuring [13] as shown in Figure 3. CAN message does not specify a transmitting station or a node. As a result, an Identifier Field (EID) is included in each message In the CAN 2.0 A spec, this field is 11 bits. In the CAN 2.0 B spec, it is 29 bits. Such a message identifier has to be unique within the whole network and it defines not only the content but also the priority of the message. IEEE 802.15.4 supports a short addressing mode of 16 bits. In the design implemented, the 29 bit CAN Message identifier is broken down into two fields, *Node Type* and *Node ID*. The 5 bits will be used as the Node Type and the remaining 24 bits for the Node ID. Because the CAN protocol does not provide a destination address, only the source address (EID), the first 3 bytes for the message are reserved for the destination node ID. For the initial design, all nodes are programmed with a 24 bit Node ID, but while communicating wirelessly, nodes will use the 16 least significant bits of the Node ID as its address. Along with the change in addressing noted above, the destination address must be extracted from the first 3 bytes of the payload and inserted into the destination address in the 802.15.4 MAC addressing fields. Similarly, Wireless to-CAN requires the reverse packet re-organization [13]. The destination Node ID from the wireless message must be placed in the first 3 bytes of the CAN message. Secondly, the CAN EID must be replaced with the sending Node ID's address.

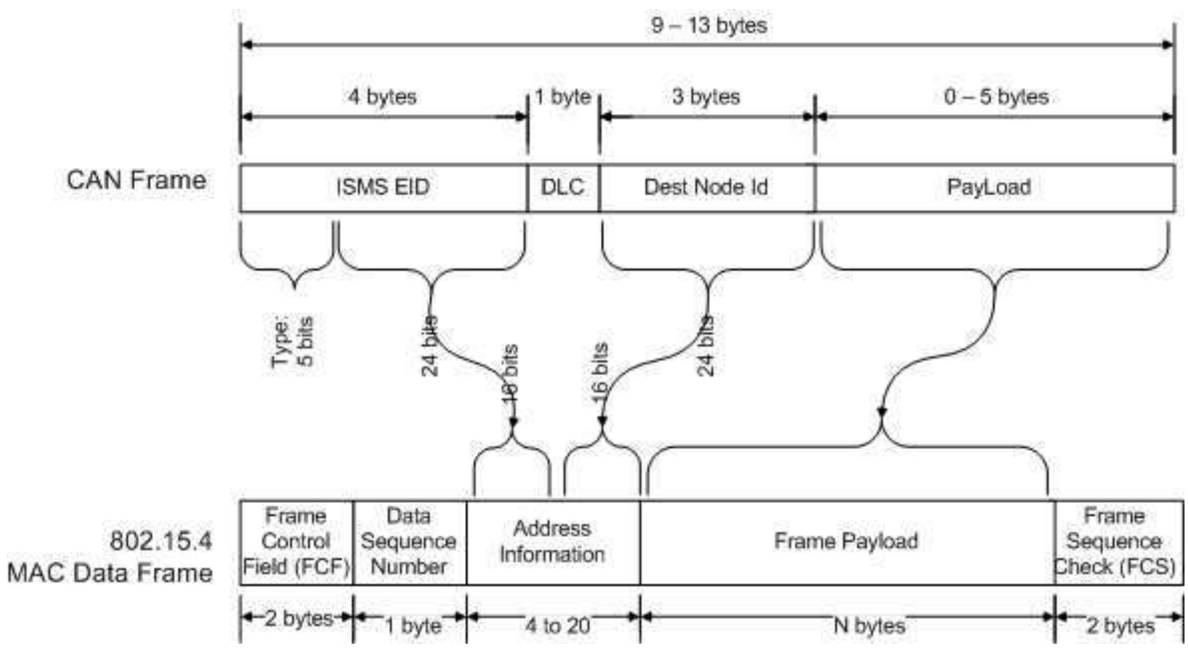

Figure 3 Mapping of CAN and ZigBee data frames

CAN-OVER-UWB IMPLEMENTATION

Ultra-Wideband (UWB) provides an interesting new technology for short-range ultra-high speed communications in the frequency band 3.1 GHz to 10.6 GHz. It supports a bit rate greater than 100 Mbps within a 10-meter radius for wireless personal area communications. The advantages of UWB include low-power transmission, robustness for multi-path fading and low power dissipation. The low power transmission of the UWB is the key characteristic that might allow it to coexist with other wireless networking standards.

