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ADAPTIVE BODY AREA SENSOR NETWORK FOR IOT BASED REMOTE HEALTHCARE

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ABSTRACT

Humayun Rashid: Adaptive Body Area Sensor Network for IoT Based Remote Healthcare
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Chronic health condition is considered as one of the key significant reason of death in the modern world. Chronic conditions are long lasting disorders of human beings that commonly can be controlled but a complete recovery is not possible for most of the cases. Persons with chronic health issues face various signs or symptoms of illness every day. It has an impact on their quality of life that can reduce life expectancy. data collection in medicine and healthcare performs a very important role as researchers utilize chronic disorder data to find out the proper method to reduce the impact of chronic disorders. The traditional method of data collection is complicated and does not provide enough support for remote patient monitoring. An Internet of things (IoT) based architectures based on Wireless body area Network (WBASN) can be employed to solve this problem. A key limitation of an IoT based remote patient monitoring system is that the patient monitoring period is greatly influenced by the wearable sensor node's power consumption. In the first phase of our work, a multi-goal multi-policy IoT-based patient monitoring system is presented that has utilized a self-aware power manage. It is tested and compared to a baseline system to study the higher power efficiency of the developed sensor node. Investigation of the first phase of the research is presented in "The 10th International Conference on Ambient Systems, Networks and Technologies (ANT-2019)" and available in [1].

In the second phase, the development of wearable health sensor nodes based on IoT and WBASN is presented that can be employed for vital sign collection for research purposes and will exhibit all the ideal characteristics. Implementation of the proposed system is demonstrated where development process of several wireless health sensor nodes in two different approaches, implementation of fog-assisted smart gateways using several Linux based platforms for data collection from the sensor nodes and cloud integration of the data collection process are presented. Sensor nodes are constructed based on 8-bit and 32-bit microcontrollers along with nRF and UDP data transmission over Wi-Fi network. Dynamic goal manager based working modes is adapted to increase the power efficiency for achieving extended operating periods compared to the baseline system for both 8-bit and 32-bit microcontroller-based sensor nodes. Different fog-assisted gateways are constructed with different backend system to evaluate different performance analysis.

Keywords: IoT, WBASN, Remote Health Care, Fog Computing, Cloud Computing

The originality of this thesis is checked using the Turnitin OriginalityCheck service.

PREFACE

I consider myself fortunate enough that I got the opportunity to work at the University of Turku for my master's thesis under the supervision of Prof. Pasi Liljeberg. I would like to specially thanks Prof. Pasi Liljeberg for giving me this opportunity to work with his research team, IoT for Healthcare and providing a research fund for my thesis. I would like to express my special appreciation and thanks to my other supervisor, Prof. Jari Nurmi for his guideline to improve the thesis. I would like to express my special thanks to Mr. Arman Anzanpour for all his efforts to improve my research skills and deal with problems during the thesis. He is the key person behind the conference proceeding that was accepted and presented in the *"10th International Conference on Ambient Systems, Networks and Technologies (ANT-2019)"*. The paper was awarded the best paper award at the conference. I would like to thank all my co-authors, Prof. Amir M. Rahmani, Prof. Axel Jantsch, and Prof. Nikil Dutt. I would like to thank Mr. Matti Kaisti for giving me the opportunity to work as a teaching assistant that has helped me to enrich my experience and knowledge. My sincere gratitude goes to all the group members and colleagues of IoT for Healthcare and Health Technology of the University of Turku.

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Last but not least, my special gratitude goes to my beloved wife, Nazia Hassan. She is the person who has always take care of me and supported me in every stage of life. I am grateful to her for all the support.

Turku, 10 June 2019

Author

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LIST OF SYMBOLS AND ABBREVIATIONS

ADC	Analog to Digital Converter
AP	Access Point
BAN	Body Area Network
BLE	Bluetooth Low Energy
BOD	Brown-out Detection
BP	Blood Pressure
BSN	Body Sensor Network
CDC	Center for Disease Control
CPU	Central Processing Unit
DMP	Digital Motion Processor
DTIM	Delivery Traffic Indication Map
ESB	Enhanced Shock Burst
EWS	Early Warning Score
GPRS	General Packet Radio Service
I2C	Timer, Two-Wire Interface
IMU	Inertial Measurement Unit
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical
LED	Light Emitting Diodes
LEDE	Linux Embedded Development Environment
MAN	Metropolitan Area Network
MBAN	Medical Body Area Network
MEMS	Micro-electro-mechanical System
Multiceiver	Multiple Transmitters Single Receiver
NB	Narrowband
ODA	Observe Decide Act
PPG	Photo Plethysmography
QoS	Quality of Service
RTC	Real Time Clock
SCL	Serial Clock
SDA	Serial Data
SMS	Short Message Service
SPI	Serial Peripheral Interface
SpO2	Oxygen Saturation of the Blood
TPM	Transition Probability Matrix
UDP	User Datagram Protocol
ULP	Ultra-low Power
US	United States
WBAN	Wireless Body Area Network
WBASN	Wireless Body Area Sensor Network
WDT	Watchdog Timer
WHO	World Health Organization
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

1. INTRODUCTION

This chapter presents a discussion on chronic diseases, significances of the Internet of Things (IoT) in healthcare and the importance of data collection for clinical research purposes to develop methods and approaches to deal with chronic diseases. In addition, different research problems are discussed that have scope for research contributions. Finally, research objectives and contribution for the thesis are stated along with the overview of the thesis structure. This chapter consists of following sections: i) Chronic Disease ii) Data Collection for Healthcare Research iii) Internet of Things (IoT) for Healthcare iii) Research Problem Statement vi) Research Objectives and Contribution vii) Structure of the thesis outline.

1.1 Chronic Disease

Chronic health condition is considered as one of the key significant reasons for death in the modern world [2]. The phrase chronic disorder is frequently utilized to determine several physical states of human physique mostly affected by long-time diseases or impairment. In term of medicine, a chronic illness is usually distinguished from acute or severe illness. An acute illness generally has an effect on one particular portion of the body as well as does respond to treatment and therapy. On the other hand, a chronic circumstance frequently has an effect on a number of portions of the body, and the affected patient is not thoroughly responsive to prescribed medication and treatment. One of the principal characteristics of chronic disease is that it persists for a prolonged period. The expression chronic health condition is frequently used on whenever the actual illness continues for more than a couple of months. It is identified as prolonged or long-lasting human health disorder such as coronary heart conditions, respiratory system diseases or asthmatic diseases, diabetes and even varieties of cancers [3]. A chronic condition can certainly prevent self-sufficiency along with the health and fitness of people with afflictions, since it may potentially cause supplemental activity restrictions. Chronic conditions are durable disorders which commonly can be controlled nevertheless complete cure and recovery are certainly very rare. Persons experiencing chronic health issues typically ought to deal with everyday signs or symptoms that have an impact on their quality of life and encounter severe health difficulties along with additional complications that can also reduce their life expectancy [2]-[4].

In the United States (US), 25% of adults' men and women are experiencing with a minimum of two chronic disorders. According to the investigation and findings of Center for Disease Control (CDC), chronic disease is the biggest reason of fatality, impairment, and disability in the US that are accountable for 70% of all deaths. Records coming from the World Health Organization (WHO) show that chronic disorder is the leading reason of early death all over the globe, possibly even in locations where contagious illness are usually unrestrained [4] [5]. In Finland, chronic disease is identified as the main reason for premature death [3]. "Global action plan 2013–2020" is released by the WHO for the prevention of chronic diseases with the goal to reduce the rate premature mortality due to chronic diseases up to 25% [3].

Medical records indicate that the possibility of death associated risk of chronic disease affected individuals' raises quickly whenever they deal with an unexpected health decadence. It is proven also that the avoidance and prevention of chronic diseases' impact are achievable as well as minimization of mortality rate is possible if unexpected health decadence due to chronic disease can be detected early. In many instances, the unexpected deterioration begins through various early symptoms several hours prior [4] [5] that can be identified by analyzing patients' physiological vital signs such as heart and pulse rate, breathing or respiration rate, the temperature of the human body, blood oxygen saturation level, and blood pressure. Discovering these earlier warning symptoms through uninterrupted patient supervising or monitoring offers a possibility to greatly reduce the threat of health damage as well as help to prevent a prospective fatality [6].

Research and developments of different methods and applications are going on to create an efficient health monitoring system to predict and prevent chronic diseases. The development procedure of this kind of apparatus in clinical and hospital ambiance is on a particularly advanced level. Even though specifications regarding these kinds of approaches are exceptionally distinct in out-of-hospital surroundings. Affected individuals remaining at residence need monitoring apparatus that usually is expected to be compact, convenient, lightweight, portable and hassle-free to use [6] [7]. Essential key prerequisites of making use of this sort of apparatus at residence demand that the system requires to fulfill the requirement of small size, ease of mobility and consumer favorable structure. A consumer-friendly design implies that the system ought not to disrupt in any daily activity of the individual during monitoring the vital signs of the users.

1.2 Data Collection for Healthcare Research

Protective factors regarding chronic conditions can be effectively utilized to prevent chronic diseases as well as reduce the impact of the chronic situation. Researchers utilize the data of chronic disorder in order to understand chronic illnesses as well as exactly what procedures, treatment, and method can be performed most effectively to reduce the effect of chronic disorders. The investigation established on these types of information assists the researcher to structure and provide health and wellbeing applications. This facilitates researchers to recognize exactly how chronic health conditions influence individuals and the best way for community health and wellbeing services to perform to deal with chronic disease.

The data acquired by means of medical and clinical data collection through remote health monitoring methods can be utilized by researchers to develop a medical treatment to deal with chronic disease [7]-[9]. Data collection in healthcare performs a vital role in research and development. Data collection in healthcare typically relates to the measurements and recording approach of patients' physiological essential signs which are regarded as highly significant and necessary to assess human health and fitness. Physical vital signs of the human being physique can be measured, monitored and stored to the database with the purpose to utilize the data for better realization of physiological health conditions [12]. Clinical research signifies diverse physical essential signs and symptoms, which are recommended to be observed to be able to identify health degeneration. Five essential signs are blood pressure (BP), oxygen saturation of the blood (SpO2), pulse rate, respiratory rate, and body temperature that is regarded as highly significant to diagnose the patient's status [10]-[12].

Prospective investigation and advancement in medicine and health are often attained by making use of adequate data. Prediction and prevention of upcoming health hazard or chronic condition are possible by analyzing data. Regular and appropriate data classification from the patient's body is required regarding this specific reason. These types of accumulated records through several patients are usually beneficial for investigation and research routines to identify behavior in the data, facilitating to establish innovative approaches of forecasting or diagnosing disease and determining methods to enhance clinical and medical health care. Certainly not only that, but the information and facts can easily be established to assist and recognize more health-related hazards, as well as threats, risk, and factors of the disorder. Moreover, up-to-date medical diagnosis and treatment methods can certainly be formulated for the elimination of disease [11]-[12]. One convenient approach to collect physiological sign is to utilize the Internet of things (IoT) based patient monitoring system. Utilizing of IoT based healthcare data logger for patient monitoring will be advantageous for medical and health care area [12] to offer a prediction, abnormality identification, and medical diagnosis assistance.

1.3 Internet of Things (IoT) for Healthcare

IoT is considered as the latest innovation of the modern era. It is an internet-based system interconnecting the physical and virtual objects through the internet to enable inter-communication by sharing data with each other [15],[16]. In any IoT based system, miniature embedded sensors along with micro-processing unit and wireless transmitter allow to collect and share data using the internet. Interconnectivity among the devices enables various intelligent features including process automation, dynamic goal management, as well as efficient and reliable system development for secure data communication just to mention a few. Many modern technologies are being integrated to develop IoT based architectures such as wireless sensor network (WSN), wireless body area sensor network (WBASN), Fog Computing, Cloud computing and many more [17],[19]. There are many sectors and industry in which IoT can be utilized such as the healthcare industry, transportation, electricity and power management, security, etc.

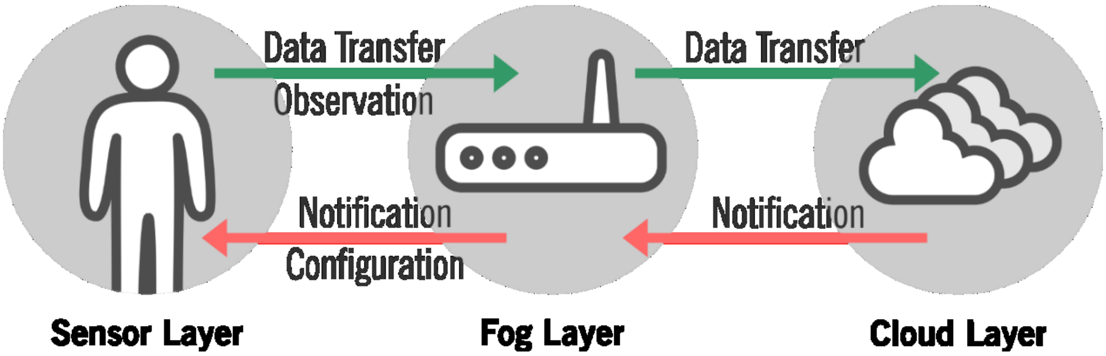


Figure 1. *IoT based remote patient monitoring system*

Latest scientific advancement in IoT along with wearable technologies provides an exhibition of in-home monitoring alternatives which can reliably determine the physiological essential signs and symptoms of the patient at home and hospital [15]-[17]. IoT is extensively utilized for example in health monitoring, clinical data collection, prediction, diagnosis and treatment of diseases. Standard features of reliability, interoperability, security, low latency, and energy efficiency should be considered during developing an IoT based health monitoring system [30]. One of the key challenging part of IoT based system is to combine all the standard features into one single compact system. IoT based healthcare system can reliably determine the physiological essential signs and symptoms of the patient at home and hospital. Basic IoT system for remote patient monitoring is illustrated in Figure 1.

1.4 Research Problem Statement

Currently, hospitals generally utilize their particular unique healthcare methods to identify affected individuals as well as keep track patients' information. Consequently, it is complicated for physicians to review patients' records. In an urgent situation, this downside turns into considerably more significant. It is observed that the performance is influenced by energy absorption as well as power supply capacity [13]. Effective deployment of sensors, implementing sensors in their specific power efficient settings, decreasing the coverage and the energy absorption of wireless transmission component, and documenting the signals systematically are some of the important energy management strategies that are recommended to extend the system operating time. Nevertheless, each one of those has some drawbacks [14]-[16]. Decreasing the number of sensors and utilizing them in the low power mode raises the ambiguity as well as decreases the transmission signal quality. Minimizing the radio transmission energy raises the transmission delay and the chance of disconnection. Regular recording, as a substitute for uninterrupted data collection, will increase the possibility of dropping some health condition variations or deterioration of early symptoms. An intelligent energy managing approach would be able to use all such solutions together with each other. To accomplish a degree of smartness, a process may benefit from self-awareness as a method related to considering its present state and present goal, taking priorities into consideration.

Previously developed health data logger has not been always qualified for practical usage because of various limitations and issues regarding data transmission method, acquiring vital signs through proper sensors, power management, data storage capability and architecture of the system. The basic architecture of an IoT based remote healthcare system comprised of one or several wearable sensor nodes and a fog assisted edge device or smart gateway. It is observed in several cases that data transmission from sensor nodes to edge devices are achieved by wires [21] [26] [27] which are not a preferable solution for wearable devices.

Previous IoT-based developed architectures exhibit high energy consumption because of using classic Bluetooth [22] or Wi-Fi [29] technology for data acquisition and data transmission. Another notable issue is identified in a previously developed system which is the absence of proper and efficient sensors for accurate data measurements. It is observed in several systems that sensors are concentrated on one single board [20],[22], [28], which causes diverse problems like not being able to place the sensor in the right place of the human body. In some devices, lack of sensors was identified which can be a reason for the inefficient reading of vital signs from the patients. Besides, some of the devices have design related issues, which leads to the facts that they are not user-friendly [27] and sometimes they became costly. Complicated operating procedures and complicated development process are noticed in some cases which can be the reason for not using these devices widely for data collection and research purposes [26], [29]. Most of the systems architecture is not based on IoT and because of that, these devices are lacking higher computation capability through system distribution to achieve power efficiency. Another key limitation of previously developed systems is that the research and development tools are not open-source ones and cannot be used by other researchers to develop a system for their research. Open source provides many advantages that can help a researcher to conduct the research process with cost-effectiveness but ensuring the latest cutting-edge technology. Commercial software vendors will not know the researcher's needs or concept, so the researcher himself is able to design or modify the concept of open source material without paying the additional cost. Its impacts are the availability of the source, field of improvement, transparency, quality improvement of research and unique idea generation.

1.5 Research Objectives and Contribution

In any IoT based system, one of the concerning issues is power management. Wearable healthcare products require efficient power management to achieve power. In the first phase of research, we have proposed a multi-goal multi-policy IoT-based patient monitoring system using self-aware power management to achieve power efficiency. In the second phase, we have presented a wearable remote health monitoring system based on IoT architecture and wireless body area sensor network that can be employed for vital sign collection. The contribution of the complete research work is discussed below:

- We have proposed a self-aware power management system that will utilize multiple goals and policies to achieve power efficiency in an IoT-based patient monitoring system. The proposed method can achieve power efficiency by classifying several prioritized goals and adopting proper policies to achieve the requirement of the goals. Demonstration of the method will be presented through a reconfigurable wireless sensor node.
- We have proposed and demonstrated an IoT-based architecture for developing wireless data logger for remote patient monitoring purposes that can be employed for a prolonged period to collect data with higher accuracy. The system consists of a sensor layer with several health sensor nodes, fog layer consisting of a fog-assisted smart gateway and a cloud layer. The development process of several health sensor nodes is implemented by two different approaches. Two different microcontroller modules (8-bit and 16-bit) and two different wireless transmission protocols (nRF and Wi-Fi) are used to create body area sensor network for developing the system. Implementation of the fog-assisted smart gateway and the cloud server is presented by utilizing several Linux based platforms for data collection from the health sensor nodes and transmitting the data to the cloud for further investigation. A brief evalua-

tion of performance analysis of all three layers (health sensor nodes, fog-assisted smart gateway, and cloud integration) along with a discussion about data processing and visualization in both smart gateway and cloud is conducted and presented.

1.6 Thesis Structure

In the first chapter, chronic diseases and its influence on human health is discussed along with a brief discussion on the data collection process, IoT based healthcare, problem statement, and research objectives. In the second chapter, background studies will be presented. In the third chapter, the proposed methodology and architectures will be discussed briefly. In the fourth chapter, multi-goal multi-policy IoT-based patient monitoring system using a self-aware power manager will be presented along with result analysis and discussion. In the fifth chapter, the development of IoT based architecture of wireless data logger will be presented. The sixth chapter will discuss the several performance result analyses of the developed wireless vital sign logger and the seventh chapter will draw a conclusion for the research. References and appendix will be presented at the end of the last chapter.

2. BACKGROUND STUDIES

In this chapter, background studies that are related to the research problems are presented. This chapter consists of five sections: i) Wireless Sensor Network (WSN) ii) Wireless Body Area Sensor Network (WBASN) iii) Differences Between Wireless Sensor Network (WSN) and Wireless Body Area Sensor Network (WBASN) vi) Communication protocol for Wireless Body Area Sensor Network v) Fog assisted smart gateway

2.1 Wireless Sensor Network (WSN)

Constant research, innovation, and development in the sector of micro-electro-mechanical systems (MEMS) have demonstrated significant advancement in developing miniature and low power consuming sensors. The sensor is a compact type of electronic apparatus having the capability to identify situations or alterations in surroundings, notice numerous factors such as object motion, illumination strength, temperature and send information to a processing unit [36]. With continuous development, physical size and weight of the sensor are getting smaller. The settlement in dimension for the sensor is certainly advantageous for constructing significantly better wearable technology including the feature of portability. Technological innovation in state-of-the-art has made it possible to develop intelligence, context, and self-awareness for the sensor to function more effectively [37]. Wireless technology is being integrated with sensors for transmitting data to create IoT based products.

The sensors can be implemented along with a microprocessor unit and data transmission module to construct low-power and small-sized sensor nodes. A sensor node provides the capacity of interacting independently with various apparatus. The principal objective of building sensor nodes is to collect data and store the captured information. Dimension and expense limitations of sensor nodes rely on power, storage area, computation capacity, and communications bandwidth. The sensor node can be employed to construct a Wireless Sensor Network (WSN). The advancement of WSN was inspired by military services for surveillance purposes. Current technology readiness level has made it possible to utilize a wireless sensor network in commercial purposes [37]-[40].

In general, a WSN is comprised of several sensor nodes and requires minimal infrastructure. All sensor nodes in the system have the ability to measure different parameters and data transmission. Sensor nodes in the WSN are independent and keep track of physical or environmental circumstances. Sensor nodes have the capability to transmit the collected data to the primary for data storing purposes [41]. The standard protocol of communications in a sensor node can be wired as well as wireless. Sensor nodes are attached along with a lightweight power module for executing different operations in a WSN.

The WSN can be broken down into two classifications that are unstructured or structured. The sensors are implemented arbitrarily above the area of interest in unstructured WSN. On the other hand, the sensors are integrated at permanent points in structured WSN. Advanced WSN provides the characteristics of bi-directional data flow, sensor activity control, and other features. The architecture of communication topology for WSN can be a convenient star network to a highly developed multi-hop wireless mesh network. The method of propagation is often either routing or flooding for establishing WSN [48]. Figure 2 illustrates some applications of wireless sensor networks [40]-[46].

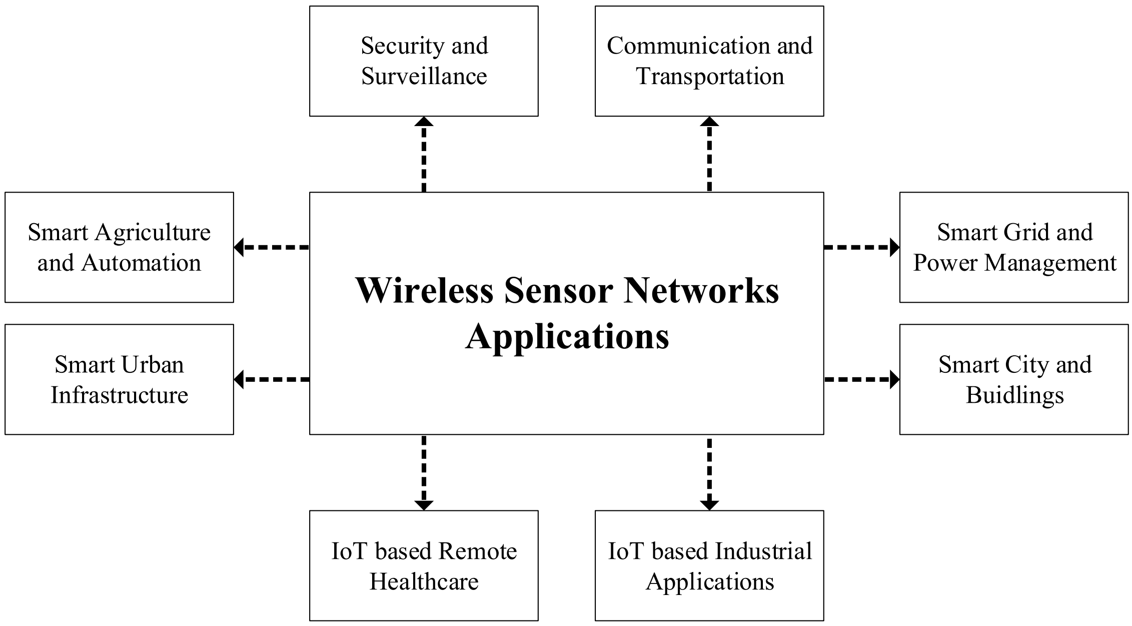


Figure 2. *Different applications of wireless sensor networks [45]*

2.2 Wireless Body Area Sensor Network (WBAN)

The term Wireless Body Area Network (WBAN) originates from Body Area Network (BAN), which is also known as Body Sensor Network (BSN) or a Medical Body Area Network (MBAN). The advancement progress of WBAN was introduced in 1995. The fundamental principle was to utilize of Wireless Personal Area Network (WPAN) systems to put into practice establishing a communication system for the human body. The expression BAN was presented in 2001 [60]. It recommends a method to establish communication completely within, on, and in the instant closeness of a human body [46] [49], [50].

