ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 8 (S8), 536-541, April 2015*
DOI: 10.17485/ijst/2015/v8iS8/51052

Implementation and Response Time Analysis of Messages in Wireless Controller Area Network

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Abstract

The Controller Area Network (CAN) is a vehicle bus standard for over two decades. In recent times CAN finds application in industrial automation as well, CAN is mostly employed for safety critical applications where low response time is essential. With the advent of wireless technology, there is a possibility for CAN messages to be exchanged wirelessly; there are several applications where wireless exchange of CAN messages is preferred. The Wireless Controller Area Network (WCAN) is a new approach of using CAN message-based protocol in wireless network. Message with higher priority gets transmitted first into the medium. This work investigates the possibilities to wirelessly communicate Controller Area Network (CAN) messages using the radio protocol IEEE 802.15.4, which is a very quick protocol and so the delays and jitter can be ignored in a small network. This work involves the implementation of Wireless Controller Area Network (WCAN) on FlexDevel board manufactured by Eberspascher. The idea is modelled and is shown to be a very smart way of sending CAN-data without using wires. SAE benchmark for Class C automobiles for safety critical control applications is used to validate the results.

Keywords: CAN, IEEE 802.15.4, Response Time Analysis, WCAN, WCAN Implementation

1. Introduction

One can find many practical applications where Controller Area Network (CAN) messages from already existing CAN network need to be transmitted wirelessly over short distances as wire connections maybe not possible or not wanted. For example the sensors and activators in the movable arm of a robot in a production line of an industry. The Sensors and activators of this system will perform better and with less hassle if they communicate wirelessly the CAN messages to their environment. If CAN messages are transferred wirelessly then there will be no need for wires between movable and non-movable parts of the system. Wireless approach is not only a good solution to access mobile and moving CAN fieldbus systems but also to access CAN nodes in hazardous environments like fire detection systems, where it is advantageous to avoid wires between CAN nodes with fire detectors and fire distinguishers. 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 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. 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. The rest of the paper is organized as follows; Section 2 explains the modelling and implementation of WCAN using the radio protocol IEEE 802.15.4. Section 3 discusses the response times of messages in the adopted WCAN system.

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2. Wireless Controller Area Network

The proposed system has seven WCAN nodes, modeling the seven different subsystems of a prototype of electric car. The seven WCAN nodes include the driver inputs like brakes, accelerator, gears, motor controller, battery, the instrument panel display and the transmission control. A set of 53 signals are sent between these seven different subsystems, some of the signal are sent sporadically and some of the signals are control data and are sent periodically. A periodic message needs to have latency less than or equal to this period while sporadic messages need to have latency as required by the application: for example, all messages that are sent by the action of the driver needs to have a latency of 20 ms, so that the response appears to be instantaneous to the driver[2]. For the wireless transfer of message frames, ZigBee module is used. ZigBee is based on an IEEE 802.15.4 standard. It is used to create personal area networks from small, low-power digital radios. The WCAN nodes are implemented by appending a ZigBee module to the serial interface of a CAN node. A copy of the CAN message is obtained at the serial interface which is converted from RS 232 standard to TTL standard by using MAX 232 IC. This CAN message frame is sent through the ZigBee module and is received by the ZigBee module of the CAN node at the other end with the corresponding message filter. In this way all the 53 messages are implemented and wirelessly transferred as per the SAE benchmark[2]. The response times of these messages are measured using timers implemented on the WCAN node and these measured response times are validated with the SAE benchmark.

