STRUCTURAL HEALTH MONITORING SYSTEM – AN EMBEDDED SENSOR APPROACH

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***Abstract*- Structural Health monitoring system is the implementation of improving the maintenance of any structures like buildings and bridges. It encompasses damage detection, identification and prevention of structures from natural disasters like earth quake and rain. This paper is mainly proposed for three modules. First module constitutes recognizing and alerting of abnormal vibration of the building due to an earth quake. This consists of two types of sensor to predict the abnormal vibration induced by an earth quake. Second module portrays the prediction of damage in the buildings after an earth quake or heavy rain. Damage detection includes identification of crack and the moisture content in wall bricks in real time buildings. Third module presents the smart auditorium which is used to reduce the power consumption. Depending on the number of audience inside the auditorium it can control the electric appliances like fans, lights and speakers. In any real time structural health monitoring system the main issue is the time synchronization. This paper also proposes to overcome the general issue arises in structural health monitoring system. ZigBee based reliable communication is used among the client node and server node. For the secured wireless communication between the nodes ZigBee is used.**

Keyword - Structural health monitoring, vibration analysis, damage detection, Smart auditorium, ZigBee.

I. INTRODUCTION

Structural health monitoring systems leads to the function of safety maintenance and extending the life time of real time buildings. In general structural monitoring includes the change of structures in properties at the geometrical and material level. In addition to that structural monitoring system should reduce the energy consumption [14]. Long term bridge structural health monitoring system have been implemented to provide secured and safety operation. In addition to that it also provides the functionality of an early alert on the damage of the structures [1]. Damage monitoring in any civil structures includes, corrosion monitoring, crack monitoring, vibration and strain measurement [19]. The main principle of structural health monitoring system is vibration analysis. To predict the initial stage of an earth quake before it is known by the human knowledge, vibration analysis technique is used. For this analysis two different sensing modules have been used. They are acceleration sensing and strain sensing module [15]. Due to an abnormal amount of vibration there is a need to control the action of building, at the time the earth quake occurs. If the level of ground vibration is between 10-25 Hz it's due to an earth quake. If the vibration level exceeds 25 Hz it leads to the high level of earth quake. There is need to understand the three concepts namely vibration of ground and building during an earth quake, design of building to withstand an earthquake and response of the building [20]. To efficiently analyse the seismic response of an earth quake there is need to derive proper algorithm for real time monitoring which includes damage detection algorithm. It can be used in online monitoring while forming the cluster. For measuring ground vibration induced by an earth quake an accelerometer and strain sensor can be used. After an earth quake experienced, crack monitoring is important. To identify the presence of crack in concrete, an accelerometer is used [14] [16]. A crack in the concrete structures has been identified by novel sensing concept which uses the fibre optic sensor. It is embedded with the real time concrete structures. By this method small opening of crack has been identified. The working principle of fibre optic crack sensor is based on the bending loss of fibre. This sensor consists of two fibre optic at an opposite angle to the concrete [2], [3].To monitor a building in real time, it should be checked for various numbers of parameters like vibration, temperature, load etc. One of the most important parameter to be monitored in real time building is the amount of moisture content in clay bricks. High moisture content can promote its deterioration. In general, most chemical and physical corrosion process occurs due to the high moisture content that leads to the damage of buildings [4]. Nowadays power consumption is an important criterion. It is needed to reduce the power consumption when the electrical

appliances are turned off. User can control the power automatically by using IR. It is need to design the automatic power cut off outlet [5]. Communication between the nodes has to be done by using ZigBee. The main advantages of ZigBee based wireless communications are low power consumption, reliable and cost effective. It is very easy to embed with many products in commercial and industrial applications. ZigBee based communication technique is suited for large range of energy management field. Wireless sensor network is an upcoming technology especially in industrial and civil application. Their role of importance has been identified by the package of IEEE802.15.4 which defines PHY and MAC layer. ZigBee has several benefits when compared with other wireless technology particularly in short distance communication and low data rate [6]. This protocol has some standard setting; it includes the specification of interface and communication and can perform the data transmission encryption mechanism [7]. In Real Time Bridge health monitoring system ZigBee is used to transmit the data about the different types of sensors that has measure the structural health parameters [8]. Time synchronization is the main disadvantage of structural health monitoring system. This has been overcome by two algorithm called ARX (auto-regressive model with exogenous input) and ARMAV (auto-regressive moving vector). This algorithm is used to record the seismic response of the data from the real time structures [17]. It can be also overcome by flooding synchronization algorithm. In this, synchronization command will forward to the client nodes or sub nodes from cluster unit [14].

