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The Performance Evaluation of Embedded Communication Networks

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Abstract*— Some Embedded systems involve multiple processors connected by a communication medium. These processors communicate with each other exchanging short messages using some message based communication protocols such as Controller Area Network (CAN), SAE J1939 etc. With the induction of new features inside such networks, the number of messages will increase. The increase of messages may affect the network performance for a given network characteristics. Performance evaluation of a message based networks is therefore desired with increasing message load. This paper presents the performance evaluation of message based embedded communication networks. Several parameters have been estimated as function of number of messages.

Index Terms—**Performance Evaluation, Message passing networks, Embedded Systems, Embedded Communication Networks**

INTRODUCTION

Embedded Communication Networks (ECN) are designed for specific applications. In embedded communication networks the electronic control units (ECU) are hooked to the communication networks, which allow the sharing of information among various intelligent modules in the system. ECN support short periodic messages injected by the ECUs. A typical example of ECN is In-Vehicle automotive multiplexing network. Several automotive network protocols were developed for implementing message communication in in-Vehicle networks [1] [2]. Some example protocols are Controller Area Network (CAN) by Robert Bosch [3], Advanced Protocol for Automotive Low and Medium speed Network (PALMNET) by Mazda [4], J1850 and J1939 by SAE [5][6], etc. CAN protocol originally developed for the automotive industry however, but it can also be used in many other applications where high-speed communication is required. Due to the distributed location of the control units, a separate communication protocol was needed for heavy-duty vehicle. The Society of Automotive Engineers (SAE) evaluated various automotive communication protocols and recommended a separate protocol for the heavy-duty vehicles. This protocol called SAE J1939 which is based on CAN protocol version 2.0 [6].

Performance evaluation of embedded communication network is needed to observe the network behavior. Some work has been reported in literature related to performance evaluation of Embedded communication networks [10][11][12]. Trevor Meyerowitz et al suggested a tool suite for the performance of scheduling policy for modules sharing a bus in real-time applications [10]. Aamir et al presented analytical model for MIL-STD-1553 embedded communication protocol [11]. They have estimated some message related parameters such as message time load, message pick up etc. Florin et al has presented a CAN performance monitoring in a distributed embedded system [12]. Network parameter relationship with number of messages has been established in the reported work. We present the performance analysis of state based message embedded communication in which the messages are injected on the network on periodic basis. We study the effects of number of messages on various network parameters. SAE J1939 protocol and in-vehicular multiplexing network has been considered as a case study. Section II introduces SAE J1939 as representative ECN protocol. Section III discusses the simulation model developed in this work. Finally, the paper is concluded in section IV.

I. SAE J1939

Controller Area Network (CAN) protocol was specifically designed for convenient inter-processor communication inside modern automotive vehicles [7]. SAE has classified the data communication over automotive multiplexing network namely class A, B and C. CAN protocol has been designed to cover all these communication classes [8]. A CAN message contains header and a data field. CAN 1.2 has message identifier field of 11 bits and a variable data field of up to 64 bits The extended CAN protocol version is called CAN V 2.0 [6]. CAN 2.0's header field is of 29 bits long and payload of up to 64 bits. Society of Automotive Engineers (SAE) (www.sae.org) is an international consortium of representatives from aerospace, automotive and commercial-vehicle industries. SAE develops recommendation practices for these industries. The SAE has recommended the CAN ver 2.0 as foundation protocol for the multiplexing networks inside heavy duty vehicles such as trucks and buses and assigned it the name of SAE J1939 [10]. Due to its basis upon CAN protocol, J1939 is also considered as high-speed class C communication protocol. According to the J1939 protocol, 29 bits of CAN protocol version 2.0 have been redefined. Among various fields in the J1939 message frame, initial three bits specify message priority. The messages with high priorities are guaranteed to arrive at destination control units with low latency (delay) times. In J1939 the messages are identified by the term Protocol Data Units (PDU). These PDUs are referred as PDU1 and PDU2. The PDU1 format contains the source and destination addresses. PDU2 format broadcast data unit which may be used to send the data frames to all nodes. Therefore, PDU2 is considered as the broadcast message format.