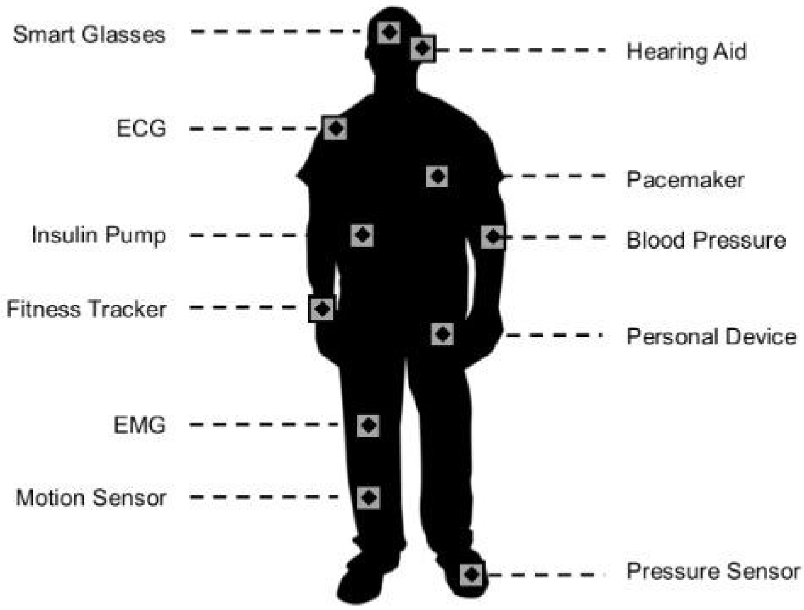


Figure 3. *Measurement of Human physiological parameters [55]*

WBASN is comprised of sensors nodes for monitoring and measuring human physiological factors. The miniature sensors in a WBASN can be classified into invasive or noninvasive [47]. Invasive is often defined as a technology that could be inserted into the human body and noninvasive can be stated as the technology which is generally are attached to the human body rather than inserting inside of the body. These types of systems perform without interrupting the person's actions nevertheless can document the physiological parameters throughout any kind of daily activity [51], [57].

The sensors carry out mostly a couple of duties including sensing, processing, and data transmission [52] – [54]. The sensors observe or sense the physiological vital signs of the human body during the sensing procedure. A sensor node has the capability to preprocess the accumulated information for assessment and storing purpose well before transmitting to a central location. The sensor node sends the preprocessed information to the central location for further processing during data transmission [55]. Sensor nodes can be placed in different parts of the body to monitor different physiological vital signs as shown in Figure 3 [50].

Communication in WBASN can be established in three ways: (a). Intra-BASN communications (b). Inter-BASN communications (c). Beyond-BASN communications. WBASN communication structure is illustrated in Figure 4.

- **Intra-BASN communications:** Zimmerman [48] studied on portable devices for the human body in 1996 and proposed this kind of tier in the body area network where data transmission can take place between the sensors and the fog assisted smart gateway through wire and wireless. It has coverage of around 2 meters for BAN. The function of the smart gateway is to process the accumulated information and broadcast that to Inter-BASN communications.
- **Inter-BASN communications:** The communication can be established between the smart gateway and several or individual access points (APs). The position of APs can be in dynamic surroundings to be able to effectively manage the urgent situation.
- **Beyond-BASN communications:** This tier is developed for metropolitan area networks (MANs). The healthcare sensor is attached to a network to be able to provide the information to the receiver entities, allowing professional medical employees to gain access to the health-related information. The receiver individual can possibly be a medical professional.

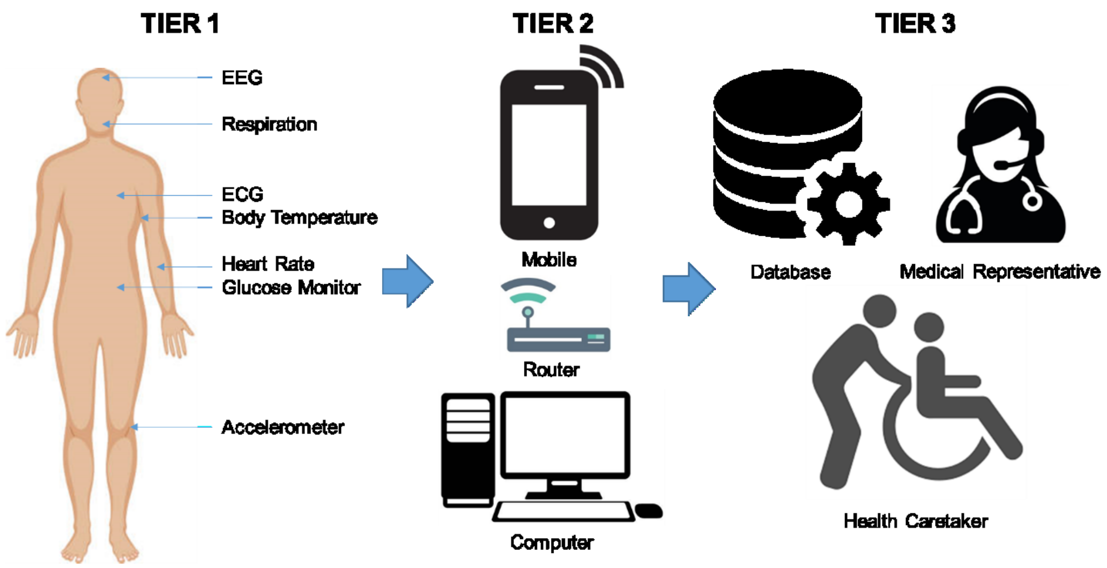


Figure 4. *WBASN communication structure*

There are many applications of WBASN that is presented in Figure 5. But one key significant application is the remote healthcare monitoring system [56] – [59]. WBASN ties together diverse kinds of networks as well as systems to allow distant or remote patient monitoring. It is feasible to link up the wearable products on the human body to the internet by utilizing fog assisted smart gateway to allow medical experts to gain access to affected individual’s data on the internet.

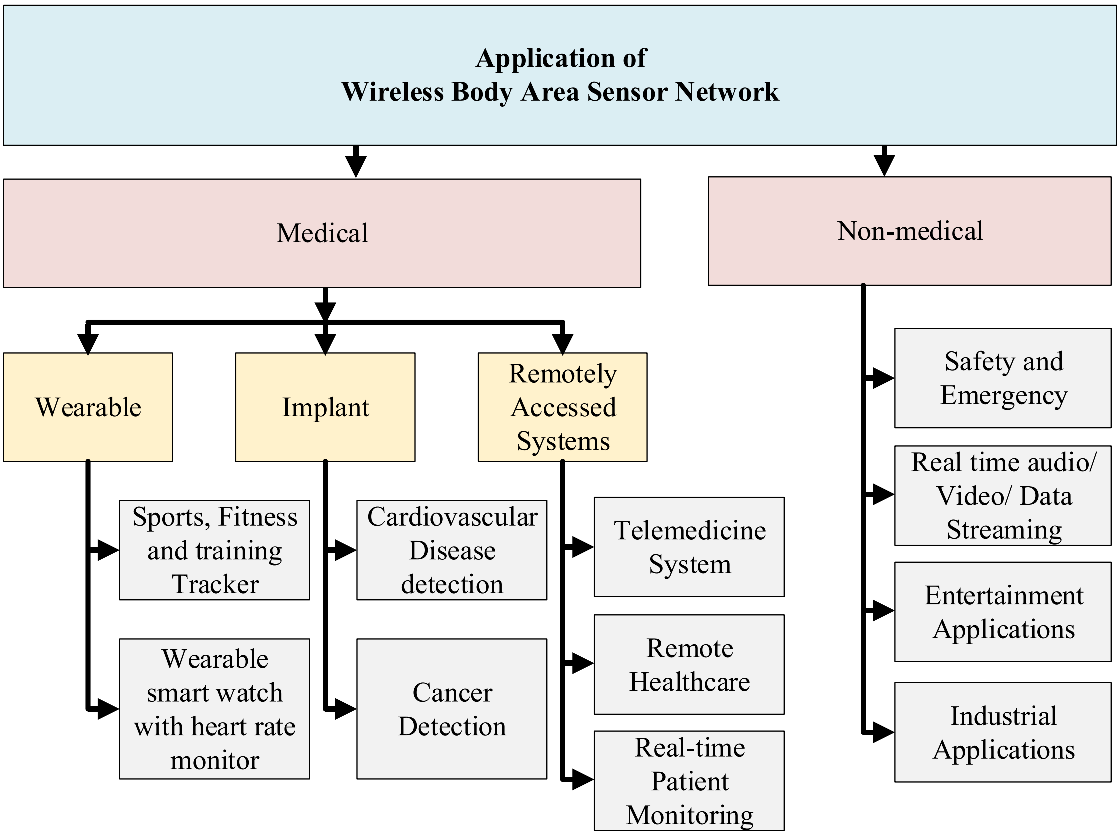


Figure 5. *Different applications of WBASN*

2.3 Differences between WSN and WBASN

Researchers have agreed on a fact that presently there are several differences between the WSN and WBASN. The density and quantity of nodes used in WSN tend to be greater than WBASN where repetitive systems are generally not integrated. Because of that, several limitations can be identified for WBASN communication protocols. Dimensions, as well as power constraints, are generally taken into more consideration during the development process to achieve higher power efficiency in WBASN in comparison to WSN. Data in WBASN consists of healthcare information that tends to make concerns of stability, safety measures, and delay sensitivity compared to WSN. The broadcast capability is significantly constrained in WBASN because of considerations on health and fitness threats. As a result, the coverage and transmitting range in WBASN are considerably lower compared to WSN. In contrast to the systems in WBASN wherever they have different requirements and components, nodes in WSN are homogenous and execute identical functions. Table 1 distinguishes all the features of a WBASN from a WSN is presented below.

Table 1. *Difference between WBASN and WSN*

Challenges	WBASN	WSN
Monitoring Scale	Human body physiological parameters	Environment parameters
Range	Centimeters to a few meters	Meters to kilometers
Channel	The medical channel, ISM (industrial, scientific, and medical), body surface	All available channel
Number of nodes	Fewer nodes are required	Many nodes are needed
Task of node	Multiple and distributed	Dedicated
Size of node	Small/ miniature that can be attached to the human body	The preferred size is small but not mandatory
Data rates	The high sampling frequency is required.	It can be high or low based on the application
Replacement of sensor nodes	Replacement of is quite difficult especially for invasive	Replacement of implanted nodes is simple
Power demand	Low power consumption	High power consumption
Biocompatibility	Yes	No
Security level	Higher	Lower
Impact of data loss	High	Low

2.4 Communication protocol for WBASN

Not all communication bands can be considered suitable for WBASN applications. WBASN generally utilizes the industrial, scientific and medical (ISM) radio bands that are reserved globally intended for industrial, scientific and medical applications. It is concluded that the 2.4 GHz band is the most suitable spectrum for the healthcare sector [61].

2.4.1 Bluetooth technology

IEEE 802.15.1 (Bluetooth) standard utilizes ISM band and it is implemented for numerous telemedicine applications [62]-[64]. The attributes of this standard are not much suitable for WBASN application because of large bandwidth demand, smaller size networks, lack of multi-hop communication, as well as a lengthy startup period for systems [65],[66]. One of the key limitations of Bluetooth classic is high-power consumption [64] that was solved by Bluetooth Low Energy (BLE) technology. BLE is considered a better alternative for WBASN applications. Less energy usage is achievable utilizing low duty cycle function in BLE. It is restricted by the transmitting range around 100 meters. Nearly every mobile phone is integrated with BLE function, which can also be used as a portable gateway [67]. Utilizing overstated low duty cycle to preserve power is not a good approach for medical health care devices because of the requirement of consistent data transmission.

2.4.2 Zigbee

The IEEE 802.15.4 (Zigbee) standard [68] is utilized broadly for WSN applications wherever it handles bigger coverage region to achieve significantly better functionality in comparison with Bluetooth [69]. The similarity between Bluetooth and Zigbee is that both technologies operate around the 2.4 GHz ISM band. A significant feature of Zigbee is the energy consumption that is claimed to be one-half to one-third in comparison to Bluetooth [70]. A key limitation of Zigbee is the low data rate due to the fact of larger delays on data delivery because of longer channel fades [70]. This fact makes it inappropriate for clinical application. Another considerable fact is that ZigBee provides no assistance regarding Quality of Service (QoS) and does not has any power management policy to achieve power efficiency [71].

2.4.3 IEEE 802.15.6 WBAN

A recent standard for WBASN is IEEE 802.15.6 WBAN standard [73] for low power devices to remove the limitations of other protocols especially Bluetooth and ZigBee. A significant fact about this standard is that it is exclusively developed for WBASN process. It provides the Narrowband (NB) that consists of the 400, 800, 900 MHz and the 2.3 and 2.4 GHz bands.

2.4.4 Low Power Wi-Fi

low-power Wi-Fi modified from the original IEEE 802.11 standard [72] is being extensively used for WSNs applications. It has significant features of high data transmission rate at low transmission power, small transmission period and several energy saving options. Nodes have the ability to switch from the working mode to the low-power sleep mode without having a larger delay. A key feature of The IEEE 802.11 is that it has higher security aspect along with improved QoS compared to Bluetooth and Zigbee. Interfacing of low-power Wi-Fi devices with surrounding networks does not involve complicated procedures. Because of many key features, it is considered as a suitable protocol to implement IoT based healthcare system for WBASN applications.

2.4.5 nRF Technology

The nRF24LO1+ ICs utilizes 2.4 GHz ISM band with an embedded protocol stack [74]. It features Enhanced Shock Burst (ESB) that is suitable for ultra-low power wireless applications with high data rates of 250kbps, 1Mbps, and 2Mbps. It can operate in 2400 MHz to 2525MHz with available125 channels [74]. One module can establish data transmission up to 6 other modules at the same time using 6 different logical pipes or addresses. Programmable customization can be implemented to increase the flexibility and data transmission rate of the sensor node.

2.5 Fog assisted Smart Gateway

Fog computing can be considered as a distributed infrastructure with decentralized resources. Fog computing is being used to extends the idea of cloud computing to bring more flexibility and robustness at the network edge that allows IoT based architecture to interact in real-time with low latency and high accuracy. In any IoT based system, a fog-assisted smart gateway at the edge of the network generally performs as a bridge device between the local sensor network and the cloud services. The gateway is responsible to receive and store transmitted information from sensor nodes, pre-process the information and send the data to the third layer of the cloud server. Some of the key features are low latency, the lower chance for Loss of connection, high data security through encryption, user-friendly interfaces and power-efficiency. Fog computing is being used to extends the idea of cloud computing to bring more flexibility and robustness at the network edge that allows IoT based architecture to interact in real-time with low latency and high accuracy. In any IoT based system, a fog-assisted smart gateway at the edge of the network generally performs as a bridge device between the local sensor network and the cloud services. The gateway is responsible to receive and store transmitted information from sensor nodes, pre-process the information and send the data to the third layer of the cloud server. It features the following functions that are also illustrated in Figure 6.

- **Data processing:** Fog assisted gateway obtains data from sensor nodes and processes the acquired bio-signals to get rid of noise from signals with the purpose of acquiring important features for further investigation. Data processing assists to increase the quality of medical care assistance as well as conserve transmission bandwidth between smart gateways and cloud.
- **Categorization service:** Different sensor nodes will collect different physiological data and transmits all the data to the fog assisted gateway. The gateway can categorize the incoming data hence it will be able to distinguish each consecutive data for the purpose of storing according to the proper category for cloud computing.
- **Local database:** Gateway acts as a local database for initially storing the sensor data before transmitting the data to the cloud for long time storage. The stored data in the local database of the gateway can be accessed by the user as it will be stored for a specific period.
- **Security:** security and cryptography methods can be implemented in the fog layer to encrypt the sensor data in order to protect information and resources of the system from unauthorized access. Encryption of data would introduce some latency.

- **User interface:** A web server along with data visualization capability can be provided at the gateway level which can act as the user interface. The user interface will allow initial data visualization from the data of local storage.

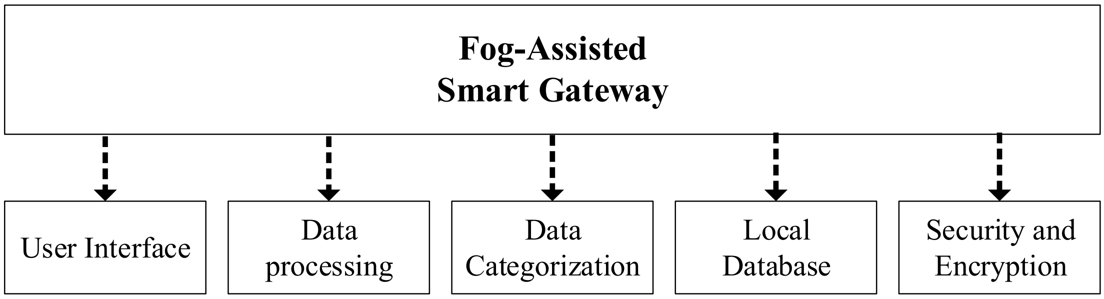


Figure 6. *Services of Fog-Assisted Smart Gateway*

3. ARCHITECTURE OF IOT AND WBASN BASED REMOTE HEALTHCARE

In this chapter, methodology and proposed architecture together with the main contributions are discussed. Proposed architectures of Dynamic Goal Management for IoT Based Patient Monitoring will be briefly discussed along with the discussion of proposed architectures for wireless vital sign logger using two design approaches. This chapter consists of five sections: i) Dynamic Goal Management for IoT Based Patient Monitoring ii) IoT based Remote Patient Monitoring System based on Adaptive Wireless Body Area Sensor Network

3.1 Dynamic Goal Management for IoT Based Patient Monitoring

Proper management of energy resources has become one of the significant concerns for today's wearable healthcare monitoring systems. Most of the previously developed systems are utilizing the single-goal fixed-policy solution. Several limitations are identified for fixed-policy solutions for providing services such as low-quality data collection, non-reliable monitoring process, and missing important health events for example. A system with more than one function needs goal management that is usually different from resource management. Goals are extracted from application prerequisites as well as tend to be specified through resource management methods. A key objective is to propose a dynamic multi-goal approach-based system architecture that can be efficiently utilized for the management of energy resources of wearable health devices. Several key features are considered for developing goal structure to choose an appropriate method for managing power policies during run-time to accomplish highest operating time for patient monitoring. The main key features are the battery life of the wearable health device, prolonged monitoring period, and the precision and reliability of the information.

The significant contribution of this research is the proposal as well as an exhibition of a self-reconfigurable architecture for providing power efficiency to achieve a prolonged operating period of an IoT based remote patient monitoring system. An approach is proposed that utilizes a dynamic observation process to evaluate data of the user and system. A fog-assisted smart gateway identifies the status, establish the appropriate policy, and readjust the power configuration of health wearable device. Several dynamic control loop-based system goals are defined and prioritized as well as a self-aware goal management algorithm is formulated for observation of the user and system status. Two main factors are considered for developing the system that is constantly monitoring approach as well as the accuracy and reliability of data collection and monitoring operation.

The proposed solution is presented by implementing a prototype of a wireless sensor node that can reconfigure with prioritized policies. Most effective configurations are identified through numbers of different tastings and performance analysis. The proposed architectures are shown in Figure 7 composed of three layers. These layers can be identified as a sensor layer, fog layer, and cloud layer. Sensor layer consists of a sensor node that is constructed with microcontroller and three sensors, fog layers consist of a smart gateway, and the cloud layer consists of a cloud server. The sensor node will consists of a 8-bit microcontroller with ability to measure several vital signs from human body using inertial measurement unit (IMU) that is composed of a 3D accelerometer,   photoplethysmography (PPG) sensor and temperature sensor to record user activity, heart rate, respiration rate, and blood Oxygen saturation (SpO2) .

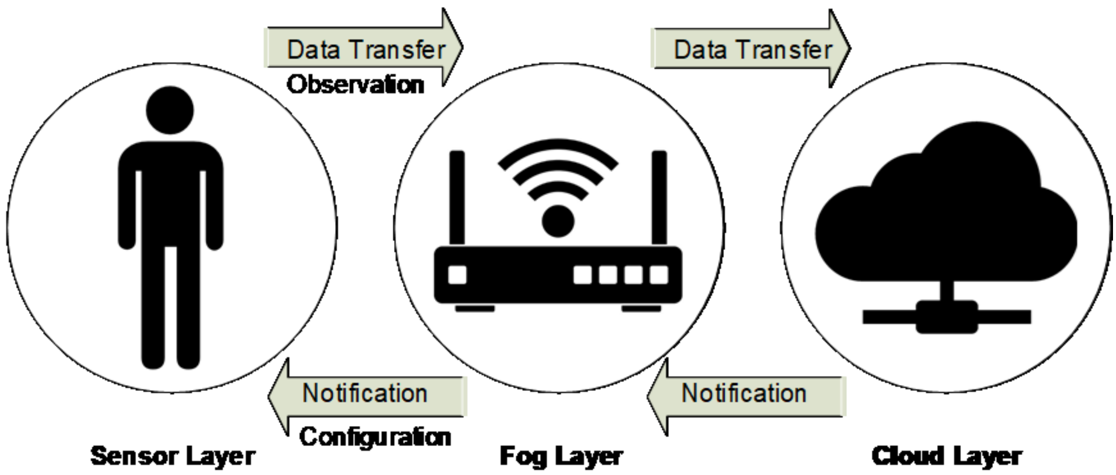


Figure 7. *Proposed Architectures of Dynamic Goal Management*

More specifically, the primary purpose of this system consists of monitoring the situation of the patient as well as the system and choose the most reliable monitoring policy for the sensor node to obtain increased accuracy and reliability with the lowest consumption of the power. The primary activity of the recommended model is to activate the data collection process only when significant changes in a patient’s vital sign or any changes in the sensor node’s health status can be identified. The sensor node frequently records all the signals for a specific time period and subsequently switch to the sleep mode. It operates based on several policies. Different quantity is assigned by the system to configuring the different length of recording time, the amount of power supplied for the PPG sensor, and the period of sleep mode. Replacement time of power source is considered through defining a power inaccessible period that indicates the period when the replacement or charge of the battery is not possible by the user.

3.2 IoT based Remote Patient Monitoring System based on Adaptive Wireless Body Area Sensor Network

One of the key targets of this research work is developing a completely autonomous and wireless data logger based on IoT architectures which can be employed to collect data to contribute in clinical and healthcare research purposes to prevent chronic diseases. Besides power management, some of the key limitations of previously developed IoT based Health monitoring device are:

- Concentrated sensors in one single board
- Lack of sensors that causes the inefficient reading of vital signs from the patients.
- Complicated operating procedures and development process
- Research and development tools are not open sources and cannot be used by other researchers to collect data for their own research purposes.
- Data transmission from sensor nodes to edge devices are achieved by wires instead of using the wireless approach

The proposed architecture is based on WBASN to monitor and record physiological essential signs of the human body and utilize a reliable data transmission method to transmit the collected information to the fog-assisted smart gateway and cloud server. The WBASN system consists of several health sensor nodes that can be placed at different parts of the human body to monitor and record different physiological signs. The main features of the sensor nodes are to measure different vital signs or biosignals and record data from patient’s body, send the data to the fog-assisted smart gateway and omit the limitations of the previously developed system. The principal tasks of the fog-assisted smart gateway are to receive data from sensor nodes, pre-process the data by sorting and encryption, visualize in the local server and finally transmit the data to the cloud server. The cloud layer is responsible to store the information. Data can be retrieved from the cloud by health caretaker for monitoring the live performance of the health sensor nodes using live graph plots.

We have proposed a system architecture of IoT based wireless vital sign or data logger utilizing body area sensor network consisting of three layers. The first layer contains wireless health sensor nodes to collect patient’s bio-signals, the second layer consists of a Linux OS based gateway and the third layer is a cloud server to store and process the data. Several different sets of sensor nodes would be developed using two different approaches to create WBASN for patient monitoring and data collection purposes. The first approach utilizes nRF wireless data transmission with 8-bit microcontroller and bio-signal measuring sensors. The second approach utilizes Wi-Fi data transmission along with the utilization of 32-bit microcontroller. The first approach has a higher energy efficiency wherever the second approach has a higher data accuracy. Figure 8 is presenting the proposed IoT based architecture of the remote patient monitoring system on adaptive WBASN.

