Optimization for the Reliability of TTCAN Bus Based on Genetic Algorithms

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***Abstract*—TTCAN protocol reduces the jitter of message and makes full use of bandwidth by introducing time-trigger mode into CAN bus. On the other hand it reduces the reliability under electromagnetic interference (EMI). Conclusion is drawn that the performance and reliability can't get the minimum value simultaneously in this paper. In order to improve the reliability of TTCAN bus under EMI, Generic Algorithms are used in the schedule of TTCAN which is a NP hard problem. Because of the unique property of schedule of TTCAN, coding, objective and fitness function, and mutation are investigated and developed to meet the requirement of optimization problem for reliability. The experiment is carried out based on the SAE benchmark and the result shows the validity of the above algorithm.**

***Keywords*—TTCAN, genetic algorithms, optimization**

I. INTRODUCTION

Nowadays CAN bus designed for the automobile originally is widely used in many areas such as industrial control, home automation and so on. Some of applications of CAN bus are high reliability systems, i.e. it is necessary for CAN bus to not only meet the transmission requirement that worst case response time (WCRT) shouldn't exceed the deadline but also meet the requirement of reliability. Ref. [1] analyzed the real-time of CAN bus and proposed the WCRT of messages transmitted over bus. Ref. [2][3] used the Poisson distribution to model faults generated by electromagnetic interference (EMI) in CAN bus and provided the calculation of the probability of failure based on the probability distribution of WCRT, which gave the analysis frame for the systems of high reliability.

Unlike the traditional event-triggered CAN bus, TTCAN which a session layer specification ISO 11898-4 [4] supports time-trigger/event-trigger and it yields better performance than CAN by reducing the jitter of messages and making full use of bandwidth [5]. Ref. [6][7] improved the performance of TTCAN by studying on schedule algorithm. As for the reliability of TTCAN under EMI, Ref. [2][3] pointed out the reliability of messages in the exclusive time window is lower than that of the event-triggered CAN bus. Ref. [8] proposed that the reliability of messages in the arbitrating time window is lower than that of the event-triggered CAN bus even under the best cases. The reliability of TTCAN depends on the types of time window and the priority of messages. This paper presents Genetic Algorithms designed for the TTCAN to overcome the optimization problem of reliability.

II. THE PROBABILITY OF FAILURE IN TTCAN

A. *The Structure of TTCAN*

Time master which is a special node in TTCAN sends periodically the reference messages which act as a benchmark in time to which all other message transactions are referenced. The schedule table of TTCAN is called matrix cycle (MC). The MC is composed of basic cycle (BC), each commencing with a reference message. The time windows which compose the MC are of three types: exclusive time window, arbitrating time window and free time window. The exclusive time windows are assigned to a single specific message and no other message can be scheduled to access the medium during this time window. The arbitrating time windows are assigned to more than one message. Within an arbitrating time window, bus conflicts are resolved using CAN's native non-destructive bitwise arbitration scheme. The free time windows have no messages scheduled during their time interval. These time windows are reserved for future expansion of the network. Fig. 1 shows a MC consisting of four BC.

B. *The Probability of Failure in Exclusive Time Window*

A fault is considered to have occurred when the state of the bus is different to the state that was transmitted. These faults are typically caused by some form of EMI and EMI can be

Figure 1. Simplified TTCAN matrix cycle

modeled by Poisson distribution. That is to say, the probability of m faults in a time interval t is

$$Po(K,t)=\frac{e^{-\lambda t}(\lambda t)^K}{K!} \quad (1)$$

Because the exclusive time window is assigned to a single specific message, the worst case probability of message being lost is the probability of it being hit by one or more faults. The probability of unsuccessful delivery is [2][3]

$$p_i(failare)=1-Po(0,C_i)=1-e^{-\lambda C_i} \quad (2)$$

where C_i is the worst case transmission time, that is the time it takes, in the worst case to send frame assuming no errors, maximum bit stuffing.

C. The Probability of Failure in Arbitrating Time Window

Within an arbitrating time window, bus conflicts are resolved using the same scheme as CAN bus, so this paper modifies the method in [2][3] to be suitable for the TTCAN protocol. Considering EMI, the WCRT of message i transmitting in arbitrating time window is

$$R_i = J_i + t_i \quad (3)$$

$$t_i = B_i + C_i + I_i(t_i) + E_i(t_i) \quad (4)$$

where C_i is the worst case transmission time, J_i is the worst case release jitter of frame i. The worst case blocking B_i is the maximum time a message may need to wait due to a lower priority message on the bus. B_i is defined as

$$B_i = \max_{\forall k\in lp(i)}(C_k) + S \quad (5)$$

where S is the length of the interframe space (3 bit times).

