Internetworking Wireless Nodes to A Control Area Network

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ABSTRACT

This paper discusses the design and performance requirements for the interconnection of wireless nodes to a standard CAN bus environment. It is focused on the network architecture as a single centralised cell consisting of a central node and wireless terminals. The central node provides data communication between the CAN and the wireless network. It maintains a self-learning algorithm for the frame filtering and forwarding requirements. The Medium Access Control Protocol used for the wireless network is specifically designed for supporting prioritised frame transmission in the wireless channel. The prioritisation is accomplished by using different sequence numbers which are added to each individual frame based on the CAN identifier. The performance of the system is analysed and presented in terms of probability, delay and channel utilisation under various traffic conditions.

1. Introduction

In today's computer and communication technology, wireless communication systems have become a very attractive method of communicating voice, data and control information throughout factories, offices, etc. **Wireless Local Area Networks** (WLAN) are such an area of wireless communication systems to connect PCs, workstations and other new devices, using radio frequency or lightwave signals.

Wireless Communication, within the context of industrial applications, is an important issue for accessing the sensors and actuators through a wireless channel. More importantly, the question of interest is to operate in the broadcast mode, where any node that needs to receive the data from any other node within the coverage area of each other. In this paper, the "**Comb**" based wireless access method is implemented for the **Control Area Network** (CAN) which is a half duplex, serial data communication protocol for automotive and industrial applications. In this scheme, the transmitter node generates a binary sequence -known as a comb- before the actual frame to solve the contention situation. If the message has a higher priority, it is transmitted before any other messages without cancelling the transmission.

In the work of Philppe Morel *et al* [1] it was pointed that a wireless connection for all sensors and actuators was not a realistic objective if there is a possibility of building traditional wire connection. However, a group of CAN applications may require a wireless connection, where the use of a cable is not feasible. One main advantage of a wireless system is that it provides flexible location of wireless nodes.

There are several considerations in wireless network design: media choice, operating frequency, network topology, and access method [2]. The alternatives for each section can be chosen according to the user applications. For example, the channel access method in a wireless environment depends on the type of application which can be specifically characterised by the **connection type** (Point-to-point or multipoint) with or without a base station, the **information type** (time-based or non-time-based) and **delivery requirements** (real-time or non-real-time applications) [3]. Since a CAN system meets the requirements of *multimaster* and *real-time* applications necessary in an industrial environment, the wireless access method for the CAN system must support the same needs.

Carrier Sense Multiple Access (CSMA) protocols are the favourite choice for many applications because of their ability to operate in distributed environments with broadcasting mechanism. There are two major CSMA protocols: Carrier Sense Multiple Access with *Collision Avoidance* (CSMA/CA) and with *Collision Detection* (CSMA/CD). Both protocols sense the carrier signal on the channel before the transmission to avoid a collision with another message which is already in the channel. The difficulty is that the wireless medium access requires more time for carrier sensing than that of the wired medium access system [4].

The extensions CD and CA are the subject of the collision situation. In the CD, the node transmitting a message monitors the bus to detect whether there is a collision or not. The Collision Detection (CD) works well in the Ethernet networks. However, to transfer a message and monitor the channel simultaneously in a wireless environment is very difficult issue to implement. For instance, in real radio systems the receiver is often completely disconnected from the antenna during transmission, otherwise the power from the transmitter will burn it up. For this reason, there is a high disparity of power levels at the transmitter to received signal from other stations, and any attempt to hear the other stations will be drowned out by ones own transmitter. One possible solution to this problem is at the cost of an independent receiver.

The Collision Avoidance (CA) has been proposed for IEEE 802.11 wireless standard by Wim Diepstraten [5]. It uses a *four way handshake* procedure to minimise the collision. However there is still a probability of collision.

The main objective of the comb based wireless access is to allow transmission of frames without cancellation, even if there is a collision [6]. More details about this access method are given in section 3. The simulation of the protocol is presented in section 4 with the results in section 5. Finally section 6 concludes the paper.

2. WMAC protocol

In terms of implementation, the architecture of a wireless system mainly consists of two sections: Wireless CAN (WCAN) chip and Physical Layer (PHY). The physical layer of the system provides modulation and demodulation of the frames. The block diagram of the system is given in Figure 1.

Although medium access contention could be solved by using a bit-by-bit arbitration in a CAN system, it is very difficult to implement this access mechanism in a wireless channel because when two or more nodes try to access the medium on the same channel at the same time, the modulated signals can be destroyed by other nodes. To overcome this problem, the comb sequence can be used.

Most of the CAN's features can be applied to a WCAN system easily. However the main difficulty is to maintain the prioritised message delivery.

