Chapter 1

Cyber Physical Systems

1.1 INTRODUCTION

In Cyber Physical Systems (Lee, 2006; Shi et al., 2011; Wu et al., 2011) the term cyber (Lee, 2006; Shi et al., 2011) defines the systems that are used for performing some actions while the term physical (Lee, 2006; Shi et al., 2011) denotes the devices that are designed by human. CPS (Lee, 2006; Shi et al., 2011) indicates the incorporation of both these features into a single governing body. CPS (Lee, 2006; Shi et al., 2011) actually acts as a controlling system over networked workstations to send out instructions for various activities. Consequently CPS gets response regarding these events. CPSs (Lee, 2006; Shi et al., 2011) are able to interact with an arrangement of systems through the Internet while perceiving activities of physical events. Moreover in any CPS application (Lee, 2006; Shi et al., 2011), it has the capability of managing unpredictable circumstances in its environment when various network elements are involved. Besides, there is a higher probability of having complexity while accessing any channel.

Figure 1.1 CPS Communication Scenario
In the figure 1.1 cyber (Lee, 2006; Shi et al., 2011) means computing instructions and physical (Lee, 2006; Shi et al., 2011) means performing some actions according to the instructions received. System means sending the responses to the server for further activities. The said process is carried out in a closed wireless loop to show how the world is connected with the Internet to perform some actions. Moreover Cyber Physical Systems are also called as smart systems. Cyber Physical System (Lee, 2006; Shi et al., 2011) actually comprised of sensor and actuator devices. In other words it has sensor cum actuator built devices for analysing and performing actions at an appropriate time. Thus CPS is a combination of various wireless networks of heterogenous type.

1.2 FEATURES OF CPS

In the year 2006, National Science Foundation (NSF) (Lee, 2006; Shi et al., 2011) group identified cyber physical system as an important area for research. In the year 2007, this NSF (Lee, 2006; Shi et al., 2011) group declared CPS as a novel embedded reserch area for those researchers who want to solve the challenges that are related not only to software but also with the hardware. CPS (Lee, 2006; Shi et al., 2011) is a wireless system that comprises of sensors and actuators that are connected with hardware devices through Internet. Either sensors or sensor cum actuators sense the information and send instructions to hardware devices which perform appropriate processes.

In figure 1.2 it is shown that sensors as well as sensor cum actuator devices are interacting with the controller through any wireless network. In other words cyber physical system is different from traditional way of computing. So it cannot be considered as hardware or software system separately. CPS provides a way for an improvement in the emerging technologies. To do CPS has the following characteristics that enable it to function differently from other wireless networks or today’s sensor based networks. As given in Wang et al., 2010, some of the features of CPS are explained below.

a. Incorporated strictly: In CPS physical entities are strongly correlated with the computational procedures to perform some actions.
b. Involvement of cyber interference in physical entity with less resource: Since CPS is a combination of hardware and software components, the use of resources like system bandwidth, operational capabilities are less.

c. Combination of various networks: CPS is a heterogeneous type of wireless network with various levels of communication mediums.

d. Difficulty range of various time-based measures: The CPS mechanisms are capable of controlling the actions that occur timely or sequentially.

e. Dynamic construction of system: As CPS is a complex computing system it is capable of organizing the system by itself.

f. Closed loop structure: CPS get responses from the physical entities for further corrective process through computational devices.

g. Reliable and safe system: CPS provides safety and consistency while it is performing activities at higher levels.

h. Combination of cyber and physical activities: CPSs are meant for processing automated activities according to the instructions given.

Figure 1.2 CPS Overview
1.3 FUNCTIONALITY OF CPS

Though CPS (Lee, 2006; Shi et al., 2011) is not widely considered as research area, it play a major role in handling critical or emergency situations. CPS (Lee, 2006; Shi et al., 2011) has the functionality of sensing, receiving instructions, computing and performing actions. To perform the processes at a particular time or in an inaccessible locations CPSs (Lee, 2006; Shi et al., 2011) should be effective and well-designed with the help of other distributed systems. These distributed systems are of subsystems which had been configured from the hardware and software elements.

Cyber physical system (Lee, 2006; Shi et al., 2011) has given a new identity to this digitized world. Nowadays the digital communication is converted as smart communication globally. The communication through smart devices had made human life more comfortable. This is due to the multi-facted of CPSs (Lee, 2006; Shi et al., 2011) that include characteristics of hardware related time based systems. Moreover CPSs (Lee, 2006; Shi et al., 2011) combine various activities of physical entities with the computational procedures to have an effective transmission in a wireless network.