II. RELATED WORK

Structural health monitoring with wireless networks involves many advantages. But it has great limitation related to time synchronization [14] [15]. In online structural monitoring system there is need to divide the main building into sub structures. This has been achieved by NS-kalman algorithm. It will leads to high power consumption. Number of steps in kalman algorithm depends upon the number of substructures. So it is not well suited for large number of sub structures [14]. Network time protocol has been used solve the time synchronization problem. But this is not suitable when large amount of data is required to send [10]. GPS has been used to solve this solution. But this method increases cost and power consumption [11]. Sensing system has to be installed permanently in the building. It is one of the drawbacks economically. Then it should consume low power to reduce the cost of replacing the batteries [15]. If there is no load exerted on the building, the amplitude response will be gradual only it varies when there is external load like earth quake and collision [5]. Wireless sensor network has been designed for transmitting the status of structural health to the base station. ZigBee has been used to transfer the data of accelerometer (ADXL 322) which is used to measure the structural vibration [12]. When dealing with the safety of real time structures the maximum amount of stress should be check not to exceed the threshold level. Strain sensor can measure the relative displacement of nodes. The existing level of more important structures has been accessed by detection and monitoring the crack. In bridges crack opening exceeds the level of 0.15 to 0.2 mm will allow the penetration of water. It will lead to the corrosion. The criteria for occurring of corrosion are high moisture content. It is need to measure the moisture absorption in the concrete structures [18]. While considering the degree of complexity and functionality, structural monitoring system can be divided into five levels. They are, detect the presence of damage, location of damage, diagnosis, prognosis and self healing. Structural health monitoring system has been known as the method that allows the damage causing condition of a building should be recorded [13]. Any home appliances user can monitor control the power by using IR and can reduce the total power consumption. This also required communicating one another. For this many power monitoring and controlling system has been implemented. In this method it is need to propose the new room architecture that can provide the low power consumption. But this method will leads to the high capital cost [5].

III. SYSTEM OVERVIEW

The overall block diagram of proposed structural monitoring of building is illustrated in fig 1. In wireless system there is need to use batteries for power management. Each unit has its own power module. So it is needed to convert the voltage into various levels to supply all the modules. Power unit should be integrating with the sensing module. Each sensor in the sensing module has received the fixed current. Sensing module consists of different types of sensors, which is used to measure the different parameters that are affecting the health of the structures. Sensing module which acquires the signal from environment and then it will send to the acquisition module. It involves vibration analysis, damage detection and power consumption. Vibration analysis is used to predict the start of an earth quake. Damage detection identifies the damage caused by an earth quake or any other external load. Third module shows how the power consumption is reduced. For example an auditorium inside a college building is taken. It can reduce the power usage when person is not present. Depends upon the number of listener inside the auditorium, this proposed module automatically control the electrical appliances which involves lights, fans and speaker. Sensing module should be embedded with the monitoring area. Acquisition module which consists of controller, signal conditioning unit and ADC. Mainly signal conditioning unit performs three major operations. They are filtering, amplifying and isolation. To meet the requirement of next stage in the acquisition module signal conditioning is needed. Signal conditioning unit can adapts the signals from the different sensors and it can filter the noise, then it can supply the desired power

supply to the ADC circuit. IEEE 802.15.4 protocol standard based synchronization module is implemented. It is needed to send the synchronization pulse to the slave device from the master device which is inside the server.