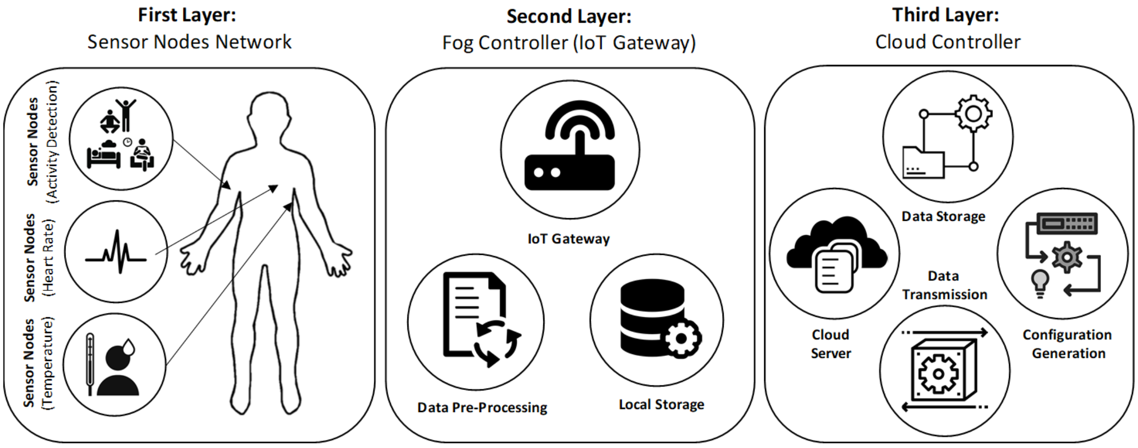


Figure 8. *IoT and WBASN based Wireless health data logger*

3.2.1 First Layer (Multiple Wireless Sensor Nodes)

The first layer is comprised of different wireless health sensor nodes. Each of the sensor nodes is constructed with a microcontroller, bio-signal measuring sensors, and a wireless transceiver. The microcontroller is responsible for playing the most vital role of acquiring sensor’s data and sending the data through the transceiver to the second layer known as Fog-assisted Smart gateway or fog-controller. Wireless transmission protocol will be employed for transmission of sensor nodes’ data over a wireless network to the fog-assisted smart gateway. Processing capacity of the microcontroller varies based on the specification of the microcontroller, which has an effect on measuring and collecting data. Similarly, different wireless data transmission protocols exhibit different performance during data transmission from one layer to another layer.

To study the different performance capability of different microcontrollers and wireless data transmission, health sensor nodes are developed in two different approaches. The first approach utilizes an 8-bit microcontroller along with the assistance of a low powered data transmission protocol nRF that can be implemented utilizing a transceiver known as nRF transceiver. The other approach is to utilize powerful 32-bit microcontroller which has a system on chip Wi-Fi transmission protocol. The health sensor nodes will be able to measure several vital signs from the human body including human heart rate and blood oxygen saturation (SpO2), the electrical activity of the heart through an electrocardiogram, body temperature, respiration rate, and human activity. User activity can be measured using inertial measurement unit (IMU). A photoplethysmography (PPG) sensor will be utilized to measure the heart rate, respiration rate, and blood Oxygen saturation (S pO2). Heart's Electrical activity will be extracted through the ECG sensor. Body temperature and respiration rate will be evaluated using a temperature sensor. Health Sensor nodes transmit the raw data without pre-processing to avoid significant computational power. Preprocessing with the complex algorithm will cause high energy consumption and introduce latency that will cause low energy efficiency [15] [16].

3.2.2 Second Layer (Gateway with Fog Layer)

A fog-assisted smart gateway at the edge of the network generally performs as a bridge device between the sensor layers and the cloud layers. The gateway is responsible to receive and store transmitted data from the sensor nodes, pre-process the data and send the data to the third layer of the cloud server. It is based on a low powered Linux OS based device. A microcontroller along with a transmitter is interfaced with the system to capture the data from wireless sensor nodes. Fog Layer can compile complex algorithms with lower latency as it is featured with a higher embedded operating system with high computation capability compared to the sensor layer. Lithium-Ion battery along with charging circuit will act as power unit that will be responsible to provide power to the smart gateway. The gateway will maintain a specific distance from the health sensor nodes. Live data collection can be monitored from the gateway which will also be able to provide live data visualization at the fog layer.

3.2.3 Third Layer (Cloud Server with Data Processing)

The third layer is a cloud server that will receive the wireless sensor nodes' data through the fog-assisted gateway. The cloud will also contain initial configuration for the sensor nodes which can be modified by the end user to achieve power efficiency. The configuration can also be obtained from the gateway depending on the operating mode. Backend infrastructure for the cloud server would be developed using object-oriented programming. The backend program could fetch the live data as well as previously stored data from the client's device and visualization of data can be constructed. It will allow for real-time patient monitoring from remote places.

4. DYNAMIC GOAL MANAGEMENT FOR ENERGY EFFICIENT IOT BASED PATIENT MONITORING

In this chapter, a discussion on dynamic power management for continuous recording of vital signs and data transmission using IoT based system presented. This chapter is arranged in the following manner i) Dynamic Goal Management for IoT Based Patient Monitoring ii) Proposed Architectures iii) Different Working Modes iv) Experimental Setup and performance analysis.

4.1 Dynamic Goal Management for IoT Based Patient Monitoring

A constant patient monitoring process will allow reducing the possibility of developing a chronic illness. An IoT based system can be employed to achieve this purpose, but it requires proper power management to ensure prolonged operating period to achieve energy efficiency and data accuracy. Several investigations in the discipline of remote health monitoring are conducted to develop an efficient method for recording patient vital signs utilizing wireless communication protocols. There are several commercial products available for recording human vital signs. Some of the renowned wearable products are Shimmer [23], ViSi Mobile [24], and VitalPatch [25] that are being extensively utilized for ECG monitoring. CE and FDA approval are awarded to ViSi Mobile and Health Patch that has a significant feature of user-friendly design for patients. However, it is observed that the mentioned technologies have not adapted dynamic power management for continuously recording of vital signs and data transmission.

Several methods are recommended regarding the sensor nodes that are being powered by a battery in various IoT industries. Ye et. al. has presented a solution in [76] where the system featured with the capability to decide its individual performance mode autonomously. The system was constructed based on reinforcement learning as well as in a decentralized approach. This method has an impact on the power consumption of the sensing devices. But the main limitation is observed that it is not able to change the goal function as it operates with a fixed goal. Another fact is that it would not take into account the health status and the accessibility of the power source during the operating period.

A constant passive observation for critical event monitoring is proposed by Guo et. al. [77] that demonstrated a significant reduction in power consumption through their hypothetical evaluation and performed simulations. But the key limitation is that a single fixed-goal situation was considered rather than dynamic. A number of studies are carried out on making use of control loop models for developing self-awareness in health monitoring systems. Azimi et al. have worked with ODA (Observe-Decide-Act) model [78] in [79] to enhance the sensor node power consumption and propose an improved model based MAPE-K [80] in [81]. Various self-awareness approaches for health monitoring systems are recommended in [82,83,84]. The significance of these studies is that the state of the system, the patient status, and a form of priorities are considered, but the key limitation is nearly similar with other that a multi-goal concern was not considered for the health monitoring process. Applications for goal management methods in the Internet of Things based medical care are studied by Juntsch et. al. [85], Nevertheless, they have not claimed the implementation and performance of their proposed methods.

Goal management methods are presented in the various nonmedical research areas. A goal-driven approach for dynamic resource management in heterogeneous multi-core processors are presented by Shamsa et. al. [86] that have demonstrated low-power and high-performance policies. The important factor of their approach is a reward function that can be employed in the controller. The significance of the reward function is that it can establish positive feedback to assign prioritized goals.

Our proposed method that is presented in the previous chapter for dynamic goal management is implemented by developing a self-reconfigurable wireless sensor node and smart gateway. The sensor node has the capability to observe a set of parametrically identified policies as well as conducted performance analysis to obtain the most effective configurations. Our assessment demonstrates that the proposed method can minimize the energy consumption by 44%, reduce missing events by 90% and data interruption can be prevented 15 times compared to the baseline system. Implementation and results are published in a conference proceeding [1].

4.2 Sensor Node Development

User’s health status is obtained by implementing a sensor node consists of three different sensors with the capability to measure and record the user’s health status, level of physical activity, and the system’s battery status. As shown in Figure 9, the sensor node is constructed utilizing ATMEGA328P microcontroller, an MPU9250 IMU sensor, a MAX30105 PPG sensor, and an NRF24L01+ wireless transceiver module.

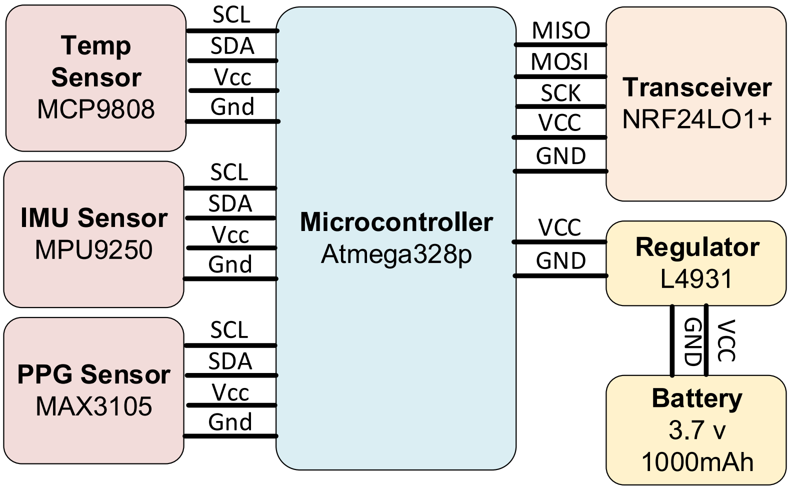


Figure 9. *Sensing device components schematic*

Each element of the sensor node is characterized by various energy consumption profiles. ATMEGA328P is an 8-bit microcontroller with a significant feature of high performance with low power consumption. Inertial measurement unit (IMU) is capable to identify the user's activity, a photoplethysmography (PPG) sensor has the ability to acquire vital signs, and temperature sensor MCP 9808 can detect body temperature and a voltage sensor to calculate the battery status. The IMU sensor is composed of a 3D accelerometer to evaluate the intensity of body movements and a 3D gyroscope for determining the body posture. The PPG sensor is composed of two light emitting diodes (LED) along with one light sensor. LEDs illuminate the body skin as well as the light sensor measures the strength of reflected light. The PPG signal exhibits the alterations in the volume of oxygenated blood in microvascular from which several essential signs which include heart rate, respiration rate, and blood oxygen saturation (SpO2) can be extracted.

Figure 10. *Vital signs measurement with the implemented sensor node*

The microcontroller can perform in normal and deep sleep modes. The PPG sensor can operate with one or two LED configurations and the current consumption of each LED can be described in a wide range from 0 to 50mA. The transceiver module can function in standby mode, sending mode, and listening mode with various radio signal strength configurations. The microcontroller transforms the analog battery voltage to digital values by the first analog input pin. The accuracy and reliability of the determined vital signs are directly associated with the quantity of power employed by the LEDs as well as indirectly associated with the user's activity. In other words, the accuracy of computed vital signs would be smaller when a user has a larger level of activity which requires more energy consumption to improve the accuracy. Figure 10 is representing the developed sensing device that is attached to the human body to take a measurement.

4.3 Gateway Development

The gateway device is a low power computer device known as Onion Omega 2+ connected with an ATMEGA328P microcontroller along with an NRF24L01+ wireless transceiver module. Onion Omega 2+ is exclusively developed for IoT applications with features of 580MHz MIPS processor and 128MB of RAM. It is capable of operating Linux OS, receives transmitted data from sensor nodes and sends them to the cloud server for long-term health investigations. It also creates a user behavior model to discover user sleeping time as well as to determine the power inaccessible period parameter. The cloud server can be connected to the Internet access and send short messages or automated phone calls through a web server when notifications are required. Figure 11 and Figure 12 are showing a schematic of the smart gateway and implemented gateway using Onion Omega 2+.

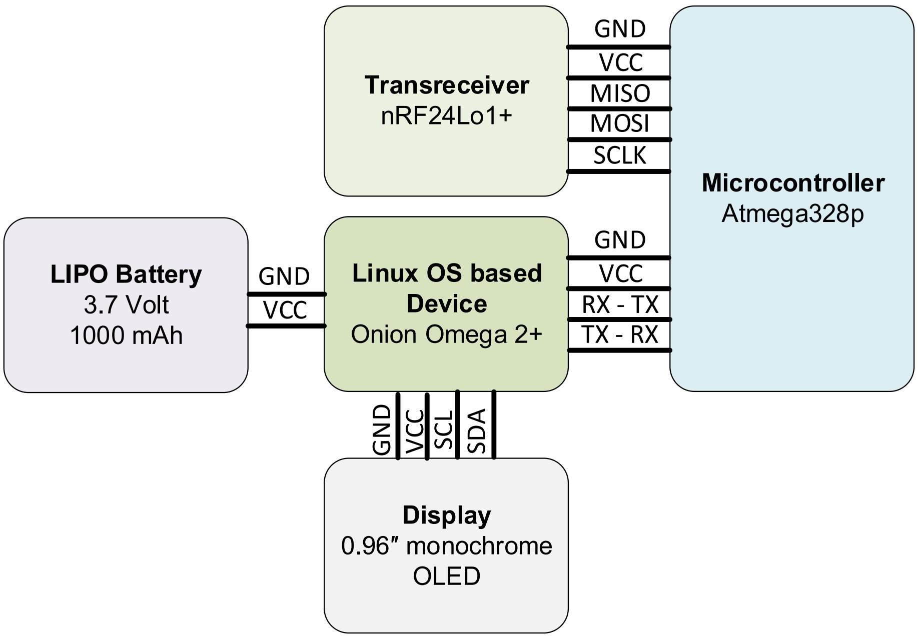


Figure 11. *Hardware schematic of the smart gateway*

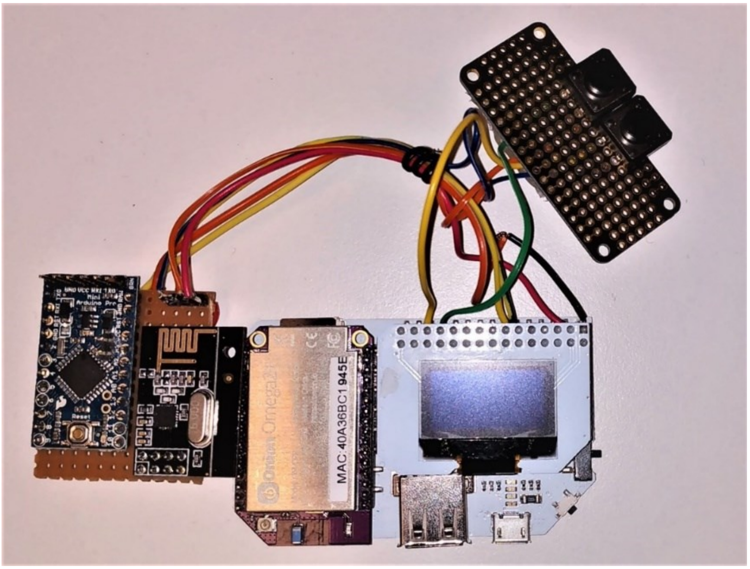


Figure 12. *Implementation of the smart gateway using Onion Omega 2+*

4.4 Different Working Modes

Seven different working modes are defined for the sensor nodes. There are three different recording modes while the other modes are sleep, observe, send, and receive modes. The sensor node is powered with a 3.3V input voltage through a 3.7V lithium polymer battery and a regulator. Power consumption of each working mode is evaluated using a power monitor device. Table 2 shows the description of all working modes and the power consumption of each one [1].

Table 2. *The state of components and the power consumption of sensing device in working modes [1]*

Mode	Trans ceiver (NRF 24LO1+)	IMU (MPU 9250)	PPG (MAX 30105)	Micro-controller (Atmega 328p)	Power Consumpti on (mW)
Sleep	Standby	Standby	Standby	Deep Sleep	0.4
Observe	Standby	On	On: 6.2 mA	Normal	35.7
Normal	Sending	On	On: 6.2 mA	Normal	39.5
Low power	Sending	On	On:3.5 mA	Normal	38.9
Accurate	Sending	On	On:12 mA	Normal	41.8
Send	Sending	Standby	Standby	Normal	20.2
Receive	Receiving	Standby	Standby	Normal	95.1

The monitoring system is developed with four modes known as observation, state detection, priority assessment, and policy enforcement. The main task of observation module is constantly checking the status of the user and sensing device and if a major change can be detected, it would send a notification to the state detection module in the fog layer.

State detection module evaluates the health and activity state of the user in accordance with the observation statement and history report from the cloud. It transmits the evaluated outcomes to the priority assessment module. The priority assessment module considers the priority of system goals. Regarding the priority of parameters in continuous monitoring, it also uses a history of the user's power inaccessible periods from the cloud layer. Policy enforcement module selects the next recording policy and sends it back to the sensor node. As shown in Figure 13 [1], the observation module is integrated with the sensor layer of three-tier IoT architecture and the other three modules are integrated into the fog [87] and cloud layers in a distributed manner.

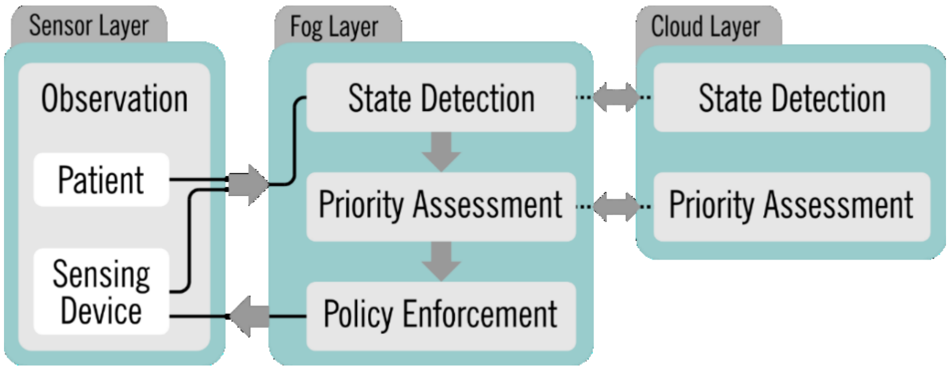


Figure 13. *Different policies in different layers of the system [1]*

4.4.1 Observation

A routine self-observation is carried out by the sensor node in every specified second. It executes a straightforward evaluation of the affected person's health condition through performance evaluation of heart as well as determining physical activity based on body position and acceleration by using Inertial measurement signal. The method analyzes the outcomes with earlier results to detect any changes. if the system can identify any significant change, the fog layer will be provided with a recorded sample for additional analysis as well as the sensor node will adopt new configuration from the fog layer for recording purposes. In any other case, it proceeds to the deep sleep mode for S minutes as well as begins a different loop soon after activated again. Manufacturer of AT-MEAG328P has set 8 seconds as the maximum duration of deep sleep mode. The repeating procedure of 8-second sleep has made it possible to achieve S-minute deep sleep. The extremely short amount of time difference (<1ms) was observed between these 8-second cycles. Another important fact is that energy consumption between switching cycles was very low and negligible. Figure 14 represents the flowchart of the observation and recording process [1].

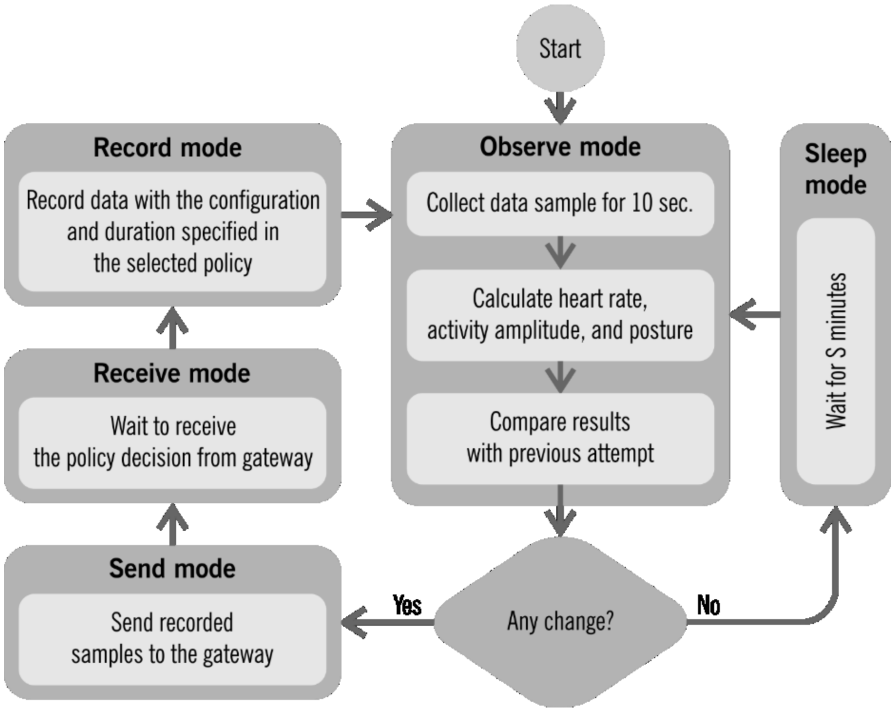


Figure 14. *Observation and recording flowchart in the sensing device [1]*

An early warning score (EWS) is a manual utilized by healthcare providers to rapidly figure out the level of health issues of an affected individual. It utilizes the vital signs to determine the health condition of the patient. A traditional range of pulse rate range is determined from the EWS table [88] to mark a significant modification in the heart rate. Table 3 exhibits traditional Early Warning Scores (EWS). 60 to 100 beats per second is considered as normal heart rate according to the EWS table [1][88].

Table 3. *A conventional Early Warning Scores (EWS) chart [1][88]*

Score	3	2	1	0	1	2	3
Heart Rate (Beats/minute)	≤39	40-50	51-59	60-100	101-110	111-129	130+
Systolic Blood Pressure (mmHg)	≤69	70-80	81-100	101-149	150-169	170-179	180+
Respiration (breaths/Minute)		≤8		9-14	15-20	21-29	30+
Body Temperature (◦C)		≤35		35.1-38		38.1-39.5	39.6+
Blood Oxygen Saturation	≤84	85-89	90-94	95-100			
Level of Consciousness				Alert	React to voice	React to pain	Unrespo nsive

The range is defined to identify a patient's status. If the heart rate value goes out of this limit it will be considered as a critical condition. When heartbeat comes back to the normal range, it will be considered as normal status. Five different types of activity are considered including sleeping, sitting, walking, jogging, and running to bring a major change in the activity level. User's posture can be utilized to detect patient's sleep and sitting activities as well other physical activity can be detected from acceleration amplitude. Major change can be identified from the difference between two consecutive observation.

4.4.2 State Detection

In our system, the fog layer is featured with the state detection module. low-power microcontroller is not suitable to execute complicated computational operations. Sensor node's data samples are transmitted to the fog layer to executes more advanced computations. The wireless transceiver module of the smart gateway is configured in the listening mode to receive a recorded sample from the sensor node. Serial communication is being utilized by the gateway's microcontroller to receive and transmit the sensor node's data to the Onion Omega 2+. Onion Omega 2+ classifies the received information. Based on the classified information, several vital signs such as heart rate, respiration rate, and blood oxygen saturation can be determined accurately. Received information also contains IMU signals and information about the battery level of the sensor node. Gateway has the classification algorithm that is able to identify different user activity and human body position from the information of gyroscope signal. Then a notification to the priority assessment module is being transmitted to the state detection module. The notification contains information about the user's health status. The user's normal or abnormal health condition can be determined from the notification. User's present activity and the sensor node's current battery level can also be determined. Since the blood oxygen saturation is considered as a major warning of patient deterioration [89], the user's abnormal health condition can be determined by analyzing this parameter.

4.4.3 Priority Assessment

This module utilizes a pre-defined priority structure to select the most reliable policy for the sensing device after receiving the user and system states. The highest priority is designated to the user's health status in the proposed monitoring solution. If the abnormal health status of the user is reported by the state detection module, an alert message will be sent by the system to the health caregivers and hospital. In such circumstance, continuous and accurate monitoring is ensured by the system by utilizing all the accessible resources. This allows the remote medical specialists a clear perspective of patient illness before emergency assistance shows up.

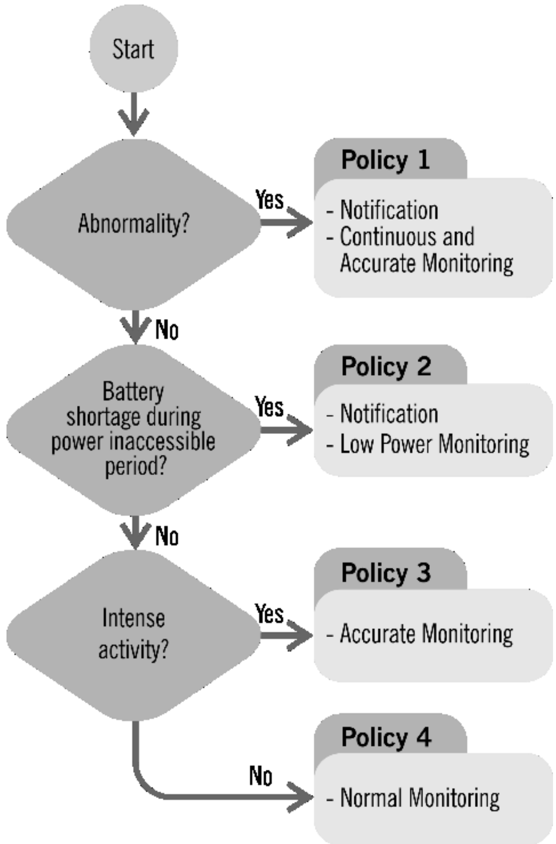


Figure 15. *Goals and priority assignment flowchart in the gateway [1]*

The next degree of priority is designated to a scenario whenever monitoring of the patient without having disruption is required. The primary disruption in the sensing device happens due to the lower charge status of the battery that requires to have a battery replacement of the sensing device. Battery replacement should not be required during such a moment when the user cannot substitute the battery (e.g., during sleeping or traveling), as this can result in a long period of monitoring being interrupted. The priority assessment module notifies to the user about the lifetime of power source in accordance to present charge status of the battery, current policy, and user's normal sleep time from the history of the user on the cloud server. If the battery health status seems to be poor during sleep time, the user will be notified to replace the power source prior to sleeping.

