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Wireless Medium Access Control Protocol For CAN

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Abstract

In this paper we study the wireless communication extension for the Controller Area Network (CAN) protocol to suit industrial applications. Two different network topologies and medium access methods have been considered. The remote frame and the prioritised frame medium access control (MAC) methods are proposed for the centralised and distributed wireless CAN based network. The performance of these protocols is evaluated by simulating the protocols in the wireless CAN network. The "SAE Benchmark" is used as the workload to illustrate the industrial applications of CAN based system. This paper discusses the applicability of the proposed wireless MAC protocols and confirms its usefulness for real-time communication base on the benchmark.

1.0 Introduction

Control Area Network (CAN) is an advanced serial communication protocol which can supports efficiently distributed real-time computer control system with a very high level of data integrity. To facilitate data transfer between mobile terminals and stationary terminals in a distributed real time control system of an industrial application requires wireless communication capability. One of the major benefits of the wireless access is to allow flexible location of terminals, avoiding re-wiring when fixed terminals are relocated [1]. Two different medium access control (MAC) protocols are proposed for the wireless environment by considering the distinct features of the CAN protocol such as the priority assignment for each message. The two proposed protocols are for the centralised and distributed wireless CAN based network as shown in Figure 1. The performance of these protocols is evaluated by using a commercial simulation software design tool. The "SAE Benchmark" is applied as the workload in the investigation to determine whether the proposed wireless CAN protocols is suitable for real time industrial applications. The "SAE Benchmark" can be considered to be a good example for distributed real time industrial application.

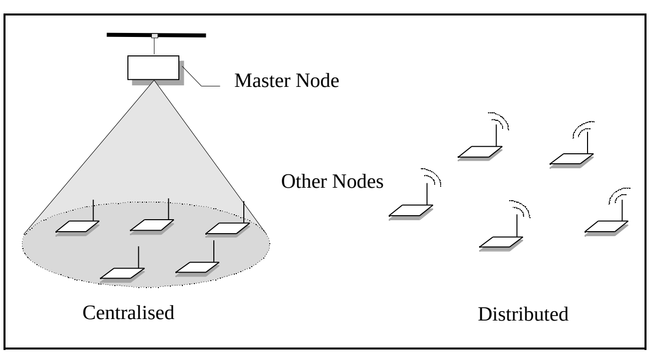

Figure 1 Wireless Network Structures

In the following section the two proposed protocols are presented. The simulation model of the protocol based on the SAE benchmark is given in Section 3. The simulation results are presented in

2.0 Wireless CAN (WCAN) Protocols

In a distributed real-time control system, the characteristic of the communication network plays a critical role on message transmission. Information must be transmitted in real time. The CAN protocol supports the real time information transfer requirements. It reduces the message delivery time with its capability to prioritise messages. Therefore, the wireless access methods based on CAN protocol must also fulfill the message transfer delay for the real time application. Moreover, messages with higher priorities must be delivered to their destination within the deadline before any other messages with lower priority. With these considerations, we have propose the remote frame medium access control (RFMAC) and the wireless medium access control (WMAC) protocols for wireless communication with regards to the existing methods such as CSMA/CA, ISMA and etc.

2.1 RFMAC Protocol

The RFMAC protocol is mainly for the centralised network structure that consists of one master (base) node and slave nodes in the range of master node. For centralised wireless networks, the performance evaluation for several contention-based channel access protocols such as ALOHA, PRMA (Packet Reservation Multiple Access), ISMA (Idle Signal Multiple Access), and etc have been made. The ISMA access protocol is partially adopted as a reference method for centralised WCAN. It enables upstream (to central node) and downstream (to terminals) traffic to be transmitted on a shared channel. Basically when the shared channel is idle the base station broadcast short idle signal to terminals. In response to the idle signal, a terminal may transmit its messages with some transmission probability [2].