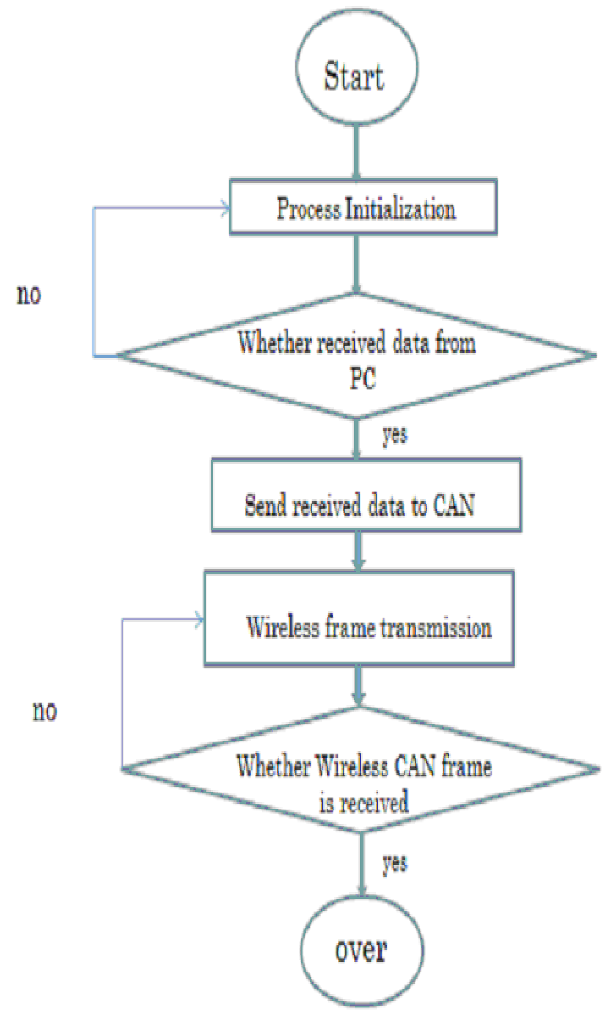
2.1 WCAN Modelling

2.1.1 Algorithm

Step 1: Start.
Step 2: Include header files.
Step 3: Configure pins.
Step 4: Initialize interrupt vectors.
Step 5: Initialize SCI mode.
Step 6: Enable and initialize CAN A.
Step 7: Assign various parameters for frame transmission and initialize values for all the parameters to be displayed using serial communication.
Step 8: Send this information within a CAN frame format.
Step 9: Configure the Zigbee module using XCTU software.
Sep 10: Check all message buffers whether a proper message is received or not.
Step 11: If a desired message is received, send information via Serial communication using SCI A port of the board which can be seen using HyperTerminal.
Step 12: Print error message if return value doesn't show a required value.

2.1.2 WCAN Implementation

The FlexDevel µController MPC5567 supports five CAN interfaces, from CAN A to E. The FlexDevel uses the interface CAN A and B.



The FlexDevel μController MPC5567 supports two SCI interfaces, SCI A and B. The SCI A is connected to a RS232 to TTL converter, MAX3227 from Maxim. The MAX3227 supports a force on feature which can be controlled via the MPC5567. The status of the MAX3227 can be checked with the two pins ready and invalid.

The 53 CAN messages of SAE benchmark are generated with the FlexDevel board. A copy of the messages is transferred to the serial port and can be seen on the hyper terminal. The messages are then converted to TTL signal with the help of RS232 to TTL converter. This message is then given to the ZigBee module which transmits the message wirelessly to the other ZigBee module. Then the TTL signal obtained is again converted back to the RS232 signal. Now this message is sent to the receiver CAN node through the serial port. The information received can be seen on the hyper terminal with the help of RS232 cable.

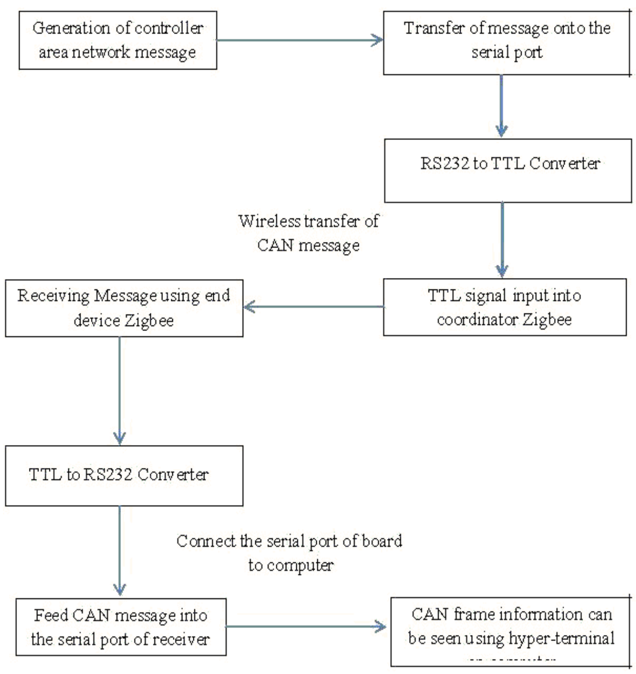


Figure 1. Wireless CAN model.

