HELPER: A Home assisted and cost Effective Living system for People with disabilities and homebound Elderly

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Keywords: Assisted Living; Automation; Zigbee; IEEE 802.15.4; Labview; OFDM; Software Defined Radio

Certificate

This is to certify that the thesis titled " **HELPER: A Home assisted and cost Effective Living system for People with disabilities and homebound Elderly** " submitted by **Sanjeev Baghoriya** for the partial fulfillment of the requirements for the degree of *Master of Technology* in *Electronics and Communication Engineering* is a record of the bonafide work carried out by her / him under my / our guidance and supervision at Indraprastha Institute of Information Technology, Delhi. This work has not been submitted anywhere else for the reward of any other degree.

Dr. Vivek Ashok Bohara
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Abstract

Although there has been significant research and development on automation devices for assisted living, there has always been trade-offs in terms of the cost, complexity, design and efficiency. Numerous researchers have published path-breaking systems & techniques over the years in this regard but the cost & complexity has always been an issue. In this work, a state-of-the-art simple and efficient yet cost effective reconfigurable assisted living system is proposed and implemented which will cater for the needs of bed-ridden patients, people with disability and senior citizens. The distinct feature which makes this implementation unique is its low cost, low power consuming hardware and user-friendly control, hence the user can operate the system without any external assistance. Additionally, the proposed work is an astute combination of embedded systems & Labview developement environment which provides a good head-start towards Internet of Things (IoT) concept. Also, It provides multitude of input options to the user like Direct DTMF mode, Voice Recognition mode, GSM call remote monitoring mode, Internet cloud monitoring mode & direct remote controlled mode, by integrating cellular communication and Zigbee protocol based wireless devices with internet.

Acknowledgement

This work would not have been possible without the guidance and support of several individuals who boosted me for completion of this work.

I would like to first thank my advisor Dr. Vivek Ashok Bohara for providing excellent guidance & encouragement throughout the project work. Without his in-dispensable guidance, this work would never have been a successful one.

Thanks to IIIT-D for providing excellent environment and infrastructure. I would also like to thank all my classmates for their valuable suggestions and fruitful discussions. Last but not the least, I would like to thank my family for supporting me spiritually and emotionally throughout my life.

Sanjeev Baghoriya

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Chapter 1

Introduction

1.1 Motivation

The concept of connecting and integrating the everyday physical entities in the world with Internet has been a topic of noteworthy and challenging research which is commonly known by the term Internet of Things (IoT) [2]. The primary aim behind such astute integration is to simplify the people's lives by having a technology that can deliver incessantly assuming ubiquitous presence of Internet. Moreover, in the world of consumer electronics, persistent efforts are being made to ensure safe and smart life by incorporating the home automation systems (HAS) [3], which are extensively based on the wireless sensor nodes where the true potentials of wireless standards are exploited. However, in spite of technological advances in IoT and HAS over the past decade, there are millions of humans who are devoid of such technological gestures, and for them apart from the cost their inability to use it is also an issue.

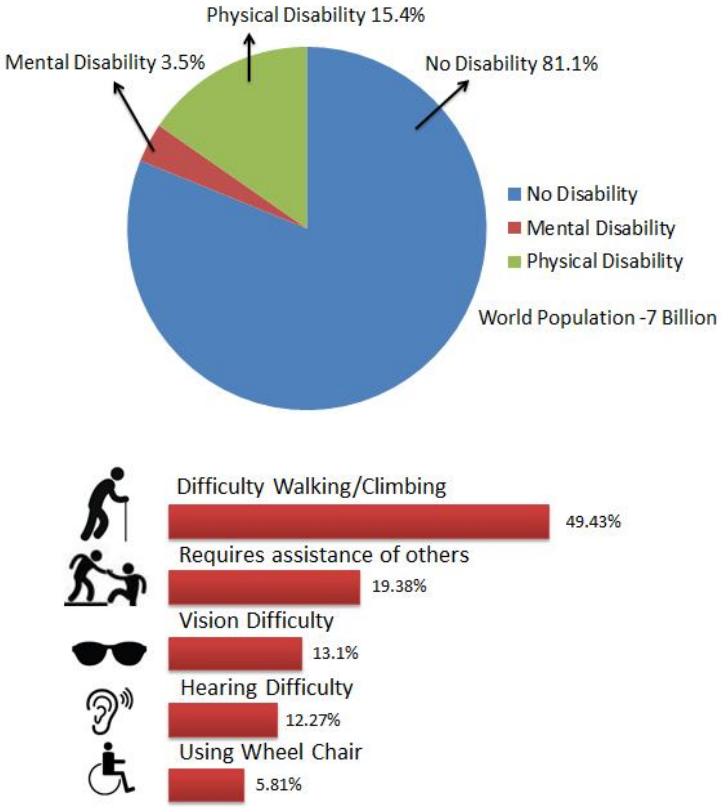


Figure.1 Data disabled people statistics [1].

Such technological advancements and smart systems are immaterial if they cannot be afforded and utilized by the people who need them the most.

According to the World Health Organization (WHO) statistics [1][2][4][5] as shown in Figure 1, out of the world's total population of approximately 7 billion, about 18.9% people are disabled and about 11% people are above 60 years of age. About 400 million people i.e. 67% of the population of the disabled and about 450 million i.e. 58% of the population of the elderly, live in developing countries and majority of them belong to the continents such as Africa and Asia. It is quite apparent from the statistics that significant portion of the world population are dependent on someone or need some sort of external assistance to carry out their day to day activities. In order to assist these people, solutions in the form of assisted living [6] have been proposed. Assisted living addresses the needs of elderly and disabled in their home environment by the use of remote services and home automation thereby assisting them in carrying out their daily living activities. It not only reduces their dependency on others but also simplifies and revolutionizes their life.

However, the currently available systems are expensive and cannot be afforded by people living in developing countries. As per International Labor Organization (ILO) [7], the average monthly income of an individual in Asia and Africa is less than 500$ however, a HAS, from basic lighting to full-fledge feature-laden configurations, price ranges from $300 to $10000 [8]. So, a full-fledge automation system is out of bound of most people living in developing countries, moreover so for the elderly and disabled who are already dependent on others for their basic day to day activities. Apart from above, most of these systems are very complex to operate and are largely ineffective in solving the diversified needs of such people. For example, a system serving the needs of bed ridden patient may be futile for a blind person or a person with no limbs/legs, etc. Thus, there is an acute shortage of cost-effective assisted living systems with numerous input options that will reduce the dependency of elderly and disabled on others.

Motivated by above & "Digital India" campaign [23], led by our honorable Prime Minister Mr. Narendra Modi, which urges for a digital revolution in every home, in this work we designed and developed a full fledge automation system which is cheap, affordable and has low energy requirement so that it can be readily used by the elderly and the disabled user. Furthermore, the proposed system has highly robust and flexible architecture incorporated with multitude of input options that can cater for diversified needs of such people.

1.2 Organization of Thesis

The Thesis is organized as follows.

Chapter 2 provides a brief understanding on the basic topics of IEEE 802.15.4 Wireless communication protocol along with an overview of the home automation scenario & the software environment that has been developed for the work.

Chapter 3 gives an insight via literature survey on the research advancements that have been made over the years in respective field.

Chapter 4 describes the problem & solution briefly with the proposed system HELPER, its architecture, hardware & software details.

Chapter 5 discusses the implementation details along with the system evaluation & the inferences.

Chapter 6 explains the current work extension which aims to provide a proof-of-concept of IoT implementation using Software Defined Radio.

Chapter 7 concludes the Thesis by summarizing the contribution of the work & the research done.

Chapter 2

Precursors

2.1 Home Automation & Introduction to Internet of Things

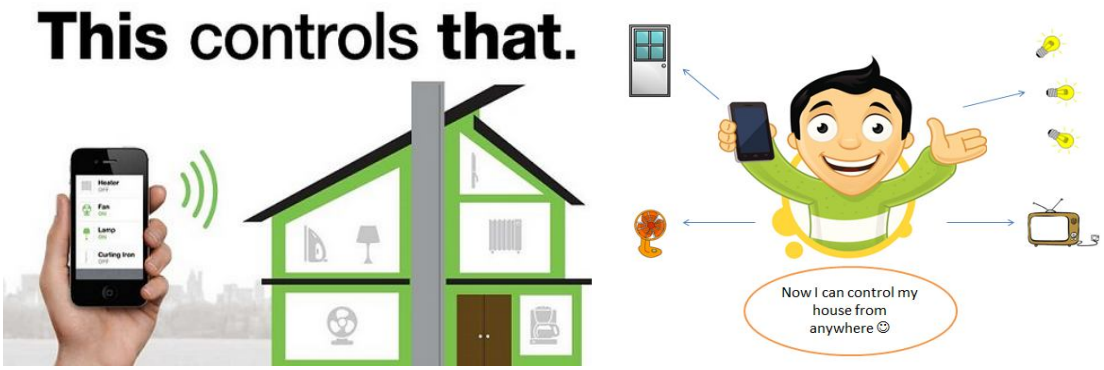


Figure.2 Graphical definition of Smart Home Automation product WeMo [35][36]

The Smart Home Automation, for instance WeMo [35] by Belkin as depicted by Figure 2, is the automation phenomena of the home, workplace or office where the everyday accessible physical entities which are electrically powered are centrally controlled by the user. This includes control of lighting, heating, air conditioning, security locks of gates & doors, etc. A smart home automation system integrates the electrical devices with each other which can be via wired or wireless techniques. There are various scenarios which exemplify the importance of the existence of the smart home automation systems, for instance centralized security rooms in the malls, banks, etc. where the locks, doors, alarm systems, monitoring cameras & screens are controlled by the security personals. Another instance can be quoted here is the most popular stair case controller. There is no doubt that smart home automation is going to prevail in the near future, moreover so their capability is further boosted when intelligent systems & sensors are integrated with them to make them interoperable with all possible communication protocols existing, thus it gives rise to the Internet of things.

Some of the popular technologies that are the foremost aid to any type of automation that is available in the world are X10, Insteon, ZigBee, Z-Wave, Bluetooth, Telephone Lines, C-Bus, KNX, UPB, Home-gateways, etc. & technologies like UPB & Telephone line

don't have RF capability to carry out the wireless communication over the automated network.

When such technologies are interoperable & they can easily exchange data over the network of networks, i.e. Internet, then any physical object or things embedded with software & sensors can be connected to each other & also with centralized systems, such technology of technologies is known as the Internet of everything (Commonly known as IoT or Internet of Things).

2.2 IEEE 802.15.4 Based ZigBee

IEEE 802.15.4 is a wireless standard that specifies Low Rate Personal Area Network communication specifications for inexpensive & low powered radio devices. It is the basis of the ZigBee & MiWi applications which are extensively being used all around the world for short range communications for commercial as well as domestic uses.

In this work, IEEE 802.15.4 based ZigBee protocol has been chosen as there is no stringent requirement of high date rate applications such as High Definition (HD) video transmission, gaming, etc. It is short range low power Personal Area Communication (PAN) and an alternative to Wi-Fi and Bluetooth with low power, data rates and range requirement. It contains the layer-1(Physical layer) and layer-2(Medium Access Controller) of IEEE 802.15.4 along with a stack software which provides network and application layer functioning. The devices based on it, primarily operate in the unlicensed industrial, scientific, and medical (ISM) bands i.e. 2.4-GHz band as shown in Figure 3, where within the total bandwidth of 5-MHz bandwidth, 16 channels are defined with a maximum data rate of up to 250 kilobits per second (kbits/s) using offset quadrature phase shift keying (OQPSK). Alternatively there is a provision for operation at 915 MHz (in the U.S.) with data rate of up to 40 kbits/s using binary phase shift keying (BPSK) modulation whereas the European version uses 868 MHz with 20 kbits/s. Its transmit power is 1mW which restricts the range up to 10-20 meters.

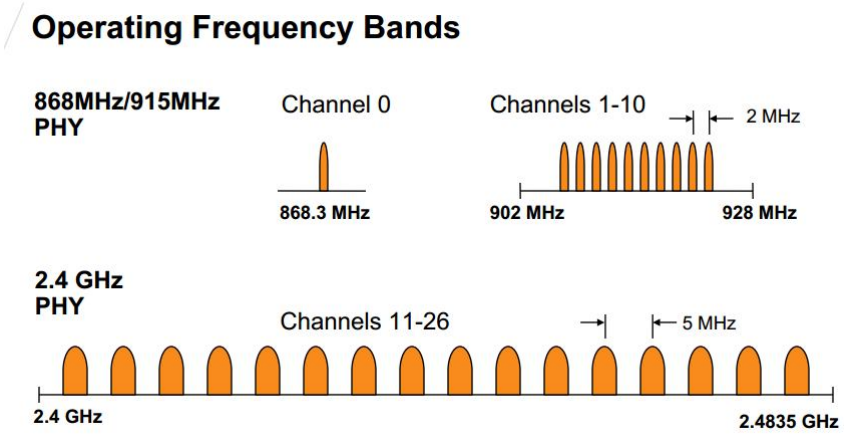


Figure.3 IEEE 802.15.4 Operating Bands

Basic IEEE 802.15.4 Signal Flow Block Diagram:

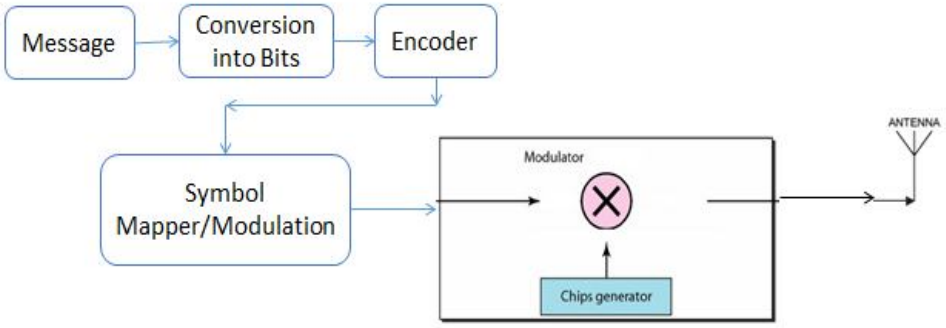


Figure.4 Physical Layer Signal Construction of IEEE 802.15.4 based ZigBee

Figure 4 shows the signal flow diagram explaining the construction of the signal at the physical layer level. After the medium access layer, the data or the message is digitally converted & channel coding is added to enhance bit error rate (BER). It is then modulated & mapped with the hopping sequences & then moves on to the transmission stage.