Similarly, CAN protocol supports on demand transmission of messages. Instead of sending periodic messages from slave nodes to the master node, remote frames can be used to initiate slave node message transfer without any contention of data frames. Therefore the master node schedules all periods of data frames. If the master node wishes to have data from any node it immediately sends a remote frame to the channel. All nodes on the network receive the remote frame and decides whether the remote frame belongs to the node by using acceptance filtering. If the remote frame identifier does not match with the acceptance filter, the slave node stays idle. A data frame is only sent when the remote frame identifier matches with the data frame identifier [3]. It is possible that more than one data frame is requested by the master node. In that case the master node decides which remote frame is sent first according to messages' priority defined by the user. Remote frame message traffic is as shown in Figure 2.

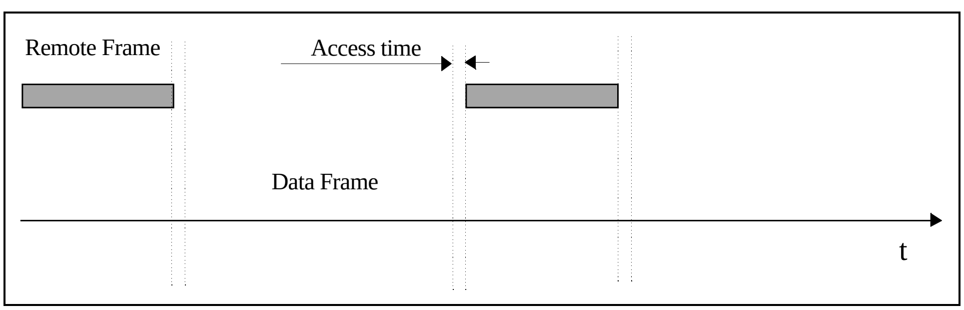

Figure 2 Remote frame message traffic

2.2 WMAC Protocol

In a distributed WCAN network structure, several nodes may work together and communicate with each other without the assistance of a central node. The proposed WMAC protocol has been designed to support sporadic and periodic messages. Hence any node can broadcast a message at any time it desire. The contention situation is resolved by using different Priority Interframe Space (PIFS) delay times for each message. In a similar study, the priority levels with CSMA/CA Access procedure have been presented to IEEE 802.11 for a wireless medium access control protocol by W. Diepstraten [4].

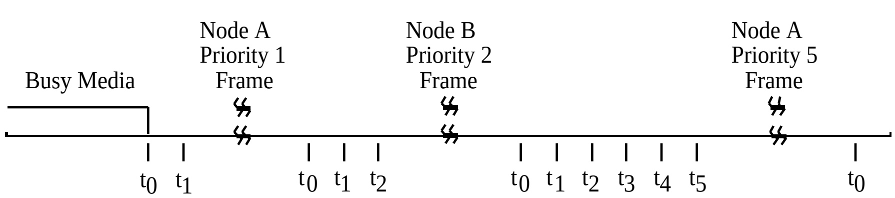

Figure 3 Prioritised Frames

There has been discussion of being able to provide prioritisation of frames using a non-TDMA (Time Division Multiple Access) based medium access control protocol. In CSMA/CA protocol; prioritisation the priority of the frame as can be seen in Figure 3 [5]. Different priority levels have been implemented for different purposes. For example, for all immediate response actions, the short priority interframe space (SPIFS) is defined as the highest priority.

In our WMAC protocol, each node must wait the message PIFS time before sending their messages. PIFS time is used to assign message priority to each message according to the scheduling scheme of the user's application. The shortest priority interframe space (SIFS) is reserved for the highest message priority which implies shortest delay in accessing the channel. After the PIFS time elapse, each node checks the channel to be sure that the channel is idle. Hence, a message with shorter PIFS will access the channel before any massage with longer PIFS.

Each node has a timer called Priority Timer. Setting the Priority Timer as soon as the message is received from the channel prevent the nodes from accessing the channel during the PIFS time. This is essential since a node may wish to transmit a message during the PIFS time and sense the medium is free although there could be a node waiting its PIFS. The Priority Timer is also set when collision situation occurs. After a collision, the nodes involve in the collision stop their transmissions and wait for their messages' PIFS times before trying to access the channel again. The value of the Priority Timer varies according to amount of messages used in the network. The timing diagram of the WMAC protocol is given in Figure 4.