According to (Baheti and Gill, 2011) CPS combine the design and development (Baheti and Gill, 2011) approaches of engineering and science techniques such as computational theory, automated learning, biomedical methods and decision-making control approaches. The following diagram (Figure 1.3) shows how CPS (Baheti and Gill, 2011) performs any action according to the commands received from the physical devices involved in the network. In (Wang et al., 2010) the functionality of CPS (Baheti and Gill, 2011) is explained through four steps such as Monitor, Communicate, Compute and Actuate shown in figure 1.3.

a) Monitor: This initial step helps the system to observe the changes that occur in the CPS (Lee, 2007) based application. It also gives feedback based on the previous action happened and ensures that the whole system processes perfectly. DC means the data collected from the sensors forwarded for communication.

b) Communicate: In this phase data is retrieved from the sensor devices which are to be circulated to the various elements of the CPS (Lee, 2007) based wireless network. The data ready for process is executed through different methodologies to send physical data to the next phase. DA means data
gathering which is to be obtained from the wireless network and used for further computation.

Figure 1.3 Functionality of CPS

c) Compute: In this phase it checks for the appropriate action to happen based on the physical data received from wireless network. According to the instructions if the data had not been communicated then it calculates and sends valid instructions for further event occurrence which is denoted as VC in figure 1.3.

d) Actuate: On receiving effective commands the corresponding events are performed by satisfying the pre-defined conditions. Once the instructions are performed successfully it will deliver the control instructions as a result to the initial phase of this closed loop process. The control instructions are denoted as CC in the above figure.

In the figure 1.3, it is shown that CPS (Lee, 2006) performs a task according to the instructions received from the sensor devices and executes those commands to achieve appropriate action. Once the event occurs it will send response to the sensor device to confirm that process had been executed. If process had not been executed at correct time it will modify and send instructions to rectify the error occurred. So CPS
functions in a closed loop to make sure that the corresponding process gets executed efficiently.

This type of closed structure process is applied in the field of tele-medicine and vehicle monitoring in emergency situations. As science technology is improving with the help of effective complicated tools and methodologies, CPS (Lee, 2006) is also playing an important role in developing the future technologies. So the above said closed structure process is considered as a key factor in designing sensor cum actuator based systems for effective wireless transmission.

1.4 APPLICATIONS OF CYBER PHYSICAL SYSTEMS

Cyber Physical System (Baheti and Gill, 2011) as mentioned, acts as a governing system over networked computers to send out instructions for various processes. As a result, the CPS (Baheti and Gill, 2011) also gets back results regarding how processes work. Cyber Physical System (Lee, 2009) is used in various areas of control and design (Dragomirescu, 2010) to make the processes automated. CPS (Cheng, 2008) is mainly used in medical departments (Cheng, 2008) and army fields (Dragomirescu, 2010) for providing automated process where human cannot perform efficiently. Following are some of the application areas in which CPS (Gunes et al., 2014) is considered as essential because it comprises of sensor cum actuator devices.

1.4.1 HOME BASED APPLICATIONS

In smart houses (Kaur et al., 2013), sensor cum actuator based devices are installed to monitor and control the activities of electrical and mechanical devices. All these devices are interlinked with the Internet to inform about the consequences that occur in emergency situations. At the same time, according to the instructions programmed, these devices manage the critical situation to put under control.

a) There are certain smart home devices such as wheel chair movement control, arm control etc. helpful for the elderly people to manage themselves in critical conditions like falling from chair or handling any tools.

b) In smart homes CPSs (Lee, 2006) are used as surveillance devices to identify the intrusion of unauthorized persons as well as unexpected fire accidents.
c) CPS (Lee, 2006) performs successfully in a satellite based applications like predicting weather conditions and management of disasters that occur accidently or naturally.

1.4.2 MEDICAL BASED APPLICATIONS

Medical CPS (Cheng, 2008) is a leading CPS (Lee, 2008) based application design which provides most promising facilities in the field of medical science. Medical CPS (Cheng, 2008) come along with Body Area Networks (BANs) (Cao et al., 2009) to control the conditions of patients in hospitals.

a) Medical CPS (Lee and Sokolsky, 2010) is used in surgery room where robots perform some complicated operations. These robots are remote controlled devices handled by medical experts.

b) In the emergency and critical units of hospitals the patients are attached by wearable devices which monitor the patients pulse rate and blood pressure levels with the help of BAN (Cao et al., 2009).

c) Medical CPS (Cheng, 2008; Lee and Sokolsky, 2010) is also helpful in providing tele-medicine services to the patients who are in the unreachable remote places where medical facilities are very less.

d) During accident situations medical CPS (Lee and Sokolsky, 2010) connected with wireless networks suggest first-aid services along with the medicines to be given to the injured people.