The IEEE 802.15.4 standard relies on two services that physical layer provides. The physical layer data service and management service. The physical layer data service controls the transmission and reception part of the physical layer data units whereas management service perform energy detection tasks, carrier sense before transmitting messages and quality indication for the received packets. The original version of this standard specifies two physical layers based on direct sequence spread spectrum (DSSS), one of them works on the frequency band of 868/915 MHz [20] and baud rate of 20 to 40 Kb/s as depicted by Table I, other in frequency band of 2450 MHz with a baud rate of 250 Kb/s [21]. The latter is the choice for this work. The multiple access control is responsible for personal area network connection, frame validation, and providing acknowledgment signal. It uses carrier sense multiple access (CSMA) with collision avoidance technique for channel access to maintain the guaranteed time slot mechanism and support device security.

Table.I Modulation scheme overview

PARAMETERS	**2.4GHZ**	**868/915MHZ**
Data Rate	250Kb/s	20/40kbps
Modulation	OQPSK	BPSK with Diff Encoding
Chip Sequence	32 Chip-PN codes (DSSS)	15-Chip m-sequence
Chip Rate	2Mchips/s	300k/600Kchipsps

In adjunction to the above theoretical information it is worth mentioning some common parameters such as transmit power is 1mW, transmit center frequency with receiver sensitivity is -85dbm(2.4 GHz) & -92dbm(868/915 MHz).

2.3 Labview Development Environment

LabVIEW is an acronym for Laboratory Virtual Instrument Engineering Workbench. It is a design platform cum development environment for a graphical programming language, built by National Instruments. It is commonly used for data acquisition, instrument control & industrial automation on various operating systems. The graphical coding is referred as ``G`` & is a data flow programming language. The Labview source code is determined by the structure & the interconnection of the block diagrams as shown by Figure 5 which has a separate function to perform just like the inbuilt functions of other programming languages.

The reason that we chose Labview instead of other Programming language/Tool because of its extensive support for various interfaces available in the home automation scenario which makes it easily reconfigurable as per the user requirements. Moreover, it is a concurrent language that builds the graphical user interface at the same time by the means of multi-threading. In addition to the development environment, there is a provision of the Labview Run time environment which is free of cost & is the base for our software in action & cuts down hugely on cost factor.

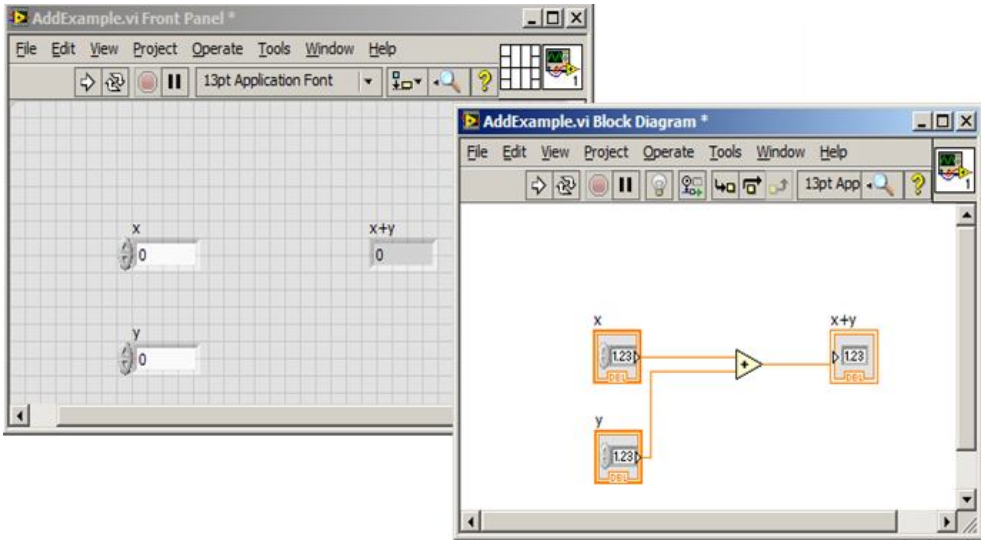


Figure.5 Front Panel & Block Diagram of the Labview Development Software.

Chapter 3

Literature Survey

Different types of wireless standards such as Wireless Fidelity (Wi-Fi), Bluetooth, IPv6 Low Power Personal Area Network (6Lowpan), ZigBee, RF, X10, Z-wave, etc have been used in one form or another for HAS depending on the needs of the consumer and/or the application. Therefore it is very important to discuss the research advancements that have taken place over the years in this filed.

3.1 Different Technologies Available

3.1.1 X10 based systems

X10 [9][24] is easily accounted as one of the oldest automation technology that is still in use & can be found out in almost 10 million US households. The greatest advantage that has kept it in the limelight till date is its cost-effective ability to communicate by both power lines as well as radio frequency whereas the decline over the years in its popularity was due to its inability to send the concurrent commands with extremely low data rate issues at the same time. Too many concurrent signals at a time results in a poor performance due to decoding problems & loss of signal.

It consists of the 4-bit binary code superimposed with the power lines depicted by Figure 6 [24] where the presence & absence of 1ms bursts of 120 kHz square wave determine the binary 1 & 0. It can support up to 256 address nodes for the devices with 16 House codes x 16 key codes.

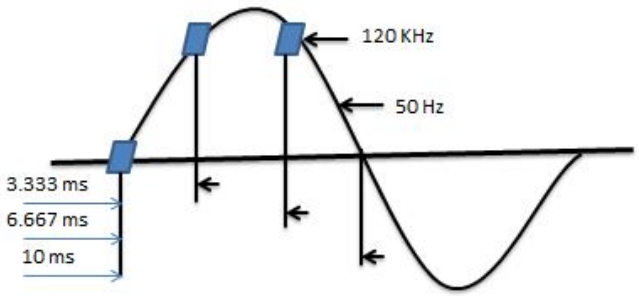


Figure.6 Burst Imposition on the power lines [24]

3.1.2 Telephone Lines Based Systems

Telephone [13] line based systems are not as robust as their counterparts are. They are dependent on the extensive wired architecture which makes them costly & are most likely to be seen in the intercoms that were being deployed many years ago. They have been designed with complexity as well to avoid the network failure in case one of the lines get disconnected. Moreover they work on the Dual Tone Multiple Frequency which is added to circuit separately via DTMF encoder decoder IC. The problem with such systems have been their inaccuracy, latency & pain of remembering the access codes as well. They have been improved in terms of DTMF algorithms & wired topologies & architectures but they still have those disadvantages with only significant improvements in the latency & connection drop department.

3.1.3 Java Based Systems

Java [11] based systems monitor & control the home devices using the world wide web where a stand-alone embedded circuitry is connected to the PC via LAN cables. The system is robust & even involves a valid user interface along with remote monitoring via Internet. But the problem persists when the cable network fails & cuts off the whole system. It is based on extensive wired architecture & the interface is developed using the combination of Java, HTML & Java-beans. The system is complex & doesn't provide editing controls to the user if his demands vary.

3.1.4 Bluetooth Based Systems

It is very important for a wireless protocol technology to work robustly in the cluttered environments. The functioning of Bluetooth [12] to back up its short range communication capability very much lies in the adaptive frequency hopping (AFH) & forward error correction (FEC). It provides secured communication with a good data rate of 720 Kbps to 1 Mbps that has the capability to support the multi-media activities in an automation environment by replacing the RS-232 cable (Which was the original idea). It supports up to 8 devices in a single network which can extend up to distance of 10-30m approximately while working on the master-slave concept. It operates in the ISM band 2.4 GHz shown in Figure 7 [12] with 1 MHz bandwidth for each channel.

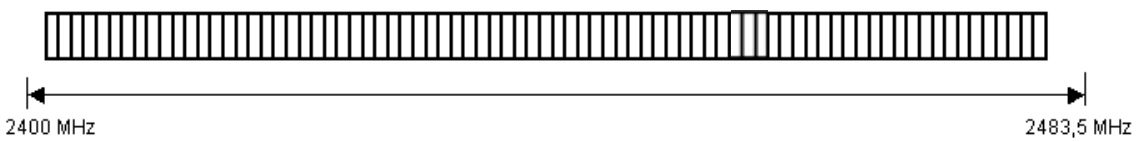


Figure.8 Bluetooth operating band with 79 channels for frequency hopping

Bluetooth is very much limited in its utilization in the field of smart home automation as the disadvantages outnumber the advantages. It not only includes the problem of one-to-one pairing with but also suffers from the interference due to the other existing standards in the same ISM band, moreover so the microwave oven also operate in the same band, thus link breakage & latency problems are frequent during its operation.

3.1.5 Z-Wave based Technology

Z-wave[9][31] has similar operation as of ZigBee but it is far more complex. Z-wave uses the ISM band of Europe i.e. 868.2 MHz with Gaussian Frequency Shift Keying (GFSK) but with new radio family of Z400 introduced in 2009 2.4 GHz ISM band can now also be utilized. The data rate supported is 10kbps to 40 kbps & range up to 30-40m. Scalability & reliability questions have always been there for the Z-wave to be accepted widely. While using as the repeaters the Z-wave can only hop up to 4 nodes beyond which the signal is dropped & thus making it fairly limited in its capability. The channel width of the Z-Wave spectrum is either 300 or 400 Khz depending upon the country's telecom regulations. Even the audio transmission in relatively difficult in automation industry using the Z-wave due to the low data rate.

3.1.6 Wi-Fi Based Technology

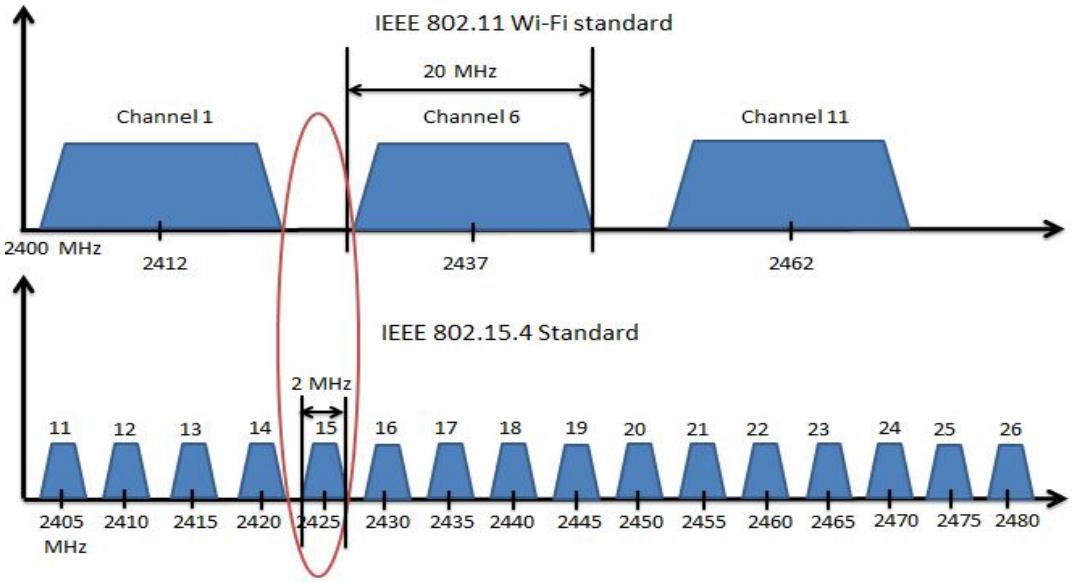


Figure.8 Channels of IEEE802.15.4 & IEEE 802.11

Wireless Fidelity, known as Wi-Fi [15][16][17] is an IEEE 802.11 based communication protocol which is specially designed for the high speed data short-range

communication. It can support up to 54 Mbps of data rate. Out of all the wireless technologies available, WiFi consumes the maximum power because of its relatively long range of up to 100m. The available bandwidth of Wi-Fi is 22 MHz, however IEEE 802.11b is prominent for the expensive multi-media based smart home automation technologies. Wi-Fi & ZigBee existing together have interference issues as shown in Figure 8. The performance of the system drop down to 41% while there is no such inference when Bluetooth is employed.

3.2 Comparison of the technologies

Before going in depth of the proposed system, it is important to understand the importance of the selected technology.

Table II.

Comparison of the available wireless standards [9]

Characteristic	ZigBee	Wi-Fi	Bluetooth	Z-Wave
Data Rate	250 Kbps	Up to 54Mbps	Up to 1 Mbps	40-100 Kbps
Nodes	65000	32 for 802.11b, Varies for MIMO Based	7	232
Range(Line of Sight)	70-100m	100m	10m	30-120m
Air Interface	FSSS	OFDM/DSSS	DSSS	FSSS, Manchester NRZ
Modulation	Oqpsk	M-psk/Qam	GMSK	FSK
Latency	30ms	Up to 3s	Few seconds	Up to 100 ms
Operating Frequency	2.4 GHz Band, 915 MHz, 868 MHz	2.4 GHz ISM band	2,4 GHz ISM band	ISM band part 15, 908.25 MHz
Comparitive Power Consumption	Low	High	Medium	Low

The greatest advantage of ZigBee is its flexibility as the application software can be reconfigured to support different applications like automation, smart energy, health care, remote control, etc. according to the need of user. Table I highlights the key differences between ZigBee and other wireless standards primarily used for HAS. From the table, it is quite apparent that ZigBee and Z-wave[9][10] are favorable standards due to their low cost deployment and low power requirements. However, by far ZigBee is more versatile than Z-wave as it can be deployed and developed for virtually any short range wireless communication. Although it has a slightly more complex protocol architecture compared to Z-wave, However it is more widely available as Z-wave is only available in 22 countries till date [9].