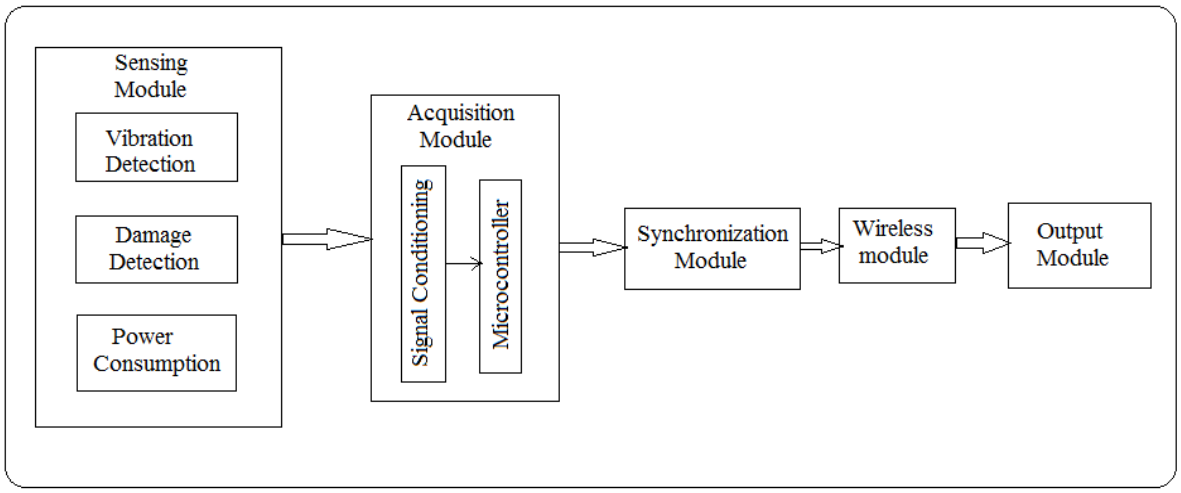

Fig. 1. Conceptual Block Diagram

For the secured wireless communication ZigBee is used. Therefore pair of ZigBee can be placed in both sensing unit and the server unit. The final module is the output module.

IV. DESIGN AND IMPLEMENTATION

A. Vibration Detection Method

The proposed module of earth quake prediction method is shown in fig 2. This module is mainly proposed to predict the earth quake before known by the human knowledge. It can measure the start of an earth quake. So it is need to identify the vibration which is induced by an earth quake. The main cause of earth quake induced damage is ground vibration. To measure this vibration, accelerometer and strain sensor is used. Accelerometers are placed in every floor of the building and strain sensors are mounted in base of the building.

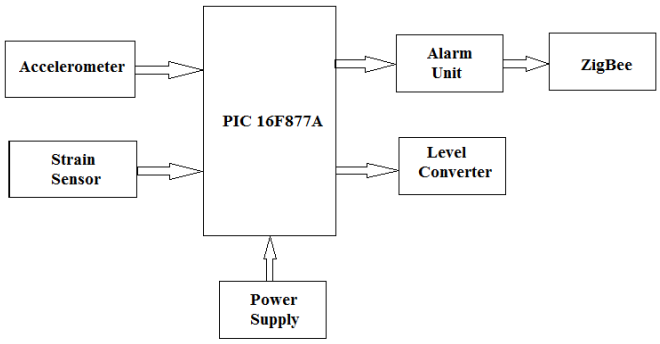

Fig. 2. Vibration analysis

The main aim of using accelerometer is to predict the initial stage of an earth quake. If the accelerometer exerts high level of floor vibration beyond the threshold it can send the alert command to the base station wirelessly. If the vibration exceeds 10-25 Hz it can send the alert command to the base station. Same as that of acceleration sensing module strain sensors are used to measure the ground vibration. Strain sensor can mount on the base of the building. Depends upon the area of building multiple number of sensors are used. If the ground vibration level exceeds the threshold level it can intimate to the base station through ZigBee in wireless. Both acceleration sensing and strain sensing can be done using earth quake detection algorithm. An Accelerometer is a device that can measure the vibration or acceleration. Accelerometer has been used in many industrial and science application. In the field of civil engineering, it can be used to measure the vibration induced by an external load like earth quake or typhoons. Accelerometer is a representative type of sensor that can measure the structural vibration. In structural health monitoring system we can use three different types of accelerometer depending upon where it is used and the range of measurement. Different types accelerometer

