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DESIGN AND IMPLEMENTATION OF CAN / CAN, CAN / ETHERNET AND CAN / ATM BRIDGES

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ABSTRACT

The Controller Area Network (CAN) is a high performance and highly reliable advanced serial communication protocol which efficiently supports distributed real-time control systems at high speed, low cost, and a very high level data security. The CAN was originally developed as an automotive standard for a serial interface between electronic control units, but in a short time, it has become a desirable, cheap solution for networks in industrial environments. The fast growth of the CAN in industrial applications results some potential problems such as the size of the area that the devices, controlled by the CAN, are distributed and the communication between the CAN and the existing network systems (such as Ethernet or ATM).

One of the solutions to these problems is to use bridges. However, the characteristics of the CAN creates problems, when CAN segments are connected by a bridge, since CAN frames do not contain any information related to destination address, source address, or LAN number that are used by traditional address-based bridges for routing decisions. Thus, new bridges (suitable for the CAN protocol features) must be designed to overcome the problems.

The objective of this paper is not only to investigate the characteristics of bridged CAN systems and to give a bridge proposal to connect CAN segments, but also to design and implement bridges that connect the CAN and existing LANs and provide communication between them.

1. INTRODUCTION

It has been shown that the CAN technology is very useful for any product/system with multiple microcontrollers and general purpose sensor/actuator bus systems for distributed real time control which could be used in industrial automation [1]. However, problems arise when the CAN is used in an industrial environment, since the CAN bus has a limited length. In this case, one of the appropriate solutions is to segment the CAN system and, then, to connect them using an internetworking devices such as bridge. In addition, in an industrial environment, while the CAN is used by manufacturing sections to control the systems, the management department can use a LAN (Ethernet, ATM LAN, etc.). Furthermore, the CAN-based industrial application may need a backbone system, such as Ethernet or ATM, to extend the size of the distributed area.

In the following, after a brief explanation about the CAN protocol, the investigation of the characteristics of the interconnected CAN systems and the presentation of the models of the CAN / CAN, CAN / Ethernet and CAN / ATM bridges are going to be discussed.

1.1. Controller Area Network Protocol

The Controller Area Network communication protocol is a contention-based serial communication. As an access method, the CAN uses CSMA/CR, Carrier Sense Multiple Access with Collision Resolution. The CAN although serial in nature is unlike many serial communication protocols; it contains no information relating to the destination or source addresses. Instead, the message contains an identifier which indicates the type of information contained in the message. The identifier is not only used to identify the message but also used in the arbitration mechanism. The CAN associates a priority with each message to be sent and uses a special arbitration mechanism to ensure that the highest priority message is the one transmitted.

In CAN, data is transmitted as a message consisting of between 1 and 8 bytes. A message may be transmitted periodically, sporadically, or on-demand and is sent as a frame (Figure 1). More detail about the CAN protocol and CAN frames can be found in [2].

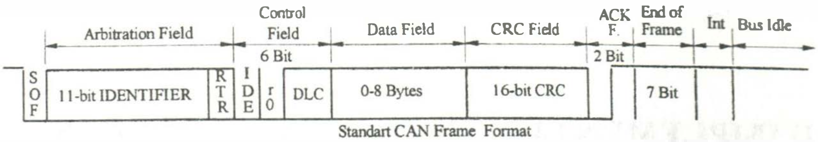


Figure 1. Standard CAN data frame format

II. DESIGN AND IMPLEMENTATION OF A CAN / CAN BRIDGE

A bridge is a device that interconnects LANs and allows stations connected to similar or dissimilar LANs to communicate as if both stations were on the same LAN [3,4]. This means that a bridge can be used to extend the size of a CAN in industrial environments and to provide a communication between the CAN and existing LANs (i.e., Ethernet or ATM). However, the characteristic of the CAN creates problems, when they are connected by a internetworking device, since its' messages do not contain any information related to destination address, source address, or LAN number that are used by traditional address-based bridges for routing decisions. Thus, a new bridge (suitable for the CAN protocol features) must be designed to extend the size of CAN systems or to provide communication between the CAN and other existing systems [5].

One of the important issues in the design of a CAN / CAN bridge is to choose the information that is used for routing decisions. The bridge to be designed should use appropriate information which is valid in the CAN protocol. It is proposed that the arbitration field of the CAN frame is used by the bridge for routing decisions. One other important issue to be considered in the bridge design is to solve the potential problems which arise when the bridge is used to interconnect systems. One example in our case is the acknowledge process of the CAN protocol. The proposed solution in the designed system is to set the related registers of CAN chips to appropriate values. A pass-through bridge design which provides a service to extend the size of CAN-based systems and a hardware proposal are presented in following.