In this section the WCAN is analyzed for real time performance in comparison to WLAN (IEEE 802.11). In systems with hard real-time constraints, the latency time is an important criterion to take in account in order to respect real-time constraints. The performance evaluation of the latency time is based on the evaluation of both the worst-case queuing delay in the MAC and physical sub-layers and the longest time needed to transmit a message. The analysis of the worst-case response time can be derived from tasks scheduling theory and real-time scheduling algorithms that can be applied by the transmitter and the receiver to guarantee a minimum latency time for the exchanged frames[3].

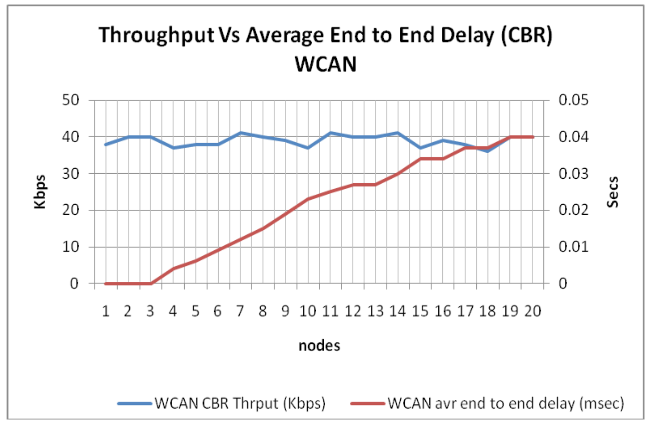


Figure 2. Performance evaluation of WCAN for periodic messages.

It is seen from Figure 2 that for periodic messages in WCAN, with the increase in number of nodes, the throughput does not vary much, but there is linear increase in the average end to end delay. The throughput is 39 kbps for an average end to end delay of 0.034, for the optimized case of 16 nodes.

While for sporadic messages, as shown in Figure 3, there is decrease in the throughput of WCAN as data arrival rate increases and the packet delivery ratio fluctuates about an average of 0.9625.

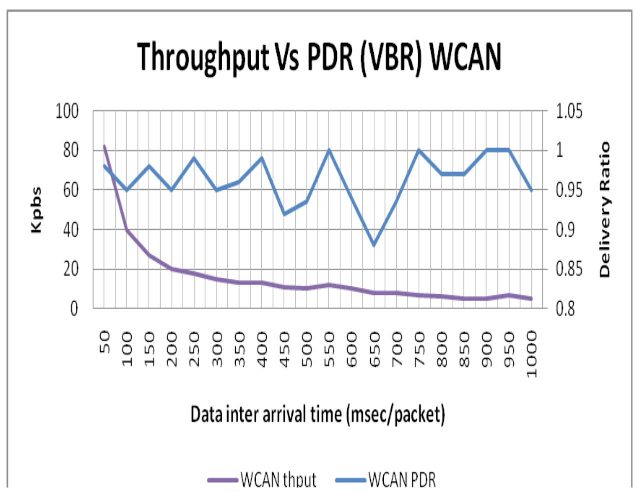


Figure 3. Performance evaluation of WCAN for sporadic messages.

These results are applied to the SAE 'benchmark' for class C automotive systems (safety critical control applications). This is done by mapping each of these messages to a WCAN message. Sporadic messages are modeled as Poisson processes with average inter arrival time of 50 ms and latency of 20 ms or less[2]. These messages may be queued infrequently. Tables 1 and 2 give the worst-case latencies for periodic and sporadic messages respectively. The worst-case latency is quite pessimistic, since it assumes that a missed deadline in the worst case is equivalent to always missing the deadline, whereas the probabilistic approach extends the knowledge of the system by computing how often a deadline is violated. Hence in our discussion we give the probability that a message may miss its deadline.

From Table 1 and by the approach discussed above, it can be concluded that periodic messages are schedulable in the WCAN system. While for sporadic messages, it can be seen from Table 2, that there is one sporadic signal, Signal 14 that is not schedulable as a sporadic messages, as it has too short a deadline. It has been earlier shown in Figure 3, for variable bit rate traffic, the packet delivery ratio of the WCAN system fluctuates about an average of 0.9645. This result guarantees that there is a high probability that the response time of sporadic messages of the WCAN system, as well, is within the deadline of 20ms.