Figure 4 Timing of the WMAC protocol

Node "B" and node "C" in the Figure 4, try to access the channel while it is busy. Node "C" sends a message while "B" waits the PIFS time. "B" sense the channel busy after PIFS time and defers the transmission of the message until the next idle channel situation. In turn, waits its PIFS time to gain the access. Channel interframe space (CIFS) time represents the time required for carrier sensing.

3.0 Simulation Model

The benchmark used in the simulation model specifies the communication requirements in a distributed automotive control system which handles 53 types of messages. These signals can be considered as a good example for real-time communication between distributed control nodes. The benchmark signals are listed in Table 1.

No:	Signal Description	Size /bits	T /ms	Periodic Sporadic	D /ms	From	To
1	Traction Battery Voltage	8	100	P	100	Battery	V/C
2	Traction Battery Current	8	100	P	100	Battery	V/C
3	Traction Battery Temp, Average	8	1000	P	1000	Battery	V/C
4	Auxiliary Battery Voltage	8	100	P	100	Battery	V/C
5	Traction Battery Temp, Max.	8	1000	P	1000	Battery	V/C
6	Auxiliary Battery Current	8	100	P	100	Battery	V/C
7	Accelerator Position	7	5	P	5	Driver	V/C
8	Brake Pressure, Master Cylinder	8	5	P	5	Brakes	V/C
9	Brake Pressure, Line	8	5	P	5	Brakes	V/C
10	Transaxle Lubrication Pressure	8	100	P	100	Trans	V/C
11	Transaction Clutch Line Press.	8	5	P	5	Trans	V/C
12	Vehicle Speed	8	100	P	100	Brakes	V/C
13	Traction Battery Ground Fault	1	1000	P	1000	Battery	V/C
14	Hi&Lo Contactor Open/Close	4	50	S	5	Battery	V/C
15	Key Switch Run	1	50	S	20	Driver	V/C
16	Key Switch Start	1	50	S	20	Driver	V/C
17	Accelerator Switch	2	50	S	20	Driver	V/C
18	Brake Switch	1	20	S	20	Brakes	V/C
19	Emergency Brake	1	50	S	20	Driver	V/C
20	Shift Lever (PRNDL)	3	50	S	20	Driver	V/C

23	12V Power Ack Vehicle Control	1	50	S	20	Battery	V/C
24	12V Power Ack Inverter	1	50	S	20	Battery	V/C
25	12V Power Ack I/M Control	1	50	S	20	Battery	V/C
26	Brake Mode (Parallel/Split)	1	50	S	20	Driver	V/C
27	SOC Reset	1	50	S	20	Driver	V/C
28	Interlock	1	50	S	20	Battery	V/C
29	High Contactor Control	8	10	P	10	V/C	Batt
30	Low Contactor Control	8	10	P	10	V/C	Battery
31	Reverse & 2nd Gear Clutches	2	50	S	20	V/C	Trans
32	Clutch Pressure Control	8	5	P	5	V/C	Battery
33	DC/DC Converter	1	1000	P	1000	V/C	Battery
34	DC/DC Converter Current Cont	8	50	S	20	V/C	Battery
35	12V Power Relay	1	50	S	20	V/C	Battery
36	Traction Battery Gnd Fault Test	2	1000	P	1000	V/C	Brakes
37	Brake Solenoid	1	50	S	20	V/C	Brakes
38	Backup Alarm	1	50	S	20	V/C	Brakes
39	Warning Lights	7	50	S	20	V/C	Ins
40	Key Switch	1	50	S	20	V/C	I/M C
41	Main Contactor Close	1	50	S	20	I/M C	V/C
42	Torque Command	8	5	P	5	V/C	I/M C
43	Torque Measured	8	5	P	5	I/M C	V/C
44	FWD/REV	1	50	S	20	V/C	I/M C
45	RWD/REV Ack	1	50	S	20	I/M C	V/C
46	Idle	1	50	S	20	V/C	I/M C
47	Inhibit	1	50	S	20	I/M C	V/C
48	Shift in Progress	1	50	S	20	V/C	I/M C
49	Processed Motor Speed	8	5	P	5	I/M C	V/C
50	Inverter Temperature Status	2	50	S	20	I/M C	V/C
51	Shutdown	1	50	S	20	I/M C	V/C
52	Status/Malfunction (TBD)	8	50	S	20	I/M C	V/C
53	Main Contactor Ack	1	50	S	20	V/C	I/M C