includes force balanced type, piezo electric type and MEMS type. This proposed method used MEMS based accelerometer to measure the vibration. The principle behind in this type of accelerometer the displacement of small mass has been etched into the silicon surface and it has been suspended by small structures. According to the Newton's second law, an acceleration or vibration is applied to any device that can experience a force and displaces the particular mass. The advantages of using MEMS accelerometer are low power output and small in size. It can measure the frequency range about 0-300 Hz. Strain sensors are most widely used sensor to measure the external strain that can be applied in any structures. The main type of sensor used in real time structures is electrical resistance type. This can operates on the principle that electrical resistance of a conductor changes with its mechanical deformation. It is highly sensitive to strain. It can measure the range of about 0-500 microstrain and the output voltage is 2.5mV. This type of strain sensor includes Wheatstone bridge, temperature sensor and amplifier circuit. PIC 16F874A type of PIC microcontroller is used to process the signal acquired from the accelerometer and strain sensor. It has the feature of high performance RISC CPU and it has only simple 35 instructions to use in programming. The operating speed is DC-20 MHz clock input and it has eight levels deep hardware stacks. The main feature is power saving mode that is sleep mode. It can with stand in commercial and industrial temperature ranges. Finally it leads to low power consumption. Microcontroller is not compatible with RS 232. So it is need to convert the RS 232 into TTL voltage level that can accepts by the microcontroller. MAX 232 can perform the operation. MAX 232 can convert the TTL voltage level into RS 232 level and vice versa. It also uses 5V power, same as that of controller. It requires 4 capacitors. If any of the sensors exceeds the threshold level it can intimate through the warning message to the base station. And also give the warning signal through alarm unit. Each device has its power supply from the major power source.

1) *Earth Quake wake up Algorithm:* The schematic representation of earth quake wake up algorithm is shown in fig 3. The detection of both vibration and strain is done by using distributed earth quake detection algorithm. When the output of an accelerometer and strain sensor in a particular number of monitoring nodes exceeds the maximum threshold level those monitoring node send the alert message to the base station. Depending on the number of monitoring nodes which can send the alert signal, base station can decide whether to wake up the monitoring nodes. So the server (base station) sends the wake up signal to the node (monitoring node). So the monitoring nodes get selected based on the location and in dynamic manner.

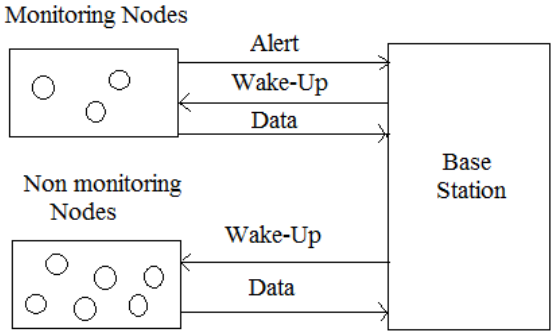

Fig. 3. Earth quake wake up Algorithm

Monitoring nodes is enabled or disabled by the base station, it is optional. In the base station all the parameters are configured. It is need to wake up the monitoring node via the base station at the time of external event. To avoid the loss of data the monitoring node should wake up in limited period. After the event occurs the data is read out by the base station in order. If another new event is occur, wake up algorithm hold the data of second event and finish read out of all the data is first event. Then it can read out the data of second event.

