USING HASH TABLES FOR SYNCHRONIZATION IN COMMUNICATION BETWEEN THE CAN PROTOCOL AND IEEE 802.15.4

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Abstract— This paper proposes the development of an heterogeneous system using the microcontroller (AT90CAN 128) where the protocol model CAN and the IEEE standard 802.15.4 are connected. This module is able to manage and monitor sensors and actuators using CAN network and, by means the 802.15.4 standard (ZigBee), communicate with others network modules. The control in the synchronization of data between the two protocols (CAN and IEEE 802.15.4) is performed using the technique of hash tables. It is used to improve network performance and avoid stack overflow in the communication between the two technologies.

Keywords— CAN Bus, IEEE 802.15.4, Hash Table, ZigBee.

Resumo— Este artigo propõe o desenvolvimento de um sistema heterogêneo usando o microntrolador (AT90CAN 128) onde protocolo do modelo CAN e o padrão IEEE 802.15.4 são conectados. Este módulo é capaz de gerenciar e monitorar sensores e atuadores usando a rede CAN e, por meio do padrão IEEE 802.15.4 (ZigBee), comunicacar com os outros módulos da rede. O controle na sincronização dos dados entre os dois protocolos (CAN e IEEE 802.15.4) é executado utilizando a técnica de programação de tabelas de dispersão. Ela é usada para aperfeiçoar o desempenho da rede e evitar estouro de pilha na comunicação entre as duas tecnologias.

Palavras-chave— Barramento CAN, Padrão IEEE 802.15.4, Tabelas de Dispersão, ZigBee.

1 Introduction

The use of wireless communication networks is no more an optional tool but a necessity for residence monitoring, automobiles and automated process controls. As it deals with wired networks transducers, the networks CAN (Controller Area Network) are utilized in modern automobiles, medical instrumentation, in tactical vehicles, in the automation processes, in the metropolitan transport and in factory control. This system is utilized in a connection among node sensors with a low cost through a wired network. Most, if not all, of critical infrastructure control systems make use of CAN in some point of the network, to connect remote sensors and to control actuators of a system, or to connect multiple controllers using a common interface. The wireless standard, IEEE 802.15.4, commercially known as ZigBee, was designed to operate with low data rates, with security and network configurations low cost. This network is commonly known as LR-WPAN (Low-Rate Wireless Personal Area Network), is utilized in domestic networks, medical instrumentation and other applications requiring low power remote sensors, in order to lengthen the battery life time and minimize maintenance sensor. Two key elements of the standard IEEE 802.15.4 LR-WPAN can be distinguished: operation at low power and implementation of inherent safety.

A network node is represented by a point of interconnection with a structure or independent network technology utilized for its development. The intelligent transducers networks are, sometimes, composed by a central node, routable nodes and terminal nodes independent if they are used in wired or wireless networks. The terminal nodes are used to perform data acquisition from the sensors or actuators control, such information is sent to nodes or routers to the central node for storage, analysis and visualization. The routable nodes eliminate collisions, obsolete packages and permit the adaptation to different physical network technologies, so it is possible to convert the wired technology into a wireless network or the wireless network to a wired network, as an example, CAN network (Controller Area Network) to wireless network ZigBee.

The ZigBee is a standard for wireless networking technology that works at low power and ability to connect a large number of devices on a single network. The ZigBee technology works in the frequency range 2.4 GHz unlicensed. ZigBee offers only low-latency communication between devices without the need for network synchronization delays of working with a set of protocols for high-level communication based on the pattern IEEE 802.15.4 (for Information Technology, 2003). Wireless networks using ZigBee technology operate using different types of communication topologies, point-multipoint, peer-to-peer and mesh. Such features allow them to be applied in several environments, such as: precision agriculture, medicine, domestic applications, industrial and climate analysis.

The CAN is based on multi-master architecture in which all drivers have equals rights and master functionality, characteristics that permeate equal rights in the transmission medium being capable of always sending a message according to a need to respond to an event. The features of CAN network are: operation range of until 1Mbps for short distances, CAN uses message short of until 8 bytes for each message, flexibility configuration and network control by priority in the messages.

Based on features of the wireless network IEEE 802.15.4 standard and the wired network CAN in this paper presents the network node that allows integrate two protocols distinct one used in wired network and other in wireless. The heterogeneous network node is capable of obtaining data from a CAN network and converts them to a standard wireless network. The nodes implemented were made using the In Fig. 1 shows the schematic with two nodes black those were implemented in laboratory.

This work was divided into four sections, section 1, it described introduction about the project, the section 2 shows the characteristics of wireless protocols and CAN. The Section 3 shows the development of the system. In Chapter 4 the implementation and testing, in the last section, the consideration of the work.