The CAN / CAN bridge architecture can be modelled as shown in Figure 2. Assuming a two port bridge, the bridge consists of two network interfaces for CAN networks, two dedicated Arbitration Field Processing Unit (AFPU), a shared memory unit for the database (look-up table), and a central processing unit to provide necessary control functions.

The Central Processing Unit (CPU) should exhibit high performance to interpret frame relaying decisions from the AFPU and reschedule the received frames. The CAN Interface (CI) unit provides an interface between the bridge and the CAN systems. This unit performs no only CAN frame reception and transmission but also al other CAN protocol functions such as CRC processing The CI units comprise two integrated circuits; the firs is a microcontroller which performs the function involved and the second is a CAN chip that implement all of the CAN protocols. The AFPU is the heart of th bridge and it is responsible for generating fram relaying decisions. Detail of the bridge processes elements and the solution of the acknowledgeme process can be found in [6].

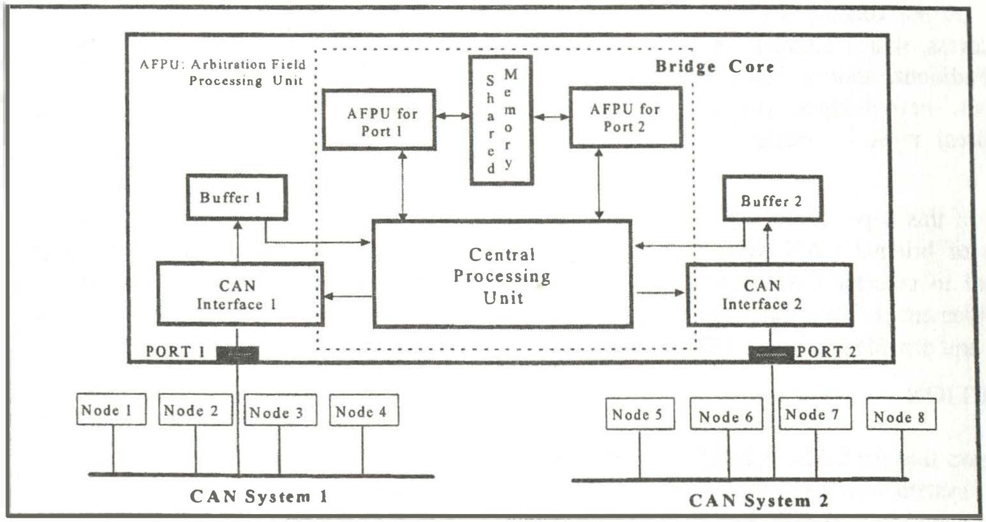


Figure 2. General block diagram of CAN / CAN Bridge and bridged CAN based networking system

2.1. The modelling environments and simulation results

A commercial simulation package that has been developed to model network systems and network devices was used to model the bridge shown in Figure 2. In the simulation, the simulation program models three processes, namely; bridge operation, bridge-CAN interconnection, and the transmission and reception of frames. It was assumed that a microprocessor, M68000, performs the bridge core processes. For simplicity the simulation model is based upon the following assumptions.

a) The features of the CAN evaluation board from I&Me products were chosen in the implementation to define the CAN interfaces [7].

b) The process times were measured as delays: receive frame and write buffer time, bridge core process time, and frame transmit or discard time.

c) The CAN system bus speed was chosen as 1Mbit/sec.

d) In the networking system (Figure 2), the message traffic was defined with various local message/remote message ratio as % 70/30, 60/40, 50/50, 30/70.

To obtain the performance of the designed CAN / CAN bridge, the system (Figure 2) was loaded with various local/remote message ratios. This model indicates that a CAN to CAN bridge overcomes the limitation (size of the CAN). The performance of the designed bridge was evaluated from the utilisation of the bridge and the bus systems (Figure 3) and the total processing time of the bridge (Figure 4) with different loads. The utilisation of the bridge elements and the CAN buses are less than 50 % utilisation when the load is about 5000 frame/second. This indicates that the designed bridge performance is adequate to interconnect the CAN segments. It can be concluded that the total process time of the bridge (two frame receive / transmit time) is acceptable for the CAN systems and the throughput of the designed bridge is satisfactory in the system.

In addition, in the bridge design, one of the most important parameters is the required buffer size. Although the required buffer size changes depending upon the message traffic, the designed system gives a general idea about the required buffer size. The size of buffer, in the worst case, must be minimum 5*108 bits in the designed system (Figure 4). This means that there are 5 frames in the queue in the worst case.

In summary, the designed bridge has fulfilled the objectives and it overcomes the limitations mentioned in the previous sections. Both parameters, delay and throughput which are related to the performance of the bridge, are satisfactory. However, the designed bridge can connect only CAN systems. But, the communication between CAN and Ethernet or ATM systems is going to be a reality in the near future.

