Edge Computing Based Conceptual Framework for Smart Health Care Applications Using Z-Wave and Homebased Wireless Sensor Network

Shouvik Chakraborty, Kalyani Mali, and Sankhadeep Chatterjee

Abstract Rapid advancement of the technology makes the system more reliable and the outcome from the system produces in a timely fashion. In this work, a conceptual framework for biomedical image analysis is considered which is based on wireless sensor networks. Here, Z-Wave based wireless biomedical image analysis system is analyzed that can be implemented to provide a concrete WSN based health care system. This work can serve as a foundation to the real-life remote health care system based on Z-Wave. Periodic study of different patients is possible from their own home which can help the physicians to take appropriate decisions in stipulated time that will certainly accelerate the physical and mental improvement. This paper studies the concepts of wireless biomedical image monitoring systems along with their features. In this context mobile edge computing can play a vital role because biomedical image monitoring systems needs to deal with huge amount of data. In general, image data consists of large volume of information. Storage and processing of such a huge amount of data is really a headache. Technologies based on mobile edge computing allows us to save valuable resources in the processing nodes and suitable to handle the resource-hungry applications. Various aspects of the WSN healthcare systems are analyzed and future directions are reported and analyzed in a comprehensive way so that this work will be beneficial for the society and can be extended towards real life implementation.

Keywords Health information management · Wireless sensor networks · Public healthcare · Biomedical imaging · Biomedical communication

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A. Mukherjee et al. (eds.), *Mobile Edge Computing*,
https://doi.org/10.1007/978-3-030-69893-5_16

1 Introduction

Biomedical image analysis is one of the most popular and necessary non-invasive tool for monitoring health and inevitable to make appropriate diagnosis for many diseases [1–3]. Recent development in the field of medical imaging makes this domain highly useful and most of the diagnostic systems have high dependency on the biomedical image processing tools [2, 4–6]. Modern healthcare industry achieves high reliability based on the advanced medical image diagnostic methods that can be employed to study various diseases and can be helpful to find a pathway towards solutions. Several components of the health care industry use image analysis [7–11] technologies directly or indirectly to enhance the efficiency of various fields like neuro-medicines, orthopedics, gynecology etc. [12].

Lots of research has been carried out in this domain addressing several issues. Section 2 describes some of the related works. Different works are focused on various section of the biomedical image analysis process [13–20]. It includes image acquisition, enhancement and noise removal [6], segmentation [21] and feature extraction [22], decision making process etc. [5, 23, 24]. The main target of these systems is to make the life of the common people easier by bringing the advantages of the sophisticated technologies in affordable price [25].

Wearable technologies have changed the face of the healthcare automation. It can help physicians to observe a human body continuously that was not possible before some decades. It can reveal some precious information about the living body that can help in further diagnosis [26–28]. Sometimes it is unavoidable and can save the life of different patients by continuously recording different parameters. It is a revolution in the field of medical imaging that is changing the life and improves the impact of the automation. The combined effort of Internet of things (IoT), Wireless technologies, wearable technologies, artificial intelligence, machine learning, big data and some other technologies is changing and forwarding the biomedical imaging industry towards a new direction [29]. Major advancements of the modern technologies can be observed in various sectors like spacecraft, vehicles, software and hardware industry. But it is true that biomedical imaging is no lagging behind. Besides the fact that many thing cannot be explored from the biomedical imaging but the advantages that can be obtained from it cannot be ignored. In recent days, researchers are interested about various virtual environments that can make the task of a physician easier.

Wearable technologies are not very widely used for biomedical imaging and needs to be improved in different ways. This technology and trend is still in its inception phase for the domain of biomedical imaging and analysis. There is a lot of scope in this filed in near future and it can be applied to predict various diseases in advance and has the power to transform the radiology by boosting the analysis tools that can enhance conventional treatment [30]. Moreover, high quality of the acquired data and a platform for its efficient automated analysis is required to precisely analyze the condition of the patient in real-time [31]. Various tools [32, 33] have been invented and available in market and for consumers which are may not be directly adapted for health care applications but can be useful in health care applications. Some of the research works can be found in literature that uses these tools directly or indirectly for healthcare applications. For example, these products are used in neuro-navigation [34], surgical and non-surgical fields [35, 36], neurology [37] etc. These kinds of wearable devices can be used with association with the radiological diagnostic tools. In general, most of the available wearable devices are not directly useful for medical applications. European union uses a definition for “medical” devices that can be found in [38].

Wearable devices can help physicians to study various conditions with the help of the augmented reality [39]. In general, biomedical images can be used as an alternative and effective tool for virtual interventional study where holographic projection is made by capturing important interest points. Good quality images can ensure the personalized care and virtual reality can explore several perspectives that may not be visible by the human eye. Design of remote monitoring systems for biomedical images is one of the growing research topics and has various prospects. It is not always possible to move a large clinical device to a remote location and therefore home-based healthcare and monitoring with the help of conventional appliances is also a troublesome and sometimes not possible at all. So, some devices are invented to give the facility and comfort to the user to wear and transmit the images with the application of wireless sensor networks. It can also be incorporated with the smart home concept [40] with some modifications that can help in further advancement. The collected signals are sent to the local hub and then transmitted to the central server which is generally located in hospital or monitoring station. The signals can be analyzed centrally or in a distributive environment but the results can be monitored centrally and more importantly patients can sit in their own home. Due to the rapid advancement in the field of sensors and medical imaging, it is possible to build such wireless technologies. Moreover, with the growth in artificial intelligence and development of various machine learning based tools, it is possible to generate automated alerts by analyzing real-time data and give some prediction based on previous history of the patient that can reduce the task of the physicians and can save some precious life. Personalized care with less cost is one of the major advantages of these systems.