PERFORMANCE ANALYSIS

In this section, we present the performance analysis of a typical short messaging embedded communication network. We have considered in-Vehicular multiplexing network as an example embedded communication network. However, the

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performance analysis can be extended to any genre of short message based embedded communication network.

Modern automotive vehicles uses several intelligent units connected to the multiplexing network inside the vehicles. Instead of using multiple buses, the auto industry is inclined in introducing single High Speed Serial Data Communication System (HSSDCS) as a central communication bus for future vehicular systems [9]. HSSDCS connects all intelligent electronic control modules including smart sensors, actuators and electronic control units (ECUs) inside the vehicle. Figure 1 shows a typical HSSDCS based Automotive multiplexing system.

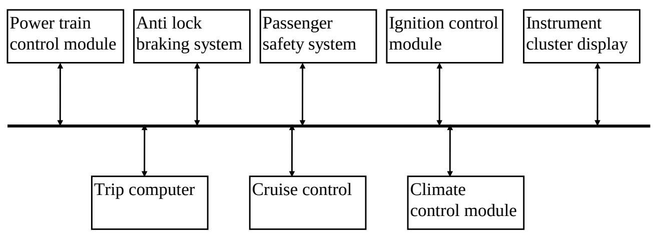

Figure 1: HSSDCS connecting intelligent modules inside modern automobiles

All smart devices attached to HSSDCS can communicate with each with short messages. Therefore, these devices will form a real time distributed processing system inside the vehicular system. As the HSSDCS is the only communication channel inside, addition of new modules in the system may lead to the elevation of data traffic over HSSDCS. Depending upon the application, information transmitted by some intelligent module must reach the other module within a specified period of time. If the information does not reach at its decision due to network congestion, the network performance will be impacted, which may lead to malfunctioning of the system.

The system designer would be interested in the performance analysis of the communication system being designed when the number of messages over the networks. The performance parameters which are effected due to proliferation of messages are as follows: average bus utilization, average bus queue length, average message delay and maximum latency. Masud Mahmud have developed performance evaluation analysis of for hierarchical multilevel bus networks Multiprocessors. This model has been tailored to establish the relationship between various performance parameters of embedded communication network and the number of messages injected on the network. The model inputs number N number of messages, processor ids, and period of messages. We run the simulation for an example embedded communication network. We consider 40 test messages with variety of test periods. Table 1 lists message IDs, processor IDs (PID) and the message generation rate for 20 messages.

Table 1: Simulation input data

MID	PID	Period (sec)	MID	PID	Period (sec)
0	0	0.005	11	1	0.028
1	1	0.005	12	0	0.128
2	0	0.05	13	1	0.128
3	0	0.05	14	1	0.028
4	1	0.05	15	2	0.028
5	3	0.046	16	2	0.028
6	3	0.026	17	2	0.01
7	0	0.028	18	3	0.128
8	0	0.028	19	3	0.01
9	0	0.016	20	4	0.128

Each message has a 64 bit long payload with constant header size. The simulation program was executed for 30 minutes of real-time to gather the results followed by another run for 80 minutes. We observed that both simulation results do not deviate significantly as they are within 5% range. Thus, we believe that the results obtained in this research show the realistic estimation of performance parameters discussed below.

A. BUS UTILIZATION

Bus utilization (BU) is a network parameter which indicates how much network has been utilized for given number of messages. BU is defined as the ratio of utilized bus time to the total time. The relationship between bus utilization and number of messages for short term and long term simulation time is shown in Table 2.