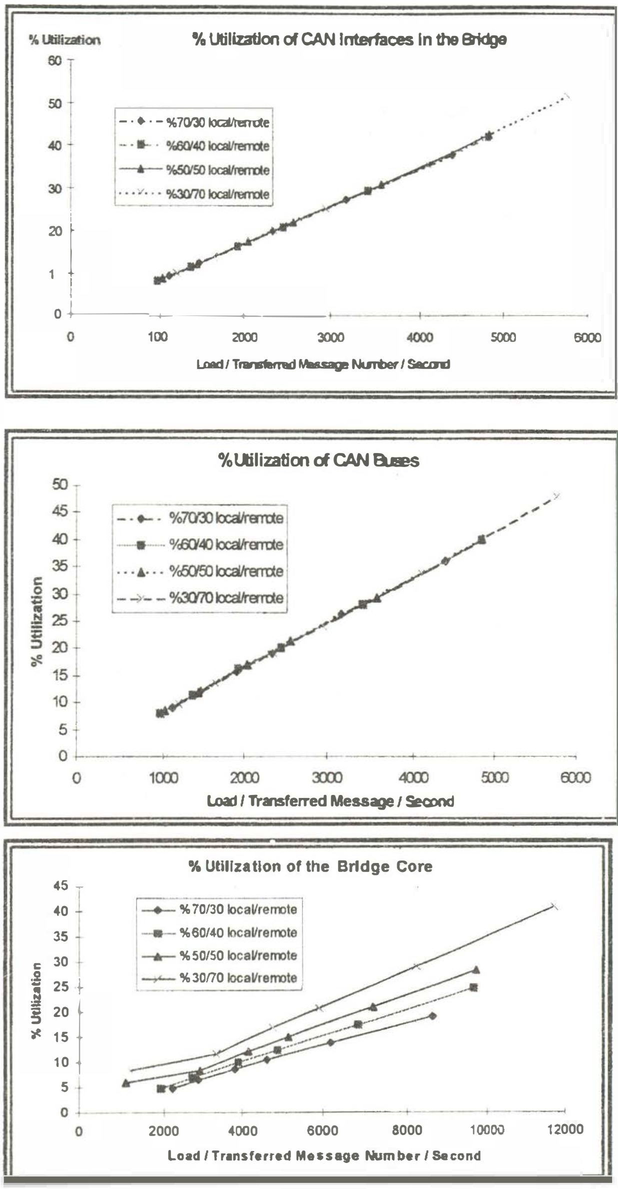
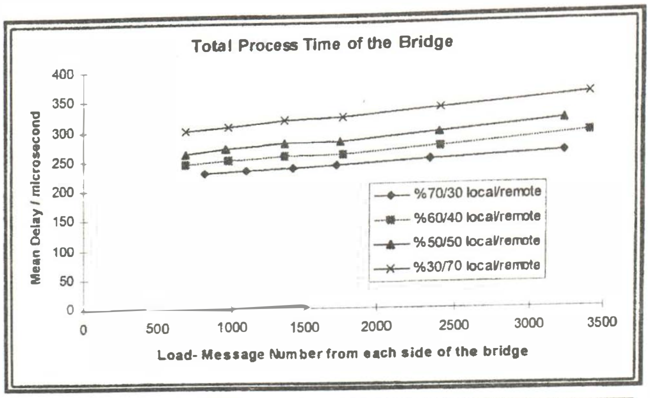


Figure 3. Utilisation of the designed bridge elements and CAN buses



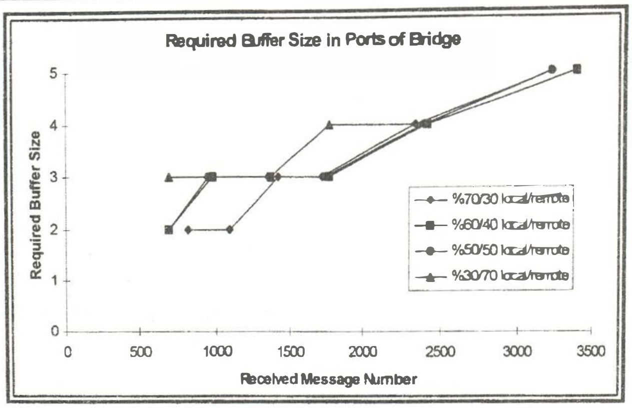


Figure 4. Total processing times of the bridge and required buffers size

III- DESIGN AND IMPLEMENTATION OF A CAN / ETHERNET BRIDGE

When a new network protocol becomes popular in the short term, one of the subjects to study is the communication between the new system and existing systems. While the CAN is used in the manufacturing unit of an industrial plant, the Ethernet may be employed by another department. In this case, it is necessity to use a bridge which is capable of connecting the CAN and Ethernet networks. The bridge should provide services to translate dissimilar frame formats and to communicate different data link layer protocols.