2 Heterogeneous Network Node

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The network nodes with CAN and ZigBee were divided in two parts: the first was realized study of protocol and development of the communication between modules using the ZigBee and the second the study of the features, protocols and development of CAN network. Section A presents the features and specification of CAN network and section B presents the ZigBee network.

1. Wireless network - ZigBee

The IEEE 802.15.4 standard is a simple packet data protocol for lightweight wireless networks and specifies the MAC and PHY networking layers. ZigBee technology takes full advantage of the IEEE 802.15.4 standard and adds the logical network, security and application software. ZigBee technology provides static and dynamic star, cluster tree and mesh networking structures that allow large area network coverage, scalable networks and single point-of-failure avoidance. Now, customers do not have to be tied to complex, costly proprietary solutions that increase their design time.

The MAC frame format for IEEE 802.15.4 standard can be showed in Table 1 that has the following components (Semiconductor, 2009):

- `MHR-` responsible by control frame, sequence number and address information.
- `MAC payload-` it has variable length, which contains specifics information about the frame. Acknowledgement frames do not contain a payload.
- `MFR-` contains the FCS.

LR-WPAN defines 4 frame structures: beacon frame, data frame, acknowledgement frame and MAC command frame (Ergen, 2004). This field variable describes the frame structures, where, in this project was used the data frame to change the protocol CAN to ZigBee in the server node and send the data for others ZigBee nodes until arrive client node. In the client node is changed the ZigBee data to the CAN protocol to management of the intelligent transducers.

1. Controll Area Network - CAN

The CAN standard is presents resolution ISO 11898 of the International Organization Standardization. Nowadays, there are two standards of CAN network, the CAN 2.0 A with identification of 11bits and CAN 2.0 B with identification of 29 bits. The CAN based on OSI model using the physical layer and link layer can be implemented in the chip all system leaving the application layer to be developed. The CAN specifies three types of buses, with a wire, in which determining the bit 0 and 1 is performed by the potential difference held between the wire and the vehicle carcass. With the two wires buses is defined as CAN_H and CAN_L in which the potential difference is made through two wires and other four-wire bus, in which two wires CAN_H and CAN_L are followed by two more power wires Vcc and GND, illustrate in Fig 2. The medium access control is done by the CSMABA protocol (Collision Multiple Sense Access/Bitwise Arbitration) in which works similarly to the CSMACD (Collision Multiple Sense AccessCollision Detect), however, when a collision occurs times are determined in according to the priority of each node.

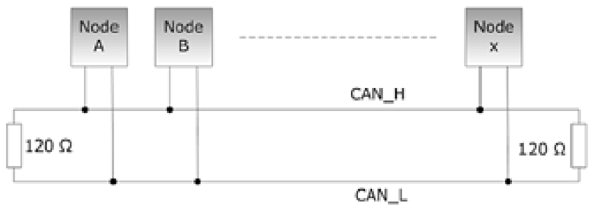

Figure 2: Example of CAN network.

The CAN has several attractive features for use in automotive or industrial environments, such

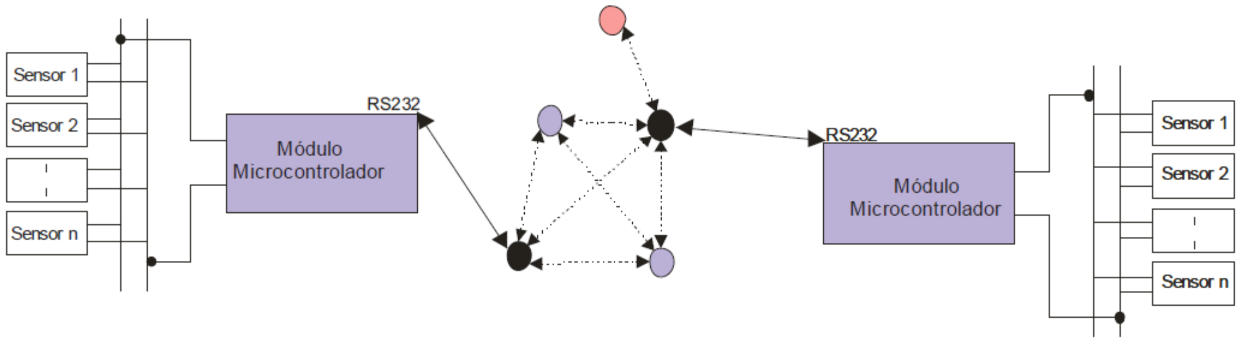

Figure 1: System implemented in laboratory.