The last priority in the goal structure is allocated to the reliability and precision of the accumulated information. The sensing device requires to adopt a higher energy consumption method to put up with high-intensity activities of the user such as running or jogging. Figure 15 illustrates the functional flow diagram of the goals and priority assignment [1]. The gateway detects the abnormality of the user's health condition by analyzing the SpO2 value in the traditional EWS table range. If abnormal health status is detected, a warning notification from the cloud server is sent to the health caretaker.

This module decides constant and accurate policy for the sensor node as well. If the user's health status is identified as normal, the system examines the present status of the battery as the next priority. Then it requires to obtain the power inaccessible time from the cloud server. If it is found that the battery health status is not sufficient to observe the affected person until the following day, the system notifies to replace the power source prior to sleeping. It chooses a minimal energy policy for the sensing device to reduce the monitoring disruption if the user cannot replace the power source. Lastly, the smart gateway chooses an accurate policy to detect intensive physical workout to accomplish the final level goal in the hierarchy.

4.4.4 Policy Enforcement

A number of policies are developed to operate the sensor node. The policy enforcement module obtains the priorities as well as designates appropriate settings to the sensor node. Four different policies are defined based upon sensing device's operating method as well as goal priorities. Table 4 demonstrates the aspects of each individual policy [1]. The sensor node delays to obtain recording configurations from the fog layer after the initial information is being transmitted from the sensing device to the fog controller. Fog controller transmits the recording settings of each policy to the sensing device.

Table 4. *The details of system policies [1]*

Policy	Description	Notification	Recording	Sleeping
Policy 1	Emergency Situation	To users, caregivers, and hospitals	Continuous	
Policy 2	Power Saving Monitoring	To users	R minutes in Normal mode	2xS minutes in Sleep mode
Policy 3	Normal Monitoring		R minutes in Normal mode	S minutes in Sleep mode
Policy 4	Accurate Monitoring		R minutes in Accurate mode	S minutes in Sleep mode

4.5 Experimental Setup and Performance Analysis

Approach for obtaining the ideal configurations for the sensing devices is identified. The modified configuration is utilized to assess the efficiency of the system. Recording duration (R) and sensor sleep duration (S) can be configured for achieving an optimized setting. Arrangement of changes from 1 to 10 minutes for each parameter is considered. 100 different combinations of configurations are examined to assess the efficiency of the system. It is identified that the different types of user's activity have an influence on the longest possible record for establishing the latest priority that changes the state of the sensor node. User's health status is considered as a healthy state as well as the battery is assumed to be fully charged for the evaluation of performance analysis. Artificial generation of daily activities is conducted by utilizing the human daily activity pattern explained in [90]. It is essential for the experimental purpose because it is required to collect the diverse type of user information for performance evaluation of all possible settings along with a very long duration of total records, and a large amount of historical data. Table 5 shows the transition probability matrix (TPM) of human activities [1] that are studied in [75].

Table 5. *Transition probability matrix for human activities [1]*

Activity Type	Sleeping	Sitting	Walking	Jogging	Running
Sleeping	0.85	0.01	0.04	0	0
Sitting	0.02	0.85	0.12	0.01	0
Walking	0	0.1	0.84	0.04	0.02
Jogging	0	0.01	0.22	0.76	0.01
Running	0	0.01	0.57	0.02	

300 days of daily activity patterns are generated to test the solution with significant consideration of a random selection of 5 to 8 hours of user sleeping state, the TPM of human activities, and a set of randomized posture changes. The proposed algorithm is tested with 300 daily activity patterns using all 100 combinations of the configurations (totally 30000 tests) to evaluate the configuration for best performance. Our primary objective was to minimize the total energy consumption of the sensing device. This objective is feasible through selecting the minimum length for the record mode and the highest length for the sleep mode.

Another fact to consider that a long sleep period leads to the system to lose several of the activity states or posture changes events. To solve this problem, the total number of missed events during all sleep modes are also investigated. Figure 16 demonstrates the level of physical activity, variation in different postures, different the system states as well as the missing events of one test case [1]. A specific baseline system is established for each setting that used a fixed recording and sleep duration without employing any goal management. This baseline system is compared with the outcome of the tests. Figure 17 demonstrates the result outcomes in two intersecting surfaces [1]. The blue surface displays the percentage of power consumption reduction in each configuration compared to the corresponding baseline system. In the same way, the orange surface demonstrates the percentage of missing events reduction. It demonstrates that the highest energy consumption reduction can be achieved by employing 2 minutes time both for recording and sleeping modes. It is also investigated that the lowest value of missing events also can be achieved within a similar configuration.

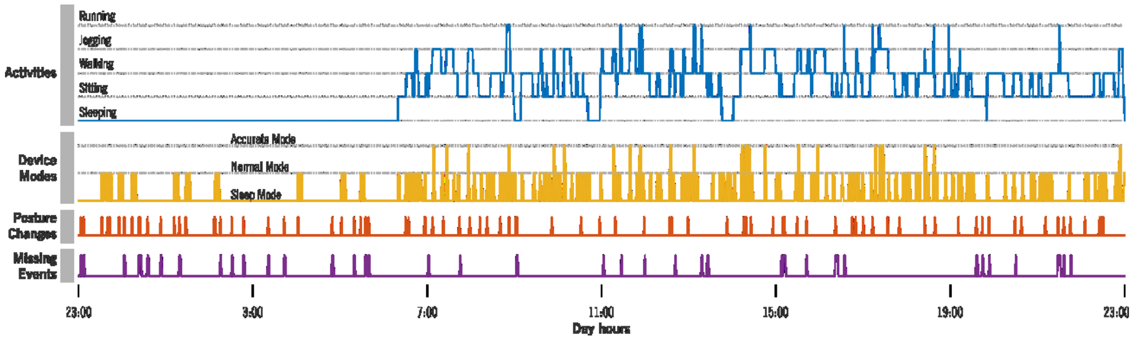


Figure 16. *A sample of generated activity and posture change pattern, sensing device states and missing events [1]*

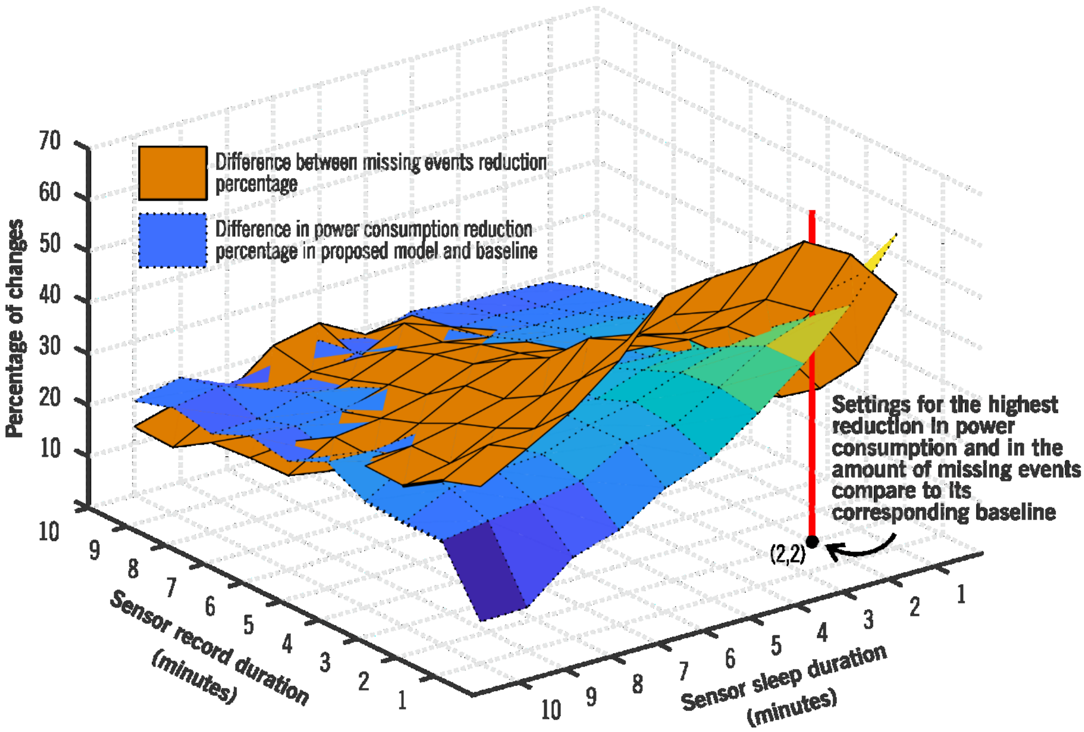


Figure 17. *The percentage of changes in power consumption and missing events comparing the proposed method and the baseline in different sleep duration and record duration settings [1]*

During the investigation for the baseline system, the power consumption of 19.95 mW is observed. On the other hand, the average energy consumption of our developed sensing device is 11.16 mW. It can be stated that the power consumption is minimized up to 44% compared to the baseline system. The similar reduction is identified for missing events where 90% reduction is observed compared to the baseline system. Operating time of sensing device is found around 62 hours along with selected configuration utilizing a single-use 230 mAh 3V CR2032 coin cell. For a rechargeable 1000mAh 3.7V Lithium-Polymer battery, the sensor node can be operated for 13 days.

Continuity of data collection is analyzed through employing the priority assessment algorithm on different activity sample day of three hundred (300) days. It is observed that the interruption of data collection procedure can be prevented by proposed priority assignment algorithm up to 15 times compared to a baseline system that is approximately prevention of fifty-six (56) hours of potential data loss.

5. DEVELOPMENT OF REMOTE PATIENT MONITORING SYSTEM BASED ON IOT AND WBASN

In this chapter, the development of a remote patient monitoring system based on IoT and WBASN is discussed. This chapter is arranged as follows i) Wireless Vital Sign Logger for IoT based remote Patient Monitoring System based on WBASN ii) 8-bit microcontroller and nRF communication-based Sensor Nodes iii) 32-bit microcontroller and Wi-Fi communication-based Sensor Nodes iv) Fog assisted Smart Gateway and Cloud Server v) Working Procedure of the Smart Gateway

5.1 Wireless Vital Sign Logger for Remote Patient Monitoring System based on IOT and WBASN

WBASN based health sensor nodes for remote healthcare should have the capability to measure and record physiological vital signs by fulfilling some requirements. Some of the essential requirements of wearable health sensor node include low energy consumption, miniature or compact size and wearable design [91]. In general, a sensor node is comprised of several components including microcontroller, sensor and wireless transceiver. The main processing unit of a sensor node is a microcontroller and another key essential part of the sensor node is a sensor which is responsible to measure and collect the vital signs from the human body. Sensor node needs to transmit data to a smart gateway through a wireless transceiver. A wearable health sensor node should have the capability of fast response and a higher rate of data sampling along with accuracy, minimum sample loss, low latency, and noise compared to other industrial sensor nodes [92]. It should have a battery management unit consisting of a battery and charging circuit.

The central processing unit of a sensor node is a microcontroller that is required to be energy-efficient because it is the most essential part to construct the sensors node. Power efficiency depends on choosing proper microcontroller as it is responsible for a significantly greater level of power consumption compared to other peripherals of an embedded system [93]. Essential tasks of microcontroller include communicating with and controlling the sensors as well as other peripherals through the different protocols (I2C, SPI), data transmission and management of various I/O devices [94]. Inefficient performance by a microcontroller will cause high energy consumption in any kind of sensor node.

Several bio-signal acquisition sensors require to be employed and interfaced with microcontroller to collect physiological vital signs from the human body. The low powered and high-quality sensor should be utilized to construct health sensor nodes as the sensor is also responsible for a significant amount of energy consumption as well as signal quality, service quality, and latency depend on utilizing proper sensor [93]. A key requirement to develop a power-efficient sensor node is to utilize low-power and high-quality sensor along with fast response capacity. The sensor should have different working modes including idle and sleep mode to reduce power consumption. Another important requirement is that the sensor should have the capacity to generate different sampling rates because different sampling rates have an effect on power consumption as well as low sampling rates exhibit lower accuracy whereas higher sampling rates have higher accuracy. Interfacing between sensors and microcontroller is implemented via SPI or I2C communication protocol [94].

Wireless data transmission can be achieved through utilizing different kinds of wireless transceiver modules such as Bluetooth, Zigbee, nRF or Wi-Fi. Power and battery level of sensor nodes are monitored by the power management unit. The fog assisted smart gateway acts as the medium between the data transmission of wireless sensor nodes and the cloud [95]-[97]. A smart gateway can provide different services of data storing space, local web server with a graphical interface for health caretaker, preprocessing of sensor data through sorting, categorization, and encryption [98]-[100]. The fog-assisted smart gateway along with all sensor nodes are completely portable and can be transported and utilized anywhere with Wi-Fi availability.

For experimental purposes, two different types of health sensor nodes are developed using two types of microcontrollers and two types of wireless data transmission technologies. The first approach is based on an 8-bit microcontroller that utilizes nRF communication and the second approach is based on a 32-bit microcontroller that utilizes UDP data transmission over Wi-Fi network. Several smart gateways are constructed along with cloud integration as well as different performance analysis of health sensor nodes and smart gateways are conducted to evaluate performance analysis of the developed system. A brief discussion on the development process for both the health sensor nodes and the smart gateway is presented in the rest of the chapter.

5.2 8-bit microcontroller and nRF communication-based Sensor Nodes

In this architecture, four different sensors along with an 8-bit microcontroller are utilized to develop three health sensor nodes to create wireless body area sensor network for remote patient monitoring. These three different health sensor nodes are able to measure and record the performance of heart by determining blood volume changes in the microvascular and electrical activity of the heart, physical activity, and body temperature. The wireless data transmission of the sensor nodes is achieved using low power data transmission technology that is known as nRF communication. An 8-bit AVR RISC-based microcontroller Atmega328P is employed to develop the wireless health sensor nodes because ATMEGA328P is featured with fast response time, higher data sampling and accuracy with a lower level of noise compared to PIC microcontroller [101]. A microcontroller can be operated with low power mode to reduce power consumption [102]. I2C is utilized to interface the multiple sensors as SPI has issues with data categorization and verification when more components are connected via it. The standard-mode of I2C supports transfer rates up to 400 kbit/s through bidirectional serial data (SDA) and serial clock (SCL) [103].

An MPU9250 IMU sensor is utilized for activity detection, which consists of the three-axis gyroscope (showing the body posture), accelerometer (representing the level of physical movement), and magnetometer. It has features of 16-bit ADC, Digital Motion Processor (DMP) engine, primary, and auxiliary master I2C bus and SPI serial [104]. The sensor has very low power consumption characteristic. The standard current consumption rate of the accelerometer is generally 450µA during operating as well as the standard operating current of the gyroscope is 3.2mA [104]. As a matter of fact, the current consumption is only 3.5 mA when all the sensors are activated. During sleep mode, it has a power consumption of the only 8uA. MAX30105 PPG sensor is employed for extracting heart rate, respiration rate, and blood oxygen saturation (SpO2) through two light emitting diodes (LED) and one light sensor [105]. PPG sensor operates by illuminating the LEDs on the skin of the body and then the intensity of reflected light can be measured by a light sensor to identify any variation in the quantity of oxygenated blood in the blood vessel to detect heart rate, respiration rate, and blood oxygen saturation (SpO2). The sensor communicates with the microcontroller through a standard I2C-compatible interface. It features ultra-low power consumption along with programmable sample rate and reconfigurable LED current configuration for reducing power consumption [105]. MCP9808 is an I2C based digital temperature sensor with high precision that is employed in our implementation for temperature measurement [106]. The electrical activity of the human heart can be represented as ECG or electrocardiogram through an analog reading which can be measured using the AD8232 single lead heart rate monitor. The component is featured with integrated signal conditioning block for performing electro-cardiography. The principle operation of the AD8232 single lead heart rate monitor is to perform as an op-amp to acquire a clean signal coming from the PR and QT Intervals [107]. It is interfaced with the microcontroller utilizing two digital pins and one analog pin for collecting the data from the sensor.

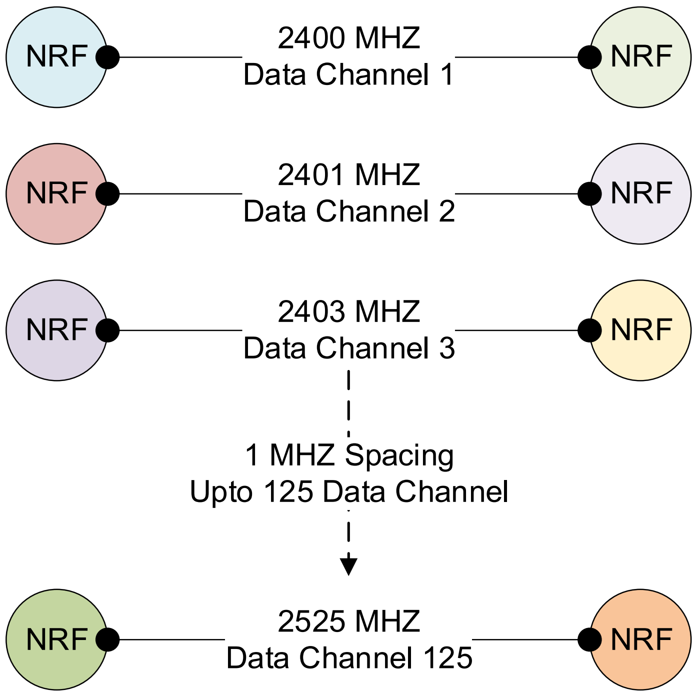


Figure 18. *Architectures of NRF Data Channel*

An NRF24L01+ wireless transceiver module is interfaced with each sensor node to transmit the data to the smart gateway. SPI is utilized to interface nRF transceiver with micro-controller to develop our system because the SPI protocol offers a higher data transmission rate with lower consumption of energy compared to UART and I2C. nRF24L01+ is a highly integrated RF transceiver IC with built-in on-PCB printed antenna with features of an embedded baseband protocol engine known as Enhanced shock Burst (ESB) suitable for Ultra Low Power (ULP) wireless applications and high data rates of 250kbps, 1Mbps and 2Mbps on-air data-rate [108]. It utilizes a specific spectrum that is known as the 2.4GHz ISM band with available 125 channels that are illustrated in Figure 18. The ISM band is reserved especially for the purpose of Industrial, Scientific, and Medical use. Every single channel in nRF utilizes a bandwidth that is lower than 1MHz. RF channel frequency of a specific channel can be set according to the following formula [108]:

$$\text{Frequency (Selected)} = 2400 + \text{Channel (Selected)} \tag{1}$$

A key reason of choosing nRF communication in the developed sensor nodes is that one module can communicate with up to 6 other modules at the same time using 6 different data pipelines using its unique features known as Multiceiver (Multiple Transmitters Single Receiver) as illustrated in Figure 19. This feature allows for developing several sensor nodes to create a body area sensor network. A data pipe generally refers to a logical channel and every data pipe features its individual configurable physical address. Reason of using nRF technology to develop the sensor node is that programmable customization can be implemented to increase a sensor node's flexibility and transmission data rate that can be reached up to 100 meters [109]. Enhanced shock burst allows variable length payloads that can differ from 1 to 32 bytes for data packets [110]. It offers packet ID for every packet that needs to be sent and every packet will be able to request an acknowledgment. The packet structure is illustrated in Figure 20. Schematic of the 8-bit microcontroller-based sensor nodes is presented in Figure 21 and implemented sensor node is presented in Figure 22.

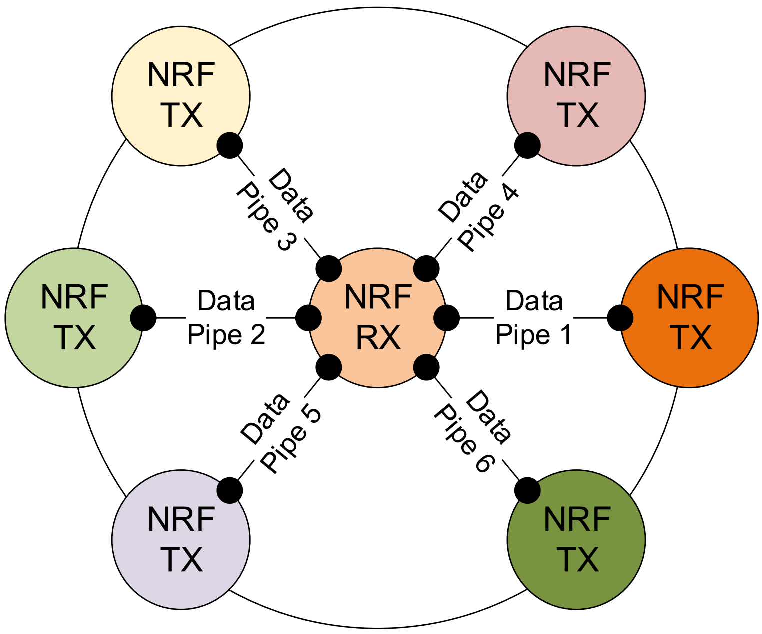


Figure 19. *Communication between nRF RX and TX*

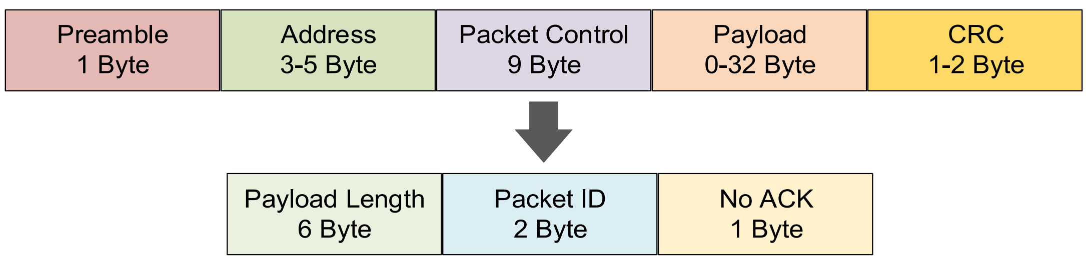


Figure 20. *The architecture of the NRF Packet*

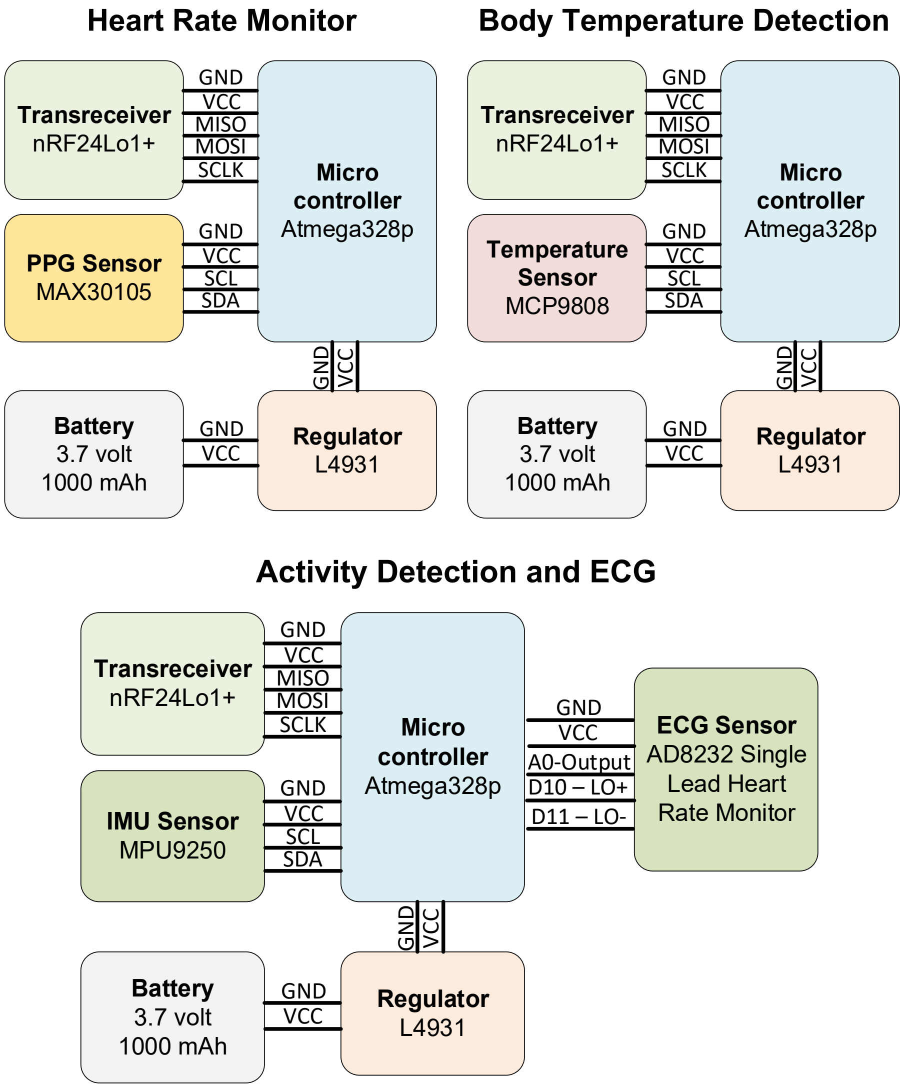


Figure 21. *Schematic of 8-bit microcontroller-based health sensor nodes*

(a) *(b)* *(c)*

Figure 22. *Implemented 8-bit microcontroller-based sensor nodes (a) PPG sensor node (b) Activity detection and ECG sensor node (c) Temperature sensor node*

5.3 32-bit microcontroller and Wi-Fi communication-based Sensor Nodes

Another approach of developing the health sensor nodes is using the 32-bit microcontroller that utilizes UDP protocol to transmit the sensors data to the smart gateway over Wi-Fi. The 8-bit microcontroller-based architecture is developed to create three sensor nodes utilizing four sensor nodes, but 32-bit microcontroller-based architecture is utilized to develop five different sensor nodes. In the previous architecture, the temperature sensor is used for measuring body temperature only, but in this architecture, the temperature sensor has also been utilized to develop two different health sensor nodes to measure breathing respiration rate and body temperature. Health sensor nodes for this approach are developed utilizing ESP8266 that is specially developed for the Internet of Things based products [110]. Each sensor node is composed of one ESP module and a specific sensor. The ESP8266 features of ultra-low power consumption along with a strong 32-bit dual-core CPU. One of the most significant features of ESP8266 is that it is provided with Wi-Fi on chip (802.11n @ 2.4 GHz).