UWB (IEEE 802.15.3a) radio is based on the radiation of waveforms formed by a sequence of very short pulses; very short refers to pulse duration which in communication applications is typically of about a few hundreds of picoseconds. The information to be transferred is usually represented in digital form by a binary sequence, and each bit is transferred using one or more pulses. The way by which the information data symbols modulate the pulses may vary; pulse position modulation (PPM) and pulse amplitude modulation (PAM) are often considered modulation schemes [19,20]. In addition to modulation, and in order to shape the spectrum of the generated signal, the data symbols are encoded using pseudorandom or pseudo-noise (PN) sequences. In a common approach the encoded data symbols introduce a time dither on generated pulses leading to the so-called time-hopping UWB (TH-UWB). Direct-sequence spread spectrum (DS-SS), i.e., amplitude modulation of basic pulses by encoded data symbols in its impulse radio version, indicated as DS-UWB, also seems particularly attractive [21,22,23]. Methods such as for example orthogonal frequency division multiplexing (OFDM) and multi-carrier code division multiple access (MC-CDMA) are capable of generating UWB signals, at appropriate data rates. Recent proposal refer to a multi-band alternative in which the overall available bandwidth is divided into subbands of at least 500 MHz [24,25]. Frequency-hopping spread spectrum (FH-SS) might also be a viable way. Among the existing PHY solutions, multiband orthogonal frequency division multiplexing (MB-OFDM), a carrier-based system dividing UWB bandwidth to sub-bands, and direct-sequence UWB (DS-UWB), an impulse-based system that multiplies an input bit with the spreading code and transmits the data by modulating the element of the symbol with a short pulse have been proposed by the WiMedia Alliance and the UWB Forum, respectively.

For UWB wireless communications in particular, the applications and hardware that have been developed and demonstrated in the past few years include the following [15,16,17]: (a) For short range operation up to 5m, data rates up to 600 Mbps are possible within the limits specified in the Code of Federal Regulations for intentional radiators [18] while introducing only negligible interference to coexisting users; (b) At a range of 10m with an effective average output power of 50 mW, a simplex 2.0 GHz data link can support a data rate of 5 Mbps at less than 10_8 bit error rate without forward error correction; (c) At a range of 1–2 km, a full duplex 1.5GHz handheld radio unit provides a data rate of up to 128 kbps with an average output power of 640 mW; (d) At a range beyond 16 km, a full duplex 1.3 GHz radio system has a variable data rate of either 39 kbps or 156 kbps with an average output power of 250 mW.

Table 1 Comparison of the Bluetooth, Zigbee and UWB protocols

Standard	Bluetooth	UWB	Zigbee
IEEE spec..	802.15.1	802.15.3a	802.15.4
Frequency band	2.4GHz	3.1-10.6 GHz	868/915 MHz; 2.4 GHz
Max signal rate	1 Mb/s	110Mb/s	250kb/s
Nominal range	10 m	10 m	10-100 m
Nominal TX power	0 - 10 dBm	-41.3 dBm/MHz	(-25) - 0 dBm
Number of RF channels	79	(1-15)	1/10;16
Channel bandwidth	1MHZ	500MHz-7.5GHz	0.3/0.6 MHz; 2 MHz
Modulation type	GFSK	BPSK, QPSK	BPSK (+ ASK), O-QPSK
Spreading	FHSS	DS-UWB, MB-OFDM	DSSS
Coexistence mechanism	Adaptive freq. hopping	Adaptive freq. hopping	Dynamic freq. selection
Basic cell	Piconet	Piconet	Star
Extension of the basic cell	Scatternet	Peer-peer	Cluster tree-mesh
Max number of cell nodes	8	8	> 65000
Data protection	16-bit CRC	32-bit CRC	16-bit CRC

Bluetooth, ZigBee and Wi-Fi protocols have spread spectrum techniques in the 2.4 GHz band, which is unlicensed in most countries and known as the industrial, scientific, and medical (ISM) band. Bluetooth uses frequency hopping (FHSS) with 79 channels and 1 MHz bandwidth, while ZigBee uses direct sequence spread spectrum (DSSS) with 16 channels and 2 MHz bandwidth. UWB uses the 3.1-10.6 GHz, with an unapproved and jammed 802.15.3a standard, of which two spreading techniques, DSUWB and MB-OFDM, are available as given in the comparison Table 1.

CONCLUSION
This paper presents implementation of wireless controller area network for industrial, home automation and medical applications. Various alternatives of wireless implementation of the CAN protocol is discussed. Implementations of CAN over Bluetooth, CAN over ZigBee and CAN over UWB were presented. Each of the alternatives have more of advantageous and less limitations, CAN over Bluetooth has an advantage of forming the wireless network automatically once in the range of the other nodes and good data rate of transmission, but has a limitation of smaller range of 10 m and piconet topology, with master node having to communicate to a maximum of seven slaves. CAN over ZigBee is very suitable for low cost and low power applications but very low data rate of 250 Kbps/sec. Among the three alternative of WCAN implementations discussed here, CAN over UWB is a promising candidate due to its high data rate, low power consumption and wider bandwidth capability, but for low power, low cost and lower data rate CAN over ZigBee is recommended.

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