Table 1: General MAC

Oct: 1	1	0/2	0/2/8	0/2	0/2/8	Var.	2
Frame Control	Seq. Num	Dest. PAN ID	Dest.	Sour. PAN ID	Sour	Frame	F C S
	Address Field						
MHR						MAC	MFR

as: Multi-master, error detection, retransmission of data after corruption of messages, the distinction between temporary errors and permanent errors, consistency of data, prioritization of messages and multiplex with the time synchronization ((CIA), n.d.).

The CAN can be described by two formats: the standard and base frame format define as 2.0A, and the extended 2.0B. The difference between A and B is that the Version A supports the format 11 bits to identifier field and the Version B support length of 29 bits to identifier field. For the development of the heterogeneous network node was used the version 2.0A that is described by Table 2 (Jaman and Hussain, 2007).

Table 2: CAN Protocols version 2.0 A.

Length (bits)	**Field Name**
1	Start-of-frame
11	A identifier for the data
1	Remote Transmission Request
1	Identifier extension bit
1	Reserved bit
4	Data length code
0-8 bytes	Data field
15	Cyclic Redundancy Check
1	CRC delimiter
1	ACK slot
1	ACK delimiter
7	End-of-frame

For the development of the node module was used for programming Atmel's AVR Studio, recording module STK 500, STK 501, radio transceiver RZ502 and the microcontroller AT90CAN128.

3 Project Development

In wireless sensor network the node is a point on the network with the ability to manage the data related to an application involving sensors and actuators. The model has the ability to manage the sensors / actuators through a bus and send the collected information using the serial port (RS-232) to a remote base station. It is relevant to emphasize that to reach the base station wireless sensor network, information can jump by several points until the final destination. Fig. 3 shows a schematic of the system for the interfacing and communication network of wireless sensors to the wired network (Hongiang and Shuangyou, 2008).

In Fig. 3, Block 1 is illustrated the CAN bus in which they can attach a mesh of sensors and actuators; a CAN network will have interfacing with the microcontroller proposed. The network works in high data rate up to 1Mbps and reliably, because of the CAN does not work with communications address, the microcontroller will have to perform a conversion to packet format to the format of IEEE 802.15.4 and may thus be sent to other meshes of sensors and actuators of the wireless network (E. Ding and Zhou, 2007).

So that the battery power of sensors is optimized, the IEEE 802.15.4 standard is used for interfacing with other software modules wireless network. The conversion done by the microcontroller shown in Fig. 3, Block 2, it is also held between the ZigBee standard for CAN network illustrated in Table 2 of that figure. One feature that should be emphasized is that the Zigbee operates with transfer rates of up to 250 Kbps messages, which will be needed for a bidirectional commu-

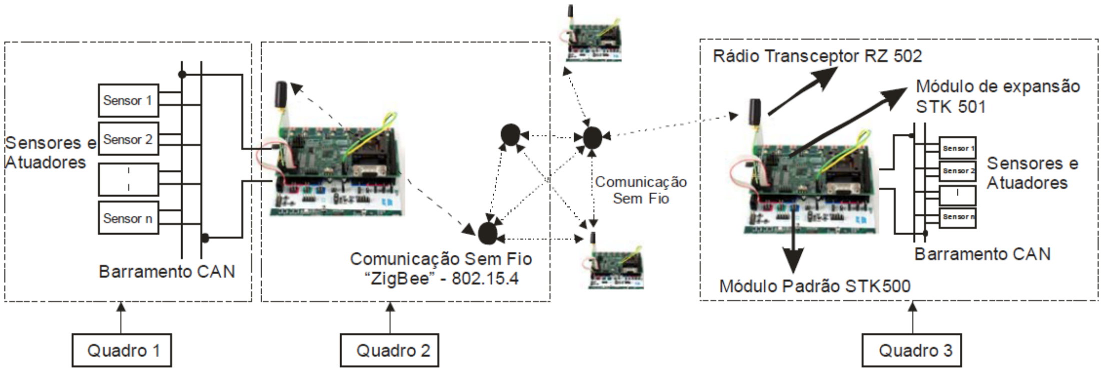

Figure 3: Detailing of the implemented communication module.

nication, which the packets of the IEEE 802.15.4 are also processed in the format of the CAN protocol for being recognized by the sensors and actuators. Communication between the two modules work reliably and there is a confirmation of receipt by the client module, a feature called handshacke. For communication between the modules is being used RZ502 kit (radio transceiver) with support for standard Zigbee.