The term $I_i(t_i)$ is the worst case interference that message i may receive in t time units and it is defined as

$$I_i(t_i)=\sum_{j\in hp(i)}\left|\left((t_i - C_i + J_j + \tau)\right)/T_j\right|(C_j + S) \quad (6)$$

According to the protocol of CAN, if fault is occurred during the transmission of message, the message is retransmitted automatically. $E_i(t_i)$ is the worst case overhead due to network faults and extra frame during the retransmission. It is defined as

$$E_i(t)=A_i(t)\left(\max_{j\in hep(i)} C_j + E\right) \quad (7)$$

where $A_i(t)$ is a random variable, meaning the number of arrivals in time t, and it follows Poisson distribution as described in section B, $P_t(A_i(t)=K)=Po(K,t)=\frac{e^{-\lambda t}(\lambda t)^K}{K!}$. E is the maximum length of error frame.

The probabilistic WCRT is

$$R_{i|K} = B_i + C_i + I_i(R_{i|K}) + E_{i|k}(R_{i|K}) \quad (8)$$

where $E_{i|k}(t)=K\left(E+\max_{\forall j\in hep(i)} C_j\right)$. As for the arbitrating time window, (8) produces a set of $R_{i|k}$ over all K for which the analysis is useful. That is, $\forall K$, $R_{i|k} < D_i \cap R_{i|k} < T$. D_i is the dead line of message i and T is the length of arbitrating window.

$p(R_{i|k})$ is defined as the probability that a frame i is affected by exactly K faults and hence may arrive no later than $R_{i|k}$ as and it is calculated by [2][3]

$$p(R_{i|K})=Po(K,R_{i|n})-\sum_{j=0}^{K-1}p(R_{i|j})Po(K-j,R_{i|K}-R_{i|j}) \quad (9)$$

where $R_{i|k}$ is calculated by (8).

The probability of failure for frame i is given by (10).

$$p_i(failare)=1-\sum_{\forall k|R_{i|k}<D_i,R_{i|k}<T}p(R_{i|k}) \quad (10)$$

D. The Relationship between Performance and Reliability

Better the performance is, smaller the WCRT is. Higher the reliability is, higher the ability of resisting the interference is. The experiments in [2][3] shows that the performance of messages transmitted in exclusive time window are better than CAN, while the reliability are lower than CAN. The experiments in [8] shows that the reliability of messages transmitted in arbitrating window are lower than CAN. The reason is the retransmission on fault. This aim of retransmission is to provide an assured delivery service, meaning that a transmitted frame will arrive eventually. On the other hand retransmission increases WCRT as shown in (4). That is to say the performance and reliability can't get the minimum value simultaneously because of retransmission.

As for the messages transmitted in the exclusive time window, retransmission is disabled and so the performance increases. But the reliability becomes very low without retransmission as shown in (2). Normally C_i is small, for example, if the baudrate is 250kb/s, the C_i of message which is 8 bit data length and in extended format is 528 us. So the result of (2) is always greater than (10). As for the messages transmitted in the arbitrating time window, although the arbitration scheme is the same as CAN bus, the length of arbitrating window is always smaller than the deadline. And accordingly the probability of failure of TTCAN is greater than that of CAN.

Equation (2) and (10) show that reliability of different time window type is different. So it is possible to improve the reliability of TTCAN by schedule, i.e. by putting messages to different time windows.

III. Optimization by Genetic Algorithms

Scheduling is a NP hard problem because it resembles the bin packing problem in mathematics. Genetic Algorithms yield better results in solving NP hard problem such as Traveling Salesman Problem [9], Job Shop Scheduling [9] and Tasks Scheduling [10]. This paper constructs the schedule table by Generic Algorithms. Although the skeleton of Genetic Algorithms is same to different applications, the parameters and operators should be designed to the problem's property. The main issues such as coding, objective and fitness function, and mutation will be discussed in detail.

A. Objective Function and Fitness Function

The probability of failure is a (0, 1) decimal, so the objective function is defined as

$$min\left(\sqrt{\left(\sum_{i=1}^{n} p_i^2(\text{failure})\right)\Big/n}\right) \tag{11}$$

where n is the numbers of messages, $p_i(failure)$ is the probability of failure of message i. The reason for defining objective function as (11) is this function reflects the probability of failure of the whole system and it is in normalization form, i.e. it is also a (0, 1) decimal, which can be regarded as the pseudo probability of failure of the whole system. The fitness function is defined the same as the objective function because the objective function is greater than zero.