Table 1 Benchmark Signals

From the work of Tindel [6] the 53 types of benchmark signals are shown to be unschedulable at 125Kbit/s data rate when using the deadline monotonic (DM) scheduling algorithm. With DM, messages with shorter deadlines are assigned higher priorities. To overcome the scheduling problem and to reduce the bus utilisation they have employed the message piggybacking technique. This is implemented in the form of message server which polls to collect several messages from the same source and then sent out as a single long message [7]. The newly transformed benchmark signals now consist of only 17 message types as shown in Table 2. We have also adopted these newly transformed benchmark signals in our simulation model for the proposed WMAC and RFMAC protocols.

Message Number	Signals Number	Size /bytes	T /ms	D /ms	Periodic /Sporadic
1	14	1	50.0	5.0	S
2	8,9	2	5.0	5.0	P
3	7	1	5.0	5.0	P
4	43,49	2	5.0	5.0	P
5	11	1	5.0	5.0	P
6	29,30,32,42	4	5.0	5.0	P
7	31,34,35,37,38,39 40,44,46,48,53	4	10.0	10.0	S
8	23,24,25,28	1	10.0	10.0	S
9	15,16,17,19,20,22 26,27	2	10.0	10.0	S
10	41,45,47,50,51,52	2	10.0	10.0	S
11	18	1	50.0	20.0	S
12	1,2,4,6	4	100.0	100.0	P
13	12	1	100.0	100.0	P
14	10	1	100.0	100.0	P
15	3,5,13	3	1000.0	1000.0	P
16	21	1	1000.0	1000.0	P
17	33,36	1	1000.0	1000.0	P

T: period D: deadline

Table 2 Transformed Benchmark Signals

The message number of the newly transformed benchmark represents the message priorities according to DM scheduling algorithm. Therefore message number 1 is assigned as the highest priority. The message transmission rate used in our simulations are chosen as 1 Mbit/s, 500 Kbit/s, 250 Kbit/s and 125 Kbit/s. To ensure that worse case scenario exist in the simulation environment, all the 17 types of messages are initially generated simultaneously. The PIFS times for WMAC protocol are assumed as multiple values of 20 microsecond. This is determined by the transmitter turn-on time, signal propagation time over the operating distance and signal detection time in the receiver. The frame length of the messages are as specified in Table 2 and adopted a common 44 bits overhead. The network model is assumed to be free from node failures and transmission errors.

4.0 Simulation Results

1	1	50	5	1.296	0.544	0.434	0.120
2	2	5	5	1.916	0.884	0.634	0.250
3	1	5	5	2.476	1.204	0.834	0.390
4	2	5	5	3.136	1.584	1.074	0.560
5	1	5	5	3.736	1.944	1.314	0.740
6	4	5	5	4.588	2.440	1.632	0.969
7	4	10	10	5.460	2.956	1.716	1.218
8	1	10	10	9.932	3.376	2.016	1.458
9	2	10	10	10.692*	3.856	2.356	1.728
10	2	10	10	99.940*	4.356	2.716	2.018
11	1	50	20	-	4.592	3.076	2.318
12	4	100	100	-	5.208	3.514	2.667
13	1	100	100	-	7.904	3.914	3.007
14	1	100	100	-	8.444	4.334	3.367
15	3	1000	1000	-	9.084	4.814	3.767
16	1	1000	1000	-	9.664	5.274	4.167
17	1	1000	1000	-	10.264	7.112	4.587