There has been a discussion of being able to provide the prioritisation of frames using a non-TDMA (Time Division Multiple Access) based Medium Access Control Protocol. In the CSMA/CA protocol, the prioritisation is accomplished by timing the interframe gap. In other words, the longer the channel is idle, the lower the priority of the frame [7]. Different priority levels have been implemented for different purposes. For example, for all immediate response actions, the short priority interframe space (SIFS) is defined as the highest priority. This can be applied to wireless CAN but if there are a large number of messages, lower priority messages will have to wait too long.

Node B Node C

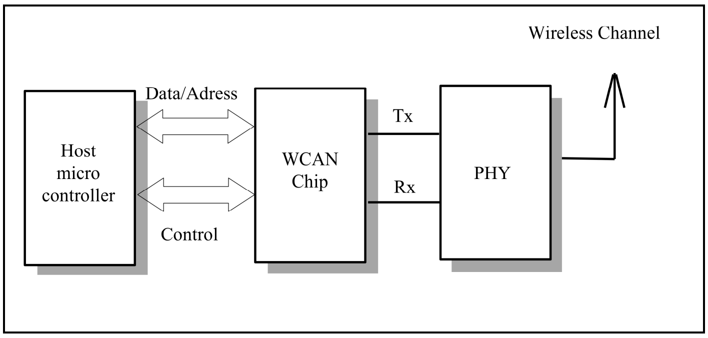

Figure 1 WCAN Block Diagram

In the comb system, a transmitter node first senses the channel to check whether there is a message on the channel or not. Assuming the channel is idle, it begins to generate a short binary sequence. At the same time, it sets the busy flag on the wireless CAN. This indicates that the message is being transferred but has not been delivered yet. Therefore, the user application program, running on the central host, cannot send a new message unless the busy flag becomes reset.

Binary sequences consists of binary 1 and binary 0 levels. For a binary 1 in the sequence the transmitter sends a short signal level to the channel, but for a binary 0 in the sequence it switches to the receive mode and senses the channel during the binary 0 period. These receive and transmit periods continue until the sequence number is complete. After that, the transmission of the main frame proceeds.

If there is more than one node that tries to transmit their messages, all the nodes in the contention must proceed to transmit the comb sequence. Since every message has a different sequence number, only one message at a time will be transmitted. Figure 2 shows the multiple access method.

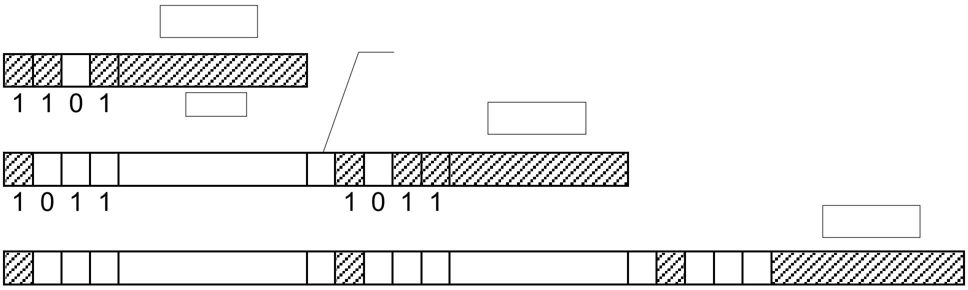

Figure 2 Wireless Access Method

In the example, Node A, B, and C are transmitting their messages with binary sequence numbers. Since the first bit of the sequence is binary 1 for all the nodes, they all in transmit mode and hence they all transmit a short signal during this period. After that, they go into the next sequence bit time. In the second event, Node B and C go into the receive mode because their next binary bit is 0. When node B and C sense the channel they hear the Node A's binary 1 signal and interpret that there is a higher priority message on the channel. Therefore, they drop out of contention and continue to receive the message on the channel. Node B and C defer transmissions until the next idle time and the protocol procedure steps on. This time, Node C drops out of the contention after the third sequence. When it checks the channel it senses the node B's transmission.

There might be a situation that disturbs the transmission of the frame on the channel. In as much as that, during the second bit sequence, another node which has just started to transmit a message, senses the channel and interprets that the channel is available for transmission. Because, both node B and C are in the receive mode and there is no carrier on the channel. To overcome this problem, each node in the network set their **busy flags** when the first bit of the sequence is received. Setting the busy flag will prevent other nodes from interfering with the transmission of the frame on the channel. Since the busy flag is set the node will not be able to send a message unless the busy flag is reset.

(The busy flag is reset when the message on the channel is completely received). Therefore the first bit of the sequence must be 1 for all messages.

The length of the comb is dependent on the number of messages existing on the network. It should be noted that all the messages must take different comb binary sequence numbers, otherwise there could be a conflict of transmission.

