Traffic Prediction of CAN Network System with Dual Communication Channels

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Abstract: The increasing number of electronic control units, sensors, and actuators in intelligent vehicles, and the increasing need for more intelligent functions require a network with increased capacity and real-time capability. As an example of enhancing the capacity of a controller area network (CAN) system, this paper presents a CAN system with dual communication channels as well as a traffic prediction method that predicts the traffic of each channel to allocates frames to the more appropriate channel. An experimental testbed using off-the-shelf microcontrollers with two CAN controllers was used to prove the feasibility of the traffic prediction method.

Keywords: traffic prediction method, double exponential smoothing method, controller area network (CAN), in-vehicle network system

1. INTRODUCTION

Intelligent vehicle technology, which focuses on ways to enhance safety and convenience for both drivers and passengers, is widely used in automobiles, trucks, and public transportation [1,2]. An intelligent vehicle has many electronic control units (ECUs) that link sensors with actuators [3,4] to handle intelligent functions such as power window systems, window lock systems, or adaptive cruise control (ACC). Automobile venders and parts manufactures have developed in-vehicle networking (IVN) systems to connect electronic components, such as window motors, switches, and limit sensors, to an ECU through a shared network cable [5–7]. A common application of IVN systems is the integrated chassis networking system consisting of an electronic stability program, a continuous damping control, and an electro-hydraulic power steering system. In a chassis networking system, many ECUs communicate through a controller area network (CAN) with various sensors such as body acceleration sensors, wheel acceleration sensors, and steering angle sensors.

On many CAN systems, various data types, including hard and soft real-time data, share a single network even though they have different real-time requirements. Hard real-time data become completely useless when their transmission is delayed beyond a certain time limit, while soft real-time data lose only some of their usefulness after the time limit. As the number of ECUs, sensors, and actuators grows, and the requirement for more intelligent functions increases, and these devices need to exchange larger amounts of data amongst themselves [8]. This makes it difficult to handle all messages on only a single CAN system segment without degradation of the real-time performance. Hence, it is necessary either to guarantee the real-time requirements or to increase capacity of the network system.

Recently, significant progress in enhancing CAN performance has been made by researchers. Hong [9] proposed a bandwidth allocation scheme with a time-division interval, and Cena [10] introduced a new medium access control (MAC) for CAN systems using a round-robin method. Nolte [11] used server-based communication in a CAN with a scheduling method, and Pedreiras [12] introduced earliest deadline first (EDF) message scheduling to reduce network traffic. Almeida [13] reported a time division multiple access (TDMA) MAC-based flexible CAN, known as a flexible time-triggered CAN. Xia [14] described a priority-driven control network system with carrier-sense multiple-access and a non-destructive bitwise arbitration mechanism, while Ayavoo [15] and Schmidt [16] developed a time-triggered CAN with message scheduling using the TDMA mechanism. In addition, Garroppo [17] and Hwang [18] suggested various resource allocation methods based on traffic prediction in a network.

As an alternative to increasing the capacity and enhancing the performance, this paper presents a CAN system with dual communication channels. Recently, several off-the-shelf microcontrollers have been introduced with two and more CAN protocol controllers and communication channels. It should be possible to increase network capacity and enhance the real-time requirements of a network system if two or more communication channels can be used for exchanging data among ECUs in a CAN. In particular, to achieve efficient operation in a CAN system with dual communication channels, this paper presents a traffic prediction algorithm that allocates frames to the more appropriate channel.

The remainder of this paper is organized into three sections. Section 2 describes the structure of the CAN system with dual communication channels, and presents the traffic prediction methods. Section 3 describes implementation details and experimental results for the traffic prediction algorithm. Our summary and conclusions are presented in Section 4.

2. CAN SYSTMES WITH DUAL COMMUNICATION CHANNELS

Theoretically, if two channels are used in the CAN, it should be possible to reduce the traffic on each channel to half. However, since messages are generated probabilistically, it is difficult to create an ideal condition where the traffic of both channels is the same. For example, suppose that the CAN system uses a strategy where a CAN node can transmit a message through a channel with low traffic. When the traffic of one channel is low, all CAN nodes try to transmit through that channel. As a result, traffic in that channel may increase rapidly, whereas the traffic in the other channel may decrease. Hence, it is necessary to develop a traffic-balancing algorithm to make the traffic in both channels more even.

Figure 1 shows the structure of a CAN system designed to smooth out the traffic between the dual communication channels. The system consists of a traffic prediction node and duo-CAN nodes with two CAN controllers and transceivers. The traffic prediction node transmits the forecast traffic information for the two channels using the traffic prediction method, and the duo-CAN nodes decide whether a channel is appropriate using the message allocation method.