B. Coding

If all the time windows in MC are exclusive, the reliability is the smallest. The reliability can be improved by changing the exclusive time window to arbitrating time window. But the Genetic Algorithms will become very complex if there're too many arbitrating time windows in MC. For simplification of the problem, it is assumed that there is only one arbitrating time window in one BC and all of the others are exclusive time window. Eq. (2) and (10) shows that the reliability depends on the type of windows and is independent of the location of transmission column in the BC, so it is assumed that the location of the arbitrating time window is always at the end of BC as shown in Fig. 1. Based on the above assumption, the chromosome is formed by a matrix $Y = \lfloor y_{ij} \rfloor, i = 1,\cdots,m, j = 1,\cdots,n$, where y_{ij} is the message in i th BC, j th transmission column. The $1,2,\cdots,k-1$ th column in each BC are exclusive time windows and the $k, k+1,\cdots,n$ th column are combined to one arbitrating time window.

C. Selection

The fitness function of individual which is a schedule table in the optimization of TTCAN is calculated and the results of all individuals are sorted in ascending order. According to the requirement of TTCAN some bad individuals with greater value of fitness function are removed.

D. Mutation

According to (2) and (10), the fitness function doesn't change if two BCs are exchanged or two messages of exclusive time window are changed. The fitness function varies only if the message is changed from exclusive time window to arbitrating time window or reversely. And accordingly two new mutation operators are defined here. One is eliminating column operator and the other one is adding column operator. The eliminating column operator puts the messages belonging to the exclusive time window to the arbitrating time window and then modifies the exclusive time window to free time window. Fig. 2 gives an example of eliminating column operator. The adding column operator has two different actions according to the property of messages. If the messages in arbitrating time window exist in all BCs, adding column operator should be taken as following, at first adds a transmission column with exclusive time window and then puts the messages belonging to arbitrating time windows to exclusive time windows. If the messages in arbitrating time window exist only in part of BCs, adding column operator should be taken as following, at first adds a transmission column and then puts the messages belonging to arbitrating time windows to exclusive time windows, at last set the residual windows as free time window as shown in Fig. 3.

E. The Initial population

Although the initial population can be generated by stochastic method, the individuals maybe can't meet the requirement of TTCAN. So the initial population is generated as following, firstly construct a schedule table of which all the BCs consist of only one arbitrating time window. The period of BC is the greatest common divisor of the periods of messages and the period of MC is the lowest common multiple [8]. Then the population is generated by the adding column operator and eliminating column operator described in Section D.

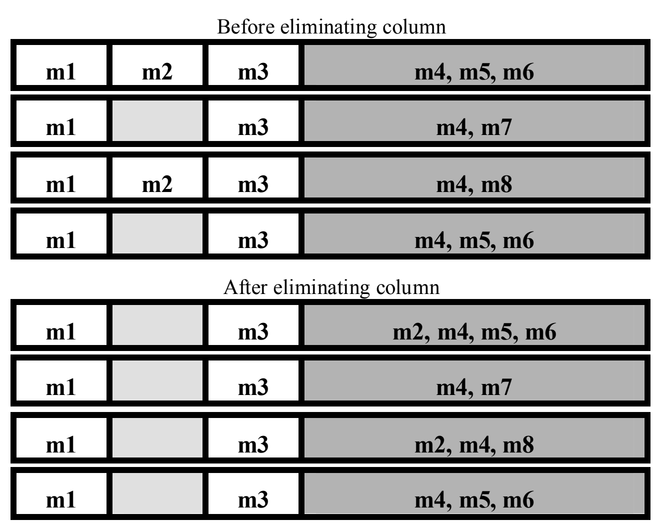

Figure 2. eliminating column operator

before adding column

m1	m3	m2, m4, m5, m6
m1	m3	m4, m7
m1	m3	m2, m4, m8
m1	m3	m4, m5, m6

after adding column

m1	m2	m3	m4, m5, m6
m1		m3	m4, m7
m1	m2	m3	m4, m8
m1		m3	m4, m5, m6

Figure 3. adding column operator

IV. EXPERIMENTS

To test the validity of Generic Algorithms, experiments based on SAE benchmark was carried out. The data is listed in Table 1. The parameters were set as following, the population size was set to 20, and the mutation adapted the eliminating column operator and adding column operator with the rate 0.01. The λ of Poisson distribution was 30 , which was the same as Ref. [2][3]. Fig. 5 is an individual of the initial population and Fig. 4 is the final result. Table 2 shows the comparative results. The reliability of final schedule table is greater than that of the initial one. It can also be found that the utilization of bandwidth of the final schedule table is lower than that of the initial one, which proves the validity of the conclusion that the performance and reliability can't get the minimum value simultaneously.