Moreover, X10[9] is the oldest industry standard which was developed in the 1975 establishing a communication between the electronic devices using power lines. Java [11] based systems have also been developed where the electronic devices are controlled via a web server based PC however it requires extensive wired installations which is certainly not a cost effective solution. Bluetooth[12] based home automation systems provides good amount of data rate and security but incurs latency issues and

Table III.

Comparison of the already existing Automatiion technologies

Technology Type	Advantages	Disadvantages
Java Based[11]	User Interface, Secured, Reliable	Complex, Costly, Extensive Wired installation
Wi-Fi Based[16]	Accurate , Fast, Supports Multimedia, Interoperable	High power consumption, complex, costly
Phone line based[13]	Easy access, simple, Remote access	No GUI , user has to remember access codes, Wired Architecture.
Bluetooth based[12]	Secured, Supports Multimedia	Medium power consumption, Pairing, supports up to 7 nodes only.
ZigBee Based	User Interface , interoperable, easy , Cost effective simple implementation	Link Breakage problems, Interference issues ,No multimedia support, Low data rate
Home gateway web server based[15]	User Interface, remote access, accurate, Fast.	Costly , Dependent on Internet.

one-to-one pairing which make them less efficient to be utilized in automation scenarios. Telephone lines [13] based systems are heavily dependent on separate telephone cable architectures which again requires heavy cable installation with no graphical user interface and furthermore it also involves the pain of remembering numerous access codes. A hand gesture [14] based automation and control system give rise to user fatigue and inaccuracy problems. Home gateway [15] systems are also used in various homes and industrial applications to interconnect the private area network along with the public network or Internet but they consist of very complex architectures. Wi-Fi based [16][17] systems are efficient and interoperable but they suffer from higher cost and comparatively high power consumption. Table II summarizes the advantages and disadvantages of various technologies that have been predominantly used to implement a HAS.

Chapter 4

Proposed Architecture

4.1 Graphical view of the problem & the solution

Figure 9 below reflects the problem in a pictorial manner that this thesis is intending to solve. It can be distinctly seen from the figure how a crippled woman is helpless to operate her own house.

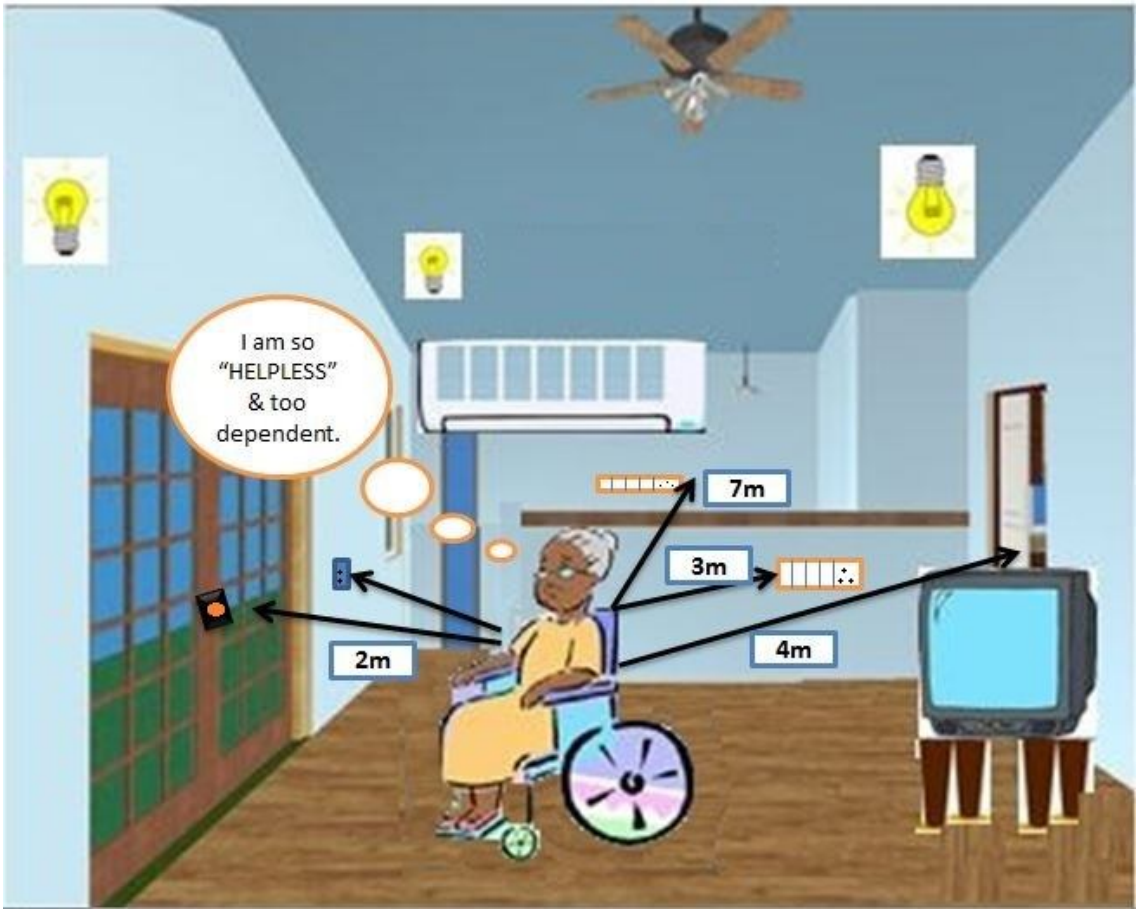


Figure.9 Graphical representation of the problem in general. [36]

So the above problem can be solved by the system that we have titled as "Helper". Figure 10 shows the pictorial representation of the solution where not only the crippled but every possible type of case can be taken in the account for.

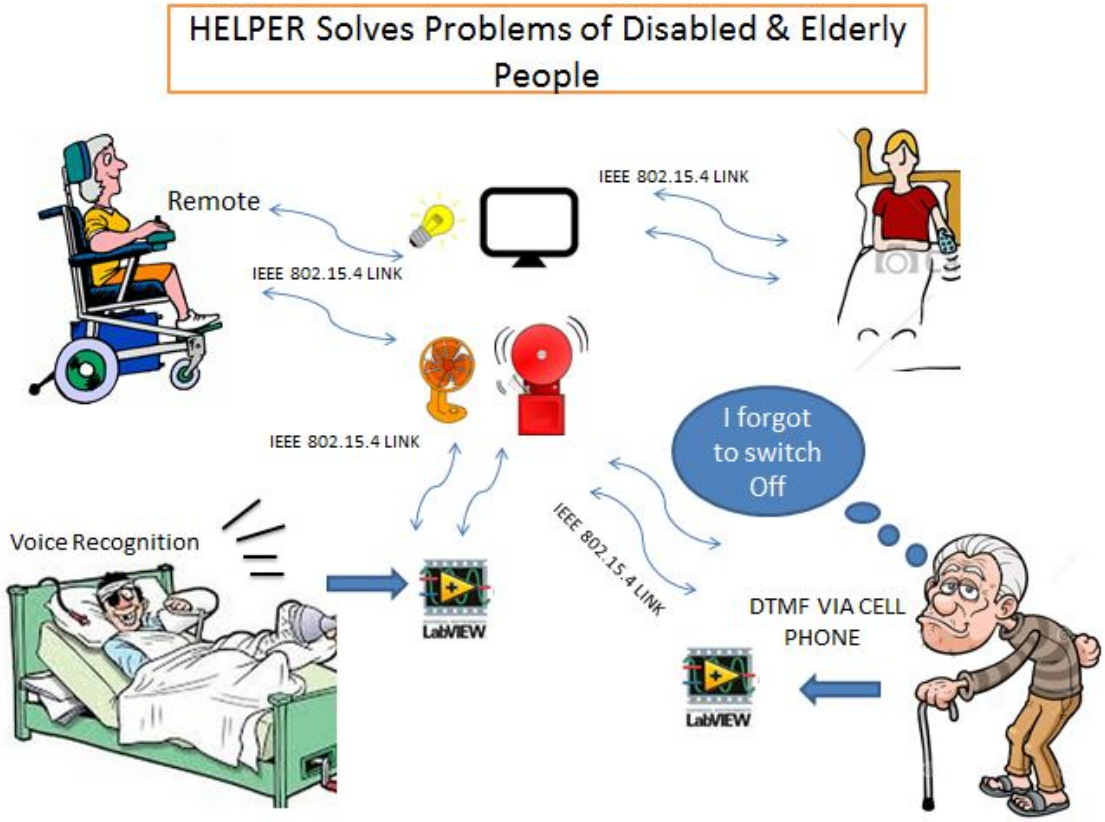


Figure.10 Graphical representation of the solution in general. [36]

4.2 System Architecture

Most of the assisted living based works [16][18] use sensor based devices to shift the dependency of the elderly and disabled to the machines, however excessive use of assisted devices might adversely affect the well-being of the user [6]. Figure 11 shows the possible side-effects of excessive use, with lots of devices, wires and sensors around one can really feel uncomfortable. In the proposed work, depending on the user requirement, input can be configured. For instance, if a person is blind then a remote with braille keypad and speech recognition is provided to control the home devices If Internet is unavailable, then all the devices can be controlled and monitored via cellular call. If a user is handicapped or armless then in-voice response system can be activated and intended devices can be controlled using speech recognition. Similarly there are other ways like direct DTMF (dual tone multiple frequency) tones[19], type mode and cloud instruction mode which not only let the users to control the devices from inside the house but remotely as well depending on the comfort of the user.

This work also includes a text messaging and alarm system combined with multi-task automation which paves way for a low-cost, power efficient, portable, secure and flexible solution. Moreover, it also includes a monitoring device which is specifically designed to display the status message and monitor the network by getting a feedback from other end

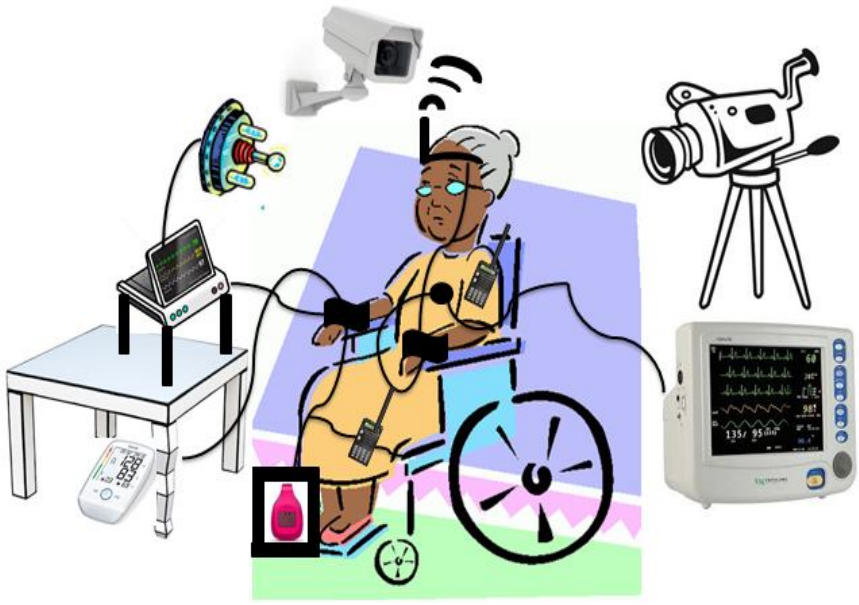


Figure.11 Side-Effects from the Excessive use of the Assisted Devices[36]

devices. The proposed work is also global and unique in the sense, that it could be easily integrated for home, office, factory and network monitoring environment.

In order to prevent unauthorized access to malicious devices, all the devices connected to the network are equipped with Personal Area Network ID (PANID). A device will be able to access the network if and only if it knows the PANID. Furthermore, if someone deliberately breaks in the system, the monitoring unit will display the unauthorized access.