Figure 2 shows a flowchart of the traffic prediction method in the traffic prediction node. After initializing the CAN system, the traffic prediction node captures each frame from the two communication channels in the network, and analyzes the message identifiers (IDs). After a predefined interval, it calculates the total received message length and forecasts the traffic on each channel using the double exponential smoothing method. Finally, it assigns the highest ID to the forecast traffic information and periodically broadcasts that message to the other duo-CAN nodes on the network for the traffic-balancing algorithm.

To forecast the system traffic, the traffic prediction node uses a traffic prediction method based on exponential smoothing, one of several time-series forecasting methods [19–20]. The exponential smoothing method assigns exponentially decreasing weights as the observations get older. In other words, recent observations are given relatively more weight than older observations in the forecast. Furthermore, the double exponential smoothing method removes random variations and shows trends and cyclic components. The double exponential smoothing method may be appropriate for forecasting traffic patterns corresponding to a sine wave.

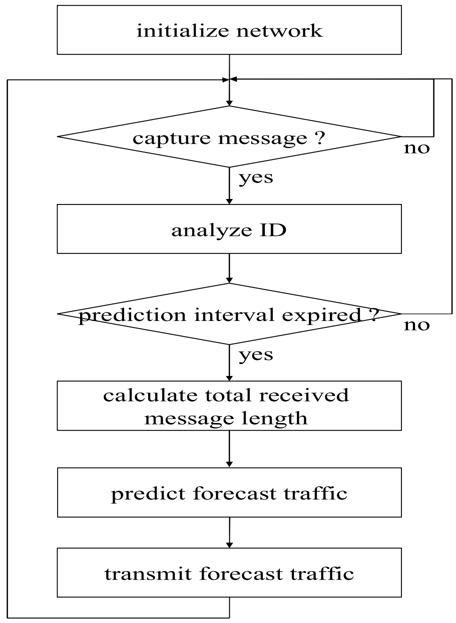

Fig. 2 Flowchart of the traffic prediction method used by the traffic prediction node

For forecasting the kth forecast traffic $T(k)$ in the traffic prediction node, the double exponential smoothing method can be expressed as follows :

$$
\begin{aligned}
T^{[1]}(k) &= \alpha RT(k) + (1-\alpha)T^{[1]}(k-1) \\
T^{[2]}(k) &= \alpha T^{[1]}(k) + (1-\alpha)T^{[2]}(k-1) \\
T(k) &= \left(2 + \frac{\alpha}{1-\alpha}\right)T^{[1]}(k) - \left(1 + \frac{\alpha}{1-\alpha}\right)T^{[2]}(k) \\
&\quad \textit{where} \quad RT(k) = r(k-1) - r(k-2)
\end{aligned} \tag{1}
$$

where $T^{[1]}(k)$ and $T^{[2]}(k)$ are the first and second step forecast traffic levels determined using exponential

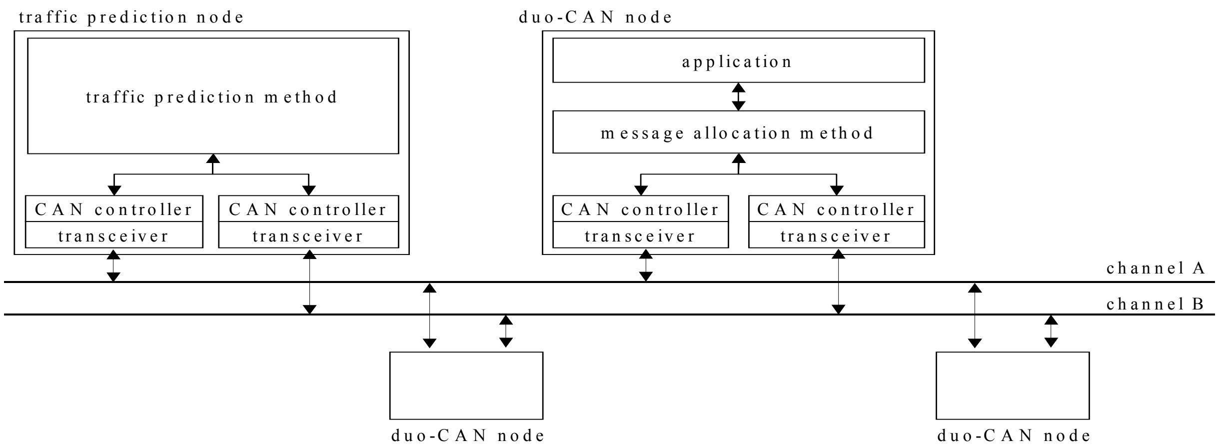

Fig. 1 Structure of CAN network system with dual communication channels

smoothing in the kth cycle, $RT(k)$ is the current traffic in the kth cycle calculated from the total received message length, $r(k)$ is the traffic information transmitted in the kth cycle, and α is the double exponential smoothing parameter generally selected to be in the range of 0.05–0.3. $T(k)$ is the forecast traffic in the kth cycle. Here, $r(-1)$, $r(-2)$, $T^{[1]}(0)$, and $T^{[2]}(0)$ are initially set to zero; $r(0)$ is assumed to be the average of the first traffic of the CAN system measured during a predefined interval.