TABLE I. BENCHMARK OF SAE (unit us)

number	message	period	length
m1	torque/speed control	10 000	1040
m2	wheel angle sensor	10 000	656
m3	engine controller	20 000	656
m4	AGB	10 000	584
m5	device x	20 000	808
m6	device x	40 000	808
m7	device x	10 000	736
m8	bodywork sensor	40 000	808
m9	device y	20 000	736
m10	engine controller	80 000	968
m11	AGB	40 000	808
m12	device x	80 000	504

m4	m2	m6	m1, m7, m3, m5
m4	m2		m1, m7, m9, m11
m4	m2		m1, m7, m3, m5, m8
m4	m2		m1, m7, m9, m10
m4	m2	m6	m1, m7, m3, m5
m4	m2		m1, m7, m9, m11
m4	m2		m1, m7, m3, m5, m8
m4	m2		m1, m7, m9, m12

Figure 4. The Final Schedule Table

m1	m7	m4	m2	m3, m5, m8
m1	m7	m4	m2	m9, m6
m1	m7	m4	m2	m3, m5, m11
m1	m7	m4	m2	m9, m10
m1	m7	m4	m2	m3, m5, m8
m1	m7	m4	m2	m9, m6
m1	m7	m4	m2	m3, m5, m11
m1	m7	m4	m2	m9, m12

Figure 5. The Schedule Table in Initial Population

TABLE II. THE RESULT OF GENETIC ALGORITHM

number	probability of failure of the final schedule table	probability of failure of the schedule table in Fig. 5
m1	3.1×10^{-4}	3.0×10^{-2}
m2	1.9×10^{-2}	1.9×10^{-2}
m3	4.7×10^{-3}	1.7×10^{-3}
m4	1.7×10^{-2}	1.7×10^{-2}
m5	6.2×10^{-3}	4.3×10^{-3}
m6	2.3×10^{-2}	9.3×10^{-3}
m7	2.7×10^{-4}	2.1×10^{-2}
m8	2.3×10^{-4}	5.1×10^{-3}
m9	4.8×10^{-3}	2.3×10^{-3}
m10	7.2×10^{-5}	6.2×10^{-4}
m11	2.3×10^{-3}	4.1×10^{-3}
m12	5.2×10^{-5}	4.5×10^{-5}
objective function	1.0×10^{-2}	1.3×10^{-2}

V. Conclusion

Although the reliability of TTCAN is not as good as CAN, the reliability of TTCAN can be improved by schedule. This paper presented a schedule algorithm based on the Genetic Algorithms assuming that there is only one arbitrating time window in each basic cycle. Coding, objective and fitness function, mutation were designed to meet the requirement of TTCAN and the experiment showed that the above algorithm yields good performance. The conclusion drawn in this paper is the performance and reliability can't get the minimum value simultaneously, so it is necessary to balance the performance and reliability in the application of TTCAN. Generic algorithm has been proved to be valid in the multi-objective optimization and the study in the future is to use the Generic Algorithms to optimize both performance and reliability at the same time.

References

[1] K. Tindell, A. Burns, and A. J. Wellings, "Calculating controller area network (CAN) message response times," Control Engineering Practice, vol. 3, no. 8, pp. 1163–1169, 1995.

[2] I. Broster, A. Burns, and G. Rodriguez-Navas, “Probabilistic analysis of CAN with faults," in Proc 23rd Real-time Systems Symposium., Austin, Texas, pp. 269-278, 2002.

[3] I. Broster,A. Burns, and G. Rodriguez-Navas, “Timing Analysis of Real-Time Communication Under Electromagnetic Interference," Real-Time Systems, vol. 30, pp. 55-81, 2005.

[4] ISO 11898-2 Road vehicles -- Controller area network (CAN) -- Part 4 Time-triggered communication[S]. 2004.

[5] G. TitLeen and B. Heffernan, “TTCAN: a New Time-Triggered Controller Area Network," .Microprocessors and Microsystmes, vol. 26, pp. 77-94, 2002.

[6] F. Coutinho, J. Barreiros and J. Fonseca, “Scheduling for a TTCAN network with a stochastic optimization algorithm,” in 4th FET., Nancy, France, June 2001.

[7] Liu Luyuan, Wang Renjun and Li Bin, "Scheduling Algorithm Based on TTCAN and its Application in Automotive Process Control System", Automotive Engineering, vol. 27, no. 1, pp. 60-63, 2005.

[8] Chen Xi, Lv Weijie and Liu Luyuan, “Transmission Reliability Analysis on TT-FPS Algorithm Under EMI,” Control Engineering, in press.

[9] Wang Xiaoping. Cao Liming, Thoery, Application and Implementation of Genetic Algortihms, Xi'an: Publishing house of Xi'an Jiao Tong University, pp.123–135, 2002.

[10] C. Ricardo, A. Ferreira, and P. Rebreyend , “Scheduling multiprocessor tasks with genetic algorithms". IEEE transaction on parallel and distributed systems , vol. 10, no. 8, pp. 825-837, 1999.