In this work, Z-Wave is considered for the wireless communication purpose. In general, zigbee, Z-Wave, Bluetooth etc. are more or less similar. However, in case of interoperability, Z-Wave outperforms the Zigbee or Bluetooth and proven to be run smooth [41]. It is because Z-Wave is standardized by private organization and it is guaranteed that every device can communicate with one another. Some recent developments made the Bluetooth and zigbee interoperable to some extent. Z-Wave does not interfere with the other devices and works very fast [42]. Moreover the signal strength of Z-Wave is higher than Bluetooth [43]. Near about 1.5 k products are running currently using Z-Wave [42]. Z-Wave is widely used because unlike zigbee or Bluetooth, Z-Wave alliance [44] makes it certain that all devices follow some standard set of rules and definitions which makes it interoperable which is highly desirable in remote health care systems and these property makes Z-Wave more suitable than zigbee or bluetooth. Z-wave uses very low energy radio waves for communication that in turn reduces the power consumption [45]. This work is focused to develop remote biomedical image analysis system using wireless sensor networks with the help of Z-Wave and smart home concept to make the biomedical image analysis process simpler. Properties and other advantages of using Z-Wave is illustrated in Sect. 3. Comparison of Z-Wave with some other standard technologies are given in Table 1. However, Z-wave plus can also be adopted in place of traditional Z-wave.

Typically, every industry requires sophisticated methods for real-time data analysis. The availability of important and critical information in real-time is one of prime importance for almost every industry. It certainly helps in their productivity. But, when we are talking about the healthcare industry, the availability of critical information at an appropriate time is highly essential and it can make a difference between life and death. Typically cloud-based infrastructures process the data at some particular distance from the location from where data are being collected. It has some obvious drawbacks like communication de-lay due to congestion in bandwidth, poor reliability, etc. Although, we are living in an era of 5G still, these issues persist and can be well understood when every second count. Moreover, some security and s are also involved. Mobile edge computing can address this issue by bringing the data processing approaches closer to the data collection points by reducing the communication-related overheads. It is helpful to take immediate actions depending on the processing results without depending on the updation delays.

The rest of the article is organized as follows: Sect. 2 illuminates the concepts about Z-Wave and its applications in smart home-based health care monitoring. Section 3 discusses about the wireless biomedical image analysis system using Z-Wave. Section 4 gives an overview of the various challenges and future direction of this work. Section 5 concludes the article.

2 Literature Review

The development of remote healthcare systems is very prominent and gained the attention of many researchers and scientists. A residential health care monitoring system is developed in [26] to process ECG signals using existing ECG sensors. This article reports the concepts and future directions to acquire and process ECG signals using Zigbee communication network. The study reveals the possibility of developing a real-world system by using residential wireless sensor network. A distributed system for remote healthcare is developed by the media laboratory of Massachusetts Institute of Technology (MIT). The system is based on mobile communication and known as LiveNet [46]. This system has the capability to process real-time data using a Linux based personal digital assistant and a sensor hub. To handle data, a three-layered software architecture is developed which is capable to efficiently process and transmit real-time data. Another wearable sensor for remote health monitoring is developed and reported in [47]. It is a wrist-worn

Table 1 Comparison of different standard wireless technologies

Attributes	Zigbee	Bluetooth	Wi-Fi	Z-Wave
Design focus	Home automation, smart grid, and remote control	Exchanging data over short distances	Connection to WLAN for devices	Wireless communication for home automation and security
IEEE Standard	802.15.4	802.15.1	802.11 standards	802.15.4
Network Type	Mesh	Mesh	Star	Mesh
Network	ZigBee	Bluetooth	Wi-Fi	Z-Wave
Distance	Approximately 10–20 meters	Approximately 10–100 meters	20 meters	100 meters with no obstructions
Max Nodes Connected	65,536	7	Router-dependent	232
Operating Band	2.4 Ghz, 915 MHz and 868 MHz (license-free ISM band)	ISM band, 2.4–2.485 GHz	2.4 gHz UHF and 5 gHz SHF ISM radio bands	915 MHz ISM band and 868 MHz RFID band
Spread Spectrum	Direct Sequence Spread Spectrum (DSSS)	Adaptive Frequency-hopping spread spectrum (AFH)	Direct-sequence spread spectrum (DSSS)	Direct sequence spread spectrum (DSSS)
Throughput	110 kbps maximum	24 Mbit/s	900 Mbps	40 kbit/s
Data	Monitoring and control data	Exchanging data	Transporting data	Monitoring and control data
Voice Capable	Yes	Yes	Yes	Yes
Security	AES encryption, cipher block chaining message authentication code	Confidentiality, authentication and key derivation	Wi-Fi Protected Access encryption (WPA2)	AES-encrypted
Power Consumption	Low	Low	High	Low
Modulation	Quadrature phase-shift keying (OQPSK)	Gaussian Frequency Shift Keying (GFSK)	Quadrature Phase Shift Keying (QPSK)	Gaussian frequency shift keying (GFSK)

device can measure body temperature, blood pressure, ECG etc. This project is named as AMON and is sponsored by EU FP5 IST program. A physiological parameter screening device is proposed in [48] which is based on a wireless telephone, a GPS device and a biomedical examination device. This device can monitor several parameters like blood pressure, temperature etc. This device uses radio frequency which is obsolete and the device is too bulky.

Another remote health care and monitoring system is proposed in [49]. This system is known as LifeGuard and it is mainly used for space related applications. This device can measure heart rate, oxygen level etc. and can record different parameters in data card. It can store data up to 9 h. The collected data are transmitted via satellites. A cell phone based ECG monitoring system is proposed in [50]. A mobile based physiological data monitoring system is proposed in [51]. This device uses Bluetooth sensors to collect data and transmits it using GPRS system. This wearable system is can detect abnormal patterns from the ECG signal by using machine learning methods. A new approach is proposed in to track the status of the brain. It can collect and record various parameters like oxygen level, rate of respiration etc. and store it on a storage card. The data is transmitted using a Bluetooth to a home personal computer and then the data is transmitted to a local medical hub. This device is not very suitable to be worn because of its wired connectivity between different modules. An another approach for ECH monitoring is proposed in [52]. In this work ECG signals are processed by a personal digital assistant. Signals are continuously transmitted by the ECG sensors. This system can detect arrhythmia symptoms with more than 99% accuracy. A medical hub can be informed with some significant parameters which are processed and transmitted by the hand-held device using GPRS so that doctors can take necessary actions.