3. PERFORMANCE EVALUATION OF THE TRAFFIC PREDICTION METHOD

This section describes the experimental CAN testbed and the results of evaluation of the traffic prediction method using that testbed. The testbed included one traffic prediction node and four duo-CAN nodes connected to the CAN system with dual communication channels. This setup was intended to simulate in-vehicle network systems in which a sensor, such as the limit sensor of a window, transmits data to a controller, such as the driver door module that receives a control signal. The testbed used TTTech's TTP power nodes, which contained a Freescale MPC555 microcontroller with two independent CAN 2.0 A/B communication controllers (TouCAN), for traffic prediction node and duo-CAN node. The traffic prediction method was implemented using the general function block of MathWorks' MATLAB Simulink and Stateflow software. The method was downloaded to the traffic prediction node using MathWorks' Real-Time Workshop for MPC555. In addition, a simple message transmission program was downloaded to each duo-CAN node to create traffic for the CAN system. Finally, a monitoring program was created for gathering message information using Vector's CANoe. The data rate of the CAN system was set to 500 Kbps.

To evaluate the performance of the traffic prediction method, we had each duo-CAN node that generates two types of messages with a length and generation distribution shown in Table 1. Periodic messages were generated cyclically every 4 ms, while aperiodic messages were generated with a uniform distribution in the range of 0.5–1.5 ms.

Figure 3 shows the experimental results of the traffic prediction method using the double exponential smoothing method. Here, the traffic was defined as the total length of data fields generated in 1 sec multiplied by the data rate (500 Kbps). First, the traffic prediction node captured all messages from each channel and calculated the length of messages during 100 ms. Then it calculated the traffic for specific channels. In the figure, the predicted traffic appeared to equal to the real traffic. For example, the tenth traffic prediction was 66.6%, while tenth real traffic level was 66.8%. This close agreement indicates that the traffic prediction method using the double exponential smoothing method is an appropriate algorithm for forecasting the traffic in each channel in a CAN system with dual communication channels.

4. SUMMARY AND CONCLUSIONS

For enhancing the performance and increasing capacity of the network system, we introduced a CAN system with dual communication channels. We presented a traffic prediction algorithm that allocates frames to the more appropriate channel. To demonstrate the potential performance enhancement offered by two channels, we implemented an experimental testbed using off-the-shelf microcontrollers with dual CAN controllers.

Our experiments indicated that the traffic prediction is useful for channel allocation. This result means that the traffic-prediction algorithm is an effective method

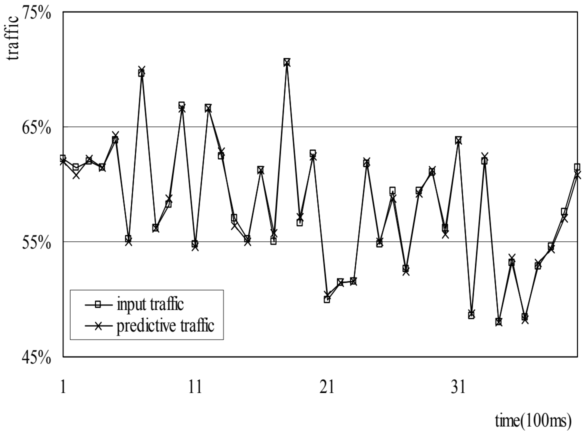

Fig. 3 Performance evaluation result of the traffic prediction method

Table 1. Message generation conditions for duo-CAN nodes used to evaluate the traffic prediction method

node number	CAN message ID	data length (bytes)	generation distribution
traffic prediction node	0x00	8	cyclically every 100 ms
duo-CAN node 1	0x01	1	cyclically every 4 ms
	0x02	7	uniform distribution 0.5–1.5 ms
duo-CAN node 2	0x03	6	cyclically every 4 ms
	0x04	1	uniform distribution 0.5–1.5 ms
duo-CAN node 3	0x05	5	cyclically every 4 ms
	0x06	4	uniform distribution 0.5–1.5 ms
duo-CAN node 4	0x07	6	cyclically every 4 ms
	0x08	2	uniform distribution 0.5–1.5 ms

for channel selection using traffic-balancing in a CAN system with dual communication channels. In particular, the traffic-balancing CAN reduces the transmission delay of all priority messages over what a simple message allocation method such as channel-switching CAN would deliver, without sacrificing the performance of high-priority messages.