Table 2: Bus utilization versus number of source messages

Number of messages	BU (%) Short-term Average	BU (%) Long-term Average
5	56	57
10	79	80
15	93	95
20	100	100
25	100	100
30	100	100
35	100	100
40	100	100

It is obvious that the bus utilization increases when new messages are introduced in the vehicular system. From this result we can determine with how many messages, the bus utilization will reach to 100%. The graphical representation of relationship between bus utilization and number of source messages is shown in Figure 2.

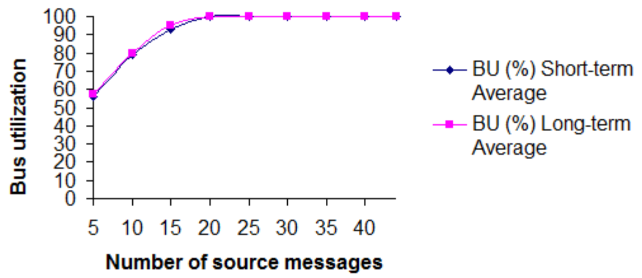

Figure 2. Bus utilization versus number of source messages

B. AVERAGE MESSAGE DELAY

A message generated by an intelligent unit will attempt to access the multiplexing bus. If the bus is idle, then its access will be granted to the processor for the complete message transmission. On the other hand, if the bus is busy with some other message transmission then the newly generated message will be placed in a queue. A queued message will have to wait for random time before it reaches to its intended recipient. The average amount of time a message spent by a message in bus queue is defined as Average message delay (AMDL). AMDL is useful parameter used for the evaluation of a given embedded communication network. Table 3 shows the effects of increase in source messages over AMDL. The graphical representation of data in Table 3 is shown in Figure 3.

Table 3: Average message delay versus number of source messages

Number of source Messages	AMDL (m Sec.)	
	Short-term Average	Long-term Average
5	0.902	0.872
10	0.916	0.892
15	1.17	1.147
20	1.558	1.465
25	1.784	1.715
30	1.919	1.841
35	2.138	2.006
40	2.226	2.112

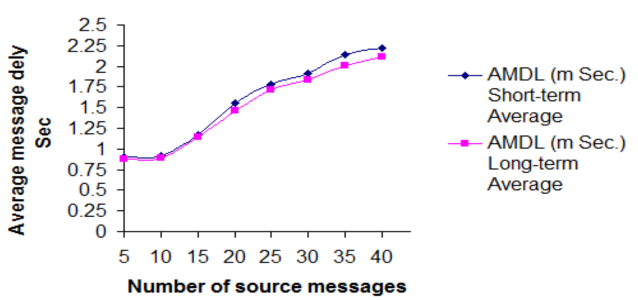

Figure 3: Average message delay versus number of source messages

It is obvious from the results shown in table 3 and figure 3 that the average message delay increases when message traffic increases. A system designer can predict the average message delay with increasing number of messages. The network characteristics or number of messages can be tuned for desired message delay.

C. AVERAGE BUS QUEUE LENGTH

Average bus queue length is defined as the number of messages waiting in the bus queue on average. Average bus queue length increases with the induction of new messages in the system. Bus queue length increases in terms of number of messages and in term of number of bits when messages do not get access from a busy bus. The simulation model introduced in this research provided the estimation average bus queue length with increase in number of messages. The results are shown in Table 4a and Table 4b in terms of messages and size of bus queue length in bits respectively. Figure 4 and 5 shows the graphical representation of relationship between number of source messages and average bus queue length in terms of messages and number of bits respectively. These results show that the bus queue length increases with the induction of new messages on the automotive multiplexing network.