B. Damage Detection Method

The proposed module of damage detection method is shown in fig 4. This module is mainly proposed to identify the damage in the real time building. For the damage analysis it is need to use two types of sensors. They are crack sensor and moisture sensor. Crack sensor is used to identify the crack in the concrete structures. If any abnormal condition occurs, it can intimate to the base station through ZigBee. In generally crack monitoring and detection has been done by visual inspection. This method is leads to time consuming. To automate this process there is a need of sensor. An optical fibre sensor is embedded with the concrete to identify the crack. Due to high level of moisture content corrosion can occur. Humidity sensor based on fibre optic is used to measure moisture absorption. When the corrosion affects the concrete it will increase the area of concrete. Sensor which is used to measure the moisture level should have some requirement. It should be good in sensitivity in high level moisture content and cost should be low. Same as that of module 1 power supply, microcontroller, level converter and ZigBee is used.

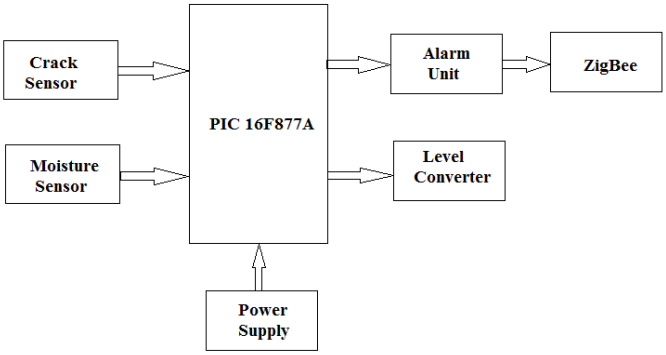

Fig. 4. Damage Detection

1) *Working principle of Crack Sensor:* The working principle of fibre optic sensor which is used to measure the crack is shown in fig 5. Depending upon the transmission signal propagation crack is identified. Crack opening of about 0.2 mm will allow the penetration of water that will leads to high level of corrosion. To avoid this main issue it is need to monitoring the cracks. The figure shows a zig zag type of fibre optic sensor is embedded with the concrete. This type of sensor is feasible to identify the small cracks about 0.1-0.2 mm openings. In normal condition (no cracks) the signal from the fibre optics versus time makes relative smooth curve of signal. The loss in the signal with its corresponding time is only due to the increased distance which is travelled by the fibre optic signal. Depending on the radius of curvature of the cracks presented in the structures fibre optic signal intersects the crack. So it will bend to stay in continuous. Sudden bend in the fibre optic, cause signal drop in optical signal. This proposed method need not require any past experience about crack and their location. According to this method, a single fibre optic sensor is used to monitor and detect the presence of cracks in the structures because it can perform the function of both sensor and communication link. The main application of fibre optic sensor is to monitoring the cracks in the bridges. To detect the crack efficiently there is a need of several sensors. The optical fibre sensor intersects by the cracks at the location, where the change of fibre direction the output is very hard to interpret. The advantage of this proposed method includes, it does not require the past knowledge of crack and their location. Then less number of sensors is used to identify the large number of cracks.

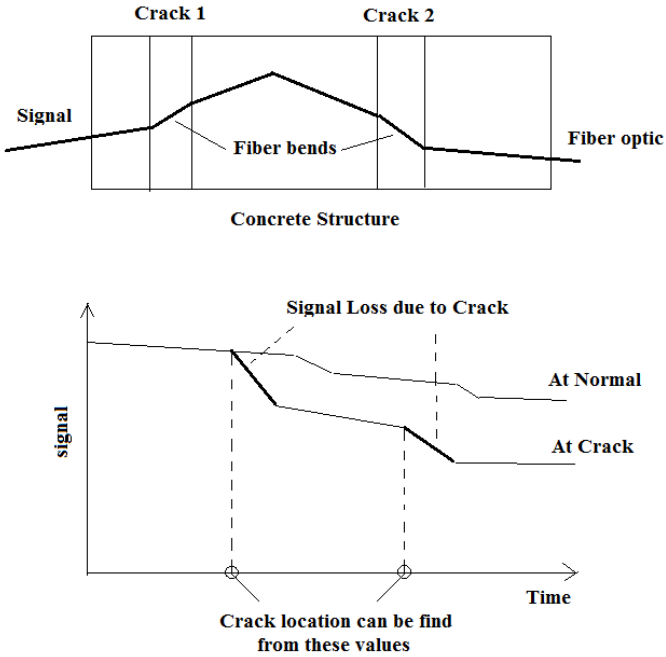

Fig. 5. Principle of Crack Sensing

C. Smart Auditorium

This module is mainly proposed to reduce the power consumption in the building in a particular area. For this, an auditorium is taken to monitoring the power consumption and controlling the high power consumption. This smart auditorium leads to controlling of electric appliances automatically when not needed. Block diagram for smart auditorium is shown in fig 6.