Several other wearable devices and technologies are available using which remote health care systems can be established. Smart textiles based frameworks are proposed in some articles [53–58] where bio-sensors are incorporated with the garments. A remote health care system can also comprise of some small nodes with wireless transmission capability (known as motes). Various researches [59–63] reports the efficiency and application of the mote based wireless sensor networks in remote healthcare. Motes creates a body area network (BAN) [64] that collects data about one or more than parameter and transmits it to a central hub. Some other real-time patient monitoring systems are discussed in [65]. In this work, a comprehensive collection of IoT based healthcare system is presented. Apart from this article also discusses about the fog computing based remote healthcare systems. A mobile and handheld devices based remote health monitoring system is designed in [66]. Four different parameters i.e. ECG, pulse rate, oxygen saturation, and the temperature of the body is monitored using a mobile application in IoT environment. In this work, the Arduino microcontroller is used. A comprehensive study on IoT based smart health care system is presented in [67, 68]. Different applications of the IoT based infrastructures in smart healthcare monitoring systems is presented in this work that is beneficial to understand the recent advancements in this field. A solution for smart and remote healthcare systems based on mobile edge computing is presented in [69]. In this work, internet of medical things environment is used to provide a smart healthcare solution. A multiclass edge computing solution is presented in [70]. This approach is a solution for the energy efficient smart healthcare systems. This approach is named as s-health and this approach is efficient enough to adopt according to specific applications or data. A comprehensive overview of the Z-wave based smart healthcare infrastructure is presented in [71–74].

In this work, a concept is presented to process biomedical image as a part of remote healthcare system using Z-Wave. Magnetoencephalography is used as a tool for demonstrating the concept of the biomedical image analysis framework coupled with home based wireless sensor network that can be implemented in reality. This work shows a new dimension to the remote health care industry by providing a concept of real-time biomedical image processing system.

3 Z-Wave Based Smart Homes and Their Application in Health Care

Smart home-based health care system is one of the emerging trends and has huge prospect in future. These types of systems are based on wireless networks and wearable devices that can take some input from the body. In case of biomedical imaging devices, it can continuously take images of different organs and sends it to the central hub or node. It can be beneficial in several situations like, wearable head-mounted devices can continuously scan the head and send some scanned images that can be useful to monitor head injuries and can predict different diseases like strokes and can provide quick response and treatment. Various applications of the smart home-based systems are found in the literature. In includes energy control and monitoring [75, 76], home control and automation [77], controlling and monitoring environmental issues [78], home area networks [40, 79], wireless device control [80, 81], integration and collaboration of different devices [82–86]. Smart home based frameworks also support some types of robots to perform different jobs [21, 87, 88].

3.1 Architecture and Illustration of the Monitoring System

Wearable biomedical imaging devices can scan different parts of the body but the most popular type of wearable scanning device is used for cognitive neuroscience. Several types of applications include MRI, functional neuro-imaging like magnetoencephalography etc. To illustrate the system, the magnetoencephalography based wearable system is considered. It helps in the understanding of the functional behavior of certain parts of the brain and the relationship with different segments [89].

3.2 Basics of Magnetoencephalography

Magnetoencephalography (abbreviated as MEG) is based on the magnetic fields those are generated in the brain due to the natural electrical activity of the brain. There are several applications of the MEG process starting from simple experiments to detect several abnormalities. It is based on the magneto meter that can sense the magnetic activity which is occurring in the brain [90].

To understand the MEG signals, we have to start from the basics of magnetism. Let the electric field E that has been generated due to the charge density ρ and the magnetic field B is generated by the movement of the charge. The current density is denoted by J. Now based on these parameters we have four Eqs. (1) to (4) namely Faraday's equation, the Ampere's circuital law including Maxwell's correction, Gauss's general law and Gauss's law for magnetism respectively.

$$\nabla X E = -\frac{\partial B}{\partial t} \tag{1}$$

$$\nabla X B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t} \tag{2}$$

$$\nabla \bullet E = \frac{\rho}{\varepsilon_0} \tag{3}$$

$$\nabla \bullet B = 0 \tag{4}$$

In the above equations, ε_0 denotes the permittivity of the free space and μ_0 denotes the magnetic permeability. These four equations are considered as the fundamental equations that describes functionality and the generation process of the electric and the magnetic fields from the charge and current density. The presence of the time derivatives in the above equations describes the fact that the magnetic field is generated from the varying electric field and electric field is generated from the varying magnetic field. These four basic equations can be used to form the equation that describes the propagation of electric and magnetic fields [91]. The propagation speed of these waves is similar to light. The electromagnetic wave equation is given in (5) and (6).

$$\left(v_{phase}^2 \nabla^2 - \frac{\partial^2}{\partial t^2}\right) E = 0 \tag{5}$$

$$\left(v_{phase}^2 \nabla^2 - \frac{\partial^2}{\partial t^2}\right) B = 0 \tag{6}$$

Here the term v_{phase} is the phase velocity which is given (7). It similar to the speed of light. The symbol ∇^2 denotes the Laplace operator.

$$v_{phase} = \frac{1}{\sqrt{\mu\varepsilon}} \tag{7}$$

This is the basic concept behind the MEG signals generated due to the electromagnetic activity in the brain which can be measured from outside of the brain. These waves are generated from the neuronal sources and propagates with the speed of light [89]. The wearable devices are helpful in detecting these changes (i.e. change in magnetic and electric fields) instantly because these devices are placed close to the head and the speed of these signals are very fast. It is beneficial over other methods like PET, MRI etc. because these methods depend on the change of the body fluids or other substances and give indirect response of the neuro-functions. Hence MEG signals are more prominent and give better results [92].