Table 4a: Relationship between number of source messages and average bus queue length in term of umber of messages

	Bus Queue Length	
Number of source messages	Short-term Average	Long-term Average
5	0.405	0.367
10	0.591	0.553
15	0.885	0.851
20	1.613	1.519
25	2.221	2.126
30	2.589	2.474
35	3.473	3.266
40	3.876	3.684

Table 4b Relationship between number of source messages and average bus queue size in terms of data bits

	Bus Queue Length	
Number of source messages	Short-term Average	Long-term Average
5	51.78	47.02
10	75.62	70.83
15	113.32	108.99
20	206.44	194.42
25	284.28	272.07
30	331.34	316.66
35	444.58	418.10
40	496.17	471.58

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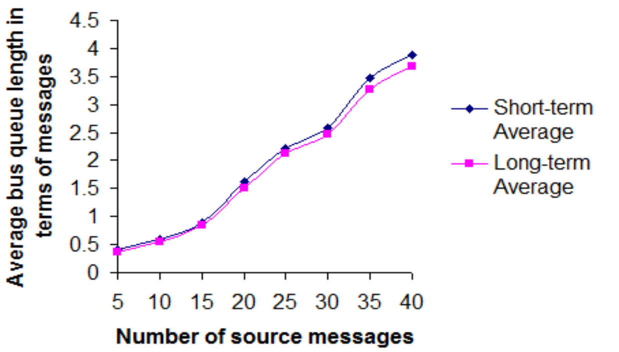

Figure 4a. Average bus queue length in terms of messages versus number of source messages

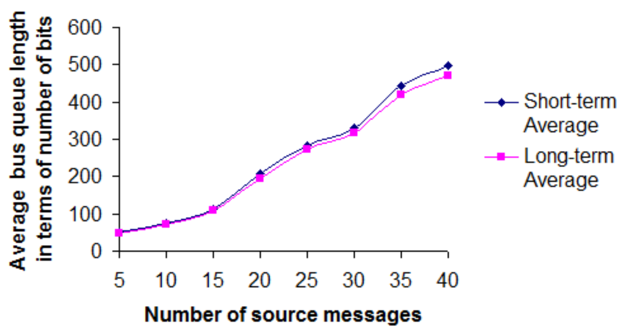

Figure 4b. Average bus queue length in terms of bits versus number of source messages

E. MAXIMUM LATENCY TIME

A message is said to completely transfer until its last bit is received by the receiving unit. The taken for complete message transmission is defined as latency time. Depending upon the applications, some messages must arrive at their specific destination within desired time limit. Due to bus congestion, the maximum latency time also increases as the number of messages increases in the system. Table 5 shows the relationship between number of source messages and maximum latency time. Figure 5 shows the graphical representation of Table 5. The maximum latency time increases due to the induction of new messages in the system.

Table 5: Relationship between number of source messages and Maximum latency time

	Maximum Latency Time	
Number of source messages	Short-term Average	Long-term Average
5	6.407	6.65
10	8.848	9.58
15	10.374	11.53
20	12.816	13.49
25	15.257	15.26
30	15.379	15.38
35	14.952	14.95
40	16.112	16.42

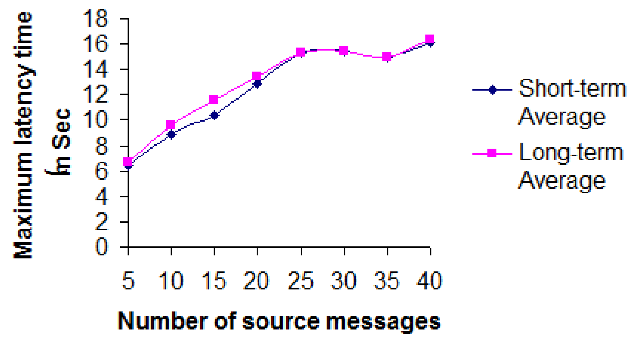

Figure 6: Number of source messages versus maximum latency time

II. CONCLUSION

Embedded communication networks connect several intelligent electronic control units (IECU) which communicate with each other via short message passing. Either by introducing more IECUs or reprogramming the existing IECU, number of messages increases over the embedded communication network. The proliferation of data traffic will impact many network performance parameter of in-vehicle network. In this paper, we have studied the impact of increase of number of messages on various network parameters. SAE J1939 protocol has been considered as representative networking protocol.

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