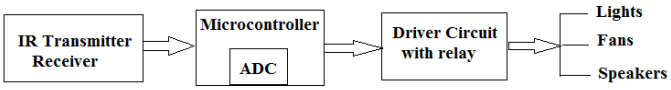

Fig. 6. Smart Auditorium

The main objective of proposed method is to control the fans, lights and speakers are controlled depend on the number of listener in the auditorium. This is designed with set of IR transmitter and receiver, signal conditioning unit, microcontroller and driver circuit with relays. IR transmitter is nothing but a type of LED which can emit infrared rays. The main important thing is both IR transmitter and receiver has to place in straight line. For every four rows of auditorium, IR transmitter and receiver is placed in straight line. If anyone entered in particular four rows, he will cut the first and second IR rays. Microcontroller can count the particular values. In same way if anyone leaves from the particular four rows he will cut the second and first IR rays. The corresponding count value is equal to the number of audience in the particular area. Depends upon the number of audience, microcontroller activate the relay circuit to switch on or switch off the relays. The relay output is directly connected to the appliances like lights, fans and speaker.

1) *Working principle of IR transmitter and receiver:* Two groups of eight slide switches are divided for address and data. Three LED's are made to glue in the short side of the inbuilt box of transmitter. The first oscillator is made by using gate U1A and U1B of 4001. The transmission speeds of the pulses are set by the oscillator. Another oscillator is made with U1D and U1C. This is used to make high frequency of the infrared signal. Inbuilt IR transmitter is shown in fig 7.

Fig. 7. IR Transmitter

IR receiver has two different sections they are amplifier and phase locked loop. The main concept in the receiver is supply voltage. Amplifier has 12 V supply and phase locked loop has 5V supply. From the 12v supply it is very easy to get good amplification and low noise level. 5V supply is made possible to connect with the input of microcontroller or small computer. Inbuilt IR receiver is shown in fig 8.

Fig. 8. IR Receiver

D.Output module

The output module includes ZigBee module and PC. The output is displayed through the PC. The proposed output module is shown in fig 9

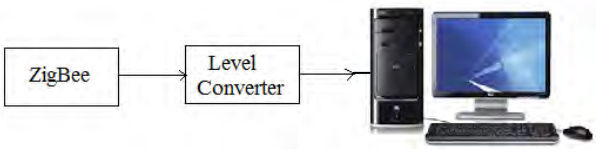

Fig. 9. Output Unit

The data from the input modules is received by the ZigBee which is connected with the PC. This proposed method assumes that the input module as client node. The output module will be the server node. Data from the client node sends data to the server node through ZigBee wirelessly. The ZigBee pair which is used in both nodes should be match. Output of each module is displayed in the PC. The output of first module is abnormal vibration and initial stage of an earth quake. For the second module the output is damage detected, which is either crack identified or high moisture level. In third module the output is switch off the particular fan and light. These outputs are displayed in PC by using HyperTerminal. This unit is act as master unit. The output of these three modules should be synchronized with each other.