Table 3 shows the parameters of ZigBee protocol which suits the WCAN based critical applications.

Table 4 shows the comparison between ZigBee and other competitive wireless protocols and the choice of ZigBee for WCAN based application are justified. ZigBee protocol has minimum latency, sufficient data rate and supports encryption standard suited for WCAN based critical applications[4].

Table 5 shows how the range of transmission of ZigBee protocol can increased with increase in transmission power if desired, else by lowering the data rate, the increase in range of transmission can be achieved[5].

3. Conclusion

The WCAN implementation adopted in this paper for Response Time Analysis uses IEEE 802.15.4 standard for wireless transmission of CAN messages. The wireless CAN messages obtained from experiments are classified as periodic and sporadic messages and validated using SAE benchmark for Class C automotive systems used for safety critical control applications. From Table 1 and by the probabilistic approach discussed in section 3 of this paper, it can be concluded that periodic messages are schedulable in the WCAN system. While for sporadic messages, it can be seen from Table 2, that there is one sporadic signal, Signal 14 that is not schedulable as a sporadic messages, as it has too short a deadline. It has been earlier shown in Figure 3, for variable bit rate traffic, the packet delivery ratio of the WCAN system fluctuates about an average of 0.9645. This result guarantees that there is a high probability that the response time of sporadic messages of the WCAN system, as well, is within the deadline of 20ms. These experimental results show that for an optimized number of nodes the

Table 1. Details of SAE benchmark for periodic messages to be scheduled

Signal Number	Size /bits	J /ms	T /ms	D /ms	End to End delay /ms WCAN -CBR
1	8	0.6	100	100	12
2	8	0.7	100	100	15
3	8	1	1000	1000	27
4	8	0.8	100	100	23
5	8	1.1	1000	1000	40
6	8	0.9	100	100	19
7	8	0.1	5	5	0
8	8	0.1	5	5	0
9	8	0.2	5	5	0
10	8	0.2	100	100	25
11	8	0.1	5	5	4
12	8	0.4	100	100	27
13	1	1.2	1000	1000	30
21	2	0.3	1000	1000	34
29	8	0.3	10	10	9
30	8	0.4	10	10	6
32	8	0.1	5	5	4
33	1	1.6	1000	1000	37
36	2	1.7	1000	1000	40
42	8	0.2	5	5	0
43	8	0.1	5	5	0
49	8	0.2	5	5	0

Table 2. Details of SAE benchmark for sporadic messages to be scheduled

Signal Number	Size /bits	J /ms	T / ms	D / ms	Sporadic/ Periodic
14	4	0.1	50	5	Sporadic
15	1	0.2	50	20	Sporadic
16	1	0.3	50	20	Sporadic
17	2	0.4	50	20	Sporadic
18	1	0.3	20	20	Sporadic
19	1	0.5	50	20	Sporadic
20	3	0.6	50	20	Sporadic
22	3	0.7	50	20	Sporadic
23	1	0.2	50	20	Sporadic
24	1	0.3	50	20	Sporadic
25	1	0.4	50	20	Sporadic
26	1	0.8	50	20	Sporadic
27	1	0.9	50	20	Sporadic
28	1	0.5	50	20	Sporadic
31	2	0.5	50	20	Sporadic
34	8	0.6	50	20	Sporadic
35	1	0.7	50	20	Sporadic
37	1	0.8	50	20	Sporadic
38	1	0.9	50	20	Sporadic
39	7	1	50	20	Sporadic
40	1	1.1	50	20	Sporadic
41	1	0.3	50	20	Sporadic
44	1	1.2	50	20	Sporadic
45	1	0.4	50	20	Sporadic
46	1	1.3	50	20	Sporadic
47	1	0.5	50	20	Sporadic
48	1	1.4	50	20	Sporadic
50	2	0.6	50	20	Sporadic
51	1	0.7	50	20	Sporadic
52	8	0.8	50	20	Sporadic
53	1	1.5	50	20	Sporadic