In Fig. 3, Block 3 it is shown the microcontroller module for interfacing between the 802.15.4 standard and the CAN network of wireless sensor network. This module is the concatenation of the features of Fig. 4, Block 1 with Block 2 of. For implementation we used the tools and kits: AVR Studio 4 (WinAVR) module STK500, STK501 expansion kit, a radio transceiver integrated circuit and RZ502 with AT90CAN128 TQFP package. For the testing phase will be implemented sensors for monitoring temperature and humidity, besides driving devices such as motors, lights, heaters etc.

In researches held in the laboratory of Integrated Circuits, Faculty of Engineering of Ilha Solteira (Department of Electrical Engineering) a serial communication was implemented succeeding in capturing and recognition of the messages. Also, we studied the exchange communication messages using the IEEE 802.15.4 (Zigbee) between two nodes of a peer network, as shown in Fig. 4. Another analysis performed in the laboratory was the communication between a PC and RZ502 communication module using the standard serial interface RS-232, in which the data were successfully transferred. The test software for this communication was prepared using the Java language. Java has a library JAVAX.COMM that encourages the implementation of systems for this purpose. Because it is a synchronous communication it was held the following configuration on both devices (microcomputer/RZ502): 9600 bits / second, 8 data bits, parity N (None) and 1 stop bit.

4 Test Implementation

The integration of heterogeneous protocols is complex because it requires a great effort to synchronize the transmission and reception of data, knowing that, the wireless standard IEEE 802.15.4 as already stated, it operates at a transmission rate of up to 250 Kbps while the CAN protocol at a rate considerably higher than 1 Mbps, which can cause malfunction of the system and even loss of critical system information.

For synchronization of data between CAN protocol and IEEE 802.15.4 Protocol was adopted hash tables because the data transfer rate of the CAN protocol is considerably higher than IEEE 802.15.4. The possibility of using hash tables to control the allocation of memory in microcontrollers are techniques of data structure accepted (Palsberg, 2005).

Hash table is a special data structure, which combines search keys to values. The goal is, from a simple key, do a quick search and get the desired value. Hash tables, if well designed, can be used to get a table element in the order shown. The way to solve the problem of spending too much memory, but still ensuring quick access is through the use of hash tables.

Figure 4, shows the transmission of temperature data, monitored by the wired network for wireless sensor network (IEEE 802.15.4), we adopted a function to the dispersion of the data collected within the proposed structure, thus guaranteeing, direct access to information and eliminating duplicate information unnecessary.

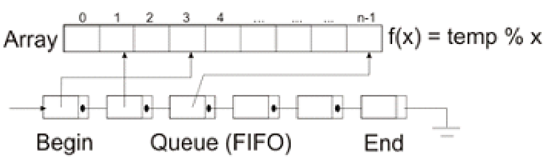

Figure 4: Schematic of the model implemented using the hash table to synchronization and data store.

When the information is collected by the temperature sensor, this information can be sent to the base station using the wireless network. Due the difference in the rate of transmission between the CAN protocols and IEEE 802.15.4 be different, the use of a simple linked stack could result in a stack overflow quickly. With the use of data structures and based on the concept of hash tables has been defined a hash function that indicates the correct position which the data collected will be stored in structure. The spread function $f(x)$ seeks to define a function that reduces the collisions of the information collected, and provides a constant value in the search, given the fact that we already know where the information within the vector. This work we defined a hash function given by $f(x) = 63\% temp$, where temp is the temperature value and prime number 63 which defines the amount of structure elements of Array.

In model describe was applying the hash function $f(x)$ and checked if in the position $f(x)$ of array ($Array[f(x)]$) there is some element, if the array position there is some element, this element is discarded. However, if the position $Array[f(x)]$ is empty the information is allocated and the address of $Array[f(x)]$ is assigned to queue elements to be sent by the IEEE 802.15.4 protocol, and consequently released from the queue (linked list). With this strategy, have a linked list that in the pessimistic case of the hash function will take $n+1$ memory locations, and more $n+1$ positions of the Array.

The implementation and configuration of the proposed protocol has been defined by laboratory tests. Figure 5 illustrates the communication of a block composed of a display to visualize the captured charge by a temperature sensor (LM35) and monitored by an attached module (slave) of a wireless sensor network and send them to a coordinator node (control unit) network using the IEEE 802.15.4.

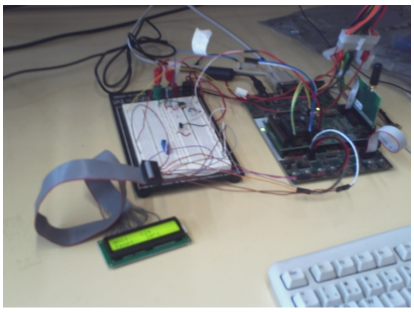

Figure 5: Slave node monitoring temperature using wireless communication ZigBee.