1.4.3 OTHER APPLICATIONS

a) CPS (Lee, 2007) involved devices are deployed in the road ways to record the probability of traffic congestion and provide solutions to clear the way for the vehicles to avoid more accidents.

b) In war fields robots with sensors are directed to clear the obstacles and also to identify the locations of mining elements where human cannot intrude.

c) In automobile industry (Dragomirescu, 2010) to automate the process of vehicle functioning like controlling the speed of a vehicle. If it exceeds certain speed limit then sensor cum actuator based devices installed in these vehicles control the speed.
d) In agricultural research laboratories devices with CPS (Lee, 2007) properties are used to monitor the growth of plants. These devices send instructions to the wireless network periodically about the growth scale of plants to avoid decomposing.

In addition to above mentioned applications, CPS (Lee, 2008) identifies error occurrence in power electronic (Karnouskos, 2011) industries. In disaster management and land slide areas CPS (Li et al., 2009) involvement assists the scientists to predict the future happenings to minimize the human loss. CPS (Lee, 2009) plays a major role in aeronautic systems (Dragomirescu, 2010) for testing automic elements and findings of satellite communications (Dragomirescu, 2010). In electronics appliances like airconditioning (Dragomirescu, 2010) devices, CPS (Lee, 2009) acts as a controller to manage the cooling process according to room temperature. Also, CPS (Lee, 2009) with Global Positioning System (GPS) (Wan et al., 2013) provides appropriate routing information to locate unmanned (Wan et al., 2013; broy, 2013) vehicles with the help of Wireless Sensor Networks (WSNs) (Wu et al., 2011).

1.5 STATE OF ART

The proposed work in Cyber Physical System based wireless networks influences the researcher to give more significance to collision avoidance as a key factor while accessing a medium. In CPS based application collision affects the system performance as well as fairness access of medium. The following existing research work states that collision avoidance while accessing a medium has to be enhanced to obtain a better throughput in a heterogeneous network’s environment. Components like MAC efficiency and energy consumption need to be elevated to a certain percentage comparatively with existing procedures (Misra et al., 2013). Various approaches have been made to avoid collision using sequencing technique (Krishna and Iyengar, 2008) in IEEE 802.11 protocol. In (Sayuti et al., 2014) IEEE 802.15.4 protocol based collision avoidance is done on most prioritized data rather than most critical data.
1.6 THESIS STATEMENT

In Cyber Physical Systems, Medium Access Control (MAC) protocol holds a major part in increasing the efficiency of data transmission among different wireless networks. Hence to study and design the energy-aware MAC protocol for CPSs to minimize the number of collisions among various wireless technologies like IEEE 802.11 and IEEE 802.15.4 and also to improve the performance of the system in terms of packet delay, packet throughput, fairness and reliability.

1.7 OBJECTIVES

The objective of the thesis is to provide medium access methods by reducing collisions in cyber physical systems. The following are the key objectives of the proposed research:

- To study and analyze the issues of medium access methods in Cyber Physical Systems.
- To propose energy efficient collision avoidance method for CPS based heterogeneous wireless networks.
- To propose a critical factor imposed priority based method to avoid collisions in CPS based Wireless Sensor Actuator Networks.
- To implement a methodology to avoid collisions that occurs at consecutive stages of CPS based Smart Wireless Networks.

1.8 THESIS ORGANIZATION

The organization of the thesis is as follows. Chapter 2 discusses the related work on collision avoidance methods using IEEE 802.11 MAC protocol; IEEE 802.15.4 MAC protocol and discusses CPS based MAC protocol. Chapter 3 describes about energy aware medium access control method for CPS based wireless networks. Chapter 4 elucidates how priority focused medium access control method is applied in CPS based wireless sensor actuator networks to reduce collisions. Chapter 5 explicates the concept of two-level medium access control in cyber physical system based smart wireless networks. Chapter 6 discusses various applications in which CPS act as Internet of Thing (IoT) to manage the critical situation arises. Finally conclusions and future work are exemplified in chapter 7.
1.9 SUMMARY

Cyber physical system is an emerging area in the field of research. So this chapter introduces the concept of cyber physical system and explains how it has an impact on new smart technologies used globally. Cyber physical system features are discussed and shown how the interaction is carried between the physical and computational entities involved in it. The functionality of CPS shows how it performs or executes any event based on closed loop structure. The closed loop structure helps the CPS to ensure that appropriate action had been performed according to the instruction sent from the sensor devices. At the same time CPS gets response from the actuators about the accomplishment of a task assigned to it. At last various applications of CPS are discussed.