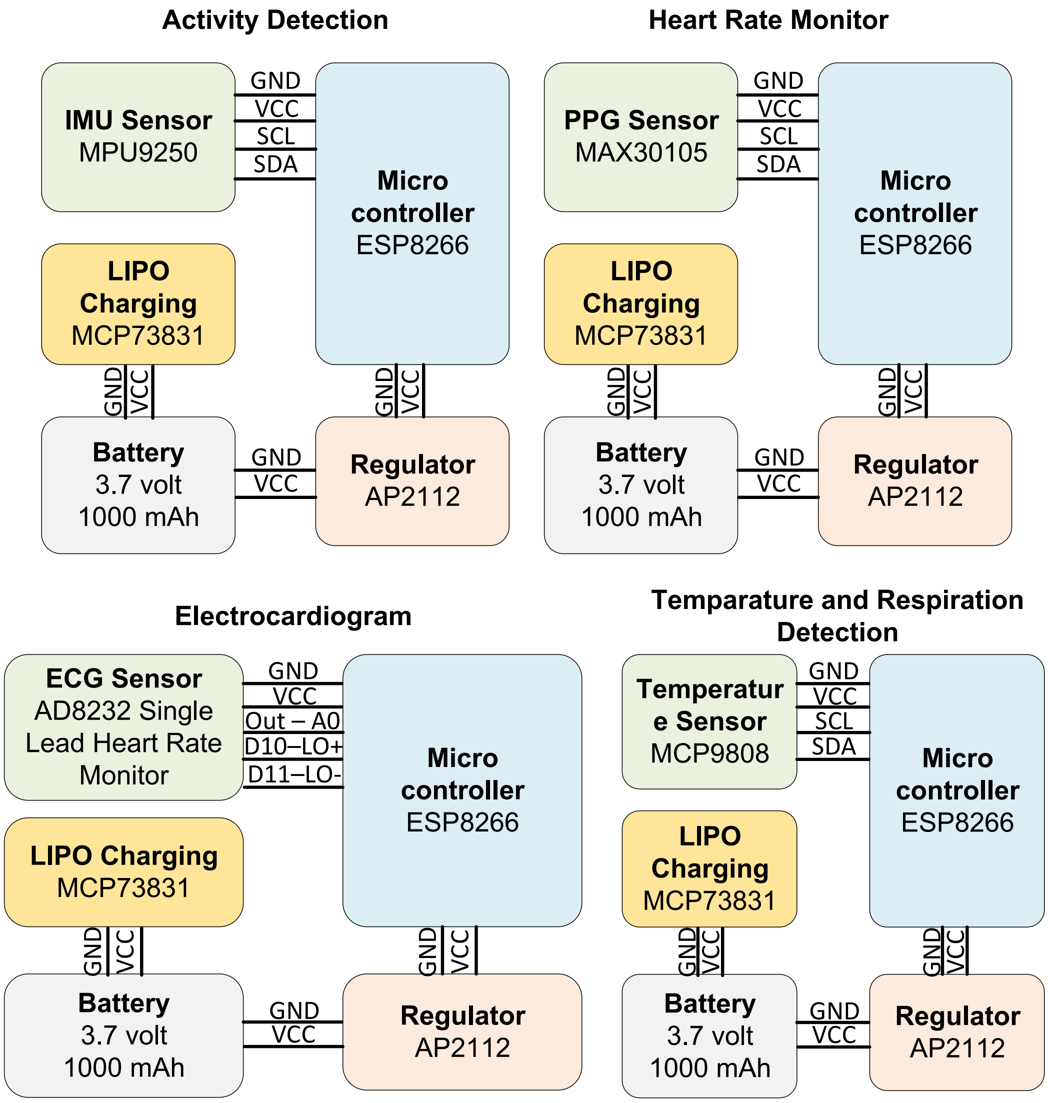


Figure 23. *Schematic of 32-bit microcontroller-based health sensor nodes*

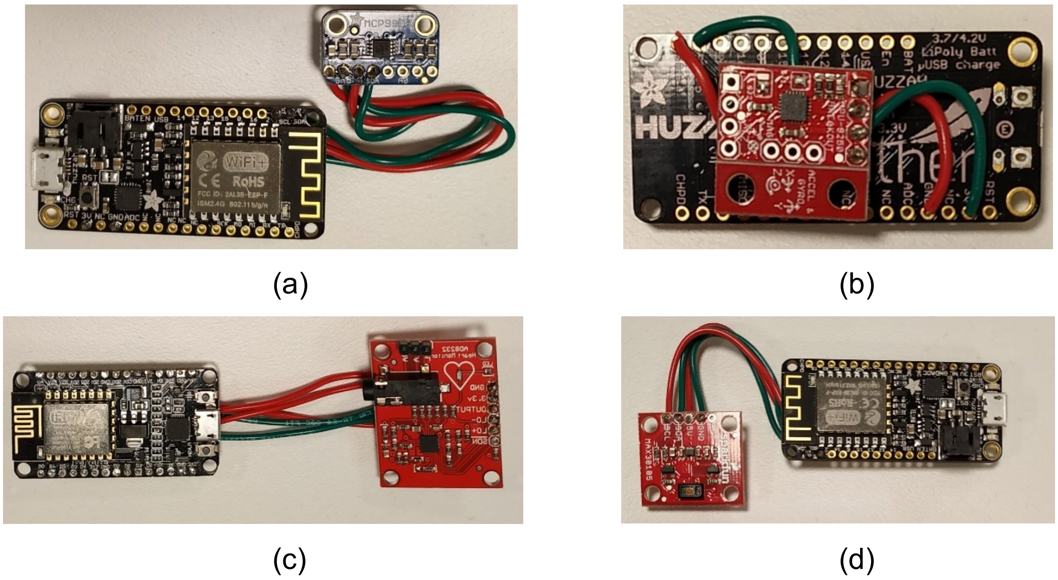


Figure 24. *Implemented 32-bit microcontroller-based health sensor nodes (a) Temperature and respiration detection sensor nodes (b) Activity detection sensor node (c) ECG sensor node (d) PPG sensor node*

It also contains other data transmission protocols such as I2C, SPI, and UART to interface with sensors and other peripherals. The health sensor nodes utilize the UDP data transmission protocol for transmitting the sensor data to the smart gateway over the Wi-Fi network. User Datagram Protocol (UDP) is generally considered as a good option for wireless sensor network communication that is utilized in this architecture [111]. ESP based system utilizes UDP protocol to transmit the sensor data to the gateway over Wi-Fi. The UDP is a connectionless as well as lightweight protocol [112]. The purpose of utilizing UDP is that it will allow the real-time performance of the sensor nodes that can be monitored and visualized in real time in the smart gateway. It utilizes a small packet size along with a small header (8 bytes) that causes less time in processing the packet and need less memory. The processing is considered as fast processing as establishing a connection is not required as well as the absence of acknowledgment field in UDP makes it faster. Five different types of a health sensor node can measure and monitor heart rate, physical activity, body temperature, respiration rate and electrical activity of the heart. Schematic of the 32-bit microcontroller-based sensor nodes is presented in Figure 23 and implemented sensor node is presented in Figure 24.

5.4 Fog assisted Smart Gateway and Cloud Server

For the 8-bit microcontroller-based sensor node architecture, the main component of the gateway consists of a single-board computer known as Onion Omega 2+. It is very small, low cost and has a low power consumption but has high computational capability due to 580MHz MIPS processor, 128MB of RAM and customized version of the LEDE (Linux

Embedded Development Environment) Linux operating system with the support of many programming languages [114]. It is equipped with a web server which allows interacting with the Omega through a browser. It has the characteristics of power efficiency, processing, networking, and encryption capabilities. The Omega2+ is plugged in one of the available boards made by Onion known as the Power Dock to allow providing power using a lithium-Ion battery. To receive the data from sensor nodes, an Atmega 328p microcontroller and nRF transceiver via SPI are equipped with Onion Omega 2+. Serial communication is employed for data transmission between the microcontroller and Onion Omega 2+. Both the microcontroller Atmega328P and Onion Omega 2+ have a serial port.

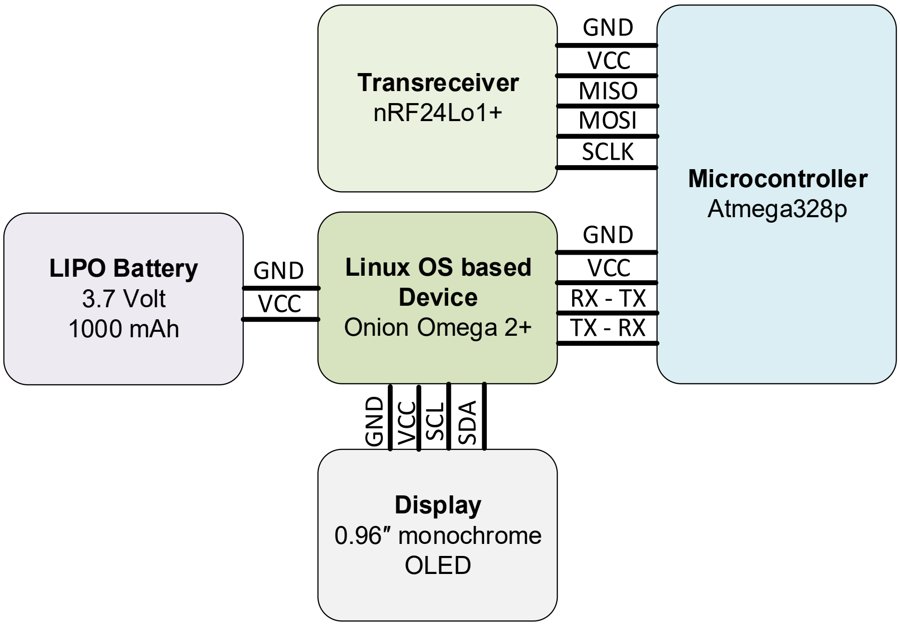


Figure 25. *The architecture of Smart Gateway for 8-bit microcontroller-based system*

For the 32-bit microcontroller-based architecture, Raspberry Pi is utilized as the main gateway [115]. Several other platforms which include Onion Omega 2+, Odroid XU4 [116], and Nvidia Jetson TX2 [117] is tested as the gateway for evaluating performance. There is an additional function for the smart gateway that is creating a Wi-Fi hotspot to establish the communication through Wi-Fi among the wireless sensor node and the smart gateway.

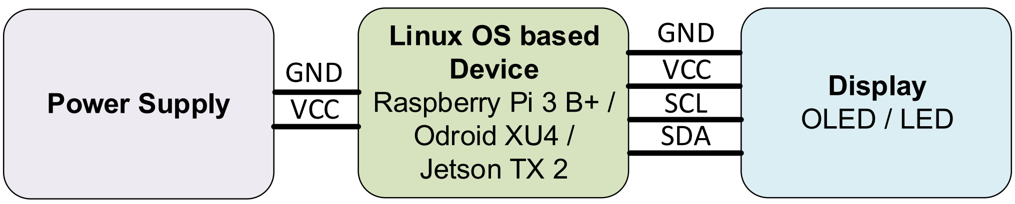
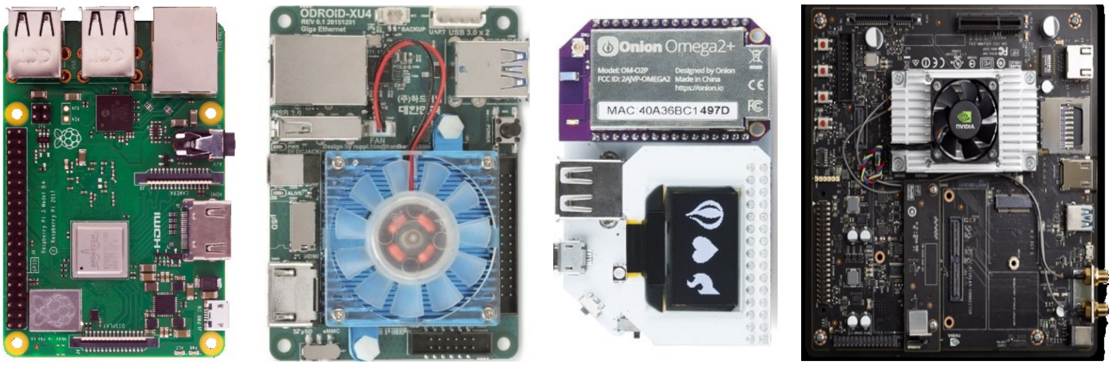


Figure 26. *The architecture of Smart Gateway for 8-bit microcontroller-based system*

The smart gateway acts as a local database for initial storage of the data to reduce data loss in a cloud server in case the communication between smart gateways and cloud servers is interrupted. Gateways transmit all recorded data in the database to cloud upon reestablishment of the internet connection. An OLED or LED display is connected with the smart gateway for controlling and monitoring the gateway through the command line and user interface. Figure 27 represents the different Linux based computer device for fog-assisted smart gateway and Table 6 represents the specifications of the different gateways.



(a) (b) (c) (d)

Figure 27. *Different Linux based computer device for the fog-assisted smart gateway (a) Raspberry Pi 3 B+ (b)Odroid XU4 (c) Onion Omega 2+ (d)Jetson TX2 Developer Kit*

For 8-bit microcontroller-based architecture, a python backend program is developed to receive the data from three sensor nodes, pre-process the data, store it in the local storage, and finally transmit the data to the cloud server. For 32-bit microcontroller-based architectures where the sensor node acts as a client, a web server application is developed to receive the UDP data, preprocess the data by categorizing and transmit the data to the cloud server. Local host with user interface makes it possible to observe and visualize the real-time data through the gateway.

Table 6. *Specifications of the different gateways*

Name	CPU	Ram	Connectivity
Onion Omega 2+	Mediatek MT7688 580MHz MIPS	128MB	b/g/n Wi-Fi
Raspberry Pi 3 B+	1.4GHz 64-bit quad-core ARM Cortex-A53	1 GB LPDDR2	802.11ac wireless LAN, Bluetooth, Ethernet
Odroid XU 4	2.0 GHz ARM Cortex-A15 & A7 quad-core	2GB DDR3	Ethernet
Jetson TX 2 Developer Kit	Denver 64-bit CPUs + Quad-Core A57	8 GB DDR4	802.11ac Wi-Fi, Bluetooth, Ethernet

Two different types of web servers are developed for evaluating different performance analysis. One web server is developed entirely in Python and another one is implemented using HTML5, CSS, and Node.js. In the Python-based web server, incoming data can be stored with low data loss, data can be preprocessed with data encryption and the data can be transmitted to the cloud server. Major disadvantage the python server is that data visualization at the gateway is not possible, and the user interface is based on the command line. To solve this problem, another web server is developed using HTML5, CSS, and Node.js that can provide real-time data visualization at the gateway as well as a user-friendly Interface that can be operated by general people. The user interface for the gateway is represented in Figure 28.

Data preprocessing, data categorization and data encryption are implemented in the fog-assisted smart gateway. The process is discussed below.

1. **Data categorization:** The gateway receives data from all the sensor at random sequence without categorization. Sensor nodes transmit the sensor data along with some additional data which assists the gateway to identify which sensor nodes is sending what kind of data. Each sensor node transmits the data with a specific ID, timestamp during data collection and the sensor data. Smart gateway receives the sensor node data and analyzes the ID. Based on the ID, the gateway can classify all the data and store it with different log files, process the data with encryption and transmit the data to the cloud within a specific location.
2. **Data encryption:** Data encryption is implemented using a cryptography library for a Python-based web server. Data encryption is based on symmetric encryption that encrypts the data utilizing the symmetric or secret key based authenticated cryptography. It also supports key rotation that provides an extra layer of security. A URL-safe base64-encoded 32-byte key is generated to encrypt and decrypt the data. Data cannot be decrypted by any other mean without the key.

5.5 Working Procedure of the Smart Gateway

The sensor node acts as a client for transmitting the UDP packet to a UDP based web server in the smart gateway. The firmware for the sensor node is developed to transmit the data utilizing the UDP protocol. The Wi-Fi connection is initiated utilizing the Smart gateway's hotspot and the UDP connection is established utilizing standard library functions named "WifiUDP" which is imported in the ESP code for managing the UDP connection and receiving data over it. After powering the system, the smart gateway initially checks if all the wireless sensor nodes are powered and connected so that data can be recorded. An OLED/LED display is attached with the smart gateway controller showing the connection status of the sensors. The system can be started with the successful connection of at least one wireless sensor node. When the end user starts the recording process through the Smart gateway, wireless sensor nodes collect the vital signs from patients' body and transmit the data to the smart gateway. For the 8-bit microcontroller-based architectures, the smart gateway collects the data from sensor nodes using the Python backend program. The python script receives the data from sensor nodes, preprocesses the data by categorizing and data encryption and transmits the data to the cloud.

For 32-bit microcontroller-based architectures, the UDP web server based on Python or Node.js is utilized for data collection. Sensor node acts as a client and transmits the sensor data as a packet with the identification of a specific IP and port. The UDP web server is able to establish server-client communication by identifying and receiving the packet from the sensor node based on IP address and port number. Fog assisted smart gateway stores the data to an SD card attached with it for temporary storage purpose which can be initially excessed by the user. In the cloud, the data are stored against a key. So, data can be accessed as a key-value pair by a user through a python script.

Google based Cloud and app-development platform known as Firebase is used as the cloud server. Firebase offers real-time database, authentication, cloud messaging, storage utilizing faster protocol WebSocket instead of HTTP. It has the capability for automatic syncs through the single WebSocket with real-time data updates with any new information. Firebase offers free hosting with acceptable and interesting features for experimental and research purposes [128]. It is very scalable as it is designed for millions of users. Storing sensor data in the cloud server is illustrated in Figure 29. Backend program has also been developed which can fetch live data from the Google cloud and create live visualization of different sensor nodes' data in end user's device. The backend program is based on Python along with several unique libraries that are known as Dash, Plotly [129]and Flask [130]. Figure 30 is illustrating live visualizing of the backend program during live data transmission.

6. RESULT ANALYSIS AND DISCUSSION

In this chapter, different performance analysis of health sensor nodes and fog-assisted smart gateways are presented. This chapter is arranged as below: i) Method of measuring Power Consumption ii) Power Consumption Analysis of Microcontrollers ii) Power Consumption Analysis of nRF iii) Effect of Different Sampling Frequency on Power Consumption iv) Performance analysis of PPG and ECG v) Performance Analysis of Different working Modes of Health Sensor Nodes vi) Performance Analysis of Fog-Assisted Gateway.

6.1 Method of measuring Power Consumption

To monitor and measure the power consumption of our developed system, power monitoring device and software provided from Monsoon Solutions [70] is utilized. The power monitor hardware is equipped with a software known as “Power Tool” that can provide accurate and reliable analysis of power consumption. The device and the software have the ability to evaluate the power consumption analysis of devices that are using a single lithium (Li) battery. The main features of this power monitoring solution are that it can utilize three channels to monitor and measure the power consumptions. These channels are known as Main, USB, and Auxiliary. The Main channel is considered as a default channel for most of the measurements but in our experiments, we have utilized the USB channel that is considered as AUX channel. The Power Tool software is featured with a user-friendly graphical user interface to monitor power analysis and record data.

6.2 Power Consumption Analysis of Microcontrollers

Several power consumption analyses are conducted for both 8-bit and 32-bit microcontroller-based health sensor nodes. It is found during investigation that the major power consumption for both health sensor nodes are caused due to the onboard peripherals such as Analog to Digital Converter (ADC), Serial Peripheral Interface (SPI), Timer, Two Wire Interface (I2C), USART, Watchdog Timer (WDT), and the Brown-out Detection (BOD). ATmega328P and ESP2866 perform several million instructions per second constantly during active mode. The hardware of both microcontroller modules is modified to reduce power consumption. Several power consuming elements from both microcontroller modules are removed. Energy consumption of the microcontroller can be reduced significantly by switching off rarely used peripherals. Low energy consumption can be achieved with programming, hardware modification as well as adopting proper sleep modes. AVR sleep and power libraries are used for 8-bit microcontroller-based sensor nodes' sleep mode [33]. For 32-bit microcontroller-based sensor nodes, the library from the manufacturer of ESP8266 is used [34][35] to adopt sleep mode. Active peripherals of Atmega328P can be set into sleep mode for 8 milliseconds using the low power library which specifically disables the ADC and the BOD along with the external oscillator. Table 7 and Figure 28 are showing the power consumption of a modified and unmodified 8-bit microcontroller during active and sleep mode without having any other components interfaced with it.

Table 7. *Average current consumption of Atmega 328P (8-bit microcontroller) during active and sleep mode at 5 volts*

Modification Details	Active Mode (mA)	Sleep Mode (mA)
Without Hardware Modification	5.71	1.43
With Hardware Modification	4.3	0.11

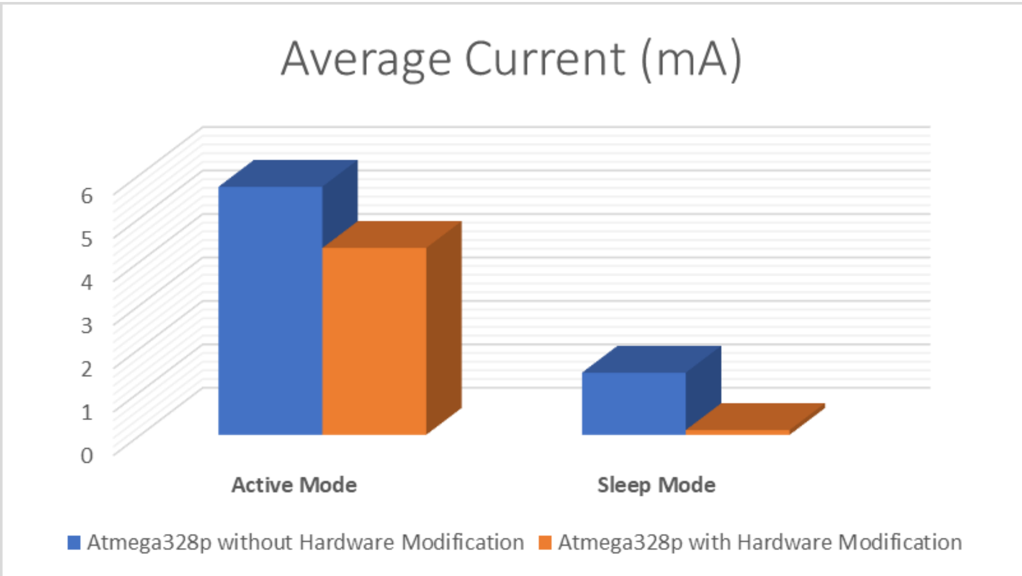


Figure 28. *Average current consumption of Atmega 328P (8-bit microcontroller) during active and sleep mode at 5 volts*

Essential components that are responsible for major power consumption in ESP8266 are Wi-Fi, system clock, Real Time Clock (RTC) and Central Processing Unit (CPU). It is observed during the investigation that the highest average current consumption occurs during active mode because of the continuous running of Wi-Fi, system clock, RTC, and CPU. The default mode of ESP is known as modem-sleep that can be activated only if it is connected to a wireless access point. While in modem-sleep, the ESP8266 disables the Wi-Fi as much as possible during Delivery Traffic Indication Map (DTIM) intervals or message beacon intervals that are set by the wireless network providing the router. Light sleep reduces the power consumption by turning off the system clock and set the CPU in the idle mode. Least power consumption is investigated during sleep mode, that can disable all the components except RTC.