The proposed solution for the connection of CAN and Ethernet systems is to use a translation bridge. A translation bridge connects LANs which use dissimilar frame formats and different data link layer protocols. A CAN / Ethernet translating bridge design and a hardware proposal for the designed system are presented below.

Both the CAN and the Ethernet systems have different frame formats (Figure 1 and 5) and practise different Medium Access Control (MAC) mechanisms and routing algorithms. For routing, the CAN uses the selection mechanism (algorithm) and the Ethernet practises the address routing mechanism. As the MAC mechanism, the CAN protocol uses the Collision Sense Multiple Access / Collision Resolution (CSMA/CR), whilst Collision Sense Multiple Access / Collision Dedection (CSMA/CD) is used by the Ethernet protocol.

The bridge contains the worst case translation that requires creation or loss of fields representing unmatched services. For example, the CAN supports priority but the Ethernet does not. In this case, the translation process loses the priority. When forwarding in the opposite direction, the bridge must insert the priority. Another incompatibility is in frame sizes. The Ethernet supports a larger frame size than the CAN. Therefore, translation requires the adding or removing of padding.

The structure of the bridge may be different from the implementation point of view. However, in general, the processes which should be performed on the frames and the desired services in a CAN / Ethernet bridge will be the same. The number of bridge elements, their domain of operations, and their relations to each other should be such that they are able to perform the processes required and provide the necessary services. The detail of the required services and design principle of the bridge can be found in [8].

4.1. The modelling environment and simulation results

In the implementation of the system, the bridge elements, the CAN network, and the Ethernet LAN were modelled. For simplicity, the simulation model for each system and each bridge entity is based on the following assumptions.

i-The CAN and the Ethernet systems: In the implementation of the CAN system and the CAN Interface Entity, the CAN board features from the I&Me product were used [7]. The IEEE 802.3 standard (10BASE-5) is used to model all the Ethernet features.

ii-The CAN / Ethernet Learning and Filtering Entities : The learning and filtering processes of each port of the bridge is done in parallel by each 'Learning and Filtering Entity'. A M68000 microprocessor with its peripherals is used to implement each of the Learning and Filtering Entities.

iii-The CEFE and ECFE modules: Each of the these entities comprises two parts; a M68000 microprocessor based forwarding part and a memory. It is assumed that in order to manage the database tables of the CEFE and ECFE, Contents Addressable Data Managers (CADM) were used.

iv-The BME and Memory: A M68000 microprocessor with its peripherals was used to model the BME. The Sony product memory features were chosen for memory to build up the database tables.