Table 3. Parameters of ZigBee protocol

Property	Range
Raw data rate	868 MHz: 20 kb/s; 915 MHz: 40 kb/s; 2.4 GHz: 250 kb/s
Range	10–20 m
Latency	Down to 15 ms
Channels	868/915 MHz: 11 channels 2.4 GHz: 16 channels
Frequency band	Two PHYs: 868 MHz/915 MHz and 2.4 GHz
Addressing	Short 8-bit or 64-bit IEEE
Channel access	CSMA-CA and slotted CSMA-CA
Temperature	Industrial temperature range –40 to +85 C

Table 4. Comparison between ZigBee and other wireless protocols

Feature(s)	IEEE 802.11b	Bluetooth	ZigBee
Power Profile	Hours	Days	Years
Complexity	Very Complex	Complex	Simple
Nodes/Master	32	7	64000
Latency	3 Seconds	10 seconds	30ms – 1s
Range	100 m	10m	70m-300m
Extendibility	Roaming Possible	No	YES
Data Rate	11Mbps	1 Mbps	250Kbps
Security	CCMP/TKIP 128bit/64bit	64 bit, 128 bit	128 bit AES and Application Layer

Table 5. ZigBee range of transmission

Range	Power Consumption	Frequency	Protocol	Tx Power	Data Rate	Antenna
300 Ft	50mA @ 3.3v	2.4GHz	802.15.4	1mW	250kbps	Chip
300 Ft	50mA @ 3.3v	2.4GHz	802.15.4	1mW	250kbps	Ext./Not Included
300 Ft	50mA @ 3.3v	2.4GHz	802.15.4	1mW	250kbps	Wire
300 Ft	50mA @ 3.3v	2.4GHz	802.15.4	1mW	250kbps	PCB
400 Ft	40mA @ 3.3v	2.4GHz	ZigBee Mesh	2mW	250kbps	PCB
400 Ft	40mA @ 3.3v	2.4GHz	ZigBee Mesh	2mW	250kbps	Ext./Not Included
400 Ft	40mA @ 3.3v	2.4GHz	ZigBee Mesh	2mW	250kbps	Ext./Not Included
400 Ft	40mA @ 3.3v	2.4GHz	ZigBee Mesh	2mW	250kbps	Wire
1 Mile	295mA @ 3.3v	2.4GHz	ZigBee Mesh	63mW	250kbps	PCB
1 Mile	295mA @ 3.3v	2.4GHz	ZigBee Mesh	63mW	250kbps	Ext./Not Included
1 Mile	295mA @ 3.3v	2.4GHz	ZigBee Mesh	50mW	250kbps	Ext./Not Included
1 Mile	295mA @ 3.3v	2.4GHz	ZigBee Mesh	63mW	250kbps	Wire
1 Mile	215mA @ 3.3v	2.4GHz	802.15.4	60mW	250kbps	PCB
1 Mile	215mA @ 3.3v	2.4GHz	802.15.4	60mW	250kbps	Ext./Not Included
1 Mile	215mA @ 3.3v	2.4GHz	802.15.4	60mW	250kbps	Wire
6 Miles	210mA @ 3.3v	900MHz	Multi-Point	50mW	156kbps	Ext./Not Included
6 Miles	210mA @ 3.3v	900MHz	Multi-Point	50mW	156kbps	Ext./Not Included
6 Miles	210mA @ 3.3v	900MHz	Multi-Point	50mW	156kbps	Wire
15 Miles	256mA @ 3.3v	900MHz	Multi-Point	100mW	9.6kbps	Ext./Not Included
15 Miles	256mA @ 3.3v	900MHz	Multi-Point	100mW	9.6kbps	Ext./Not Included
15 Miles	256mA @ 3.3v	900MHz	Multi-Point	100mW	9.6kbps	Wire
28 Miles	215mA @ 3.3v	900MHz	Multi-Point	250mW	10 or 20 Kbps	Wire
40 Miles	730mA @ 5v	900MHz	Multi-Point	1W	9,600 or 115,200bps	Ext./Not Included

adopted WCAN is schedulable with maximum throughput for minimal latency and is suited for real time control applications. Hence it is concluded that for applications with real-time constraints and the necessity to extend a wired CAN network wireless, the WCAN is the best choice. Whereas for applications without real-time constraints but with an important wireless payload that requires a more important throughput, WLAN is the best choice.

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