A microcontroller can be configured into deep sleep mode for n microseconds after executing some operations and sleep mode can be prolonged by repeating the procedure. An important fact is that sleep time cannot be configured to infinite time which is set by the manufacturer and it requires to be defined in microseconds (µs). The manufacturer has set the highest sleep time of 4,294,967,295 µs, equivalent of approximately 71 minutes. Table 8 and Figure 29 are representing the average current consumption of ESP8266 (32-bit microcontroller) during active, light and deep sleep mode at 5 volts.

Table 8. *Average current consumption of ESP8266 (32-bit microcontroller) during active, light and deep sleep mode at 5 volts*

Modification Details	Active Mode (mA)	Light Sleep Mode (Wi-Fi Disabled) (mA)	Deep Sleep Mode (mA)
Without Hardware Modification	82.56	29.45	11.97
With Hardware Modification	80.69	27.36	10.62

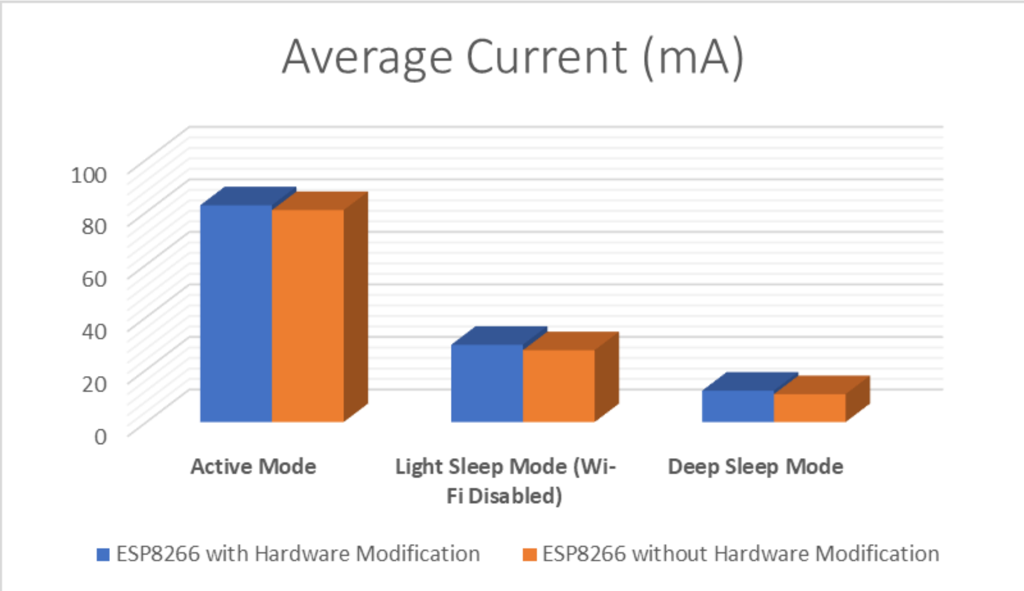


Figure 29. *Average current consumption of ESP8266 (32-bit microcontroller) during active, light and deep sleep mode at 5 volts*

6.3 Power Consumption Analysis of nRF

The nRF24L01+ module is utilized with the 8-bit microcontroller Atmega328p based sensor nodes to provide wireless transmission capacity. The coverage range of the nRF module can be reached up to 100 feet in open space. It is interfaced with the microcontroller using Serial Peripheral Interface (SPI). nRF24Lo1+ is featured with different reconfigurable properties that include 125 frequency channels, programmable output power, and different data rate of 250kbps, 1Mbps, and 2Mbps. A notable feature of this module is that the power management of the nrf24lo1+ module is equipped with an integrated voltage regulator that supports idle mode with fast startup times for advanced power management. It is mentioned in the datasheet that the ultra-low power consumption (average current consumption of 11.3mA) can be obtained during a transmission mode, whereas 13.5 mA average current consumption can be obtained during receiving of data at 2Mbps. 900nA current consumption can be observed during power down as well as 26uA current consumption can be observed during standby. Library of nRF module for Atmega328P microcontroller supports four different types of programmable power modes that can be configured for minimum, low, high and maximum current consumption. The investigation is conducted to evaluate the power consumption of the nRF module with four different power configurations during data transmission. The result is shown in table 9 and illustrated in Figure 30.

Table 9. *Average current consumption of nRF module during sending mode with different nRF power settings at 5 volts*

nRF Power Setup	Supply Current (mA)
Maximum Consumption (Max)	11.3
High Consumption (High)	9.0
Low Consumption (Low)	7.5
Minimum Consumption (Min)	7.0

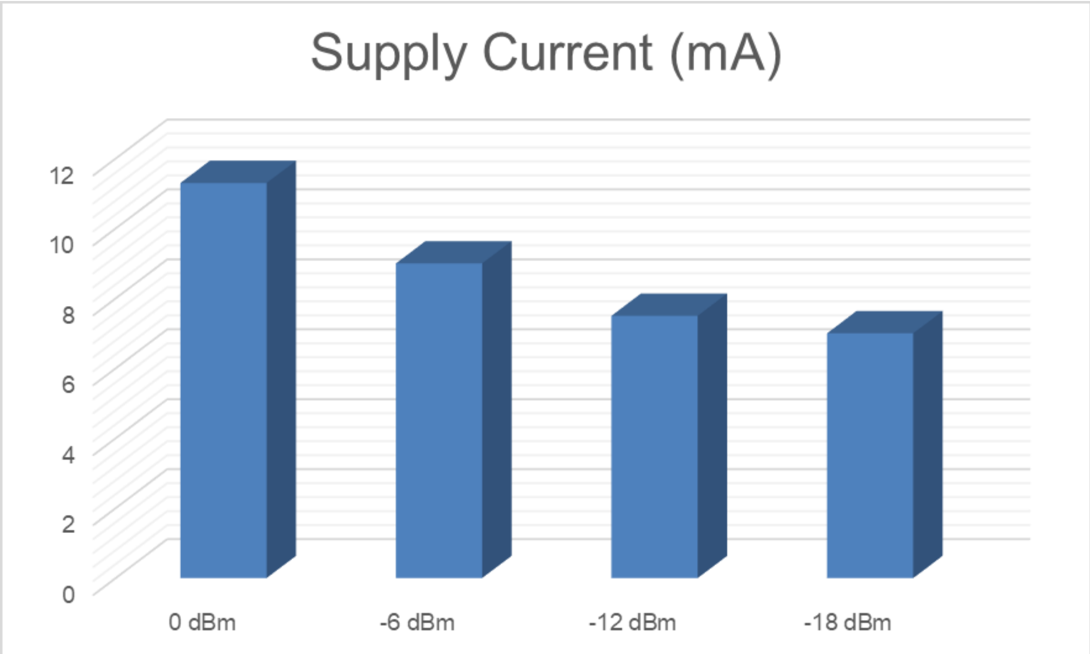


Figure 30. *Average current consumption of nRF module during sending mode with different nRF power settings at 5 volts*

Average current consumption of the nRF module during listening mode with different receiving power settings at 5 volts is presented in table 10 and illustrated in Figure 31.

In our final investigation, we have also carried out the power consumption testing of complete 8-bit microcontroller-based sensor nodes (Atmega328p with nRF modules and different sensors) to evaluate the average current consumption of each sensor nodes for different power configurations of the nRF module. The result is represented in table 11 and Figure 32.

Table 10. *Average current consumption of nRF module during listening mode with different receiving power settings at 5 volts*

Receiving Power	Supply Current (mA)
2 Mbps	13.5
1 Mbps	13.1
250 kbps	12.6

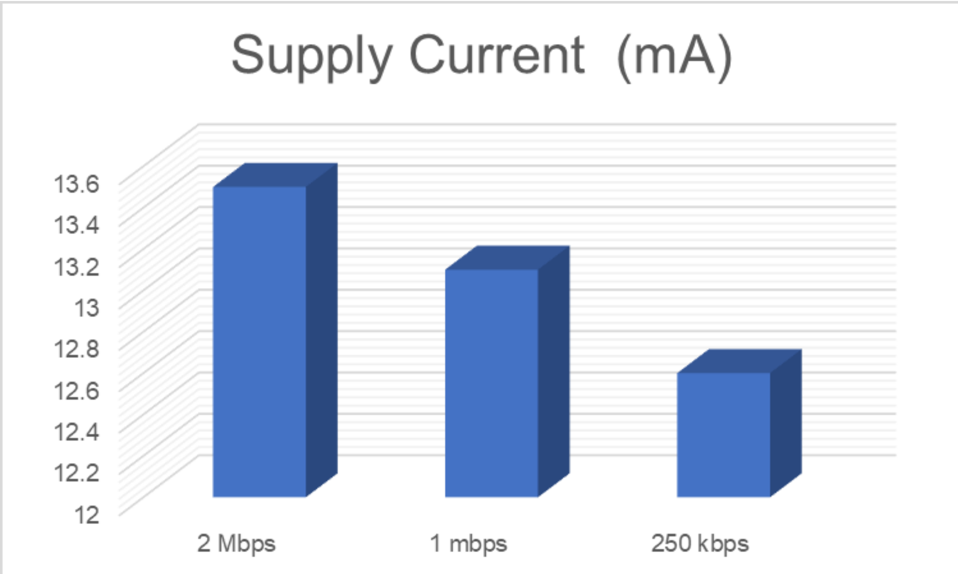


Figure 31. *Average current consumption of nRF module during listening mode with different receiving power mode at 5 volts*

Table 11. *Power Consumption of sensor nodes (sensor + microcontroller + nRF module) with different nRF power Settings at 100 samples/second*

Sensor Nodes	Min (mA)	Low (mA)	High (mA)	Max (mA)
PPG	15.61	15.98	15.88	17.08
Temp	11.62	12.20	12.88	16.41
ACC	11.72	12.36	16.62	19.24

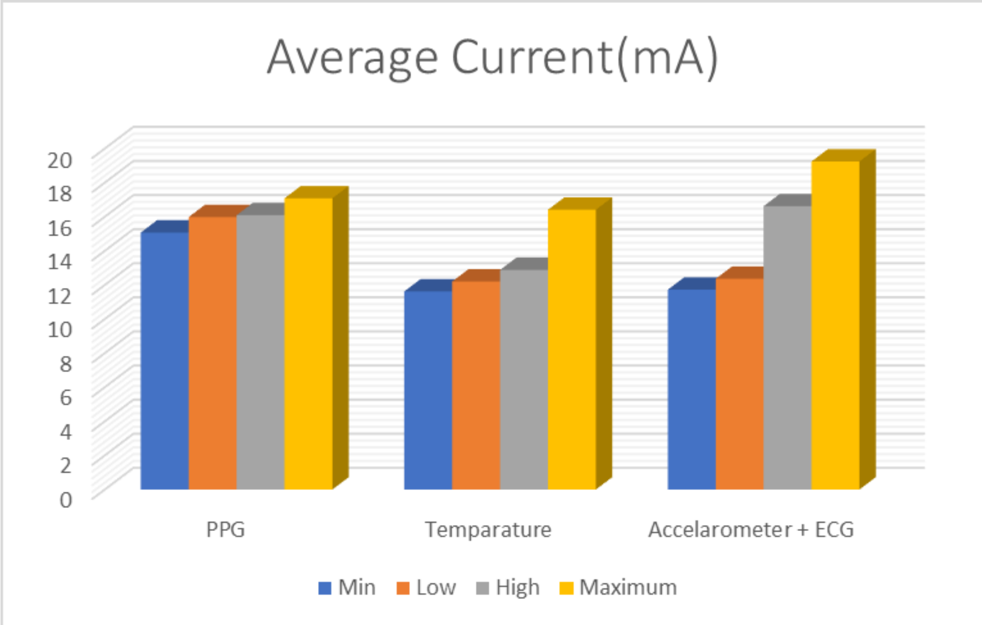


Figure 32. *power Consumption of sensor nodes (sensor + microcontroller + nRF module) with different nRF power Settings at 100 samples/second*

6.4 Effect of Different Sampling Frequency on Power Consumption

Effect of sampling rate on energy consumption of biomedical signal processing systems is previously investigated in many works [91], [97]. It is quite a complicated procedure to define a proper and sufficient sampling rate for biomedical sensors and signal processing applications as many contradictory recommendations are suggested to select the appropriate sampling rate. These facts motivate for collecting data at a high sampling rate to achieve better signal quality. But it is observed during power consumption analysis that the higher data sampling or acquisition rate has proportional relation with power consumption. It is because a higher sampling rate requires higher processing capabilities of the central processing that causes higher power consumption by the sensor nodes.

Table 12. *Average current consumption of Atmega328p with nRF module at different sampling rates and power modes at 5 volts during sending mode*

Samples/ Second	Min (mA)	Low (mA)	High (mA)	Max (mA)
50	5.69	5.69	6.13	6.64
150	8.16	8.59	9.64	11.26
300	12.33	13.04	15.19	18.15

To investigate the effect of different sampling rate on power consumption for 8-bit microcontroller-based sensor nodes, different power consumptions at different sampling rates with different nRF module power configurations are investigated with and without sensors. Table 12 and Figure 33 are representing data without sensors whereas Table 13 and Figure 34 are representing data with sensors. Investigation for a 32-bit microcontroller is presented in table 14 and illustrated by Figure 35.

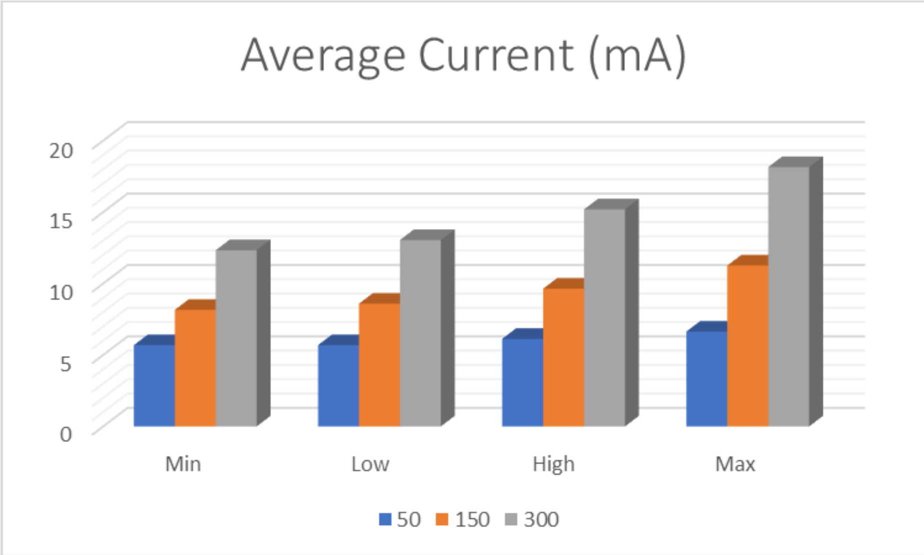


Figure 33. *Average current consumption of Atmega328p with nRF module at different sampling rates and power modes at 5 volts during sending mode.*

Table 13. *Average current consumption of 8-bit microcontroller-based sensor nodes with a high-power setting of nRF at a different sampling rate*

Samples/Second	PPG (mA)	ACC (mA)	Temp (mA)
50	12.32	13.82	10.23
100	14.88	16.88	12.88
150	16.58	18.04	14.07

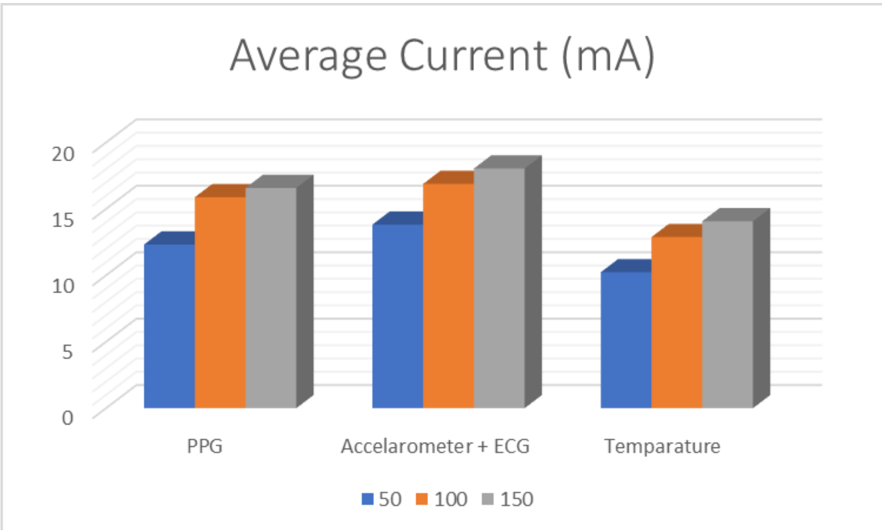


Figure 34. *Average current consumption of sensor nodes with different power configuration of the nRF module at different sampling rates*

Table 14. *Average current consumption of 32-bit microcontroller-based sensor nodes at different sampling rates*

Samples/ Second	ECG (mA)	Temp (mA)	Respiration (mA)	Acc (mA)
50	77.70	77.74	77.74	81.82
150	78.08	79.74	79.74	83.30
300	79.32	86.52	86.52	86.04

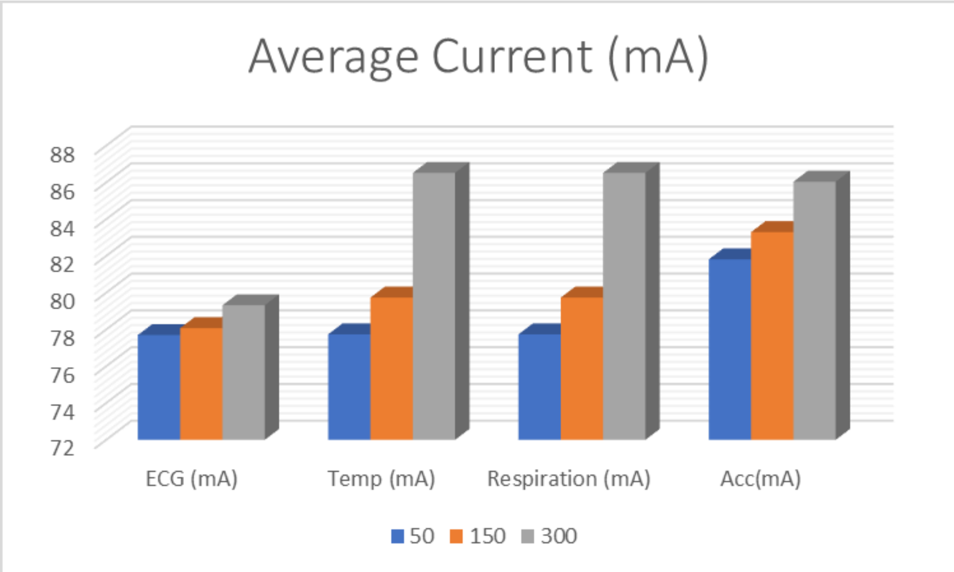


Figure 35. *Average current consumption of 32-bit microcontroller-based sensor nodes at different sampling rates*

6.5 Performance analysis of PPG and ECG

For detecting heart rate and oxygen saturation (SO_2) level, pulse oximetry and heart-rate monitor module MAX30105 is employed. The sensor utilizes the pulse oximetry method that can be described as an important noninvasive measuring method to detect heart rate and oxygen saturation (SO_2) level of the human body. Most essential components of the MAX30105 are LEDs and photodetectors. The MAX30105 is featured with three types of LEDs that are red, IR and green to generate LED pulses for detecting blood flow. PPG sensor can be configured to operate in either red, or red and IR or red, IR and green LED mode. A key feature of MAX30105 is that it supports different reconfigurable power settings, that even allows zero standby current. LED mode, as well as the current consumption of LED, can be reconfigured through programming from a range of 0 to 50mA. Another reconfigurable property of MAX30105 is the LED pulse width. The pulse width of the MAX30105 can be reconfigured within the range of 69µs to 411µs. Both reconfigurable properties (LED current consumption and pulse width) have an effect on accuracy and power consumption of the sensor node. LED modes, LED current consumption and pulse width require to be configured in a way so that the PPG sensor can provide enough sampling frequency to ensure reliability during data collection.

Table 15. *Power consumption of 8-bit microcontroller-based PPG sensor node for 1 LED mode with different LED and nRF power configurations at 50 samples/second*

nRF Power Configuration	0.8 mA (mA)	3.0 mA (mA)	6.5 mA (mA)	9.2 mA (mA)	12.0 mA (mA)
Min	12.76	13.24	13.49	14.08	14.79
Low	12.88	13.37	13.87	14.32	14.92
High	12.87	13.64	14.17	14.64	15.44
Max	15.48	15.78	17.60	17.64	18.29

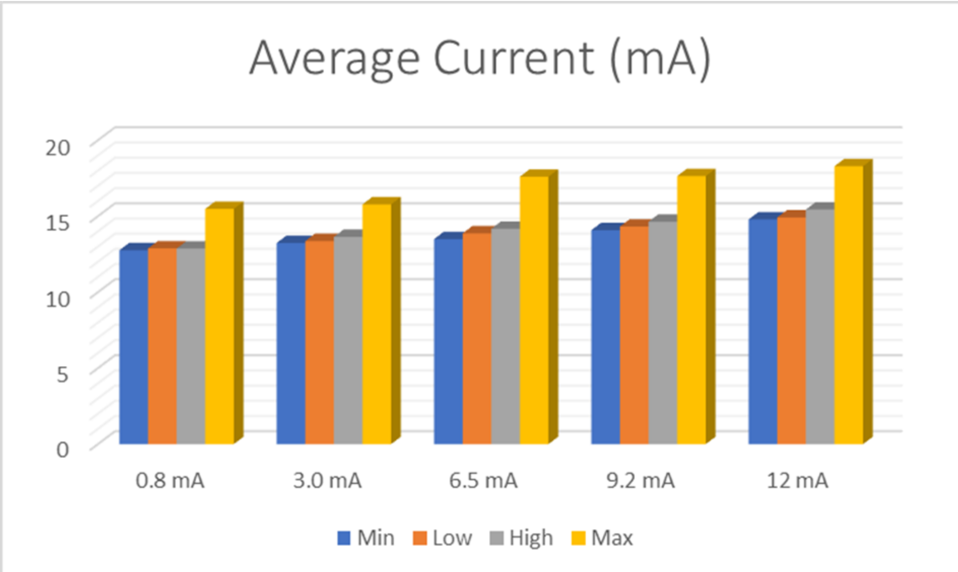


Figure 36. *Power consumption of 8-bit microcontroller-based PPG sensor node for 1 LED mode with different LED and nRF power configurations at 50 samples/second*

Table 16. *Power consumption of 8-bit microcontroller-based PPG sensor node for 2 LED mode with different LED and nRF power configurations at 50 samples/second*

nRF Power Configuration	0.8 mA (mA)	3.0 mA (mA)	6.5 mA (mA)	9.2 mA (mA)	12.0 mA (mA)
Min	12.86	13.73	14.65	15.61	16.51
Low	12.94	13.82	14.24	15.98	16.59
High	13.22	13.98	14.90	15.88	17.02
Max	14.02	14.99	16.63	17.08	18.47

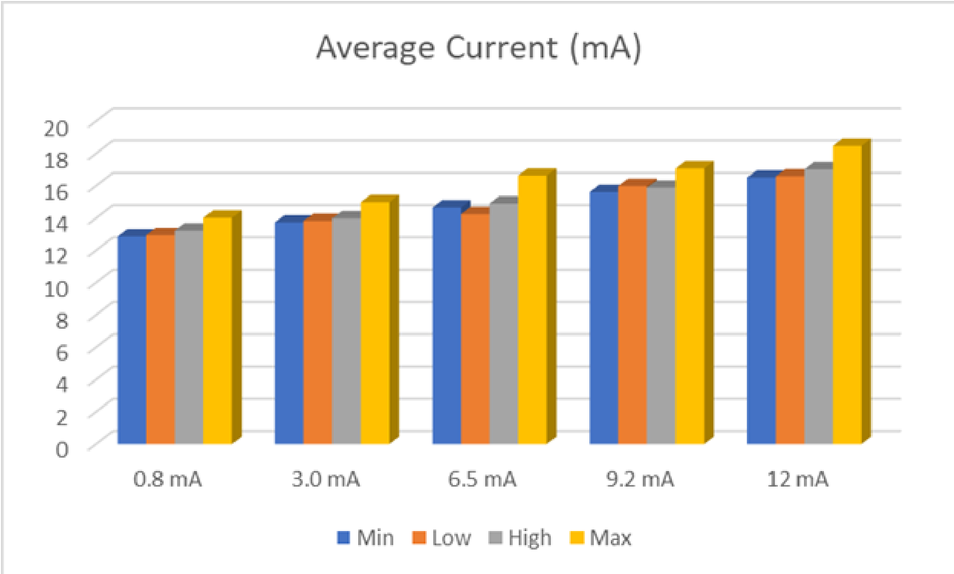


Figure 37. *Power consumption of 8-bit microcontroller-based PPG sensor node for 2 LED mode with different LED and nRF power configurations at 50 samples/second*

It is found during the investigation that power consumption of the PPG sensor nodes for both 8-bit and 32-bit microcontroller-based sensor nodes is being influenced by different configurations of LED modes, LED current consumptions and different sampling frequencies. Different case scenarios consisting of different configurations of LED modes and LED current consumption are tested and investigated for both 8-bit and 32-bit microcontroller-based sensor nodes. LED current consumption of PPG sensor is configured with red as well as red and IR LED mode along with 0.8 mA, 6.5 mA and 12 mA of average current consumption during testing. The result is represented in table 15 and 16 as well as illustrated in Figure 36 and 37. For 32-bit microcontroller based sensor nodes, the effect of different sampling rates (100 and 200 samples/seconds) with different LED power configurations are investigated and the results are represented in table 17 and 18 as well as illustrated in Figure 38 and 39.