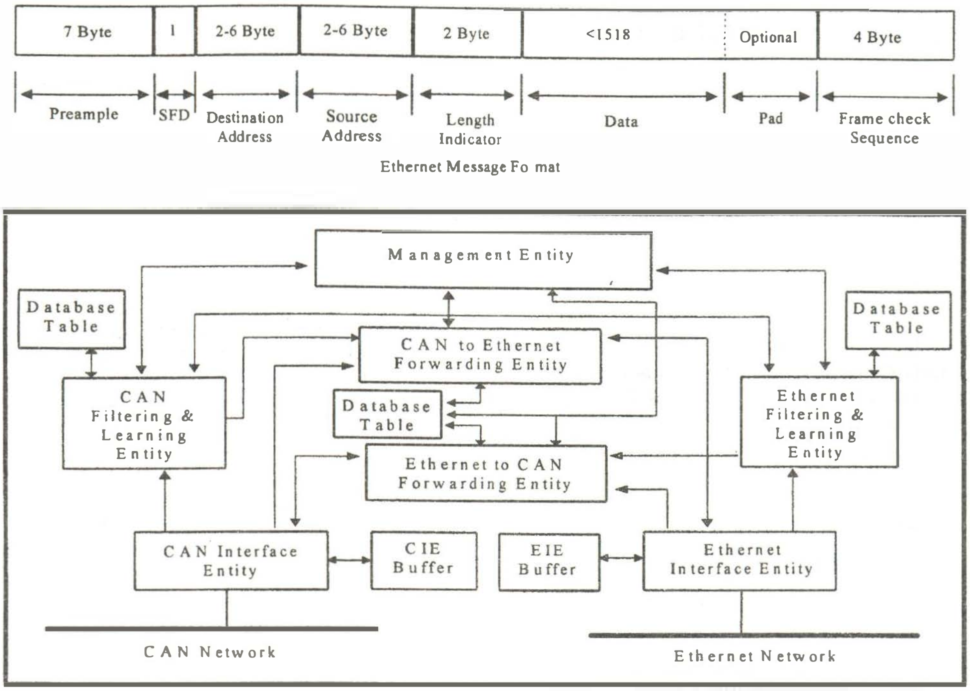


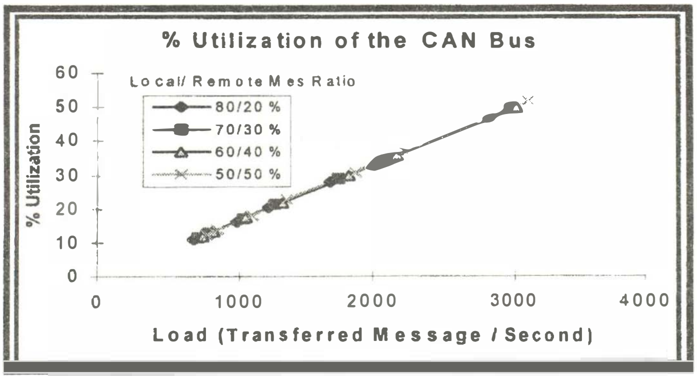
Figure 5. Ethernet message and the functionality diagram of the CAN / Ethernet bridge

v- In the internetworking system, the message traffic was defined with various local message/remote message ratio as % 80/20, 70/30, 60/40, 50/50.

To obtain the performance of the designed bridge, the bridged system was loaded with various local/remote message ratios. The performance of the designed bridge was evaluated from the utilisation of the bus systems, mean message arrival time to the destination node, and the total processing time of the bridge with different loads.

From Figure 6, it is concluded that both the systems, CAN and Ethernet, can support message traffic up to 3000 message / second. This means that the message number on both sides should be less than 3000 messages / second to work under an appropriate bus utilisation (less than 50%). It can be deduced from the graph shown in Figure 7 that the message arrival time (from CAN to Ethernet) depends on the message priority. In the designed system, CN8 to EN8 messages have the highest priority, while CN1 to EN1 messages have the lowest priority.

The rate at which frames are processed and forwarded for transmission from one port to another is called the bridge forwarding rate. As can be seen in Figure 8, the bridge forwarding rate affects the process time of the messages only under heavy loads (more than 50 % bus utilisation) and at high remote message ratios. Both the total process time of the bridge and message arrival time, about 500 microseconds, are acceptable for an interconnected CAN system.



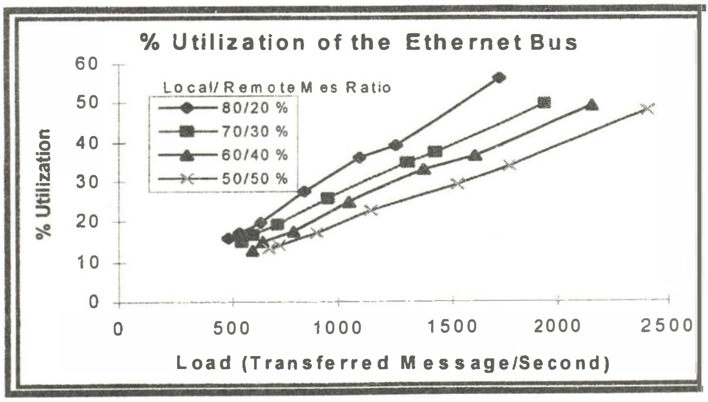


Figure 6. Utilisation of the buses with different message ratios in the proposed system