Figure 6 illustrates the simulation of the management of master/slave communication using a software model to test offered by ATMEL (AVR414), whose programming language Java wire. This software was adapted so that data collection, both in transmission and reception could be executed automatically, thus providing greater flexibility for the network of smart transducers.

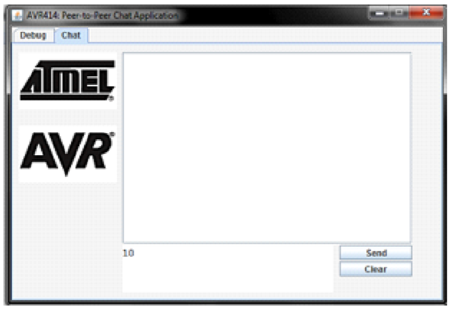

Figure 6: AVR414 application (client) adapted for communication with the network coordinator.

Figure 7 illustrates the reception of data sent by the slave node by the coordinator and this is responsible for triggering the actuators of the system based on the information provided by sensors connected to the wireless network system ZigBee. In tests, the temperature was controlled using sensors of some fans (actuators) for the cooling system.

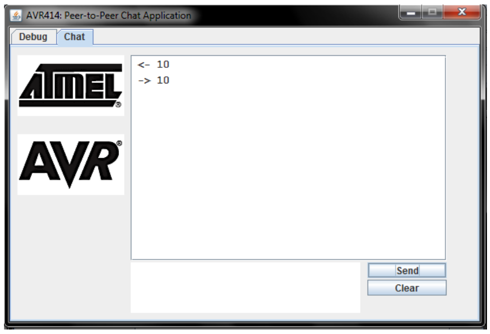

Figure 7: AVR414 Application (coordinated) modified to control and monitor data from client devices.

Finally, in Fig. 8 is defined monitoring tests of sensors and actuators using CAN bus. Also, as in the 802.15.4 standard, we used temperature sensors for data acquisition. The display shows the data collected and monitoring using the HyperTerminal application operating system Windows XP.

Authors G. Gaderer and Mahmood (2008) and Rauchhaupt (2002) indicate the possibility of integrating technology with the IEEE 802.15.4 standard CAN. It is based on these statements, that it is underway the creation of a heterogeneous protocol capable of performing communication and control technologies with different characteristics. One of the problems encountered in the implementation is to perform the synchronization between the technologies, because they, both, work with transmission rates in different bus (CAN - 1 Mbps; 802.15.4 - 250 Kbps) as stated

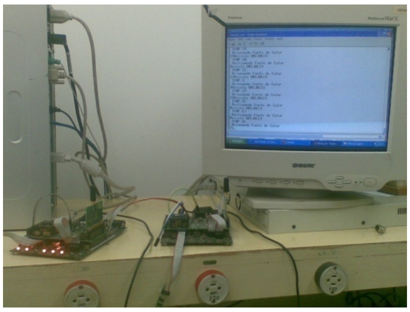

Figure 8: Monitoring bank of sensors using the protocol CAN Bus.

above. To implement the study, an integrated circuit AT90CAN128 of ATMEL was used.

5 Conclusion

In this study, we presented the development of a network node capable of integrating two different protocols (CAN and IEEE 802.15.4) for communicating and managing a wireless sensor network (WSN) using the TQFP package with microcontroller AT90CAN128 from ATMEL. The node has characteristics of being embedded and autonomous, making the routing of each packet to its specified interface. For this, each interface is identified by an address similar to the MAC address used in computer networks.

Through conducted studies, the lack of devices that allow the monitoring of various sensors in areas of relatively large scope is impossible because of the complexity in interconnecting all nodes ((CIA), n.d.). With this objective the creation of a network interconnecting the CAN node with 802.15.4 wireless standard is proposed. They use the CAN network reliability for the monitoring of sensors and data transmission to other network nodes and also the standard IEEE 802.15.4, which is reliable in data transmission, and has acceptable levels of immunity to interference in industrial environments; it can achieve higher distances, besides managing the lifetime of the battery sensor interconnected to the network sensors.

In developing the logical part of the hardware, it is used the modules from ATMEL (STK 500, STK 501 and antenna RZ502) and the tool AVR Studio also from the same company.

At the end of the project, it is intended to implement a structure that can be used for various purposes such as monitoring homes (smart homes), tracking of vehicles, checking temperature and weather conditions in planting of different crops etc.

For future works, it is proposed to develop a portable software for managing nodes through the JAVA programming language, because it is free and can be used in Web applications, desktop, mobile phones etc.

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