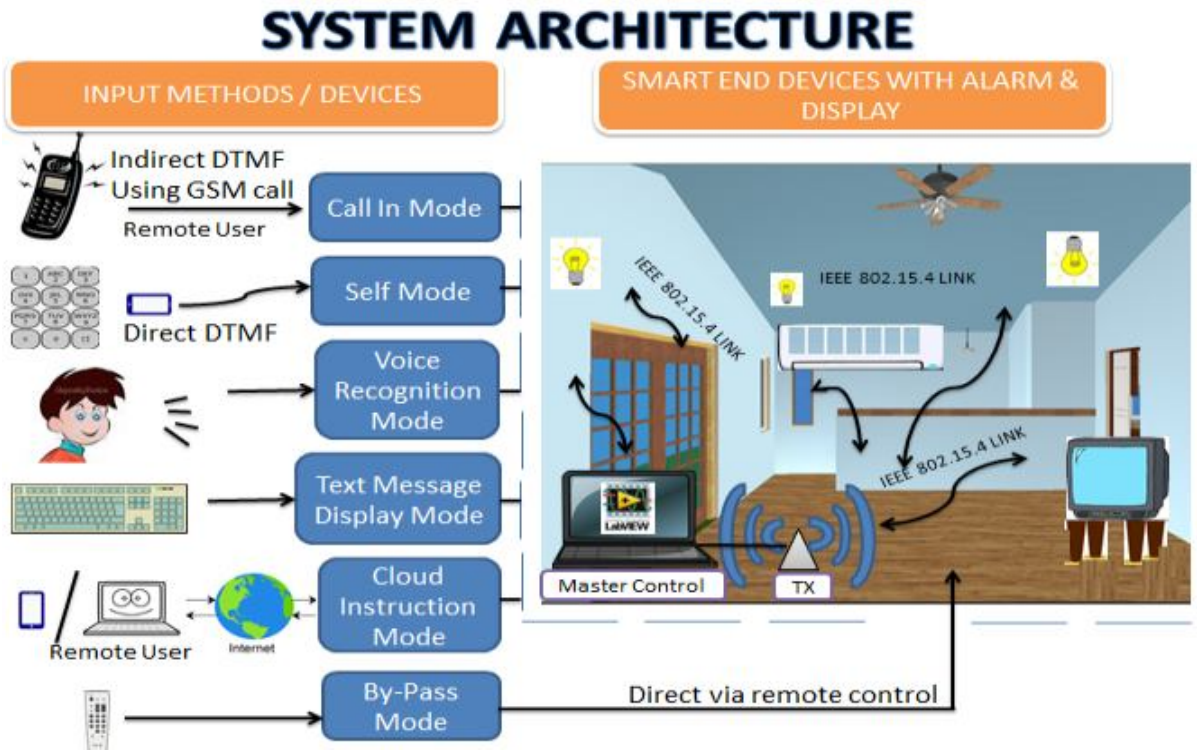
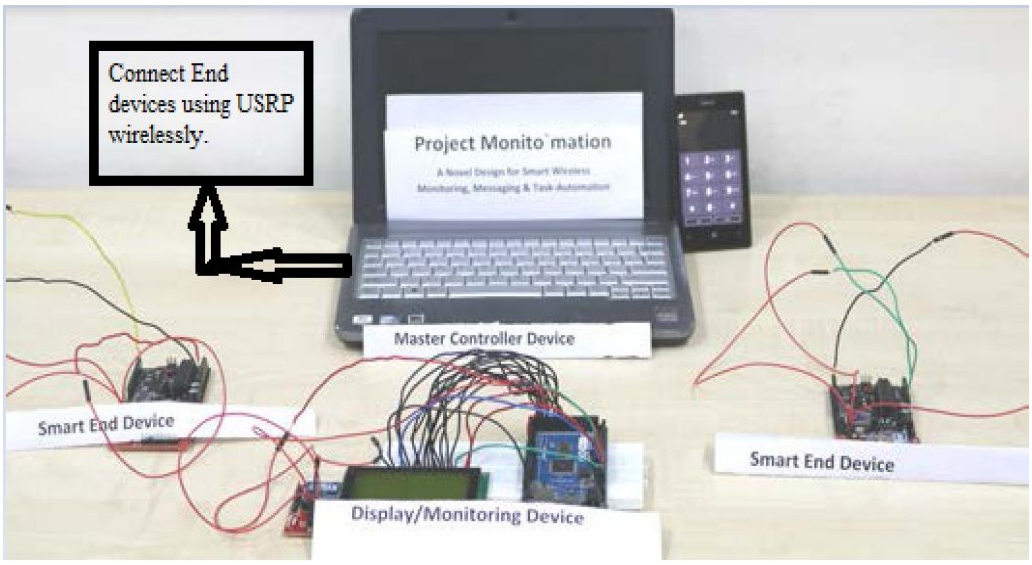


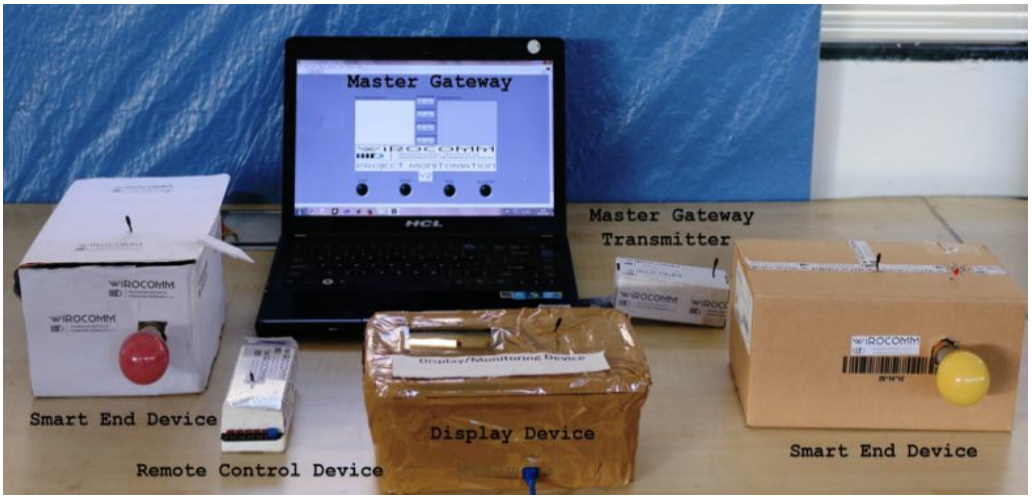
Figure.12 System Architecture Depicting the input flexibility [36]

The software for the project is developed using NI LabVIEW[21]. The main benefit of using NI-LabVIEW development environment is the software patching/updating part. Thus, developing user-defined custom applications also tend to become a lot easier as compared to other current software development kits (SDKs) available, due to its modular nature. The multiple input availability is the highlighting feature of the work presented in this work which brings out the flexibility of the system efficiently. The prototype also has an option to activate or deactivate any device except the display. The system architecture shown in Figure 12 depicts all the input options that have been incorporated in the implementation. It is then followed by the algorithms which are deployed in the software for different input methods.

4.3 Hardware Description



(a)



(b)

Figure.13 (a) Prototype showing unboxed raw configuration
(b) Prototype showing the final complete set up

For the DTMF feature to function properly there is no need for any external DTMF module as employed in the previous work [22], however the smartphones being deployed must have DTMF tones enabled in their keypad as shown in the Figure 13. There is a need for at least a Microphone or double headed Tip-Ring-Sleeve connector for higher accuracy.

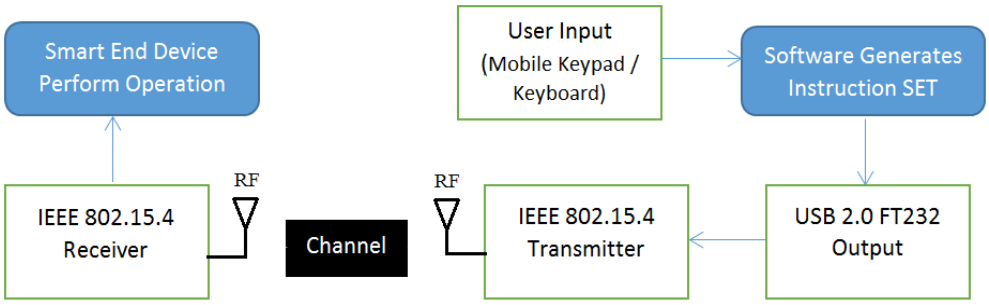


Figure.14 System Communication Block Diagram

Figure 14 illustrates the system block diagram where the receiver and the transmitter blocks are comprised of ZigBee modules. The LabVIEW decodes the user input and sends the corresponding instruction through Universal Serial Bus (USB) ports to the transmitter module. The baud rate can vary between 2400 – 115200 b/s [20]. The instruction is then received by IEEE 802.15.4 receiver, thereby enabling the end device to perform its intended function (as shown in Fig.14). The Atmega2560 and Atmera328 microcontrollers, 2 Relays, 2 Piezo buzzers, Two 0 watt bulbs, 1 DC motor, arduino board, Xbee soc with shield & connecting wires are used in this work.

4.4 Software Description

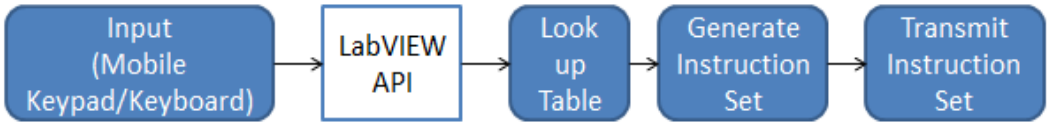


Figure.15 Software Instruction Flow Graph

As seen from Figure 15 the software once it gets the input from the user, it will traverse through a look-up table to find whether it's a one of the controlling inputs or not. If yes, then it will parse it in form of a standard instruction and transmit, otherwise it will send that input as a text which will be displayed in the form of a text message on the monitoring device. The end devices are dynamically programmed to gather all the transmitted data in the channel, however to act only when they are instructed to do so, thus making them smart. The software has an astute design that is capable of accommodating various inputs from the users and can be reconfigured whenever required.

4.5 Description of Input Methods

A brief explanation of all the possible inputs is given below.

a. Control Through a GSM/CDMA call

This feature will help the user to control the devices off-line (through GSM/CDMA calls). As long as the user is connected to the mobile network he can control and get status about each and every device connected to the network. This control works as follows: the designed central gateway will sense the Dual Tone Multi-Frequency (DTMF) [13][19] tones and will convert them to an instruction set for the network devices. Then the intended device will perform the desired function as reflected by the flowchart in Figure 16(a). The significant feature of this method is that any phone or landline capable of generating DTMF mobile keypad tone can be used.

b. Control through Remote control

A provision of a remote control device is also made with which the user can control the devices in a room directly. Moreover, a distress alarm has also been incorporated in this remote control device which will help a bed ridden patient or senior citizens to call for assistance during an emergency. This remote control device can also be integrated with biosensors, like heart rate sensor, body temperature sensor, etc., in order to enable one touch access to these vital parameters. The motive behind the sensor slot is to meet the variable requirements of the user and reduce the excessive use of the assisted devices. While using this mode of control the central device gateway should be in bypass mode so that the The remote control key can be easily engraved by the Braille words so that even visually impaired people can use it

c. Control Through Voice Command

This feature will be an on-demand feature of the implementation which can inferred from the flowchart in the Figure 16(b). For using this feature the user has to record his voice command samples so that the devices will be switched only when he intends to do it. This can act as a boon to the handicapped and bed ridden patients, so that just by their voice they can activate or deactivate any appliance.

d. Control through Internet

The master gateway [15] can be connected to the Internet for the users who want to use the Internet (through an app/email/Voice over Internet Protocol (VoIP)) as the mode of network instruction input. Then as the flowchart in Figure 16(c) suggests a user has to activate the Internet mode and then he can access the software via remote desktop connection. It is also possible that one can simply control and get status of each device through an email by typing the instruction in the Internet cloud mode.

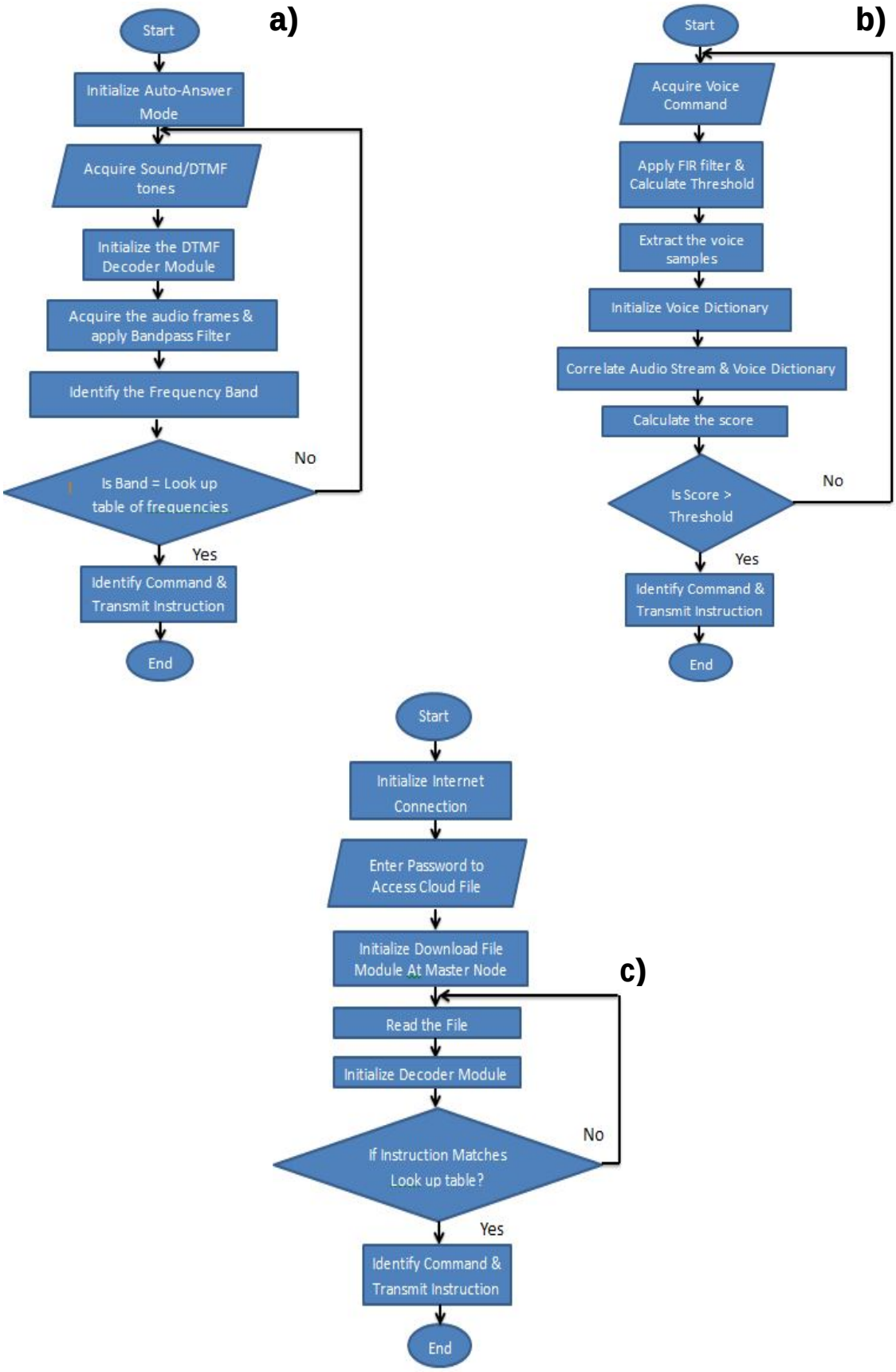


Figure.16 (a) Flowchart for Voice call/DTMF call mode as input
(b) Flowchart for Voice Command mode as input
(c) Flowchart for Internet/cloud instruction mode as input

4.6 Selected Features

Apart from the various input option, the proposed implementation has numerous additional features which can certainly fulfill the day to day needs of elderly and disabled but the most important features are Power on Self-Test and security

- Unlike the previous implementations [13, 14, 15, 16], we have included a Power On Self-Test (POST) feature where each node when powered up, (or turned on) will try to complete a switching cycle with all the nodes connected to it. It will once switch On and then switch Off each device. If this cycle doesn't get completed, then it will send a feedback signal to the central gateway & the user will be notified accordingly

  Need: POST has been included to allow the users to have a quick check on the receiver end devices for any discrepancies before executing any automation tasks.