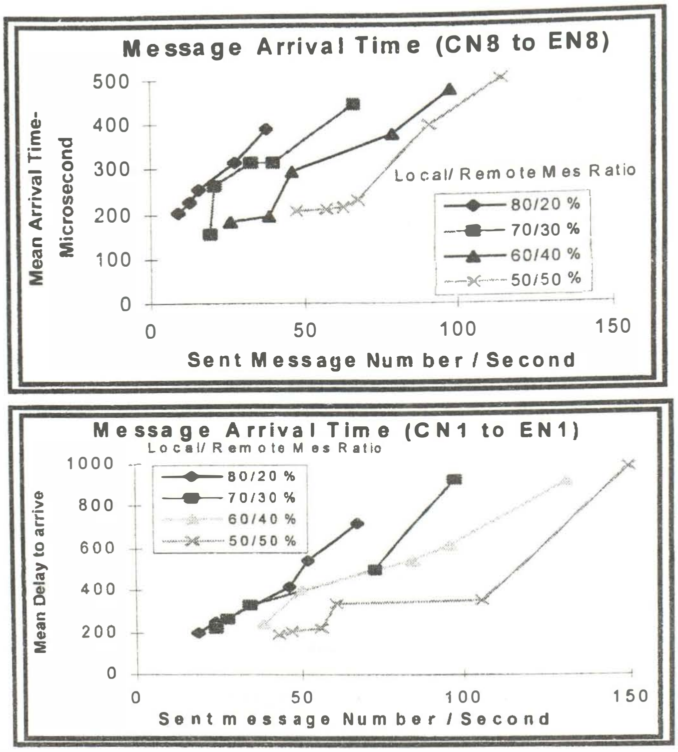


Figure 7. Mean message arrival time to destination node

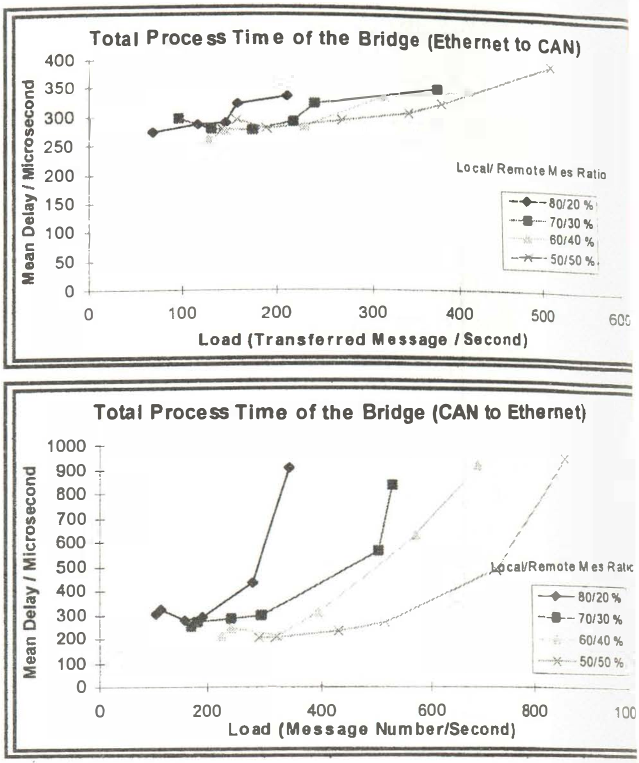


Figure 8. Total processing time in the both ports of the bridge

IV. DESIGN AND IMPLEMENTATION OF A CAN / ATM BRIDGE

The Controller Area Network (CAN) and Asynchronous Transfer Mode (ATM) are two very new communication protocols. Because of the diversity of their applications, the need to interconnect them is going to be a fact in the very near future. This part of the study is concerned with the design and implementation of a 'CAN / ATM Bridge'.

4.1. The CAN / ATM Bridge Implementation and Simulation Results

The CAN and the ATM LAN have different frame formats (Figure 1 and Figure 9) and practise different routing algorithms. For routing, the CAN uses the connectionless method while the ATM practises connection oriented routing mechanism. In addition, the CAN uses a shared bus with medium access control (MAC), while a star solution is preferred in ATM LANs. So, the internetworking device to be designed to connect two networks can be a two port 'CAN / ATM Bridge' which is capable of connecting a CAN and an ATM LAN. This bridge contains the worst case translation that requires creation or loss of fields representing unmatched services.

Figure 9 illustrates the proposed system architecture that connects the CAN and the ATM systems. In this system, the reformation from the CAN frame into the ATM cell format or vice versa is performed in three phases by the related entities:

i-Discard unnecessary parts,
ii-Modify invalid parts of frame,
iii-Add new parts.

It is proposed to use the AAL3/4 connection oriented transmission protocol for the communication in the ATM network. The MID field of the ATM cell is used as the arbitration field of the CAN frame. When a node wants to send a message to the CAN side, it puts the arbitration field value of the CAN frame into the MID field of the ATM cell. This results in that the proposed method will not need to use a database table for the incorporation of the arbitration field during the mapping process. It is also proposed that if destination of the ATM message is in the CAN side, that message can contain only one cell because of the CAN protocol features.

The general block diagram of the CAN / ATM Bridge is shown in Figure 10. Detail of the entities which are related to the CAN side and the solutions of the problems which arise during the interconnection of CAN systems can be found in [9]. In the implementation, the simulation program models three systems: the bridge elements, CAN network, and the ATM LAN.

As seen in Figure 9, the CAN / ATM bridge not only provides a service to interconnect a CAN system and an ATM LAN but also performs all the required functions for the communication between end systems. The performance of the designed bridge was evaluated from the utilisation of the CAN and the ATM sides of bridge elements and total processing time of the bridge (Figure 11) with different loads.

From the figures, it is concluded that both sides of the bridge and both systems supports message traffic up to 50% utilisation of the CAN bus. The utilisation of the ATM side bridge elements are lower than that of the CAN side and the system can support message traffic up to 6000 messages / sec on the CAN side and up to 10000 messages/sec on the ATM side. Beyond this number of messages, the performance of the CAN side bridge elements can be influenced by an increase in the load.

As can be seen in Figure 11, the bridge forwarding rate affects the process time of the messages only with a load of more than 1500 messages per second in the ATM to CAN process. This amount of message traffic is satisfactory in the CAN / ATM connection.