E. Time synchronization

The main limitation of any structural health monitoring system is Time Synchronization. The proposed wireless module is based on IEEE 802.15.4 protocol. In real time structural health monitoring system all the data from sensor should have exact time of data. Each sensor has its own oscillator based on timing signal. Oscillator frequency is varied based on their own clock pulses. To maintain the operation time in constant, sensor clock is need to synchronize with each other. In wired network also there is time synchronization problem when multiple numbers of data loggers is used. In earlier method, real time clock (RTC) is used to overcome this issue. Difference in the temperature of the building is leads to synchronization error. Then to overcome this issue, RTC is installed in gateway. Due to delay in wireless module it also leads to synchronization error. GPS includes the high cost of installation and maintenance. There are many other method is used to resolve this issue. In earlier days time synchronization algorithm is derived for wired network. But the same algorithm for wireless sensor network is a challenging task. The method has been implemented for wireless sensor network is reference broadcast scheme (RBS). In this method sensors send the beacon to its neighbour sensors. Relative drift has been calculated by this method. Multiple references pulses are needed to achieve the high precision. In timing sync protocol sensor network, the entire sensor has to maintain its own synchronized clock. In efficient protocol will leads to high synchronization error. We need to design an algorithm for analyzing these resources. So this method proposed IEEE 802.15.4 based synchronization module. Master device inside the server node is send synchronization pulse to the slave inside the client node. In this protocol the main disadvantage is layer overhead. From the physical layer to application layer call function will makes abnormal delays. So it is need to implement the direct call from physical layer to application layer. So it will leads to faster synchronization and it does not need any additional function. So it will set the considerable amount of deviation between the internal oscillators of each sensor's hardware. From this approach it is easy to establish time synchronization. This method is scalable to send large number of sensed data to the server unit. By using IEEE 802.15.4 high time synchronization is achieved. It reduces the spatial jitter to the minimum amount. To reduce the traffic occurred in server unit this proposed method is implemented.

F. Wireless Module

ZigBee technology is an emerging technology that has the important features of low power networking, cost effective and reliable. Nowadays ZigBee is embedded with the many industrial and commercial products. ZigBee is based on IEEE 802.15.4 standard protocol. This standard illustrates PHY and MAC layer. ZigBee can also provide the high potential for wireless transmission. It includes the characteristics of low power, transmission rate, short distance and simple. It has the transmission rate about 20 kbps to 250 kbps, and the transmission range about 100m. It increases the reliability of data transmission. It is capable of including 255 nodes to expand. That is the master node can monitor the 254 nodes. When compared with other wireless technology it has high flexibility and low data rate. It can be used with the products of home appliances, sensors and electronic devices. It can adapt the sleep node and it has low power dissipation because of short working cycle. It requires very less number of communication controllers so it leads to less cost. In ZigBee protocol communication delay is very small when compared to other technology. It provides high security. It has three mode for security they includes data integrity checking and authentication. And it has the frequency band range about 2.4 GHz. ZigBee module has three devices they are coordinator, it initiate the formation of network and stores the information. Routers used to provide the multi hop communication. End a device that has sensors and controller. Architecture of ZigBee network is shown in fig 10. ZigBee module is placed in both monitoring node and server node.

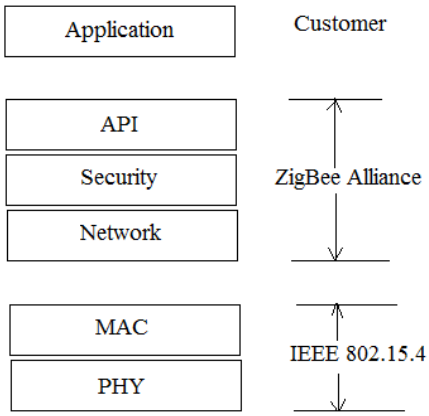

Fig. 10. ZigBee Architecture

V. FUTURE WORK AND CONCLUSION

This study developed ZigBee based structural health monitoring system for any civil structures. Vibration analysis method is used to predict the initial stage of an earth quake. Damage detection present monitoring and identifying the damage in the structures. To reduce the power consumption in the particular building, a new smart auditorium is designed. For these three modules very advanced sensors are used. IEEE 802.15.4 based protocol is used for secured wireless transmission. The main issue in the real time structural monitoring system is time synchronization. It is overcome by IEEE 802.15.4.

Though this proposed method illustrates ZigBee based wireless transmission, it is necessary to speed up the data transmission and for portability. So the advancement of technology includes the designing of web server. With the concept of earth quake alert system it is need to made loss assessment after an earth quake. Then, damage detection system, is need to update the location where the damage presents.

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