- In the proposed work we also have a feedback path between the central gateway and the end devices which allows any individual with the master control to inform all other in the same home/building by messaging across the network which will be displayed on the central display.

  Need: The device status can be controlled/operated manually as well as by the helper system, so to display the right status information a feedback path is necessary to keep the master computer updated with the right device status.

- In the cloud based control, the user need to login to edit the command file saved in storage box whereas the voice instruction control is based on user's accent and tone.

  Need: This feature brings out the security of the voice driven input option.

- For the cellular call based control, one needs to remember the access code and the user will have the option to allow only a specific cellular calls to access the system, using the block-call and auto-reply feature.

  Need: This feature brings out the security which this input option offers.

Chapter 5

Implementation Details

5.1 HELPER Transmitter Circuit Details

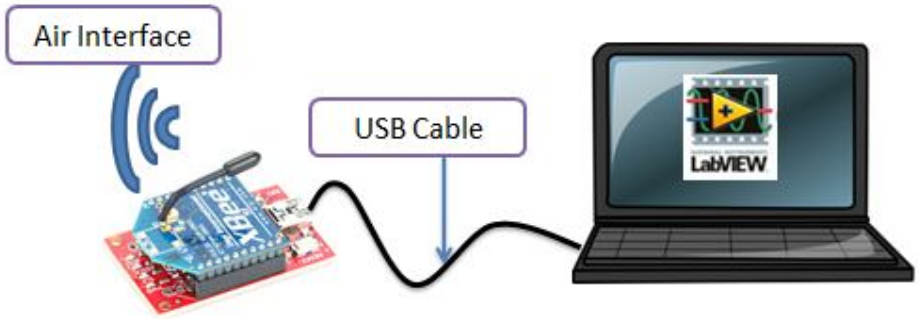


Figure.17 XBee with Shield directly connected to the PC via USB cable [36]

The HELPER transmitter circuit, which can be seen from the Figure 17, is simpler than the receiving end devices as it needs only one radio to be attached using OTG or the USB cable. The XBee is programmed using the embedded C to take the serial input from the PC & transmit the instruction in a broadcast manner. There is no rocket science behind transmitter configuration but simple logic to transmit on an already selected channel of IEEE 802.15.4 (Which will be discussed in the evaluation section).

5.2 HELPER Receiving End Device Circuit Details

The HELPER receiver circuit involves a careful connection of the components & sensors to the arduino board. The Figure 18 below shows the circuit diagrams of one of the end devices where a 0 watt bulb is connected along with the Buzzer tone. The components which are digitally driven i.e. 5v is enough to drive the component, they are connected directly to one of the digital pins with ground as other terminal where as high voltage driven components such as a 0 watt bulb, cannot be connected directly to the arduino board. It is indirectly connected with the help of a relay which closes & open the circuit of the bulb, thus allowing it to be toggled as per the transmitted instruction. The main receiving radio is Xbee SoC, whose Digital in Pin is connected to one of the inputs of the arduino board & instruction matching with the programmed microcontroller will be carried with the respective component connected to the intended pin, otherwise it will be discarded.

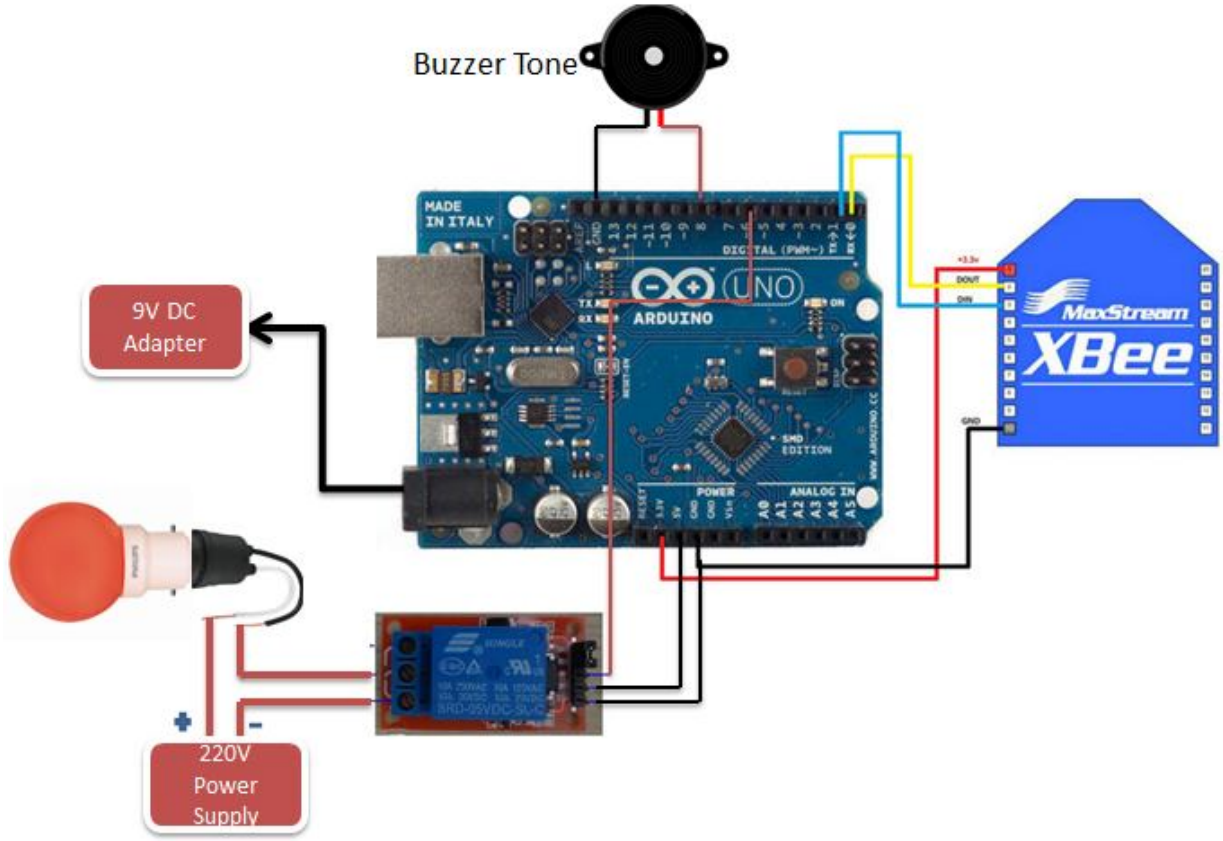


Figure.18 XBee connected as receiver to one of the end device circuitory.

5.3 ZigBee Test-Bed

To demonstrate a qualitative proof of assessment of the implemented system, a series of experiments were conducted via a ZigBee test bench as shown in Figure 18 which was created in the communications lab at IIIT Delhi campus. The focus was more to extract the observations that defines the quality of service by creating the reference benchmarks, in terms of the system response time (SRT), received signal strength (RSSI) variation under cluttered scenario, for different ZigBee operating channel selection and signal-to-noise ratios (SNR). In order to get more realistic data, the tests were done during the working hours of the week. The system performance was deliberately tested under was more chaotic and heavily cluttered environment to replicate a worst case scenario. The Figure 19 shows the layout of the Communication Lab where the human as well as non-human presence is there. The Wi-Fi access points are also laid out so as to distinctly signify that the interference performance has also been taken into the account.

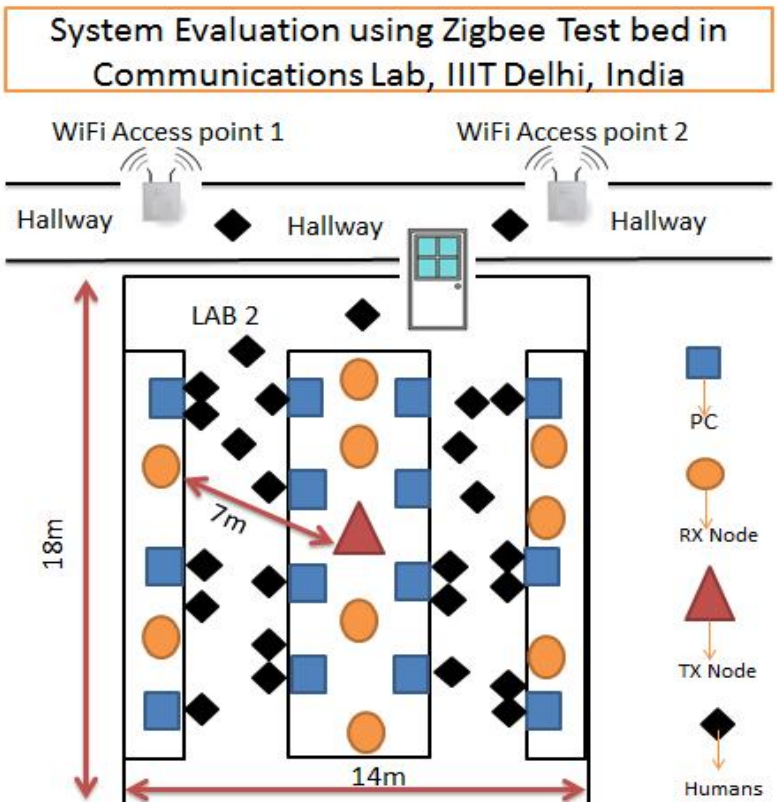


Figure. 19 System evaluation and analysis using the ZigBee test bench created in IIIT Delhi, India.

5.4 System Evaluation

5.4.1 Delay Analysis

The system response time [10] gives an outlook as how the propose implementation tend to work even in the worst possible scenarios. A time stamp module was encoded at the transmitter and received at the receiver module to calculate the system response time. The end devices used for testing purpose were: 15 watt bulbs, dc motor fan, Light Emitting Diodes (LEDs) and buzzer alarms. Liquid Crystal Display panel was used as a monitoring and display device. The observations of the implemented system were slightly different both in the Line-of-Sight (LOS) and cluttered non-Line-of-Sight (N-LOS) scenarios. The average time delay of the system gives an insight on to how swiftly the end device reacts to the commands of the centralized master computer or the remote control device. As evident from Figure 20 it takes an average 614 which is an average of the values observed from 15 trials carried out on 3 different days in cluttered condition which the past work [3, 16] have not taken into account. It i--s quite obvious that the response may well be decided by the type of end device, however SRT gives an insight on the optimal behavior of the device to process an instruction. In this

work, total three number of attempts are allowed to the transmitter until the reception of positive acknowledgement.