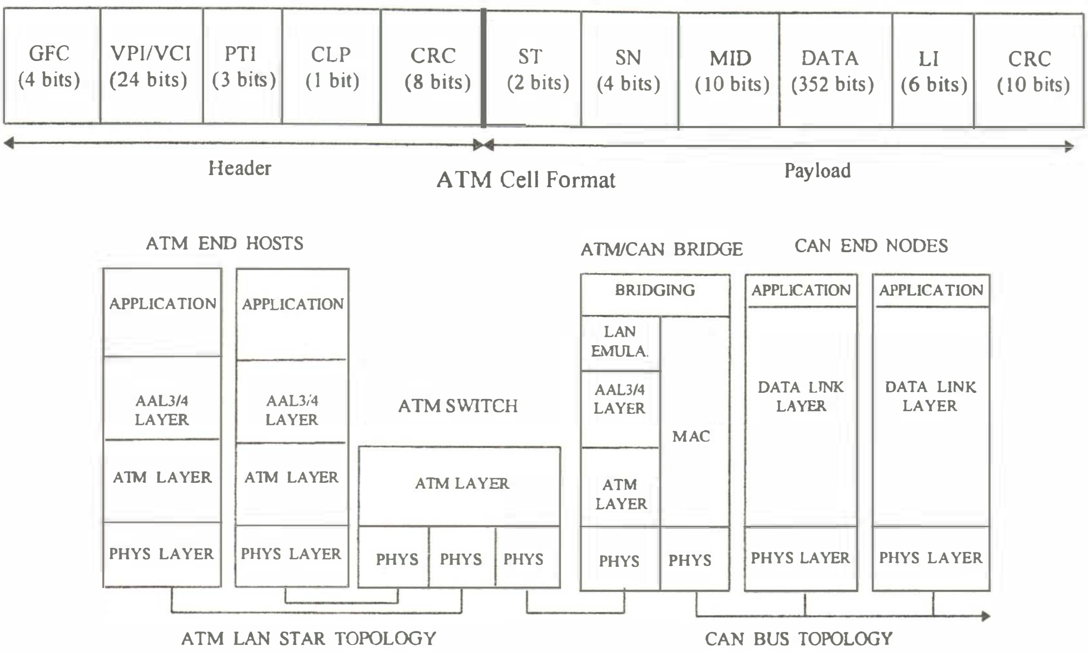


Figure 9. ATM cell structure and the layered architecture of the CAN / ATM bridge

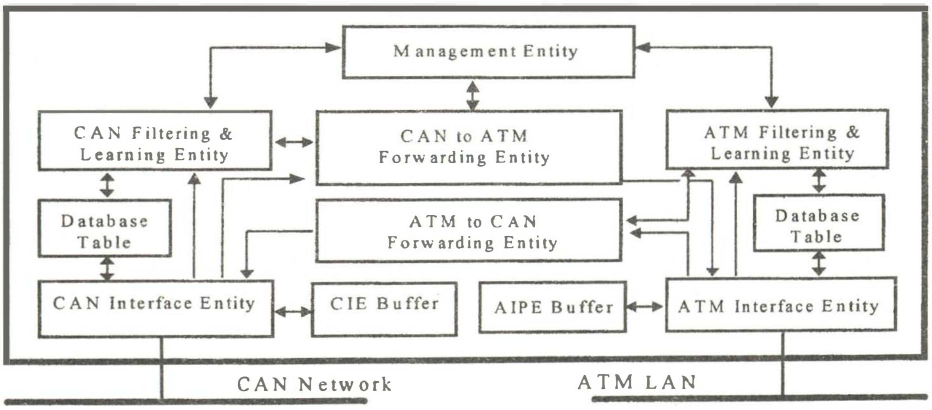


Figure 10. The functionality block diagram of the CAN / ATM bridge

Conclusion

A bridge must provide a selective frame retransmission function and interface operation which allows communication between dissimilar systems. The objective of this research has been the design and implementation of bridges which provide services that achieve the interconnection of CAN segments or interconnection of Ethernet / ATM systems.

First, bridged CAN topologies were investigated to find the appropriate solution to extend the size of the CAN based systems in industrial environments. The results were implied that bridged topologies can be applied to CAN based controlling systems in distributed environments. Second, a bridge that provides a selective frame retransmission function in the interconnected CAN system was designed and implemented. The designed bridge has fulfilled the objectives and it overcomes the limitation of the distributed area size. It is concluded that the parameters, delay and throughput which are related to the performance of the bridge, are satisfactory. Third, design and implementation of a bridge which provides a service that achieves the interconnection of CAN and Ethernet was presented. The bridge provides an adequate service between the CAN and the Ethernet system. It has been shown that the parameters, processing time, retransmission delay, and required buffer size which are related to the performance of the bridge, are satisfactory in meeting the overall requirements.

Finally, a CAN / ATM bridge proposal was presented and general characteristic of the proposed bridge were investigated. It is concluded that the parameters, process time, utilisation of the bridge elements, and required buffer size which are related to the performance of the bridge are satisfactory in meeting the overall requirements.