However, this paper focused on the traffic prediction algorithm. Hence, additional practical research is necessary, including a traffic balancing algorithm in a real application such as the distributed chassis control system of intelligent vehicles. In addition, it is necessary to develop traffic-prediction algorithms and more appropriate channel-selection algorithms to ensure the maximum performance of a dual-channel CAN system.

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REFERENCES

[1] G. Cena, A. Valenzano, and S. Vitturi, "Advances, in automotive digital communications," Computer Standards & Interfaces, vol. 27, no. 6, pp. 665-678, 2005.

[2] G. Leen, and D. Heffernan, "Expanding automotive electronic systems," Computer, vol. 35, no. 1, pp. 88-93, 2002.

[3] R. Isermann, R. Schwarz, and S. Stolzl, "Fault-tolerant drive-by-wire systems," IEEE Control Systems Magazine, vol. 22, no. 5, pp. 64-81, 2002.

[4] S. Haggag, D. Alstrom, S. Cetinkunt, and A. Egelja, "Modeling, control, and validation of an electro-hydraulic steer-by-wire system for articulated vehicle applications," IEEE Transactions on Mechatronics, vol. 10, no. 6, pp. 688-692, 2005.

[5] K. C. Lee, M. H. Kim, S. Lee, and H. H. Lee, "IEEE-1451-based smart module for in-vehicle networking systems of intelligent vehicles," IEEE Transactions on Industrial Electronics, vol. 51, no. 6, pp. 1150-1158, 2004.

[6] R. Obermaisser, "Reuse of CAN-based legacy applications in time-triggered architectures," IEEE Transactions on Industrial Informatics, vol. 2, no. 4, pp. 255-268, 2006.

[7] G. Cena, A. Valenzano, and S. Vitturi, "On the properties of the flexible time division multiple access technique," IEEE Transactions on Industrial Informatics, vol. 2, no. 2, pp. 86-94, 2006.

[8] K. C. Lee and S. Lee, "Performance evaluation of switched Ethernet for real-time industrial communication," Computer Standards & Interfaces, vol. 24, no. 5, pp. 411-423, 2002.

[9] S. H. Hong, "Bandwidth allocation scheme for cyclic-service fieldbus networks," IEEE Transactions on Mechatronics, vol. 6, no. 2, pp. 197-204, 2001.

[10] G. Cena and A. Valenzano "Achieving round-robin access in controller area networks," IEEE Transactions on Industrial Electronics, vol. 49, no. 6, pp. 1202-1213, 2002.

[11] T. Nolte, M. Nolin and Hans A. Hansson, "Real-time server-based communication with CAN," IEEE Transactions on Industrial Informatics, vol. 1, no. 3, pp. 192-201, 2005.

[12] P. Pedreiras and L. Almeida, "EDF message scheduling on controller area network," Computing & Control Engineering Journal, vol. 13, no. 4, pp. 163-170, 2002.

[13] L. Almeida, P. Pedreiras, and J. A. G. Fonseca, "The FTT-CAN protocol: why and how," IEEE Transactions on Industrial Electronics, vol. 49, no. 6, pp. 1189-1201, 2002.

[14] F. Xia, Y. Sun, and Y. C. Tian, "Feedback scheduling of priority-driven control networks," Computer Standards & Interfaces, In Press, 2008.

[15] D. Ayavoo, M. J. Pont, M. Short, and S. Parker, "Two novel shared-clock scheduling algorithms for use with 'Controller Area Network' and related protocols," Microprocessors and Microsystems, vol. 31, no. 5, pp. 326-334, 2007.

[16] K. Schmidt and E. G. Schmidt, "Systematic message schedule construction for time-triggered CAN," IEEE Transactions on Vehicular Technology, vol. 56, no. 6, Part 1, pp. 3431-3441, 2007.

[17] R.G. Garroppo, S. Giordano, M. Pagano, and G. Procissi, "On traffic prediction for resource allocation: A Chebyshev bound based allocation scheme," Computer Communications, In Press, 2008.

[18] I. S. Hwang, Z. D. Shyu, L. Y. Ke, and C. C. Chang, "A novel early DBA mechanism with prediction-based fair excessive bandwidth allocation scheme in EPON," Computer Communications, vol. 31, no. 9, pp. 1814-1823, 2008.

[19] H. Lu, W. J. Kolarik, and S. S. Lu, "Real-time performance reliability prediction," IEEE Transactions on Reliability, vol. 50, no. 4, pp. 353-357, Dec. 2001.

[20] K. B. Song, S. K. Ha, J. W. Park, D. J. Kweon and K. H. Kim, "Hybrid Load Forecasting Method with Analysis of Temperature Sensitivities," IEEE Transactions on Power Systems, vol. 21, no. 2, May. 2006.