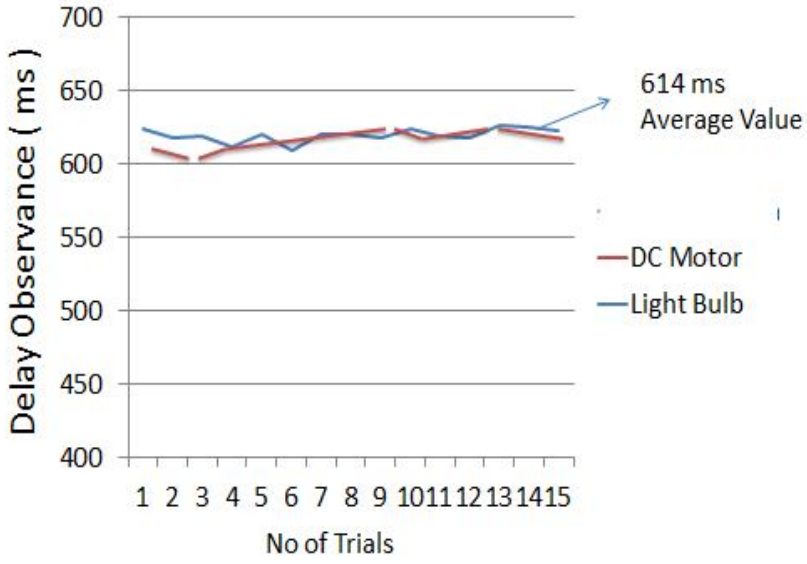


Figure. 20 Average System Delay of the Implementation

5.4.2 Channel Selection

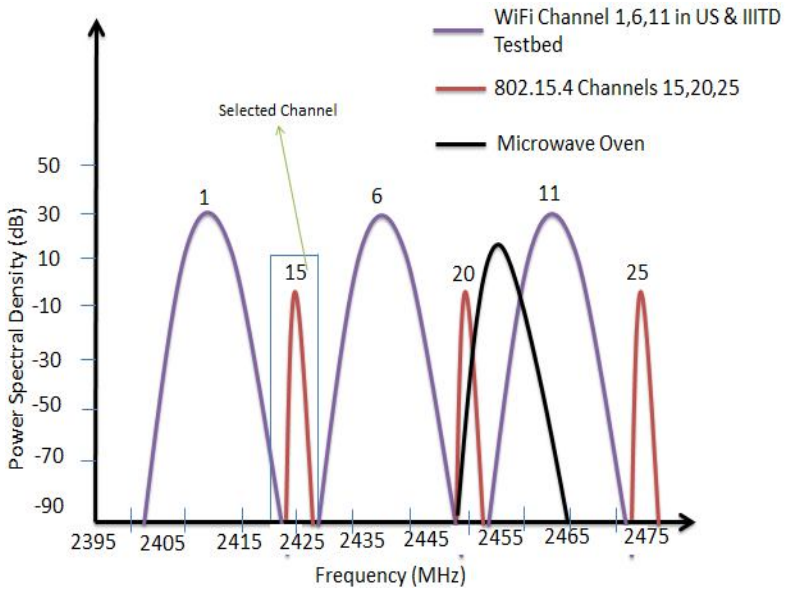


Figure.21 Wi-Fi and IEEE 802.15.4 Channel coexistence.

Channel selection is very important especially in the 2.4 GHz band where other services such as Wi-Fi also operate. The coexistence of the two standards doesn't create any problem in the communication unless the channels designated to the respective standards overlap with each other. The Wi-Fi channels 1, 6 and 11 don't overlapwith each other however coexist [17] with the channels 11-14, 16-19 and 21-24

respectively of the IEEE 802.15.4 standard. Consequently the channel number 15 is chosen as it is free from any major interference from IEEE 802.11 standard within the 2.4GHz band. Also, the channel number 20 of the IEEE 802.15.4 overlaps with the microwave oven operating frequency which can definitely hinder the system response performance. Figure 21 & 22 justify the selection of channel 15 for our operation, of which the center frequency is 2.425GHz.

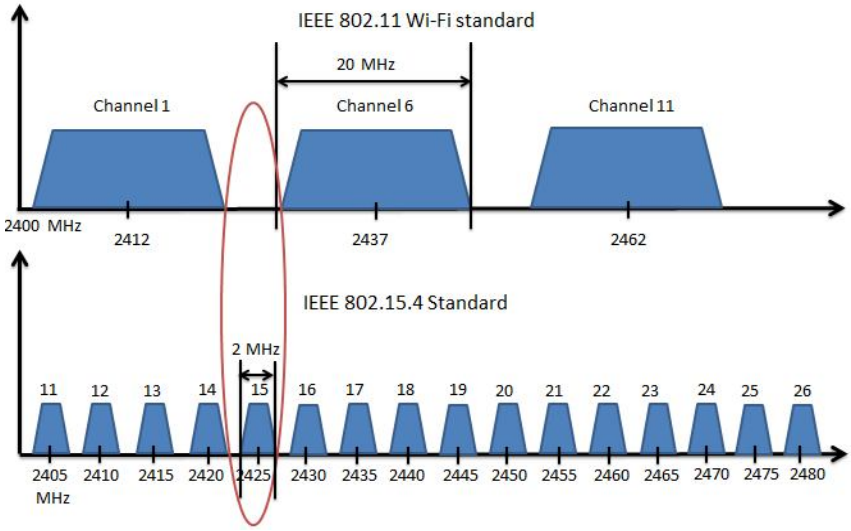


Figure.22 Channels of IEEE802.15.4 & IEEE 802.

5.4.3 Received Signal Strength Analysis

The parameter RSSI is very handy in determining if the performance of the implemented system is optimal or not. To carry out the calculation of received signal strength, various trials and the measurements were compared with the threshold of -85dBm. The threshold was calculated by monitoring the spectrum of channel 15 of the IEEE 802.15.4 using Universal Software Defined Radio Peripheral (USRP- 2922) [21] by National Instruments at the center frequency of 2.425Ghz and X-CTU software range test. The experimental flow chart in Figure 23 signifies that the received signal strength values were observed using the receiver node and USRP then it was plotted with the distance for different transmitted power values. The evaluation was carried out during the busy hour of the lab, in order to get the "worst-case" behavior of the proposed system. The USRP scanned and monitored the channel 15 of the ISM band i.e. 2.425 GHz (for ZigBee) to check for a valid signal and subsequently recorded the signal strength with each frame sent on the channel. After the noise floor value was calculated, the received signal's strength was compared with the noise threshold and the validity of the signal was established and correspondingly recorded.

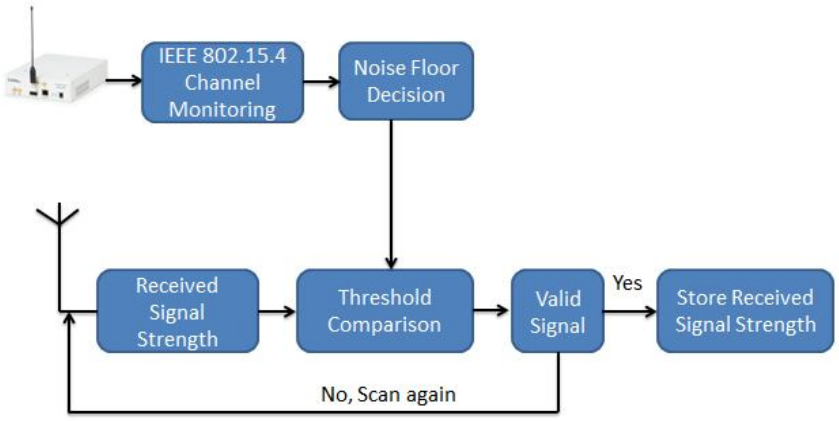


Figure.23 Flow graph of the received signal strength test.

The distance(m) vs. RSSI(dBm) data for heavily cluttered scenario was collected, to check whether or not the nodes are getting below -85dBm of received power to check for the successful packet transmission. ZigBee mesh network topology has been followed in this work in order to successfully connect maximum nodes .Transmitted and received power certainly affects the range of the communication between the two communicating devices which is evident from the Figure 24.

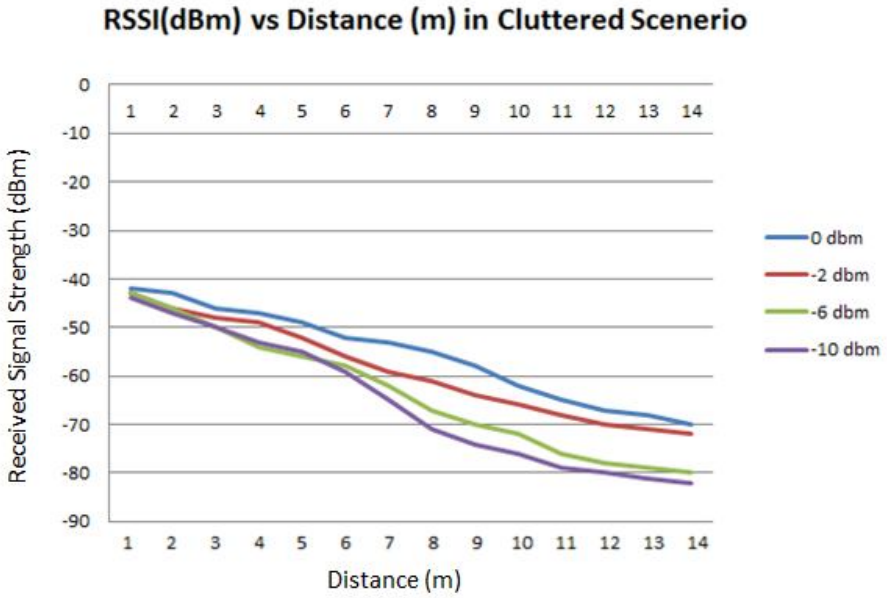


Figure.24 RSSI vs. Distance plot for different transmitted power values

5.4.4 Packet Drop Analysis and Selecting Optimum Baud Rate

To select the optimum rate, 1000 packets were transmitted with each baud rate using the ZigBee test bench and it was observed that with lower baud rate lower number of packets are dropped which is evident from Figure 25. Extremely low baud rate may result in zero packet drops but data transfer rate is adversely affected. So, keeping the text messaging feature in the view, baud rate of 19200b/s was chosen which provides good data transfer along with almost negligible packet drop.

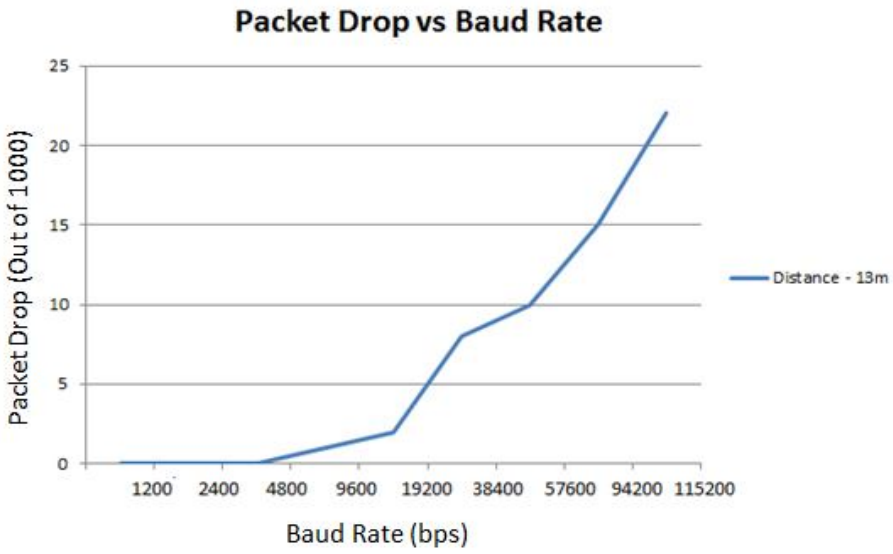


Figure.25 Number of packets dropped out of 1000 for different baud rates.

5.4.5 Interference Analysis

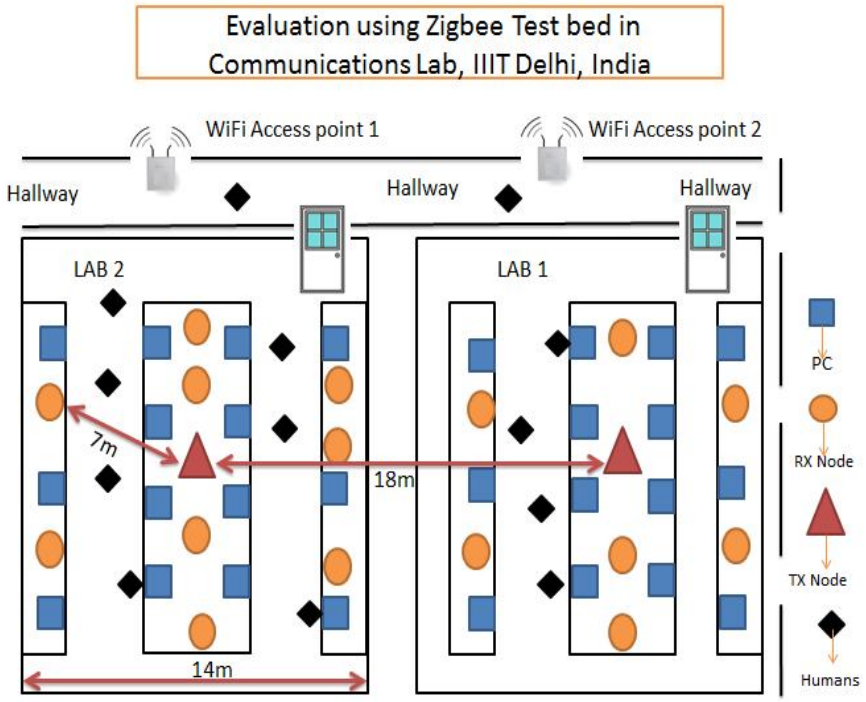


Figure.26 Experimental setup to analyze the effects of two similar networks when placed adjacent to each other.

The purpose of this work is to investigate the impact of interference when the same system is used in places (for ex. homes, offices, hospitals etc) adjacent to each other on the same number of channels. A simple experiment was conducted at the ZigBee test-

bench in IIIT Delhi to observe the effects of two similar ZigBee network which were separated by around distance of 18m and placed adjacent to each other as shown in Figure 26. The configuration immediately showed signs of interference and very little communication could take place because both the systems were assigned channel number 15 as described earlier. However at about 30-35m distance, both the systems could function properly exploiting the concept of frequency re-use. Also, when different channels were assigned, both the systems adjacent to each other were able to perform normally as there was no significant effect on the either packet drop or RSSI values. Thus, such ZigBee based systems are quite robust to interference issues as the transmitter nodes have the capability to select the idle channel.

5.6 Possible Test cases & brief discussion

Scenario-1 - Importance of the delay analysis or when the delay reading is different from the 614 ms.

The delay is not just transmission & reception time difference but also includes the no of successful attempts & time taken by the hardware. The excessive number of retransmissions can cause large delay which means that the transmitter at master computer while re-attempting, will have to wait little longer to receive the sensor data or the device status data. For instance, if too many retransmissions are allowed at the transmitter, to reattempt for a successful transmission in a highly cluttered scenario with larger distance between the nodes, then it is highly likely that due to the re-attempts it may not notice the multiple changes in the device status or sensor data. That is why the delay comparison with [3][16] has been mentioned which results due to the same reason. In this work we have allowed only three number of attempts & 614 ms was the average reading which was observed for proper functioning of the helper system.