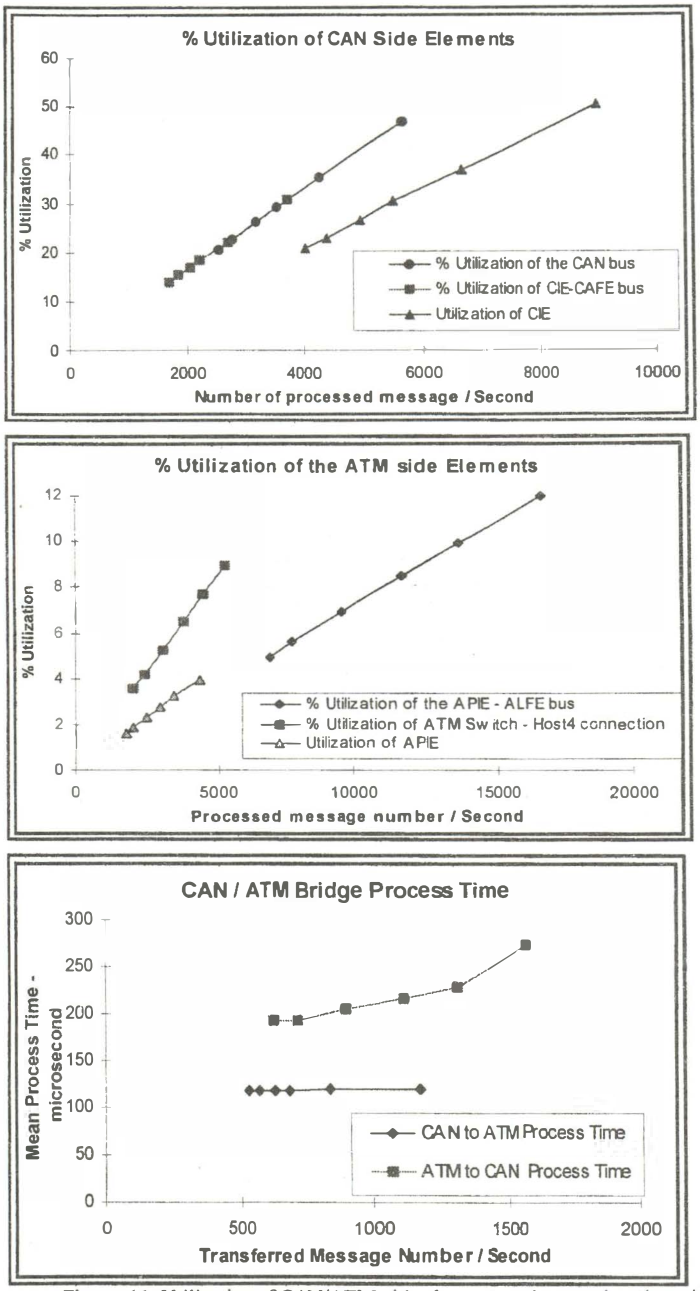


Figure 11. Utilisation of CAN/ATM side elements and processing times in the CAN / ATM Bridge

References

[1] Mclauglin R., 'CAN Controlling from cars to X-rays', IEE Networking May 95, UK.

[2]. 'Controller Area Network (CAN), LAN in vehicle communication protocol', SAE J1583 March 1990, SEA Information Report, pp. 20. 226-248

[3]. Hawe, B., Kirby, A., 'Transparent Interconnection of Local Area Network with bridges', Telecommunication Network vol. 3, no 2, 1984, pp 116-130.

[4]. Halsall F, 'Data communication, computer networks, open systems', Addison-Wesley Pub. 1996, USA,

[5]. Ekiz H., Kutlu A., Powner ET., 'Performance Analysis of CAN in Bridged Systems', Procceding of II Communication Symposium, Manchester, June 1995.

[6] Ekiz H., Kutlu A., Powner ET., 'Performance Analysis of a CAN / CAN Bridge', Proceedings of IEEE ICNP'96 Conference, 29 October-1 November 1996, Ohio, USA, pp. 181-188

[7] BCAN Network Evaluation System with 80C552/80C196 CPU User Manual, I&Me, Germany, 1990.

[8]. H. Ekiz, A. Kutlu, M.D. Baba, E.T. Powner, 'Design and Implementation of a CAN / Ethernet Bridge', Proceedings of 3rd International CAN Conference, 1-2 October 1996, Paris, France, pp. 11/17-11/26

[9]. Ekiz H., E. Stipidis, Kutlu A., Powner ET., "Design and Implementation of a CAN / ATM LAN Bridge", Proceedings of Twelfth International Synposium on Computer and Information Sciences - ISCIS, pp., 27-29 October 1997, Antalya, Turkey