3. Interconnection

The term **Bridging** in the communication is referred to as interconnecting two or more similar or dissimilar local area networks [8]. As can be seen in Figure 3, the wireless terminals may access a radio bridge that is connected to a wired CAN. The bridge transparently forwards the frames either over the CAN or over the wireless channel. The term “transparent” is used to define the bridge operation. In this scheme, the bridge learns and detects the situation, then either discharges or forwards the frames [9]. There are number of different algorithms for bridge learning, filtering and forwarding. The wireless system uses its own algorithm similar to transparent LAN bridge algorithms.

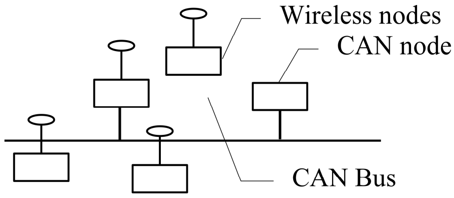

Figure 3 Interconnection

A radio bridge must know which frame is to be discharged or forwarded. In general, the frames received from the wireless terminals must be forwarded to the CAN bus if there is any node waiting for that frame. Rebroadcasting over the wireless channel is not necessary since all the members of the WCAN system also receives the message that has been received by the central node. In contrast, if the radio bridge receives the frames over the CAN, it broadcasts them only if the destination identifier is in the range of its coverage area. The bridge decides whether to forward or not to forward a frame by looking its **routing table**. The routing table is built up using **self-learning** process.

To initially built up a routing table, each wireless and CAN nodes must send at least one frame to the network when it is added to the network. If the bridge receives a frame over the wireless channel, It checks the routing table and if the identifier of the frame does not exist, it adds the identifier to the routing table. The frame, which is sent initially, informs the node, which sends the initial frame, will need to receive the same identical frames during the life of communication. If the Identifier is no longer in the range of a bridge the identifier of the frame is removed from the routing table to prevent unnecessary growth of the table.

Each frame received from the wireless channel, is stored in a buffer. If the destination identifier is found in the routing table, the frame is rebroadcast over the CAN. Otherwise, the frame is discharged. It should be noted that the frames used in this system includes the control information. For real-time delivery, the frame must be sent to the destination in time. Late delivery is not acceptable. Therefore, during the communication process, a node can create a frame before the previous frame is not delivered. Thus, Instead of transmitting the previous data, it is more convenient to overwrite it with new data. As a consequence, each frame received over the CAN or over the WCAN is compared with the previous stored frame in the buffers respectively. If they are the same identical frames, the frame which is currently received over the CAN or WCAN overwrites the previous one in its own buffer.

4. Simulation

The performance of the bridged system was investigated in a WCAN network modelling environment using commercial simulation software. There are two major methods of study on communication systems: Analytical solution and simulation. Because of its simplicity the simulation technique is used. This technique also allows the programmer to modify and reorganise the hardware and software components easily.

The simulation model consist of 3 wireless terminal transmitting messages over the wireless channel to the CAN via radio bridge, and 3 CAN nodes transmitting messages to wireless channel using the same radio bridge.

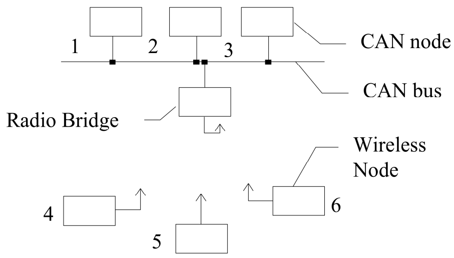

Figure 4 Simulation Model

Each node was programmed to operate the wireless access method with the following assumptions. The nodes were assumed to hear each other, and the messages were exponentially distributed with a mean of 200 to 1300 messages in 1/2 second. In this simulation, The behaviour of the transmission of messages with channel and bus utilisation was observed. Thus, the nodes are installed for broadcasting the messages, and the radio bridge is assumed to be able to forward all the messages that are received. Radio bridge delays are ignored and the bridge is assumed to be ideal.

The time for the propagation of a frame on the channel is one part of the delay time. The frame delay time is derived from the frame length (L_T) and the speed of the channel called baudrate (B). The frame length of the CAN protocol varies between 44 bits and 108 bits in the standard mode, 62 bits and 126 bits in the extended mode because of the usage of different lengths in the data field. In the simulation, all data packets were assumed to be 100 bits long.

$$t_T = \frac{L_T}{B}$$ $t_{T=}$ time for transmission of frame

The length of each binary sequence depends heavily on the physical layer characteristics. Each of them was assumed to be 20 microsecond having regard to the IEEE 802.11 carrier sense time. The length of the comb was chosen as 6 bits. The nodes can therefore handle 32 different message types (note that the first bit must be 1) and, hence, 32 priority levels. It is possible that the length of the comb could be more than that, if it is necessary.