3.3 Basic Architecture of the Z-Wave

Z-Wave is one of the popular protocols which is generally used for wireless communication. It is widely applied in home automation systems. Z-Wave architecture is based on the mesh topology that uses radio waves to communicate among different appliances inside the home. It uses low energy radio waves and consumes very less power. It provides wireless control over various devices i.e. different mobile devices like smart phones, keyfobs (a kind of wireless keypad) and can be used to control several other devices remotely. It uses a Z-Wave gateway which acts as the central device that manages the data collected from the internal network and communicate with the outside world. Different systems support Z-Wave protocol that makes it suitable for various applications. This technology was developed by Zensys in 2001. The range of the operational frequency is 800–900 MHz and it uses part 15 ISM band for communication. It has near about 100 meters operational range.

One of the important features of the Z-Wave protocol is that it uses mesh topology. One device can communicate to another device directly if the second device is within the range. If the second device is out of the operational range then the first device can use one or more than one intermediate node to communicate with the desired device. Moreover, when a particular device is communicating with another device, it can send some control signal to other devices because one particular device is connected directly to all other devices. In 2016, a public version of the interoperability layer has been published that makes several things easier for the developers. Z-Wave uses Z/IP technology to transmit Z-Wave signals over IP network.

The Z-Wave protocol has been modified and a new upgraded protocol called Z-Wave Plus [93] is published in 2013. Z-Wave provides reliable communication and functional behavior that makes it suitable for used in several wireless devices and sensor-based communications. The Z-Wave provides a low-latency architecture that is helpful in wireless data transmission. It can transmit small data packets with the rate of transmission up to 100 kilo bits/second. IEEE 802.11 architecture (i.e. WiFi) is used to handle higher data rate. In contrast to that, Z-Wave can effectively control the communication among sensor-based devices with a throughput of 9.6 kilobits/second. The throughput is improved in new chips and it can be up to 40 kilobits/second. It uses Manchester channel encoding modulation technique and it has the capability to take four hops between any two nodes. The distance between two nodes must be within 30 meters. The underlying band (i.e. Part 15 ISM band) does not interfere with other standard technologies like Bluetooth, WiFi etc. The physical and media access control layers have been included in the G.9959 standard [94] by the international telecommunication union. Data rate can be 9600 bits per second and 40 kilobits per second. The output power can be 1 mW or 0 dBm.

Z-Wave uses source routing i.e. the sending station can partially or completely specify the route that should be followed by the packet. It is helpful for a certain node to explore all paths using which it can reach the host. So it uses a mesh network topology with source routing. It is based on the wireless ad-hoc network architecture i.e. it does not depend on the predefined network resources like switches or routers in a wired network. So, here the decision about selecting the node that forwards the data is made dynamically. It depends on the connectivity and the selection of the routing method. The advantage of these kind of systems is the robustness and less cost. There is no need to install huge infrastructure and single point failure can be recovered. The Z-Wave can transmit a data packet to a distance much greater than the range of the radio wave using the intermediate hops. But it can introduce some delay in the overall transmission.

For every Z-Wave network, one network id is assigned. Similarly, for every node, one node id is assigned. Network id consist of 32 bits and it is same for all nodes in a logical Z-Wave network. One node is assigned with a node id of length 8 bits and it must be unique inside a network.

Z-Wave technology tries to optimize the battery power by remaining in the power saving state. It only consumes the power from the battery when it needs to perform some function. Nodes in the mesh network exploits the walls of the house to reflect the signal so that less power is consumed to transmit a signal. The hardware chip that is used for Z-Wave is based on a microcontroller. The clock frequency of the internal system is 32 MHz. It uses a GisFSk transceiver for communication purposes that consumes 23 mA power and requires a power supply of 2.2–3.6 volts. It also provides AES-128 encryption mechanism and supports simultaneous listening. Nodes in the Z-Wave network provides efficient power management technologies that helps to increase the battery life. Z-wave can provide large battery life that can greatly enhance the performance of the overall system [95].

3.4 Evaluation of Z-Wave Based Biomedical Image Analysis Framework

Biomedical image analysis is considered as the necessary and sometimes inevitable step for various medical applications. Wearable devices can send continuous signals that can help to monitor several parameters. Conventional analog systems are very difficult to use in some situations where continuous monitoring is necessary. The major problem related with the conventional analog systems is the sensors are connected via wires to the analog monitoring devices. These systems are definitely not suitable for continuous monitoring at home. Analog equipment is not flexible due to the movement constraint. Moreover, sometimes it is necessary to communicate the images to the expert immediately so that physicians can take proper action. Analog systems are not suitable for data communication and storage. So, wireless networks can open a new dimension in the field of biomedical image analysis. It removes the barrier of the wires that restricts the home-based continuous monitoring.

Wireless sensor network provides a flexible solution to this problem. Remote health care and monitoring is possible by using some processing nodes that monitors and analyze the data transmitted by the sensor nodes. Wireless biomedical sensor network can be carried by the patient which facilitates the personalized health care and provides a scalable solution for the smart home-based biomedical image analysis. In addition to that, local signal processing methods are used to reduce the amount of data to be transmitted to the main processing node by selecting some important features from the captured data. It reduces the overhead of transmitting a huge amount of data to the central hub. Obviously, there is a tradeoff between the amount of data to be processed and the power consumed by the sensor node. Transmission of large amount of data consumes more power. Moreover, processing at sensor nodes also consumes more power. Hence, the decision is dependent on the designer and completely subjective.

