Chapter 1
Introduction

The Control Area Networks (CAN) are widely used in real-time, distributed and parallel processing systems like manufacturing plants, networking fields, humanoid robots, etc., Robert Bosch GmbH (1991). In recent times with the advent of wireless technologies it is useful to extend the usage of CAN to applications where wireless conditions are encountered and preferred. This modified CAN for the use in wireless environment is modelled as Wireless CAN (WCAN). There are many practical applications like the moving arm of an industrial robot in a production line where CAN messages need to be transmitted over short distances while cable connections are either impossible or unwanted. It is preferable and convenient if the sensors and activators in this system communicate to their environment through WCAN. By this they continue the exchange of CAN frames while the inconvenience of a cable connection between the moving and fixed parts of this system is avoided. The wireless approach is often a good solution to access mobile and moving CAN fieldbus systems. Bluetooth Wireless Technology is a good candidate for short-range wireless communications using RF links. Radio techniques such as ZigBee, Wibree can be used when the data rate requirements are not so high. Ultra wideband (UWB) technology can be used when the amount of data is high, very fast links need to be established or transmission power needs to be limited. UWB with its sub-nanosecond pulses also has high localization accuracy due to the high time domain resolution.

This thesis is presented as two parts; one is simulation and response time analysis of WCAN using token scheme; and the other is real time implementation of WCAN using ZigBee protocol and response time analysis of the implemented WCAN based Fire and Gas safety system. The WCAN using token scheme adopted for simulation in this research is based on wireless token ring protocol (WTRP) as proposed by Lun et al. (2012). WCAN using token scheme is a MAC (medium access control) protocol for wireless networks to reduce the number of retransmissions due to collision and also has the wired CAN attribute on message based communication. This WCAN uses token frame method to provide channel access to the nodes in the system. In this method the token frame is circulating within the network for specified amount of time and all the nodes share a common broadcast channel by taking turns in transmitting the
message upon receiving the token. By this method high throughput in bounded latency environment, consistent and predictable delays and good packet delivery ratio are achieved.

Researchers have developed response time analysis to bound CAN message latencies under arbitrary error rate assumptions, Davis *et al.* (2007), in related researches CAN messages are allowed to be periodic or sporadic with less restrictions on deadlines, Tindell *et al.* (1994). A message is said to be schedulable if and only if its worst-case response time is less than or equal to its deadline ($R_m \leq D_m$). The system is schedulable if and only if all of the messages in the system are schedulable. Worst-case response-times (WCRT) introduce pessimism in analysis, resulting in over designing and under utilization of resources, Philip *et al.* (2012). Stochastic response-times provide the probability of meeting/missing any specified response-time limit; this probability is useful for system reliability and performance modelling. The probabilistic approach extends the knowledge of the system by computing how often a deadline is violated. If this measure is acceptable, the system is guaranteed and can be put to use instead of discarding the system based on worst case response times. In applications where even single deadline miss is not accepted, the worst case response times can be considered, Kyung and Hong (2004).

In this research work the WCAN proposed by Lun *et al.* (2012) is revisited, modeled and simulated using QualNet v5.1, its throughput, average end to end delay and packet delivery ratio (PDR) for constant bit rate traffic (CBR) and variable bit rate traffic (VBR) are calculated and compared with IEEE 802.11. In safety critical applications, response time analysis is more essential than performance analysis, Tindell *et al.* (1994), which is lacking in this related work, hence this research work is on the response time analysis for messages in wireless CAN. Constant bit rate messages (CBR) are classified as periodic messages and variable bit rate messages (VBR) are classified as sporadic messages. A simple attempt at executing the problem on WCAN is to map each of these messages to SAE (society of automotive engineers) benchmark for class C automotive systems for safety critical control applications. The SAE benchmark, although specified within the context of automotive industry, is an interesting option, since it allows the comparative analysis of the proposed methodology with previously available results. The calculated message latencies are applied to an SAE ‘benchmark’ and the analysis is extended for the WCAN to deal with some fault tolerance issues.

Encouraged by the simulation results of WCAN and its response time analysis for safety critical control applications, the wireless implementations of CAN is carried out using Freescale
PowerPC MPC5567 with CAN interface, CAN messages are exchanged wirelessly using ZigBee modules, which are based on the radio protocol IEEE 802.15.4. The details of the ZigBee specifications are available in ZigBee Alliance (2006), ZigBee Specifications, version 1.0 r13. Paolo et al. (2007), Zheng and Lee (2004) and Callaway et al. (2002) presents a survey on the IEEE 802.15.4 and ZigBee Standards. Wireless implementation of CAN based applications is required whenever wires become inconvenient or not possible. A typical application like Fire and Gas safety system is identified for illustration of WCAN implementation; as such systems are employed in hazardous environments, avoiding wires becomes essential.

Advantages of WCAN based Fire and Gas safety systems when compared to conventional analog systems are that

- As the control node checks the state of each fire and gas detector periodically, a breakdown in the system such as the failure of a fire detector or an open circuit in the transmission medium is recognized by the control node.

- In addition, as the control node takes the decision based on the received sensed data, the number of false alarms is less than with conventional systems.

- Further as these systems are employed in hazardous environments, a wireless implementation of the CAN based Fire and Gas safety system is more suitable and can be deployed. In a wireless CAN there is no need for a cable connection, which is an advantage in hazardous environments.

Replacing existing CAN based Fire and Gas safety system with wireless CAN based Fire and Gas safety system is proposed in this thesis. The implemented WCAN based Fire and Gas safety system is made up of control node, sensing nodes and actuator nodes as shown in Figure 1.1. ZigBee modules are used to transfer the CAN messages wirelessly. The WCRT analysis of the WCAN based Fire and Gas safety system is carried out using CANoe v7.6. The results of the implementation are validated with the National fire protection association (NFPA) regulation of maximum allowable latency of 90s.
The summary of other chapters in this thesis: Chapter 2 presents the literature review of protocols like CAN, WCAN, ZigBee used in this thesis and also the literature review of Response Time Analysis for messages in CAN along with wired CAN based Fire and Gas safety systems. Chapter 3 discusses the methodology followed for both simulation and implementation of the research work. Chapter 4 presents the simulation and response time analysis of wireless controller area network using token scheme. Chapter 5 presents the implementation and response time analysis of wireless controller area network based Fire and Gas safety system. Chapter 6 presents the results from simulation of WCAN using token scheme and the response time analysis of WCAN using token scheme, it also includes the results and analysis from the implementation of WCAN based Fire and Gas safety system with highlights of time analysis of ZigBee modules. From both simulation results and implementation results, it is concluded in Chapter 7 that the proposed wireless controller area network is guaranteed for real time applications.