Scenario-2 – When delay analysis problem is addressed using the tree topology.

The scenario 1 problem can be addressed in an alternative way where a ZigBee tree configuration can be utilized instead of the star topology. In the tree configuration one or more ZigBee nodes can act as routers i.e. nodes capable of hoping/resending the message further & increase the range of communication. Such configuration will shift the responsibility from the master computer transmitter, of receiving the acknowledgment from the end device nodes to the routers, which will thus allow the master computer transmitter to stop waiting & receive data from other sensors/nodes at the same time. It was observed that with increased distance the received signal strength didn't degrade much because of the routers. But this increased range comes at a price of having expensive ZigBee routers which contains larger RAM. Therefore, it violated out critical aim of having a cost-effective solution.

5.6 Real Time Evaluation in Dispensary

The prototype was tested in the IIIT Delhi dispensary to simulate the real time environment. The Figure 27 shows the experimental set-up which consisted of a master computer, a ZigBee remote control & three wireless nodes placed in the dispensary of dimension 4m x 2m. The three nodes are as follows: a display end device, a distress alarm device & a bio- sensor placed at 1.37m, 2m and 1.2m respectively from the master computer. The distress alarm device used a bulb & a buzzer to alert the care taker in case of emergency while the bio-sensor monitored the blood pressure of the patient. The prototype worked accurately with DTMF, voice command, remote control & cloud instruction mode.

Figure.27 Prototype Set-up in a dispensary

5.7 Cost Analysis & Comparison with recent work

We have done cost analysis through leading electronics import channels (1999-2015©Alibaba- Alibaba™ and 2006-2015©DealeXtreme- Dealextreme™) [32][33] for our work and came out with the following average pricing formula: (650 × a + 60 × b + 400 × c) INR, here, a=Number of controlling nodes, b=number of devices intended to be controlled, c= Number of Display device required. While concluding this formula we have assumed that we have ordered the components in bulk. The pricing analysis is done in Indian National Rupee (INR), which is also subjected to current currency valuation as compared to USD. Our work as shown in figure 3, has a cost of around INR 2800 (≈45$) excluding the cost of Gateway, which proves that our work is cost effective,

as compared to the current commercially available solutions of HAS, from the same goods import channel.

a) The work done in [15][16] has been more towards the sensor to utilize the ambience but on the other hand, not much of focus is given to reduce the dependency of the elderly & disabled. The self-esteem & motivation among such people can only be uplifted if control & monitor facility along with automation is provided to them & it is very well pointed by our work as well as the work in [6].
b) Moreover so, the cost is high in both the work due to ample utilization of the costly sensors & cannot be used by the low earning group so easily, rather the work is more suitable in the rich corporate parks & buildings where the professional environment has such needs for the clients & employees.
c) Also, there is no mention of the performances in the cluttered scenario & in the presence of the Wi-Fi access points. The latency issues are also not investigated with the deployment of the sensors. (The total reaction time of the wireless sensor nodes can be modeled as : Sensor reaction time + Transceiver response + CPU processing time.)
d) The work in [15] is bounded to monitor only whereas giving the complete control to the care taker.
e) The work presented in this thesis has combined all the input methods in a single user interface which eases out the complexity to the great extent. Whereas in [3][15][16] offline & online monitoring has not been considered.

Chapter 6

Current Work Extension & Future Work

6.1 Using Smartphone App

Currently a mobile app in under development & the research is being carried to let the operating system interact with the Phone-to-PC data transfer port so that using the On-The-Go cable, ZigBee SoC can be connected for the transmission/reception. Since smartphones are not provided with an IEEE 802.15.4 radio chip so with a tiny toffee sized XBee transmitter, all those functions which were being carried out by the Master Computer can also be carried out by the smartphone. It is assumed that the PC & the smartphones are available with majority of the people to complete the basic educational & technical needs. Figure 28 shows the snapshots of the app.

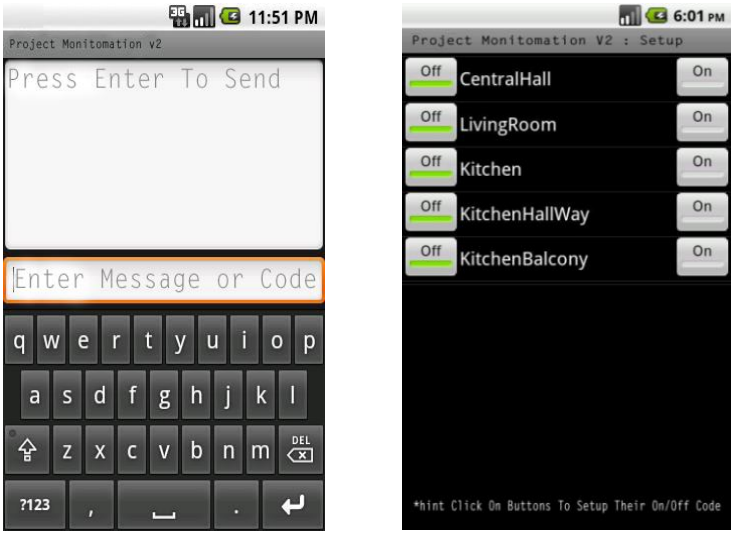


Figure.28 Future Mobile Version GUI

6.2 Complementary Learning Algorithm

A learning algorithm is currently under development to make the system more robust & intelligent so that it learns the action of the devices by the actions of the user. It has been a real challenge for the researchers to implement single algorithm to fulfill the maximum needs.

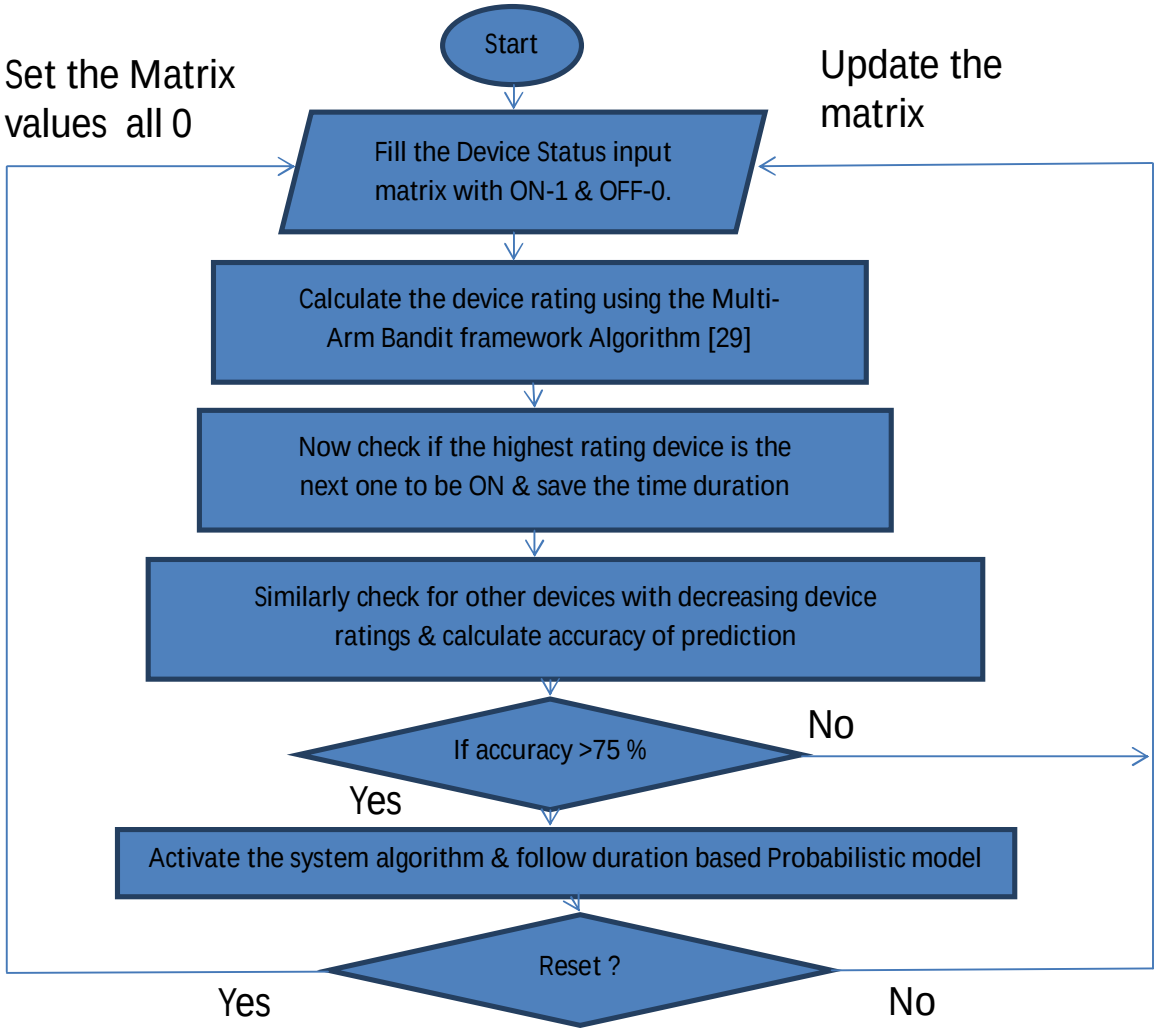
6.2.1 Brief Literature Survey

There have been many instances of successful learning algorithms like MAVHome [26]

project algorithm where the sensor based learning algorithms are implemented but the disadavantage is the cost as the sensors deployed are costly & without the sensors the addditiona circuitory also cost where the radio chips in conjunction with the embedded bodies like pie boards have been used. Data mining based approached have been prominent as well where the service [27] technique utilizes the graph theory' Kohonen algorithm to keep the track of the user's behavior. Another approach is scenario modeling [28] based where the authors have claimed to make the system self- sufficient by processing the feedbacks from the Occupational Therapists & the user itself, thereby then making the system learn from offline as well as online.

6.2.2 Current Progress

This thesis also has a running portion where HELPER is aided by a complementary learning algorithm which will learn the statuses of the device & when the accuracy of determining the statuses is greater than or equal to a threshold value of 75% then it will be activate to operate & automate the user actions without input. The proposed algorithm is reflected by the flowchart:



6.3 Providing Proof-Of-Concept for “Internet of Things” & justify the capability of Software Defined Radio for Smart Homes with ZigBee & Wi-Fi.

6.3.1 Software Defined Radios

A software defined radio [21], also known as SDR, is a radio frequency enabled communication device where the typical device components like modulators, filters, gain amplifiers & mappers etc. are implemented by the means of software. A typical example of software defined radio is a Universal Software Radio Peripheral [21] which is built for the research & analysis purpose to support various types of interfaces. For instance USRP series by National Instruments & Ettus research. SDR intends to solve the commercial wireless industry problems like interoperability of the standards, spectrum shortage & device to device communication failures etc.

6.3.2 Orthogonal Frequency Division Multiplexing

The OFDM [30] is a multiple access technique in which the high digital data stream is divided into sub stream and each sub-stream is transmitted using number of sub carriers.

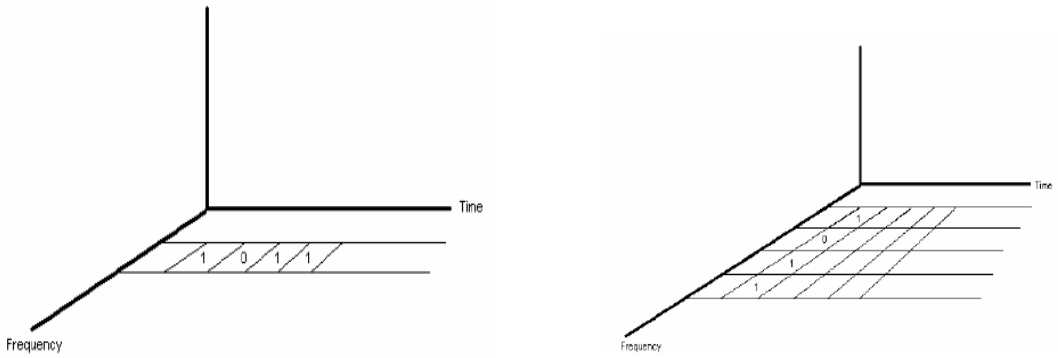


Figure 29 Single Carrier vs OFDM modulation[34]

The Figure 29 shows the transmission of 4 bit data using single carrier and the OFDM modulation. With increase in the transmission rate, the data reception time decreases but the delay time caused by multipath remains constant. This limitation in high data rate communication is ignored by sending low speed data simultaneously. Also the complexity of low date rate transmission is reduced as compared to single high speed data rate transmission.

Advantages:

1) The major advantage of OFDM is robustness against ISI(Inter Symbol Interference) and ICI(Inter Carrier Interference) using the cyclic prefix.
2) Increase in the spectrum efficiency by allowing many carriers to overlap.
3) The transmitted data-stream is divided in to many sub-streams and each sub-stream is send using different sub-channels such that is experiences flat fading and thus eliminates the use of equalizers as used in single carrier systems.
4) Channel equalization technique is simpler and easier using frequency domain equalization technique as compared to the time domain equalization technique.
5) Channel coding (COFDM) and interleaving can be used to recover the data bits lost due to frequency selectivity of the channel.