To construct a wireless health care monitoring system, a network of the sensor nodes must be created. This type of network is called Wireless Body Area Network (WBAN) [96]. It is based on the Information and Communication Technologies that can sense and transmit some early stage data that can be helpful in preventing several diseases [97, 98]. Each node is used to sense different physiological data continuously. The major advantage of it is that it reduces the frequent visits to the doctors and save some precious time. It does not restrict the patient from performing their daily activities [99]. Intelligent systems can be developed to process and display accurate results [100] by analysis the collected information. This kind of monitoring systems have some promising scope in near future to construct efficient biomedical image analysis frameworks. These types of networks are completely based on the battery and hence the energy efficient network is desirable.

Z-Wave based wireless systems are emerging as one of the latest wireless standards that provides low power consumption, installation support for many nodes in a single network, longest open-air operational range that makes the Z-Wave technology suitable for home based smart health care monitoring systems.

3.5 Function of Sensor Nodes in Z-Wave

Sensor nodes play a vital role in acquiring data from different body parts in WBAN. Sensor nodes are responsible for capturing and processing different signals and images of different organs. Sensor nodes can perform some initial processing to reduce the amount of data by selecting important information and features from the collected data. Sensor nodes can transmit the reduced data to the central hub by any four transmission methods. Anycast, broadcast, multicast and unicast are the four modes of transmission that can be used to perform data transmission from sensor nodes. In case of unicasting method, data are transmitted to one node from another. It involves less traffic overhead and faster communication. But sometimes, unicasting may not be suitable. Then the multicasting or broadcasting methods can be selected. Broadcasting refers to the one to many communication methods. Multicasting can be one to many or many to many communications. In case of anycast communication, data are transmitted from a group of nodes to one of the nearest nodes.

In Z-Wave based transmission of MEG signals, MEG sensors sense the change in the magnetic field in the brain and forms the image. The sensors are called magnetometers and it can measure the very small change in the magnetic field (in the order of femotesla i.e. 10^{-15} tesla). The sensors are Superconducting Quantum Interference Devices. Therefore, it is also known as SQUID Magnetometers. These sensors are placed within the wearable helmet of the patient. It can continuously sense and form the images from the changing magnetic field. It is one of the non-invasive biomedical imaging method and Z-Wave based wireless network can make it more useful for the patients. Not only for MEGs, other wearable imaging methods can also take the advantages of smart Z-Wave based wireless sensor networks. One thing should be noted that in case of MEG, the experiment is performed in the magnetically shielded room. MEG is considered just for the sake of example and the assumption is that the experiment is performed in the magnetically shielded rooms only. Z-Wave based module transmits the signal to the nearest hub by finding the appropriate route. To find the appropriate route, various routing protocols are used [101]. Some of the popular methods are flat routing, hierarchical routing, location-based routing, negotiation-based routing, multipath based routing, query-based routing, QoS based routing, Coherent based routing etc. Here the first three methods i.e. flat routing, hierarchical routing and location-based routing depends on the structure of the network. Rest of the methods depends on the underlying protocol [101]. Periodic data are collected from the sensor unit and useful data are transmitted by the Z-Wave enabled node.

Z-Wave based nodes uses Radio Frequency (RF) technology for the communication purpose. RF technology helps to minimize the cost of installation and increase

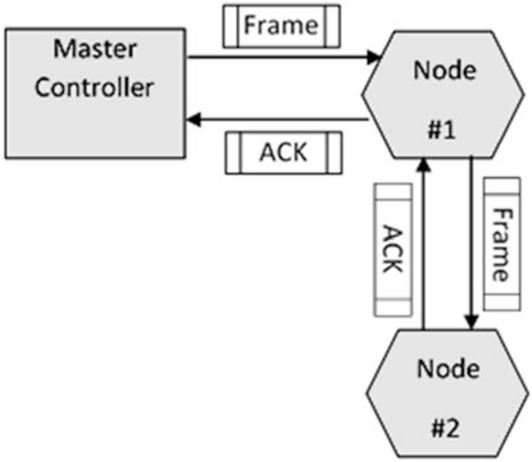

Fig. 1 Routed singlecast frame pattern

the communication flexibility [102]. Z-Wave can efficiently cover the whole room or area using the mesh topology that can use the walls, floors, and ceiling of the room to transmit and receive the control commands. Optimal route to the destination can be determined with the help of intermediate nodes in the mesh network. It can reach some node which is out of the radio range by using intermediate hops. Z-Wave uses an internet gateway that can be used to personalize the network and user can control and get the data from anywhere in the world. The general gateway that is used for this purpose is known as VERA.

There are two types of frames available in the routing layer. These frames types are applied when the data transmission is performed [102]. These two frame patterns are illustrated as follows:

Routed singlecast frame pattern: Here, single destination frame is used. It incorporates the acknowledgement packet that contains refined information. It is illustrated in Fig. 1.

Routed acknowledges frame pattern: In this method, no acknowledgement is transmitted back to the sending station. Here also, single destination frame is used.

4 Wireless Biomedical Image Analysis System Using Z-Wave

Modern diagnostic and health care industry is highly dependent on the non-invasive biomedical image analysis systems. Wireless sensors and constituting network is very much useful for acquiring data from different body parts. This process is highly dependent on the sensors that can acquire and effectively perform some initial processing and transmits it to the nearest hub. Several hospitals and medical research institutes can use these data to analyze and take useful decisions. Biomedical imaging sensors are equipped with embedded software, processing and transmission units that helps in initial processing and transmission of the collected information.

4.1 Biomedical Image Sensors

In recent years, wearable sensors gained popularity because these sensors are very useful in different scenarios and frequently used in many biomedical applications. Wireless sensors are very useful in constructing portable diagnostic tools. Biomedical images are can be collected from various body parts continuously using these sensors. In this discussion the MEG i.e. Magnetoencephalography is considered for the explanation of the concept.