* Missing Deadline

Table 3 Distributed Network Structure

No:	Bytes	T/ms	D/ms	125Kb/s	250Kb/s	500Kb/s	1Mb/s
1	1	50	5	2.128	1.108	0.594	0.337
2	2	5	5	3.160	1.644	0.882	0.501
3	1	5	5	3.456	2.140	1.150	0.655
4	2	5	5	5.144*	2.676	1.438	0.819
5	1	5	5	9.032*	3.172	1.706	0.973
6	4	5	5	10.216*	3.784	2.302	1.156
7	4	10	10	-	4.396	2.358	1.339
8	1	10	10	-	4.892	2.626	1.493
9	2	10	10	-	5.428	2.914	1.657
10	2	10	10	-	9.136	3.202	1.821
11	1	50	20	-	9.632	3.470	1.975
12	4	100	100	-	10.204	3.776	2.148
13	1	100	100	-	19.224	4.044	2.302
14	1	100	100	-	19.720	4.312	2.456
15	3	1000	1000	-	19.720	4.312	2.456
16	1	1000	1000	-	20.216	4.580	2.610
17	1	1000	1000	-	29.732	4.848	2.764

* Missing Deadline

Table 4 Centralised architecture

Table 3 shows the simulation results of message delivery time for the 17 message types at 125, 250, 500 Kbit and 1 Mbit baudrates in a distributed environment. The channel access method used in this simulation is the proposed WMAC protocol. As can be seen from this table, when the data rate is above 250 Kbit/s all the messages are delivered within the deadline. Column 4 indicates the deadline for all messages. At 125 Kbit/s, messages from number 9 to 17 are not delivered within the deadline. Therefore this protocol is not suitable for real-time communication at low data rate.

Similarly as shown in Table 4, at 125 Kbit/s data rate the proposed RFMAC protocol for centralised network structure only manage to deliver message number 1 to 3 within their deadline. In spite of this, there is not much difference in message delivery between these two architectures at higher speeds. Besides at 125 Kbit/s data rate, the protocol for the distributed architecture gives better result then the centralised case since the message numbers 4 to 8 can be delivered in time in the distributed architecture.

5.0 Conclusion

The simulation results show that the WMAC and RFMAC protocols are suitable for wireless environment for higher transmission rates. Both protocols can satisfy the requirements of the distributed automotive control system application. At 125 Kbit/s, the messages with lower priorities are not delivered within the specified deadline because of the very high load of the channel. In spite of this, these protocols can be use for real time application at higher transmission rates. It is expected that the protocol can satisfy all the timing requirements of real time communication. Our next task is to demonstrate that the WMAC protocol can also be used for centralised network with some PIFS modification.

References:

[1] C. M. Leung, "Internetworking Wireless Terminals to Local Area Networks Via Radio Bridges", *IEEE international Conf. on Sel. Topics in Wireless Comm*., ICWC' 92, June 1992, Canada, pp. 126-129.

[2] G. Wu, K. Mukumoto, A. Fukuda, "An integrated voice and data transmission system with idle signal multiple access", *IEICE Transactions Communications,* Vol. E76B (9), PP. 1186-92, September 1993.

[3] A. Kutlu, H. Ekiz, E. T. Powner, "Wireless medium access control for CAN using remote frames", Unpublished .

[4] W. Diepstraten, "DFWMAC Distributed Foundation Wireless Medium Access Control", *IEEE 802.11 Wireless*

[5] R. White, “Frame Prioritisation in a CSMA/CA Media Access Control Protocol”, *IEEE 802.11 Wireless Access Method and Physical Specification,* IEEE P802.11-93/159, September 1993.
[6] K. Tindell, A. Burns, “Guaranteeing message latencies on Control Area Network (CAN), *ICC’94, 1. International CAN conference proceedings,* pp 1-2 1-11, Germany, September 1994.
[7] M. D. Baba, E. T. Powner, “Scheduling performance in distributed real-time control system”, *ICC’94, 2. International CAN conference proceedings,* pp 7-6 7-11, London, 1995.