Table 17. *Power consumption of 32-bit microcontroller-based PPG sensor node for 1 LED mode with different LED power configurations at 100 and 200 samples/second*

Samples/ Second	0.8 mA (mA)	3.0 mA (mA)	6.5 mA (mA)	9.2 mA (mA)	12.0 mA (mA)
100	82.13	83.17	84.04	85.22	86.17
200	84.4	85.27	85.62	87.42	88.28

Table 18. *Power Consumption of 32-bit microcontroller-based PPG sensor node for 2 LED mode with different LED power configuration at 100 and 200 samples/second*

Samples/ Second	0.8 mA (mA)	3.0 mA (mA)	6.5 mA (mA)	9.2 mA (mA)	12.0 mA (mA)
100	82.68	82.84	84.42	85.37	86.64
200	84.37	85.70	86.04	87.95	88.58

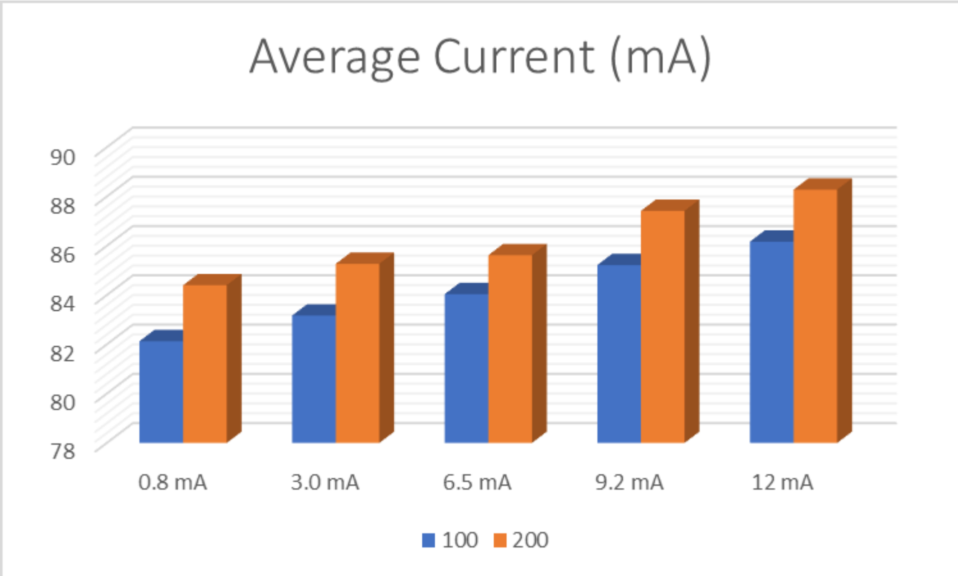


Figure 38. *Power consumption of 32-bit microcontroller-based PPG sensor node for 1 LED mode with different LED power configurations at 100 and 200 samples/second*

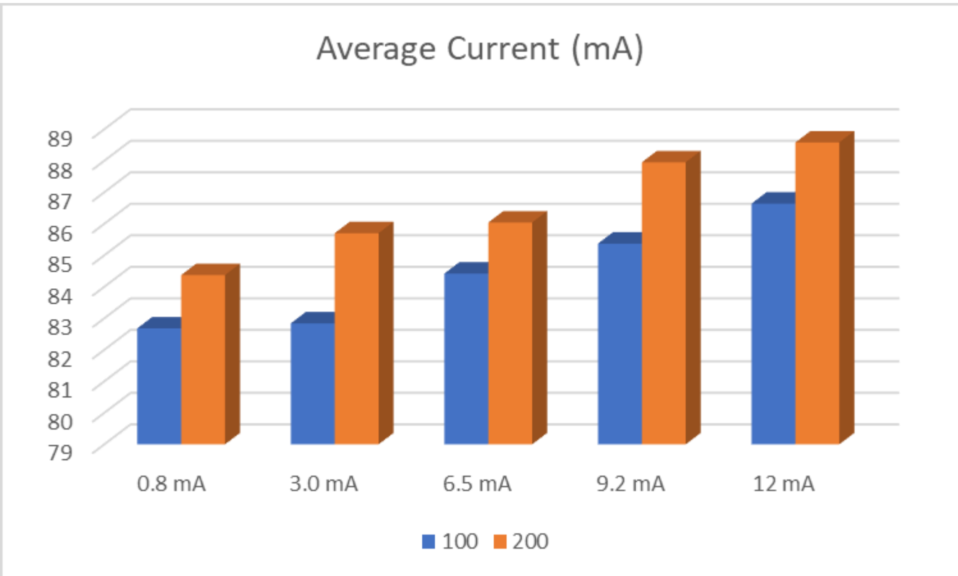
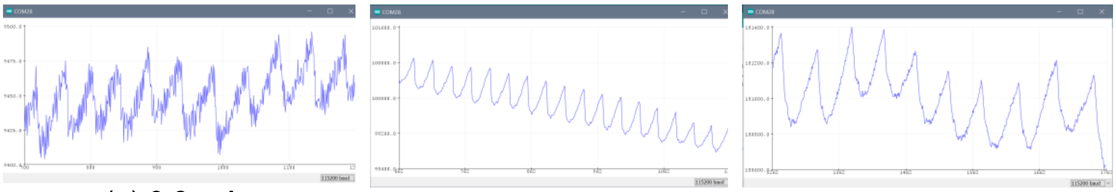


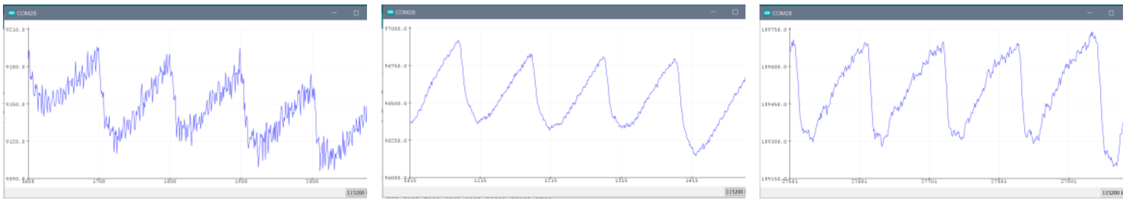
Figure 39. *Power Consumption of 32-bit microcontroller-based PPG sensor node for 2 LED mode with different LED power configuration at 100 and 200 samples/second*

The signal quality of the PPG sensor depends on different sampling rate with a different power setting of LED. To investigate the result, several testings are conducted at 50, 100 and 200 sampling rate with three different LED power settings that are 0.8 mA, 6.5 mA, and 12 mA. The results are illustrated in Figure 40, 41 and 42. It is found that low LED setting and lower sampling rate would produce a poor signal that can be observed from Figure 40(a). The high-quality signal can be obtained from a higher sampling rate with a higher LED power setting that can be observed from Figure 43(c).



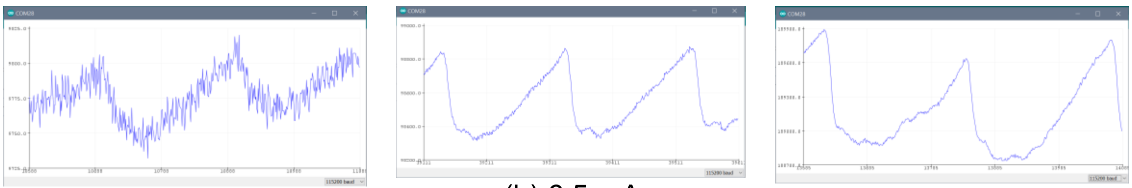
(a) 0.8 mA (b) 6.5 mA (c)12 mA

Figure 40. *PPG sensor data at 50 samples/second with different LED power configuration*



(a) 0.8 mA (b) 6.5 mA (c)12 mA

Figure 41. *PPG sensor data at 100 samples/second with different LED power configurations*



(a) 0.8 mA (b) 6.5 mA ((c)12 mA

Figure 42. *PPG sensor data at 200 samples/second with different LED power configurations*

The electrical activity of the heart can be detected by the AD8232 ECG sensor and represented by electrocardiogram graph. A general illustration of the ECG signal is presented in Figure 43 consisting of different waves that are defined as P, Q, R, S, T. An important feature of electrocardiogram can be classified into two basic Intervals of the PR Interval and the QT Interval. It is possible to identify and detect various cardiac disease by analyzing the electrical patterns through the electrocardiogram. Performance of the ECG sensor depends on the accuracy of detected T waves, P waves, and QRS complex. The electrical activity of the upper chambers of the heart is represented by P-wave. The electrical activity of the lower chamber of the heart is represented by the QRS complex and T-wave. One of the most significant properties of the ECG sensor is to detect QRS complex that allows extracting more features from the ECG signal. A signal from our developed ECG sensor node is acquired at 100 samples/second and analyzed for extracting the features. Figure 44 represents the ECG signal at 100 samples/seconds with the classification of different features. It is found that the acquired signal quality was good enough to extract Q, P, R, T, S waves along with P-R interval, P-R segment, Q-T interval, and S-T segment.

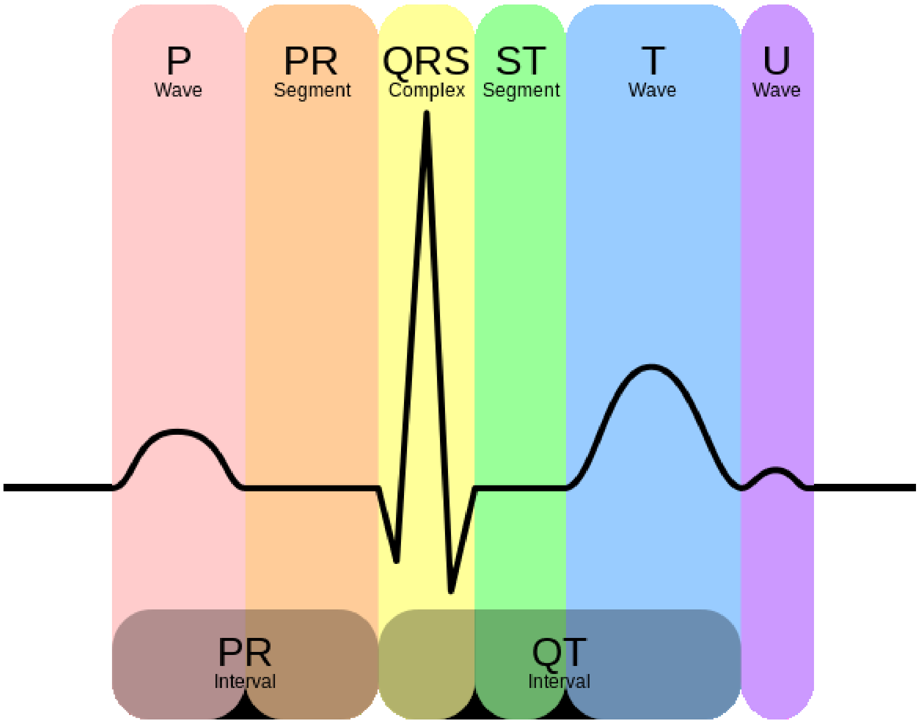


Figure 43. *An ECG signal with P, Q, R, S, T waves*

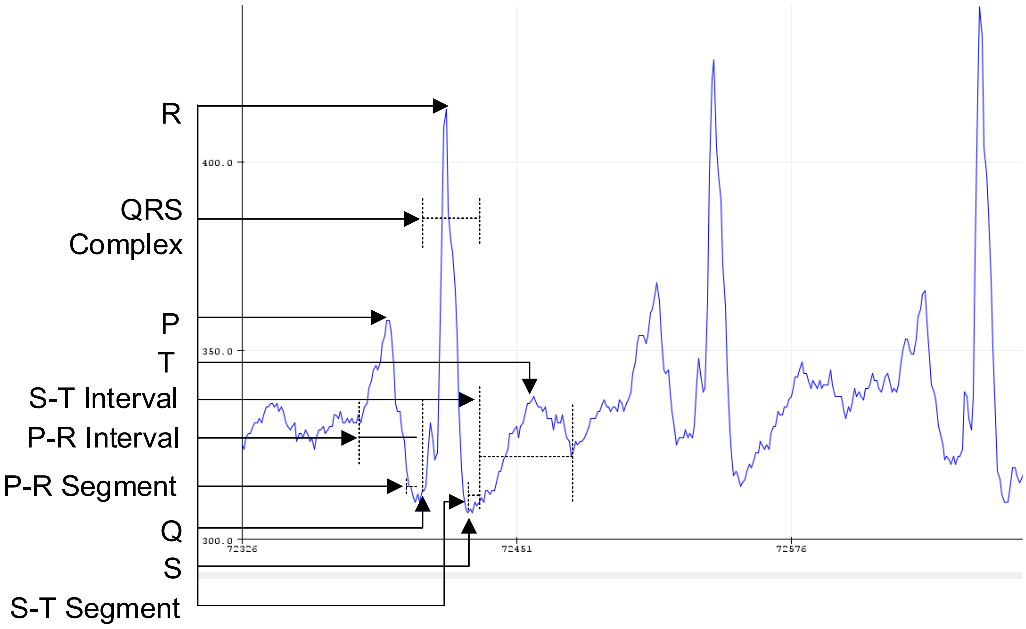


Figure 44. *ECG signal from the ECG sensor nodes with extracted features*

6.6 Performance Analysis of Different working Modes of Health Sensor Nodes

The firmware is developed using Arduino IDE that is based on C++ programming language [113]. Backend application for the smart gateway is written in Python. At the starting of the health sensor nodes, it initializes the data transmission method with the nRF protocol for the first approach and Wi-Fi for the second approach. Then it initializes the attached sensors to check if the sensors are properly working. Several modes are developed based on dynamic goal management for the sensor nodes to achieve power efficiency. Sensor node adopts the observation mode first to evaluate the patient's current condition. The process of the observation mode is illustrated in Figure 45.

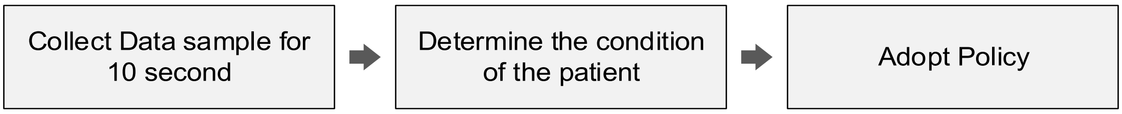


Figure 45. *Functional diagram of observing mode*

According to the condition of the patient, the sensor node adopts a different policy. Each policy is a combination of a different mode of normal, accurate or low power mode that is presented in table 19 and 20. nRF data transmission power policy from table 19 is only used for 8-bit microcontroller-based architecture and the rest of the table is the same for both an 8-bit and 32-bit microcontroller-based sensor nodes.

Table 19. *Description of different modes*

Different Modes	nRF Power Policy	Samples/ Second (8-bit sensor node)	Samples/ Second (32-bit sensor node)	PPG LED Mode	PPG Power Consumption	Micrcontroller Mode
Normal / Baseline	High	100	150	1	6.5 mA	Normal
Low Power	Minimum	50	50	1	3.2 mA	Normal
Accuracy	Maximum	150	200	2	12.5 mA	Normal
Sleep	Standby	Standby	Standby	Standby	Standby	Sleep
Observer	Standby	100	100	1	6.5 mA	Normal

Calculation of operating time is conducted using the current value in milliampere (mA) and the capacity of the battery in Milliampere Hours (mAh). General formulation of calculating battery life can be derived from the input current rating of the battery and the current consumption of the system. Higher operating time can be achieved at lower current consumption. An external factor value is considered during calculation that can affect battery life. Mathematically derivation of the formula is presented below:

$$Battery\ Life = \frac{Battery\ Capacity(mAh)}{Load\ Current(mA)} * 0.70 \qquad (2)$$

Table 20. *Description of different policies*

Policy	Description	Recording	Sleeping
Policy 1	Power Saving Monitoring	R minutes in Low power mode	2xS minutes in Sleep mode
Policy 2	Normal Monitoring	R minutes in Normal mode	S minutes in Sleep mode
Policy 3	Accurate Monitoring	R minutes in Accurate mode	S minutes in Sleep mode
Policy 4	Emergency Situation	Continuous Accurate Mode	

The estimated Battery life of 8-bit microcontroller-based sensor nodes for different policies is presented in table 14. A specific baseline system is established which is tested without the dynamic goal management based working modes. The baseline system does not switch mode and always consumes a similar amount of energy during operating. It has similar power consuming properties of normal mode. It is observed in our investigation that highest battery life of 8-bit microcontroller-based sensor nodes can be achieved up to 156.25, 175.87, and 177.66 hours (PPG, activity, and temperature sensor nodes) wherein baseline system, highest battery life can be achieved up to 75.34, 72.38 and 84.74 hours as shown in table 24 . Battery life can be increased up to 107.39%, 142.98% and 109.65% for dynamic goal management based working mode compared to the baseline system. Similarly, increased battery life is noticed for 32-bit microcontroller-based sensor nodes. It is demonstrated in table 26. It can be stated from table 26 that battery life can be increased up to 44.59%,38.73%, 42.12% and 35.74% for different sensor nodes (PPG. Activity, temperature, and respiration, ECG) compared to the baseline system.

Table 21. *Power consumption of different modes for 8-bit microcontroller-based sensor nodes*

Mode	PPG (mA)	Accelarometer + ECG (mA)	Temperature (mA)
Low power	13.24	11.72	11.62
Normal	15.17	16.62	13.68
Accuracy	18.47	19.24	16.41
Sleep	0.11	0.11	0.11
Observer	12.17	13.62	10.68

Table 22. *The estimated Battery life of 8-bit sensor nodes for different policies*

Policy	PPG (Hr.)	ACC+ECG (Hr.)	Temperature (Hr.)
Policy 1	156.25	175.87	177.66
Policy 2	91.62	81.06	101.52
Policy 3/ Baseline	75.34	72.38	84.74
Policy 4	37.89	36.38	42.65

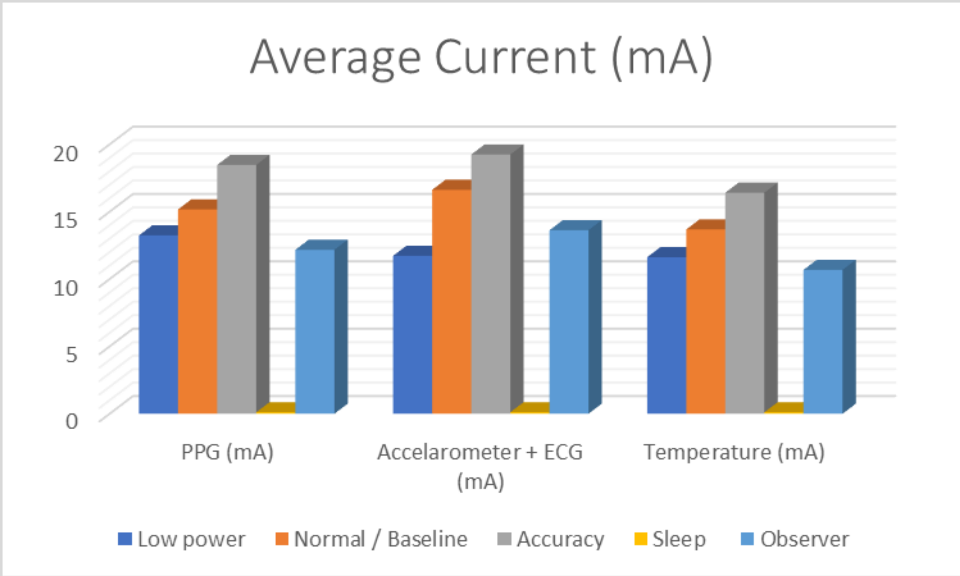


Figure 46. *Power consumption of Different modes for 8-bit sensor nodes*

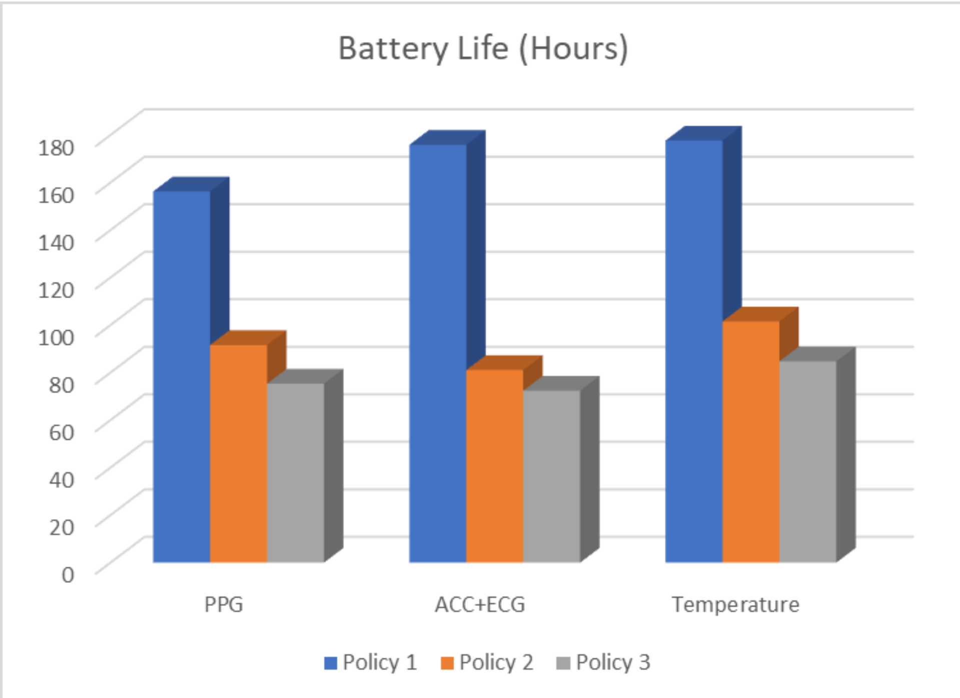


Figure 47. *The estimated Battery life of 8-bit sensor nodes for different policies*

Table 23. *Power consumption of Different modes for 32-bit sensor nodes*

Operating Modes	PPG (mA)	Acceleron-meter (mA)	Temperature (mA)	ECG (mA)
Low power	81.37	81.82	77.74	77.70
Normal	84.04	83.30	79.74	78.08
Accuracy	88.28	85.68	83.15	78.90
Sleep	10.62	10.62	10.62	10.62
Observer	84.04	82.78	78.30	77.89

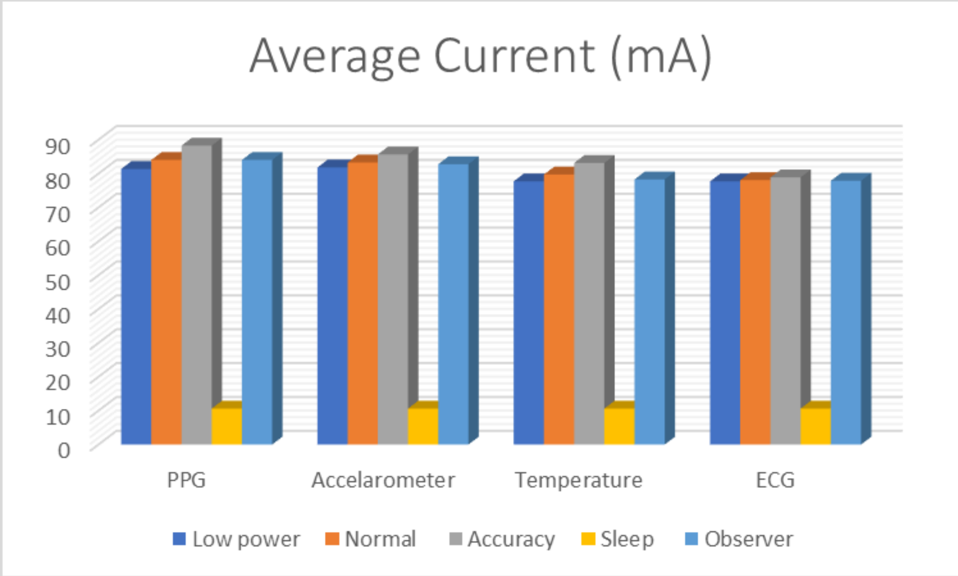


***Figure 48.** Power consumption of Different modes for 32-bit sensor nodes*

Table 24. The estimated Battery life of 32bit sensor nodes for different policies