In case of portable MEG sensors, patients can wear it in a helmet like device and allowed for free or natural movement of the head. For portable MEG image sensing purpose, quantum sensors are used that captures the magnetic activity of the brain and records the information. This technology allows imaging of the human brain by detecting the neural electromagnetic activity. These sensors can sense the signals and construct the 3-dimensional image of the human brain. Some superconducting sensors are used to place around the head to capture the weak magnetic fields which are in the range of femotesla. Optically pumped magneto meters are used as the magnetic field sensors. Now, the earth's magnetic field have a major impact on these sensors. The room is basically magnetically shielded but the residual magnetic field of the earth has significant impact on the optically pumped sensors. These sensors are consisting of 3 on-board coils. These coils are used to eliminate the static magnetic field in the cell. The change in the magnetic field can be detected using the change in the intensity of the transmitted light. Figure 2 is used to demonstrate the effect of the external magnetic field on the sensors [103].

The external magnetic field is quite large than the neuro-magnetic fields generated by the electrical activity in the human brain. To overcome this problem, field nullifying coils are used. Figure 3 demonstrates the placement of the field nullifying coils [103]. These coils are helpful in reducing the residual magnetic field of the earth so that the MEG sensors can accurately records the data. Coils are placed in both the sides of the object. The MEG contour map pattern is shown in Fig. 4 [104].

4.2 Biomedical Image Communication Using Z-Wave

Z-Wave based protocols can consist of two types of devices, one is controller and other one is slave. Controller devices send some command to the slaves for execution. Slave nodes generally does not equip with the routing table. It may contain a snapshot of the network which is nothing but the information about the network which serves like a map that helps to transmit the data in the network.

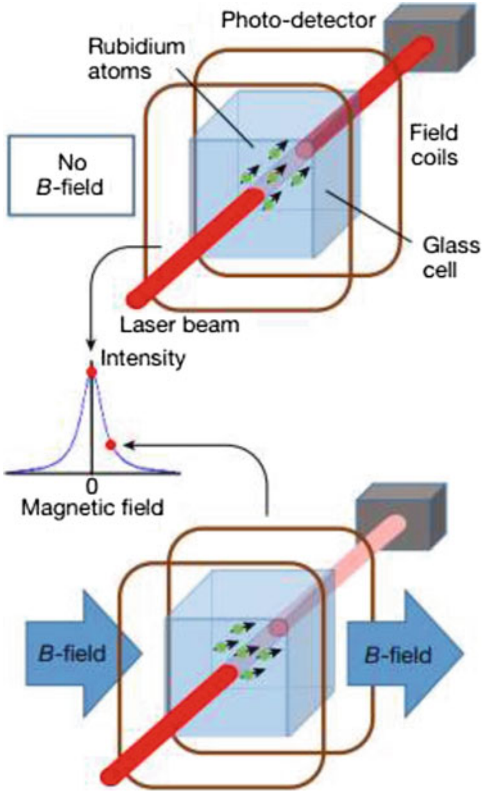

Fig. 2 Effect of the external magnetic field on the Optically Pumped Magnetometers sensors

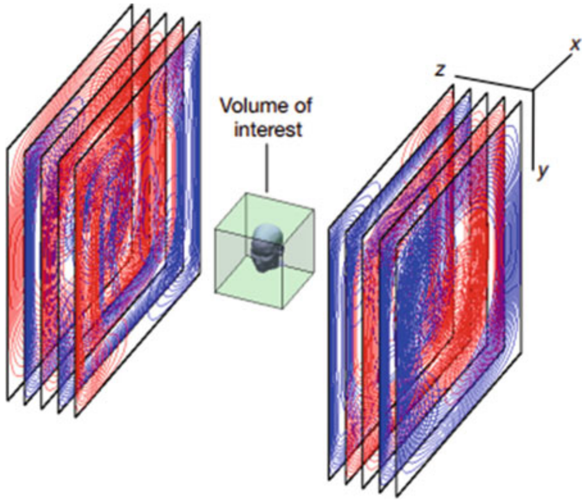

Fig. 3 Placement of the field nullifying coils

More than one controller can be used for better security and reliability but only one central controller takes care about the network topology [105]. So, the

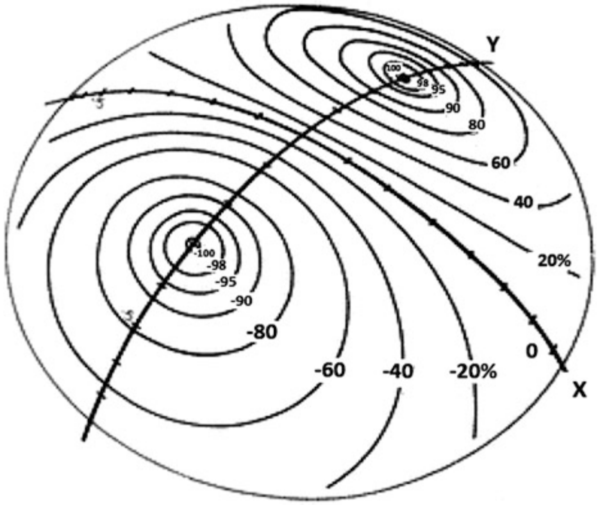

Fig. 4 The MEG contour map pattern

controllers can be classified in two ways such as primary and secondary. Primary controllers act as the administrator of the devices whereas secondary controllers decide the routing table based on the information obtained from the primary controllers. These controllers can determine the optimal path from the source to the destination by using the routing table. It also determines the hops required by a data packet to reach the destination. In standard Z-Wave network, the hop threshold is 5 and the optimal value of the hop is 2 [106]. Direct transmission is always preferable by the controllers. If the direct transmission is not possible, then the optimal path is considered for the transmission. The position of different devices must be optimal so that the efficiency of the system will be maximum. Optimization can be done with the help of different metaheuristic [1, 107–114] algorithms. Moreover, the load distribution should be done using efficient algorithms [115] for optimal results.

Z-Wave architecture is based on four broad layers as shown in Fig. 5 and the layers are described below in brief.