The time requirement for the internal process and transmitting the last bit of the frame was assumed to be 20 microseconds. The simulation models a 1 Mbit/s transmission speed.
Calculation of the delay in the case of busy channel is complicated because the messages were exponentially distributed. This means that after the busy situation, the transmitter node waits until the next idle time. During this time, another node may attempt to access the channel with a higher priority message. in that case, lower priority message will be deferred again. Depending on the number of messages generated, lower priority messages may not be able to access the channel. These situations were observed and reported in the next section.

5. Simulation Results

Figure 5 shows the required maximum time for broadcasting the frames to destinations. Average values of these propagation times are shown in Figure 6. In fact, Figure 5 and 6 show the result of the implementation of message priority. Figure 7 shows the successful transmissions. The numbers from 1 to 6 in the graphics represent the priorities (1 is the highest priority).

The simulation results show that a low priority will cause a long delay for a message at high load. In other words, higher priority messages will get access the channel with short delays as can be seen in Figure 5. In the case of a high message transmission (load), most of the lower priority messages do not access the channel within the given simulation time. When the load is increased, the probability of the message delivery time decreases depending on the message priority.

The probability shows the successful transmissions and that can be calculated as:
Probability = Transmitted message /Requested message

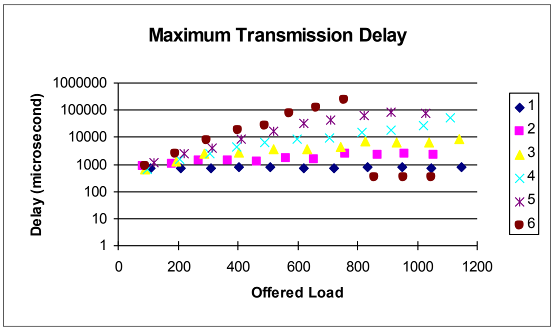

Figure 5 Max. Delay times

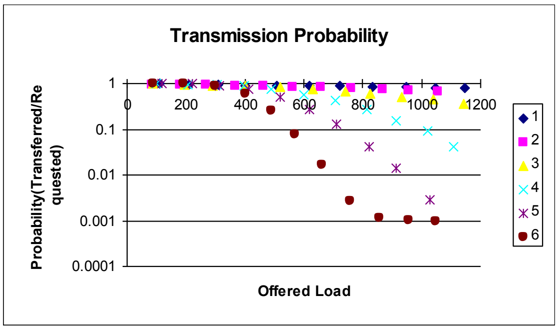

Figure 7 WCAN Successful transmissions(Probability)

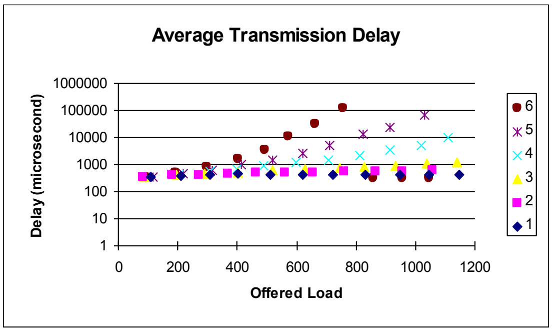

Figure 6 Average delay times

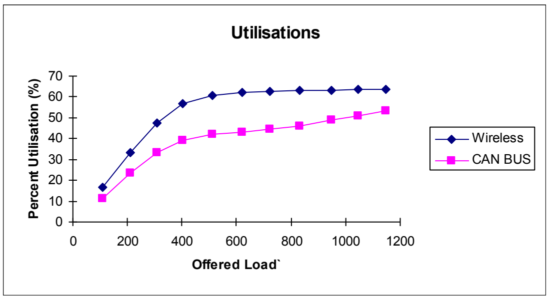

Figure 8 Utilisation

In the figures, after 800 message load, level of message sharply decreases!. This is not because of the protocol operation, it is because of the distribution of message. The simulation program generates random numbers including the firstly generation of message 6.

In this work, the Utilisation is defined as the average fraction of time in which a channel is occupied. It is expressed as a percentage value. As can be seen in Figure 8, the channel utilisation of WCAN is stable approaching to the % 65 level. It might be expected that the utilisation of the WCAN should have been higher than that. The reason why it is not, is that it varies according to the comb value because the binary 0 is operated as the receive mode and there is no transmission. This reduces the utilisation. There is another factor that influence utilisation: The cancellation of frames. (Note that bus utilisation is lower than that of wireless because the CAN bus does not use comb sequence).

6. Conclusion

In this paper, the implementation of the Interconnection of CAN to WCAN network has been presented. Comb based wireless access method is shown that it supports prioritisation of the messages in broadcast mode. The prioritisation can be implemented on the both sides of the radio bridge (CAN and Wireless). If the bridge receives a message with higher priority, it sends that message before any other messages with lower priority. The Messages with higher priority always get channel access while some of the messages with lower priority may not be able to access the channel.

It should be noted that although simulation has been done according to simulation parameters, the protocol can be used at different baudrates. Changing these values will only affect message delays and probability.

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