Disadvantages:

1) PEAK-TO-AVERAGE POWER RATIO (PAPR)[30]- The OFDM signal uses many subcarriers which when added gives large PAPR which causes nonlinear distortion in OFDM signal. This requires a highly linearity of amplifiers.
2) Decrease in the efficiency due to guard interval.
3) It is sensitive to frequency synchronization [30] problems.
4) The performance of the OFDM system is affected by frequency offset and timing mismatch which affects the orthogonality of the subcarriers.

Applications:

1) Wired- ADSL (Asymmetric digital Subscriber line) and VDSL (Very High bit rate digital subscriber line) broadband access using POTS (Plain Old Telephone System), PLC (Power Line Communication).
2) Wireless-DAB (Digital Audio Broadcasting), HDTV-Digital Video Broadcasting (DVB), IEEE 802.16 Broadband Wireless Access System, 3GPP UMTS (Universal Mobile Communication System) , LTE(Long Term Evolution) , IEEE 802.15.3a Ultra Wideband(UWB) , IEEE 802.11a,g,j,n (Wi-Fi) Wireless LAN, etc.

Difference from FDMA & TDMA:

The FDMA (Frequency Division Multiple Access) is a channel access technique in which each user is allocated one or many frequency bands. They were generally used in first generation telecommunication systems such as AMPS (Advanced Mobile Phone Service). They suffered from low user capacity, security problems. In Time Division Multiple Access (TDMA) many users uses the same frequency channel by dividing the data into number of time slots. They are generally used in 2G network like Global

System for Mobile Communication (GSM). There are some cons associated with TDMA. Firstly, an overhead is associated with the changeover between users due to time slotting on the channel limits the number of users. Secondly, the symbol rate of each channel is very high causing problems with multipath delay spread. OFDM eliminates the problems associated with FDMA and TDMA as it has higher spectrum efficiency and no overhead is required but the condition is that the subcarriers should be orthogonal to each other.

The Figure 30 signifies the construction of the OFDM signal at the physical layer :

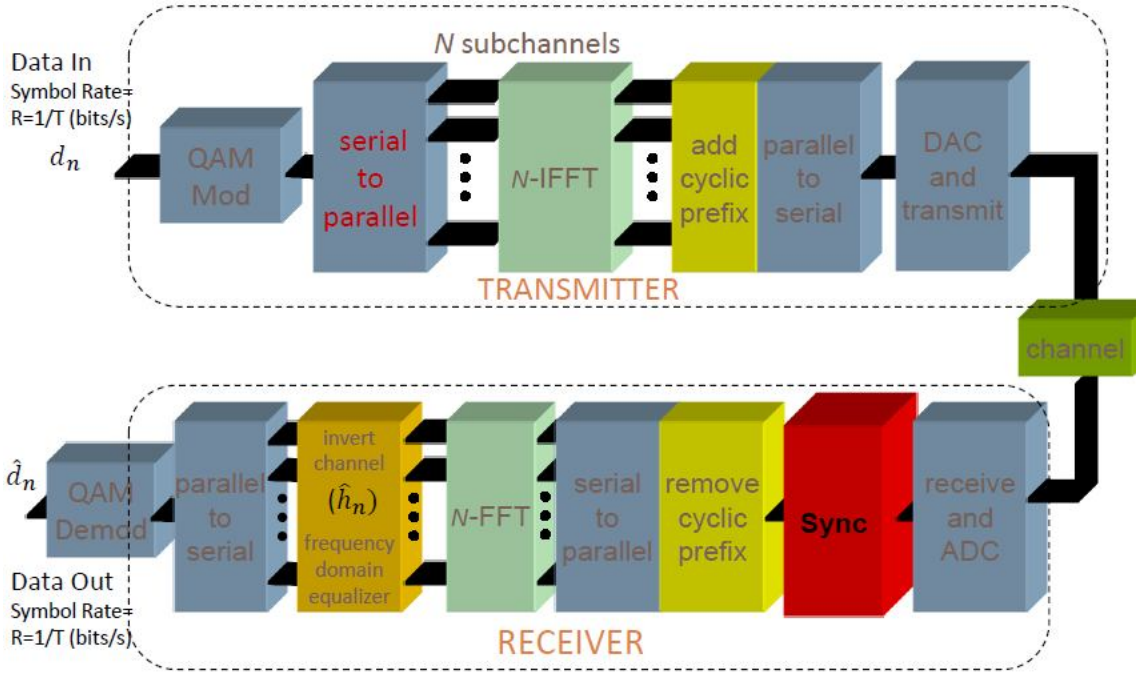


Figure 30. OFDM Baseband Block Diagram[34]

Source: Wireless & Cellular systems course, Winter 2014, ©Dr. Vivek Bohara, IIIT Delhi

6.2.3 OFDM based Wi-Fi 802.11a Implementation on NI-USRP Test-Bed

Wi-Fi protocol 802.11a [30] is based on OFDM & has specific parameters. The aim to implement the physical layer of the protocol stack was to initiate the proceedings to justify the capability of the software defined radio. With different protocols existing on the same radio chip due to different software, the need to minimize the hardware can finally be fulfilled.

Table.IV IEEE 802.11a OFDM Parameters[34]

Parameters	IEEE 802.11a
Bit Rate (Mb/s)	6,9,12,18,24,36,48,54
Modulation mode	BPSK, QPSK, 16-QAM, 64-QAM
Code Rate	1/2, 2/3, 3/4
Number of Sub-Carriers	52
Symbol Duration	4µs
Guard Time	0.8µs
FFT Period	3.2µs
Preamble Duration	16µs
Sub-Carrier spacing	0.3125 MHz

The Figure 31 below shows the design methodology of the OFDM block codes for the implementation

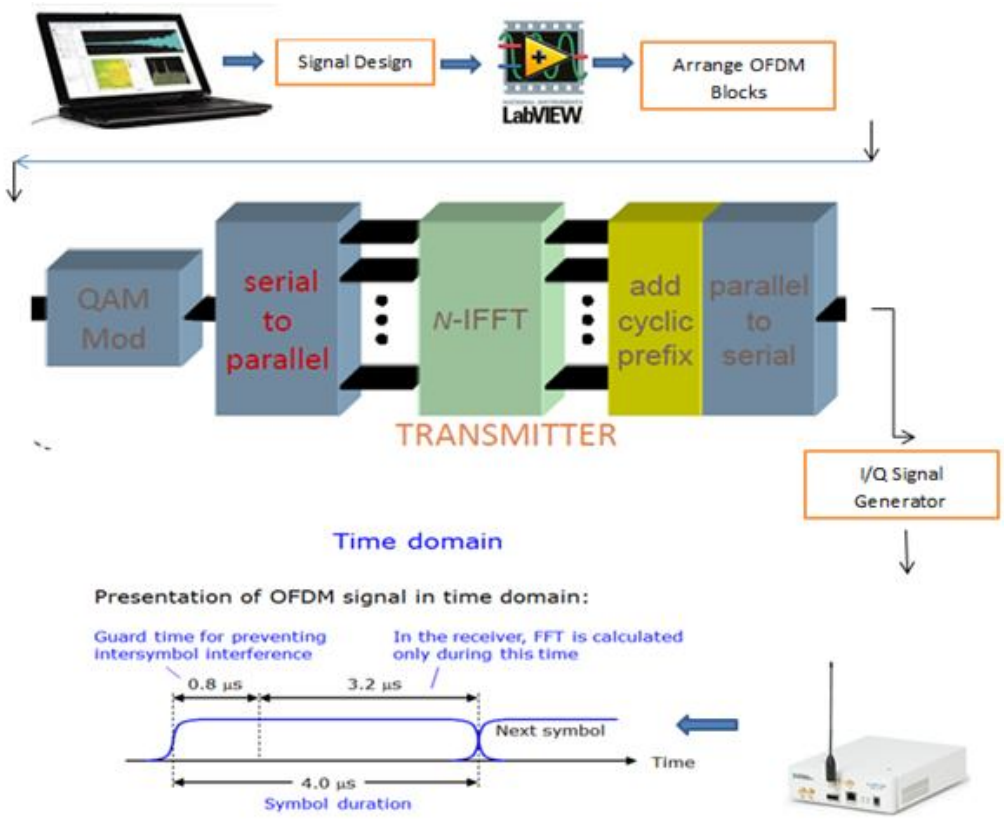


Figure 31. OFDM Implementation Design Methodolgy [34]

The results such as BER, OFDM Transmitted signal & the spectrum matched the expected results in the real time analysis for Wi-Fi physical layer. The Figure 32 & 33 below reflect the interface of the implementation:

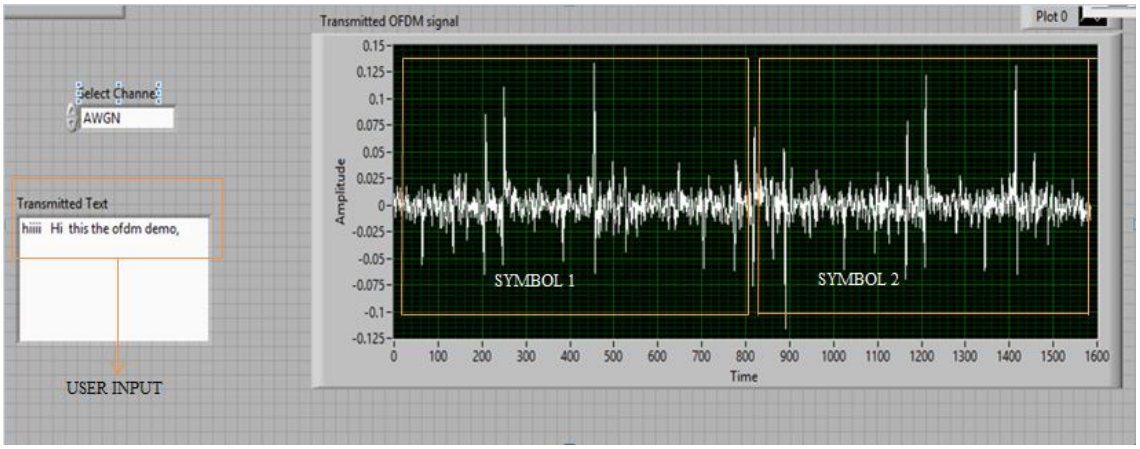


Figure 32. OFDM Real Time Transmitted Signal

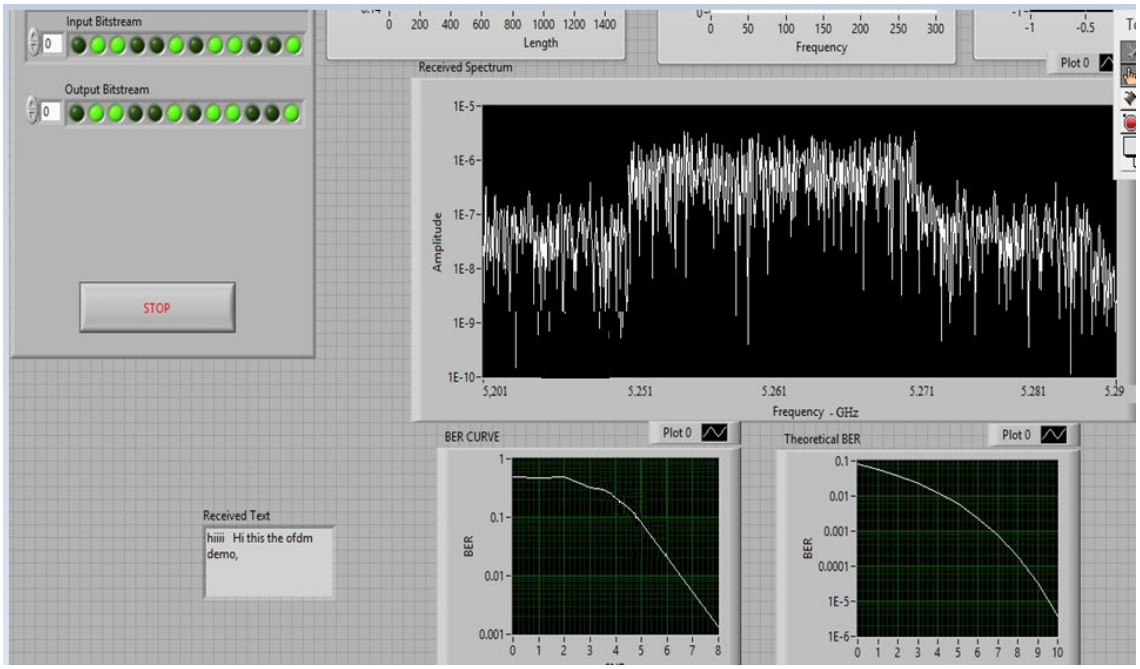


Figure 33. OFDM Simulated Spectrum & BER curves.

6.3.4 Proposal For Proof-Of-Concept

1) To demonstrate the existence of multiple protocols on the same radio i.e. by implementing both IEEE 802.11a & IEEE 802.15.4 together.
2) To demonstrate the proof-of-concept for IoT (Internet of Things) by making both the implemented protocols interoperable.
3) To implement a complementary learning algorithm & HELPER system using USRP to demonstrate IoT based Smart Home, is the ultimate goal.

Chapter 7

Conclusion

In this thesis, we proposed a ZigBee based noble cost effective living system for elderly and people with disabilities. The proposed system not only makes them self-reliant but also provides them with multitude of input options to carry out their daily living activities with more ease. The proposed system was evaluated in IIITD communications lab and also in the dispensary as shown in Figure 27 to obtain a performance benchmark in a more realistic scenario. Future work is focused on developing a mobile app to replace the master computer with only a smartphone which will control the end devices directly, thus eliminating the need of dedicated computer. The feature to automatically control using any simple phone, a smartphone based app or PC by employing a learning algorithm with HELPER using USRP, will also be there, thus justifying this head-start further towards the world of smart homes & IoT.

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