A. *Media Access Control (MAC) Layer:* The MAC layer is responsible for the radio frequency (RF) based communication. RF medium is controlled by the wireless equipment. Generally, controllers are completely independent of the RF medium. Figure 6 [116] gives an overview of the Z-Wave data transmission in different layers. In general, the encoding scheme that is used for the data stream is the Manchester encoding. Generally, the data stream is consisting of encoded digits, coherent signals and preamble. In the MAC layer, the data are fragmented into frames of length 8 bits each. These frames are forwarded in the network by the MAC layer. These data are coded and transmitted like a unidirectional flow of the electric charges

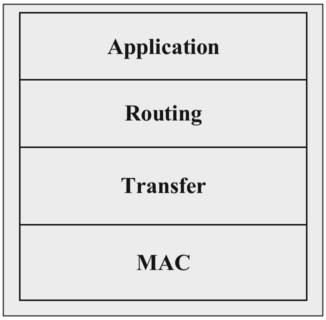

Fig. 5 Layered architecture of Z-Wave

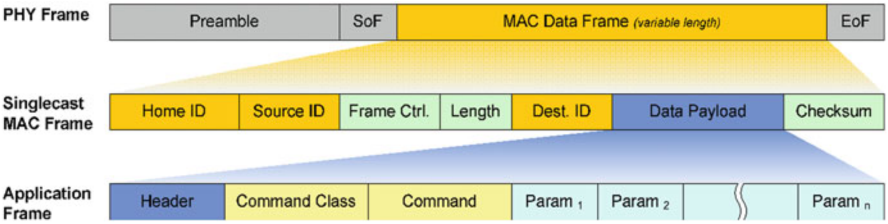

Fig. 6 Data in Z-Wave layers

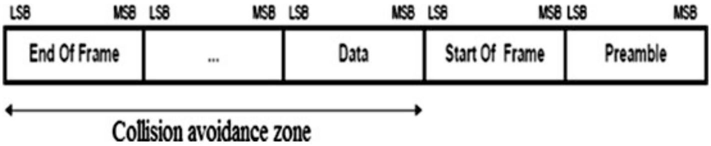

Fig. 7 Collision avoidance mechanism in Z-Wave

The MAC layer provides a collision avoidance mechanism. It increases the reliability of the total system by reducing the data loss. Transmission of the data is initiated only when the channel is vacant and there is no other competing nodes. It there is any other node(s) which is attempting to send data then, the data transmission is restrained and delayed for the random amount of time. It also provides data retransmission mechanism which is optional in nature. Retransmission method is based on the acknowledgements send by the receiver. One particular node can be in the receiving mode or in the sending mode. If a particular node is currently receiving data then there must be some delay before the data transmission by the same node [36]. The collision avoidance technique is somewhat complex for the wireless networks. Figure 7 [36] demonstrates the collision avoidance technique.

B. *Transfer Layer:* This layer acts like an administrator of two sequential nodes. It monitors retransmission, error detection, connection related issues, acknowledgement services and the error free transmission of the data. This layer contains four basic formats of the frames. These formats are used to transmit different commands of the Z-Wave in a wireless network. The four types of frames are: (i)

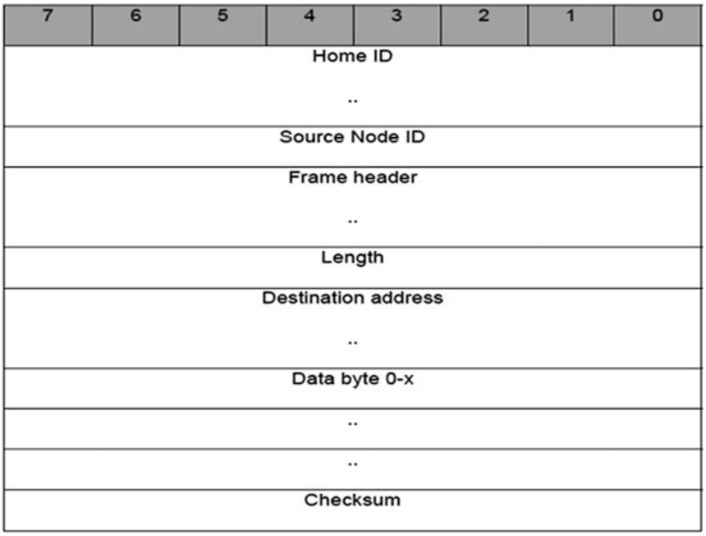

Fig. 8 Z-Wave frame format

Singlecast frame pattern, (ii) Transfer acknowledge frame pattern, (iii) Multicast frame pattern, (iv) Broadcast frame pattern. Figure 8 [102] shows the basic frame pattern in this layer.

(i) Singlecast frame pattern: In this case, the frames are transmitted to the single host only. After receiving a frame, the recipient sends an acknowledgement to the sender. If the acknowledgement is not received by the sender then the sender retransmit the frame. To avoid the collision, sender waits for some time and then retransmit the frame again.

(ii) Transfer acknowledge frame pattern: It is one of the singlecast frame pattern where the frame may not be transmitted with the acknowledgement service.

(iii) Multicast frame pattern: It is one kind of one-to-many communication. One device can send a frame to many devices. No acknowledgement is returned to the sender. Hence it cannot be used for reliable communication. To achieve reliability, one singlecast frame is transmitted.

(iv) Broadcast frame pattern: In this type of frame pattern, the broadcasted frame is received by the devices in the home area network (HAN). No acknowledgement is used in this case and hence, to achieve reliability, we need to transmit single cast frames following the broadcast frames

C. *Routing Layer:* The main job of this layer is to forward the frames. It helps in the communication throughout the Z-Wave based network. It helps to forward frames from one node to another. Forwarding procedure involves the controller and slave nodes where these nodes are placed at certain positions.

Routing layer is also responsible for accumulating various information from different nodes which are used to construct and maintain the routing table at the primary controller. This information is helpful in determining the optimal path from source to destination. It is not a very easy task because of the movement of the nodes. Primary controller takes all the responsibility and route the packet using the best possible path.