Policy	PPG (Hr.)	ACC (Hr.)	Temp & res-piration (Hr.)	ECG (Hr.)
Policy 1	20.46	20.38	21.22	21.23
Policy 2	14.73	14.90	15.49	15.78
Policy 3/Baseline	14.15	14.69	14.93	15.64
Policy 4	7.92	8.1	8.41	8.87

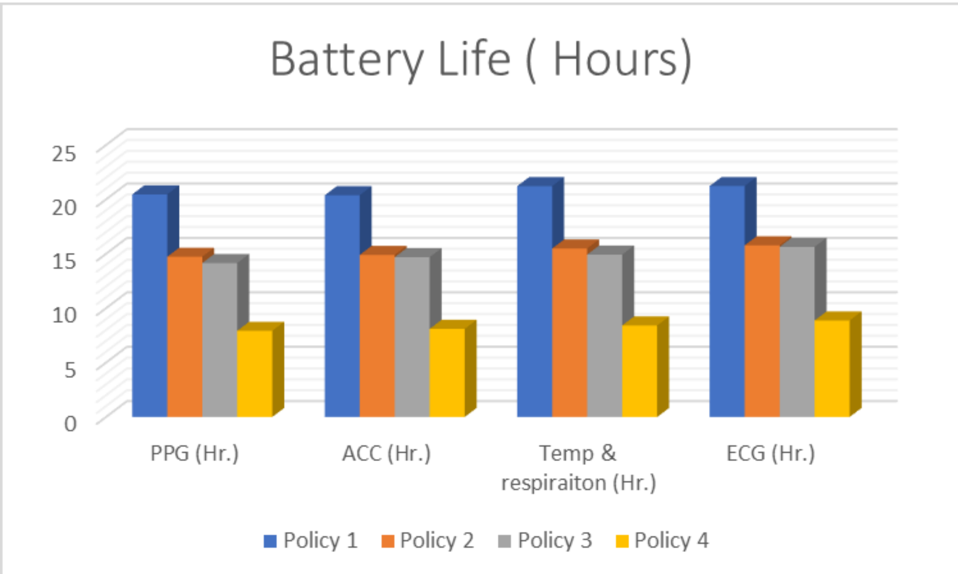


***Figure 49.** The estimated Battery life of 32-bit sensor nodes for different policies*

***Table 25.** Increased battery life for 8-bit microcontroller-based sensor nodes*

Sensor Nodes	Low Power Mode (Hr.)	Baseline (Hr.)	Increased Battery life (%)
PPG	156.25	75.34	107.39
ACC+ECG	175.87	72.38	142.98
Temperature	177.66	84.74	109.65

***Table 26.** Increased battery life for 32-bit microcontroller-based sensor nodes*

Sensor Nodes	Low Power Mode (Hr.)	Baseline (Hr.)	Increased Battery life (%)
PPG	20.46	14.15	44.59
ACC	20.38	14.69	38.73
Temperature and Respiration	21.22	14.93	42.12
ECG	21.23	15.64	35.74

6.7 Performance Analysis of Fog-Assisted Gateway

During the investigation, it is found that different power consumption can be observed during normal operating mode and data receiving mode for fog-assisted smart gateways. The reason for this variation depends on running different applications on the gateway. Power consumption significantly increases when any application starts running in the gateway. For the gateway which is employed to receive sensor data from 8-bit microcontroller-based sensor node, a python-based backend application requires to be running constantly on Onion omega that is coupled with Atmegea32P and nRF module.

On the other hand, UDP web server requires to be running continuously in order to receive sensor data from the 32-bit microcontroller-based sensor nodes. Power consumption of smart gateways for 8-bit microcontroller-based sensor nodes is presented in table 27 and Figure 50 as well as power consumption analysis is presented for two different Smart gateways (Raspberry Pi and Odroid XU4) for 32-bit microcontroller-based sensor nodes in table 28 and Figure 51. Another performance analysis of the fog-assisted gateway is performed to determine the performance of the gateway for receiving data at different sampling rate for 32-bit microcontroller-based sensor nodes. It is observed that the different sampling rate has an effect on different UDP servers (Python-based UDP web server and node.js based UDB web server) running on the gateway. Both UDP Web servers are tested for three smart gateways to evaluate the sampling loss percentage.

***Table 27.** Average current consumption of Smart Gateway for 8-bit microcontroller base sensor nodes (Onion Omega 2+ at different working mode)*

Working Mode	Onion Omega 2+ (mA)
Idle Mode	146.95
Receiving Mode	155.43

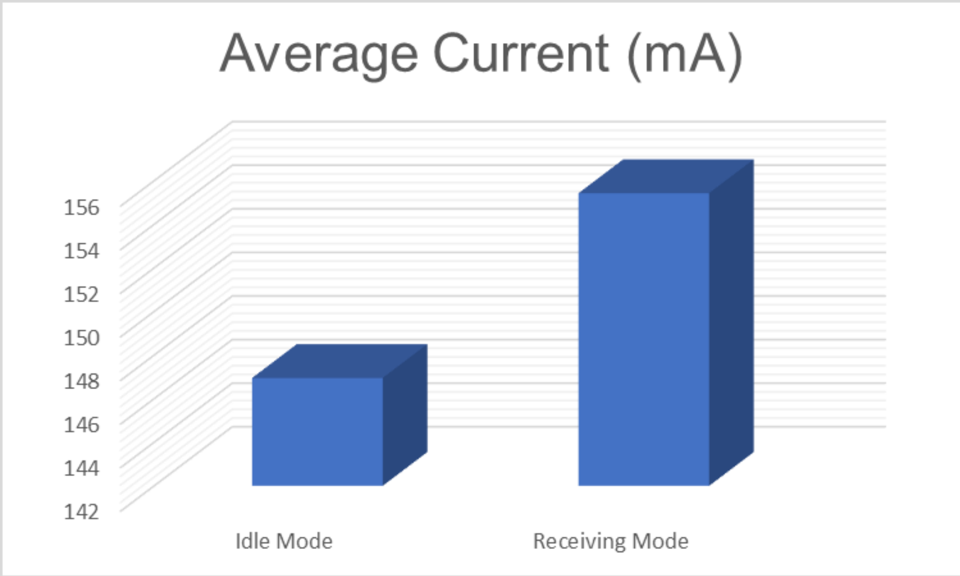


Figure 50. *Average current consumption of Smart Gateway for 8-bit microcontroller-based sensor nodes (Onion Omega 2+ at different working modes*

Table 28. *Average current consumption of two Smart Gateway for 32-bit microcontroller-based sensor nodes at different working modes*

Working Mode	Raspberry Pi (mA)	Odroid XU4 (mA)
Idle Mode	456.89	868 mA
Receiving Mode	585.38	1280 mA

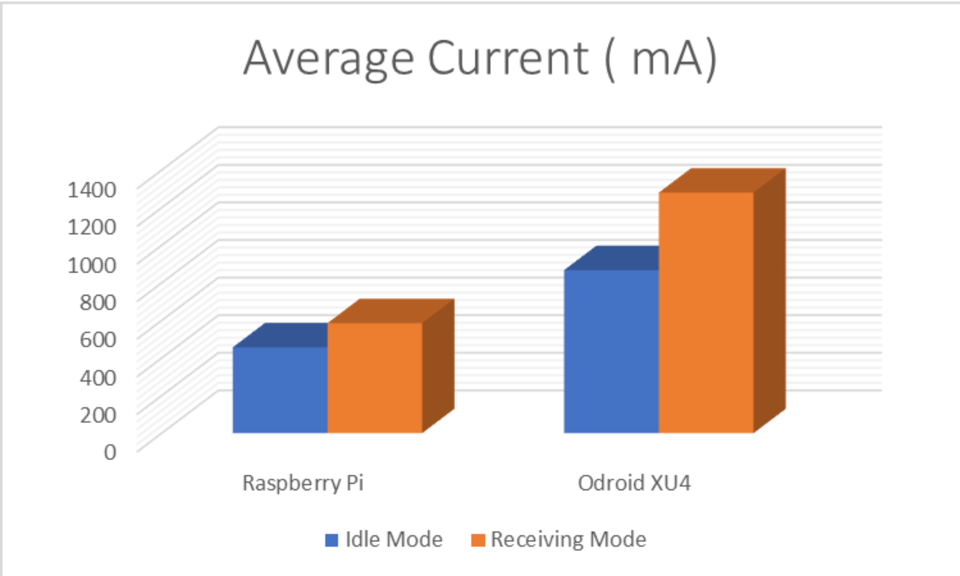


Figure 51. *Average current consumption of two Smart Gateway for 32-bit microcontroller-based sensor nodes at different working modes*

It is found in our investigation that from 50 to 100 samples/ second, sample loss of all the gateways is nearly the same and very low for both Python and Node.js based web server. But for the higher sampling rate, Python server shows better performance in term of sample loss for Raspberry Pi and Odroid XU 4 based smart gateways compared to the node.js. Jetson TX2 can be considered as the best gateway compared to other two gateways as it has demonstrated the constantly lower amount of sampling loss for both Python and Node.js web servers that can be observed from the table 29 and Figure 52.

Table 29. *Percentage of sample loss for Python and Node.JS UDP Web server of different smart gateways for 32-bit sensor nodes*

Samples/ Second	R.Pi Python [Server] (%)	R.Pi- node.js [Server] (%)	O.XU4- Python [Server] (%)	O.XU4- node.js [Server] (%)	J.TX2- Python [Server] (%)	J.TX2- node.js [Server] (%)
50	0.048	0.37	0	0.33	0	0
100	0.428	0.55	0.18	1.28	0.03	0.274
150	0.41	22.28	0.51	24.95	0.17	1.0672
200	0.44	35.48	1.77	32.09	0.23	1.64
250	1.19	45.59	6.81	43.34	0.41	2.483
300	1.25	64.50	18.09	66.39	1.02	5.124

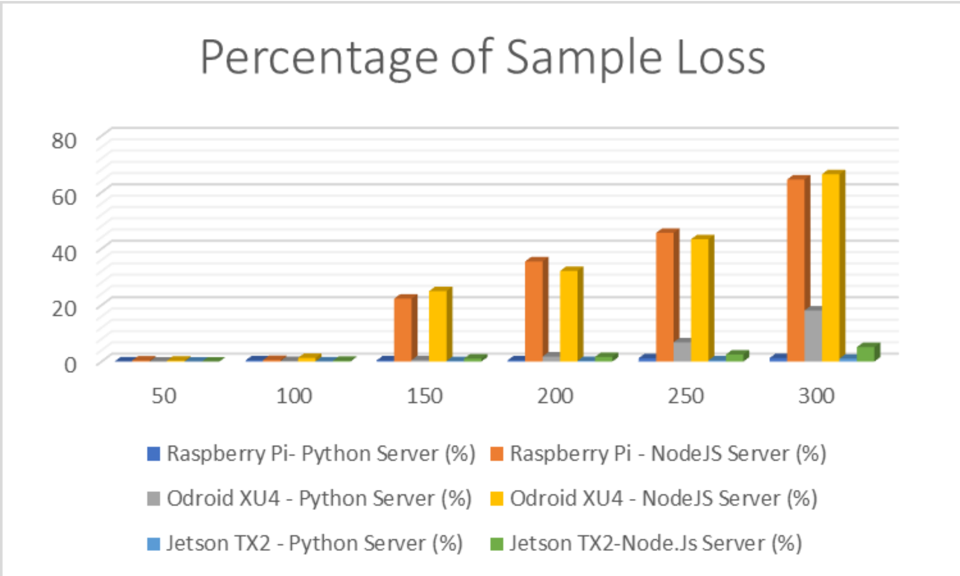


Figure 52. *Percentage of sample loss for Python and Node.JS UDP Web server of different smart gateways for 32-bit microcontroller-based sensor nodes*

7. DISCUSSION AND CONCLUSION

In our research, we developed a remote patient monitoring system based on IoT and WBASN technology that can be utilized for this purpose. One of the main objectives of our research was to create an IoT based solution for remote healthcare that can also be utilized for data collection for research purposes. The principle key challenge was to achieve power efficiency for a prolonged operating period to increase the reliability of data collection and reduce the effect of missing events. In the first phase of our research, a dynamic goal management-based solution was presented to enhance the performance of IoT based Remote healthcare system. The developed system was tested and compared with a baseline system. It is observed that the power consumption was minimized up to 44% compared to the baseline system. 90% reduction was observed for missing events compared to the baseline system. Proposed priority assignment algorithm was able to prevent data collection interruption up to 15 times compared to a baseline system that was equivalent of fifty-six (56) hours of potential data loss compared to the baseline system.

In the second phrase, WBASN based wireless data logger architectures were presented based on 8-bit and 32-bit microcontrollers that adapted dynamic goal manager based working modes to increase the power efficiency. Extended operating periods for both 8-bit and 32-bit microcontroller-based sensor node were achieved compared to the baseline system. It was found during our investigation that the operating period of 8-bit microcontroller-based sensor nodes was increased up to 107.39%, 142.98% and 109.65% (PPG, activity and ECG, temperature sensor nodes) compared to the baseline system for dynamic goal management based working mode. Similarly, operating periods of 32-bit sensor nodes were increased up to 44.59%,38.73%, 42.12% and 35.74% for different sensor nodes (PPG. Activity, temperature, and respiration, ECG) compared to the baseline system.

Different fog-assisted gateways were constructed using different Linux based computer (Raspberry Pi, Odroid XU4, Jetson TX2) with different backend system (Python and Node.js) to evaluate different performance analysis. Very low sample loss was found for both Python and Node.js based web server for a lower sampling rate (50 to 100 samples/ second). Python server showed significantly better performance compared to the node.js in term of sample loss for Raspberry Pi and Odroid XU 4 based smart gateways for the higher sampling rate (150 to 300 samples/ second). It was observed that the Jetson TX2 demonstrated higher performance compared to the Raspberry Pi and Node.js by providing a constant lower amount of sampling loss for both Python and Node.js based web server.

Chronic health condition is playing as the leading cause for the high mortality rate in the modern world. But it can be controlled and prevented through monitoring of physical vital signs through the developed system. Our implemented system can be employed to determine earlier warning symptoms through uninterrupted patient monitoring. It can assist to prevent future possible disease as well as reducing the health hazard is possible through continuous health monitoring by utilizing our developed system.

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APPENDIX: USER INTERFACE

A user interface to start recording process is developed node.js, HTML and CSS. An illustration of the user interface is presented in figure 53.

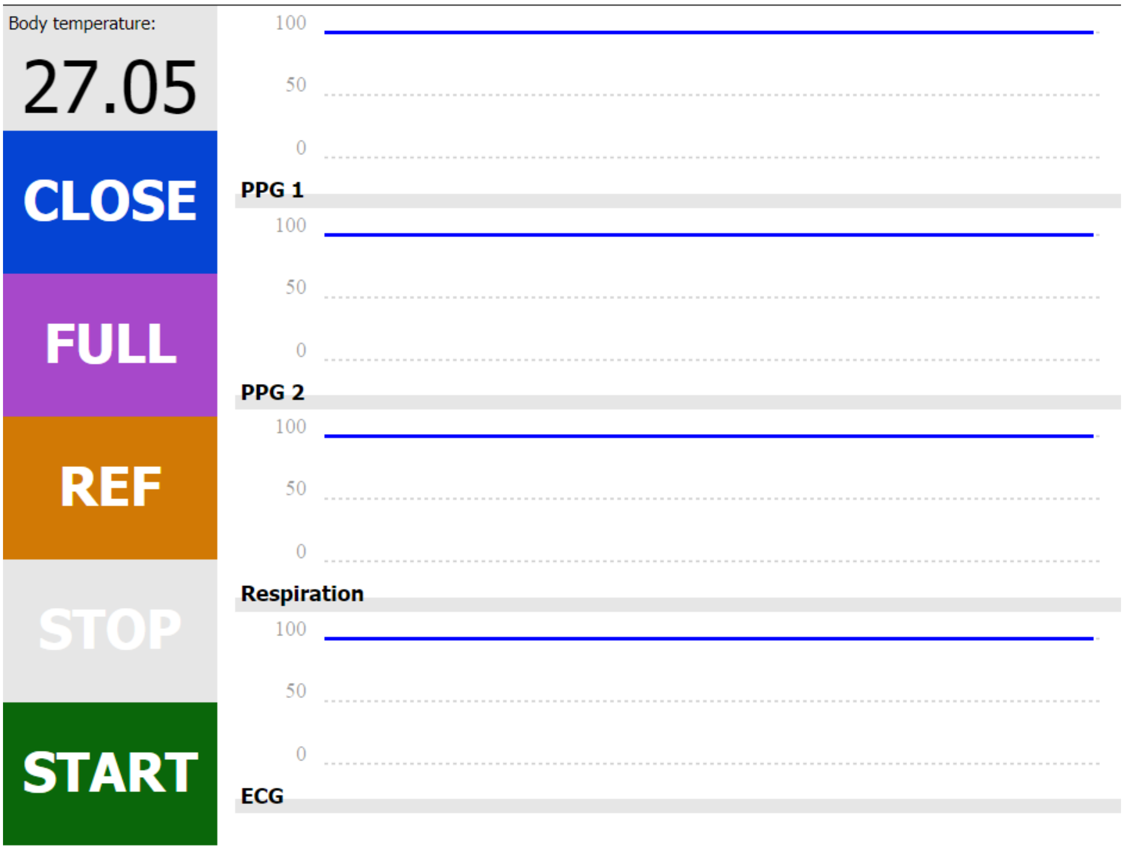

Figure 53. *The user interface of Smart gateways*

Google firebase is used as a cloud services to collect data from sensor nodes. Figure 54 is illustrating the dashboard for Google firebase cloud service.

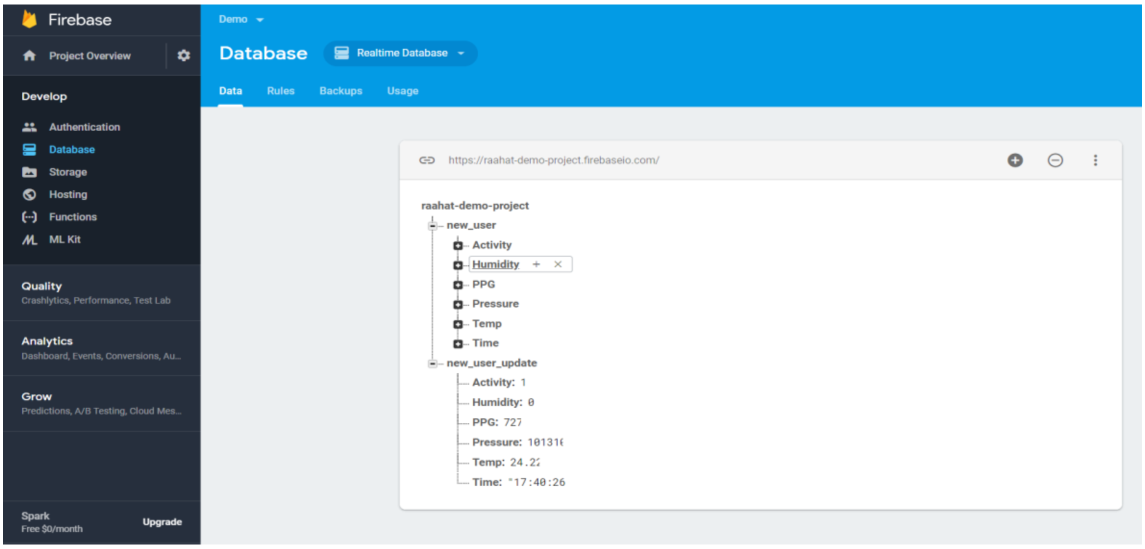

Figure 54. *Storing sensor data in a cloud server (Google Firebase)*

Power monitoring tools are used for conducting power consumption analysis of the developed system with a different configuration. Figure 55 is representing the user interface of Power Monitoring tool.

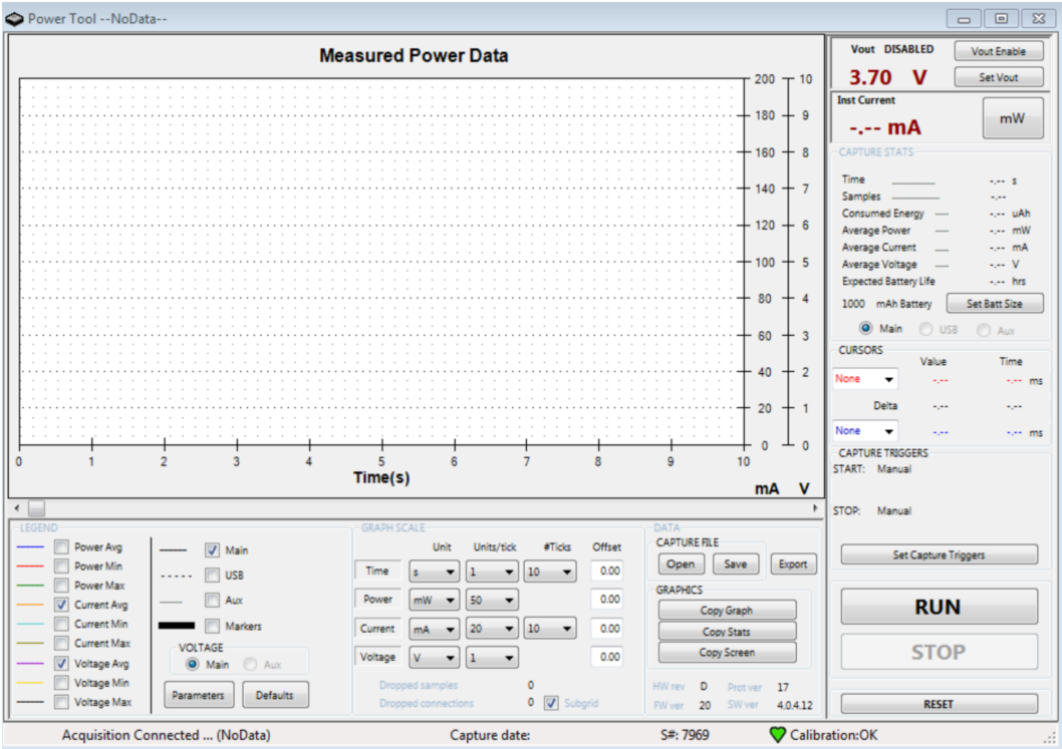

Figure 55. The user interface of power monitoring tool

A python-based backend system is developed to fetch live data from google firebase cloud server and generate live plotting of the sensor data. It is presented in figure 56.

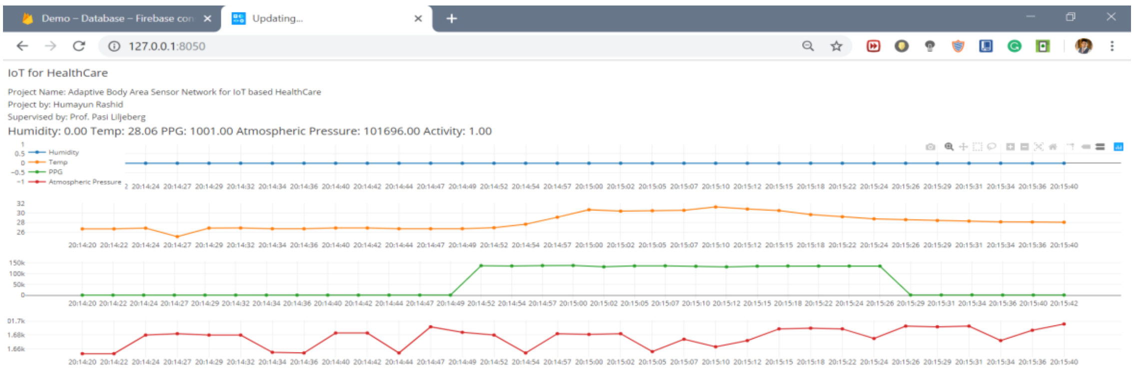

Figure 56. Live visualization of sensor data from cloud server