D. *Application Layer:* This layer provides a mechanism using which the users and other devices can communicate with the Z-Wave network. It receives and distributes the payload, decodes and executes different commands using the received parameters and performs some other tasks. The frame pattern of the application layer can be visualized from the Fig. 6. Application commands helps to interact other devices and perform different functions.

4.3 Personalized Healthcare Systems Using Z-Wave Based WSN

Personalized home-based health monitoring systems are very effective to prevent different diseases. Personalized health care systems includes ECG monitoring, blood pressure monitoring, continuous image analysis etc. [117]. Wireless sensor networks can be very helpful in this context. WSN can communicate data from one node to another without the help of any wires. Hence, the patients can be monitored from their homes and need not to be admitted in the hospitals because of the early signals. Various researches are going on to improve the home based health monitoring systems [118, 119]. Different technologies are available that can be used to transmit data in WSN. Some of the popular technologies are Bluetooth, Z-Wave, Zigbee, Radio-frequency identification (RFID), WiFi etc. Comparison of Z-Wave with some other standard technologies are given in Table 1.

Z-Wave is one of the major competitors of Zigbee protocol. Z-Wave based wireless networks have several advantages. Z-Wave based systems are inexpensive, scalable and battery efficient. It can cover up to 100 meters without any obstruction. None of the standard wireless methods can reach more than 100 meters. It possesses low latency which reduces the bottleneck. One of the major drawbacks of using Z-wave is the number of nodes that can be connected is lower than the zigbee network which limits the large-scale implementation.

One of the foremost advantages of Z-Wave technology is its backward compatibility. This feature is not there in Zigbee. All of the older versions are compatible to the newer ones which is a great advantage from the users' point of view. Z-Wave is equipped with AES encryption method which provides a secure and reliable connectivity [120]. Security can also be imposed and evaluated on the image explicitly [121–128]. Although the Bluetooth technology is energy efficient and gives better performance in terms of interference than Zigbee, WiFi and Z-Wave. But it cannot be used in congested areas. Hence it is not applicable in clinical applications. The data rate of the Z-Wave protocol is lesser than the Zigbee. It is another issue associated with the Z-Wave protocol. But, due to several advantages (as discussed earlier), Z-Wave is adapted in this work as one of the reliable protocols for smart wireless image analysis systems.

4.4 Biomedical Image Processing Method

The image processing algorithm is one of the most important part and should be designed carefully. The image processing algorithm should be optimized in such a way so that it can take optimum power and provide accurate results in a timely manner. Some of the recently developed biomedical image analysis algorithms are [129–131]. Stipulated resources make the scenario harder because complex image analysis algorithms may not be suitable in these kinds of framework. Moreover, the image preprocessing, feature extraction, classification and other required modules of the image analysis framework should be optimized and tested to get better performance. Medical image analysis algorithm should take care about the modality, noise present in the image, scale, zoom and other features, otherwise the model can deliver erroneous results. Therefore, careful investigation is required before deploying any method for real life implementation otherwise it can produce some drastic side effects to the health of the patient such as, wrong treatment can lead to many issues including death. Moreover, it can reduce the faith on the automated healthcare systems.

5 Challenges and Future Works

There is several healthcare equipment which are available and frequently used with both wired and wireless technologies. One of the major problems associated with these devices is the compatibility related issues. Moreover, those devices that uses cables or some guided media for communication are generally not easily portable. So, the systems based on the wired connections are not useful in most of the situations specifically when the home-based smart health care systems are to be implemented.

Z-Wave provides the advantage of using wireless sensor networks and provides a feasible way to communicate with different devices that makes the system portable and helps in establishing a low-power, home based healthcare monitoring system. It is reliable and can be used for continuous monitoring of different parameters associated with patients where patients can pursue their regular jobs or can stay in their comfort zone. Z-Wave based networks can be simply installed and the devices or nodes can be easily added and removed. Remote control over the network makes the data collection and analysis easier. This technology provides affordable solutions for various other healthcare systems. Interoperability is one of the major advantage of the Z-Wave based systems. Different devices can be connected in IoT domain using Z-Wave and their computational power can be exploited. Z-Wave uses AES-128 bits encryption for its security. It requires previous knowledge to prevent unauthorized access. It works on radio frequency and can be accessed by anyone from anywhere. Moreover, the number of nodes (i.e. 232) that can be connected are much lesser than the Zigbee networks. The data transmission speed is also lesser than the Zigbee network.

The operational band (i.e. 915 MHz ISM band and 868 MHz RFID band) of the Z-Wave provides a wider range of communication than other competitive protocols. The use of sub-GHz band improves the reliability and suffers with less interference. The data rate is not very satisfactory for Z-Wave protocol. Moreover, the spectrum efficiency is also not up to the mark. It is due to the GFSK modulation technique. But the latest version of the Z-Wave technology provides a data rate of 100 kbps. Although the maximum number of nodes that can be connected to the Z-Wave network is 232 but the different manufacturers recommend to restrict this number up to 40–50 nodes. This is quite a small number but it can be applied for wireless home-based biomedical image processing network.

6 Conclusion

This article is illustrating and investigating the huge potential associated with the home-based health care systems which can provide the affordable health care solutions to many people at the comfort of their homes. Lots of possibility can be observed and there is a good scope of research and development in this field. This field is a part of the smart home-based health care which needs to be investigated more deeply so that reliable infrastructure can be developed which will help the whole mankind. Moreover, this concept can be extended to the home-based signal processing which can be used to process different signal like ECG, EEG etc. Deployment of different processing nodes and the load distribution is crucial and should done using efficient algorithms. Cloud based architectures can be used for faster data storage and processing. Development of the faster, reliable and secure home-based health care infrastructure is the prime objective of this work. Since this article is not intended for proposing a new image analysis algorithm, authors give only the conceptual overview of the system. The proposed Z-Wave based framework can bring a new paradigm in IoT based health care and will be highly beneficial for remote biomedical image analysis.

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