Edge Intelligence based Realtime Healthcare Monitoring using NB-IoT

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A thesis submitted to the Department of Computer Science and Engineering
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It is hereby declared that

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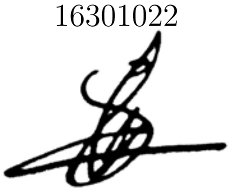

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Ethics Statement

We, hereby declare that this thesis is based on the findings of our research. All other materials used have been properly noted in the document.

This work, neither in whole nor in part, has never been submitted by anyone to any other university or institution for the award of any degree.

Abstract

The deployment of the Internet of Things (IoT) has been widespread. It is sure to bring improvements in medical care centers, better clinical convenience for patients and enhanced hospital management standards, even in remote areas where the need for real-time healthcare monitoring is very vital. We have proposed an architecture which connects the NB-IoT enabled smart monitoring devices of the hospital to the nearest Base Station (BS). Then, from there sending data to the edge to avoid the round trip directly to the Cloud to avoid the central data center mechanism to elevate security and optimality. The client nodes send the data to the edge where the main data processing takes place. This system will be based on the Narrowband-Internet of Things (NB-IoT) protocol because of its various excellencies. NB-IoT has greater connection capacity, broader coverage, better battery life, and relatively low cost. For these advantages, it is a better choice for real-time monitoring in remote areas for applications regarding medical purposes.

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Nomenclature

The next list describes several symbols & abbreviation that will be later used within the body of the document

$3GPP$ Third Generation Partnership Project

ACK Acknowledge

$AMQP$ Advanced Message Queuing Protocol

API Application Programming Interface

BGM Blood Glucose Monitor

BS Base Station

CLI Command Line Interface

CMP Internet Control Message Protocol

$CoAP$ Constrained Application Protocol

$DDos$ Distributed Denial of Service

DNS Domain Name System

$EC-GSM-IoT$ Extended Coverage-Global System for Mobile Communication

$eDRX$ Expanded Discontinuous Reception

$EHRs$ Electronic Health Records

$eMTC$ enhanced Machine Type Communication

ESL Edge Server Layer

EVB Evaluation Board

$FS1$ Frame Structure 1

GNN Graph Neural Network

$GPRS$ General Packet Radio Service

GSM Global System for Mobile Communications

$HPSP$ Health Professions Scholarship Program

$HTTP$ Hypertext Transfer Protocol

$I2C$ Inter-Integrated Circuit

$IEEE$ Institute of Electrical and Electronics Engineers

$ImHS$ Interactive Mobile Health Service

$IMT2020$ International Mobile Telecommunications-2020

IOS I-Phone Operating System

IoT Internet of Things

IPL Indian Premier League

$JSON$ Javascript Object Notation

LAN Local Area Network

LBW Leg before Wicket

$LoRa$ Long-Range

$LPWA$ Low Power Wide Area

$LPWAN$ Low Power Wide Area Network

LTE Long Term Evolution

$LTE-M$ LTE-Machine to Machine

MAC Medium Access Control

MCL Minimum Coupling Loss

MCU Microcontroller Unit

$mMTC$ Massive Machine-Type Communications

$MOHFW$ Ministry of Health and Family Welfare

$MQTT$ Message Queuing Telemetry Transport

MR Runs scored by Home team

MRN Home Team Run Rate

MTC Machine Type Communication

NAN Neighborhood Area Network

NAS Non-Access Stratum

$NB-IoT$ Narrowband Internet of things

NLP Natural Language Processing

$NPRACH$ Narrow Physical Random Access Channel

$NPUSCH$ Narrow Physical-Uplink Shared Channel

ODI One day International

$OFDMA$ Orthogonal Frequency Division Multiplexing

OR Runs scored by the opponent team

ORN Opponent Team Run Rate

PoD Point of Death

PSM Power Saving Mode

QoS Quality of Service

$R123GPP$ Release-12 Third Generation Partnership Project

$R133GPP$ Release-13 Third Generation Partnership Project

RLC Radio Link Control

RNN Recurrent Neural Network

RPM Rotation per minute

RRC Radio Resource Control

$RSPP$ Radio Spectrum Policy Programme

RU Resource Unit

$SC-FDMA$ Single-Carrier Frequency-Division Multiple Access

SDG Sustainable Development Goal

SDK Service Development Kit

SSH Secure Shell

STM Synchronous Transport Module

SYN Synchronize

$T20$ Twenty Twenty

$UART$ Universal Asynchronous Receiver/Transmitter

UDP User Datagram Protocol

$UMTS$ Universal Mobile Telecommunications Service

$UNIX$ Uniplexed Information and Computing System

$uRLLC$ Ultra-Reliable Low-Latency Communication

USB Universal Serial Bus

VS Visual Studio

WSN Wireless Sensor Network

Chapter 1

Introduction

1.1 Overview

Over the years, Low Power Wide Area Network (LPWAN) technology has provided great opportunities for changing our lifestyle with various applications. In the healthcare sector, a unified concept of a healthcare system has been built by combining wireless sensors and sensor networks with computing power that has brought the entire system under one roof. Remote healthcare monitoring established on non-invasive sensors that are wearable and consisting of advanced connectivity and information technology provides real-time monitoring of patients' very crucial physiological parameters [37].

The 3GPP has developed a new radio access technology called NB-IoT to satisfy the requirements set out by those applications. Other research publications focused on such purpose-based applications mainly focus on perpetual monitoring rather than real-time. However, emerging healthcare has also been recognized as a scope for advancement by related works [34], [46], [57], but has not been extensively explored. We are using NB-IoT for its various advantages over existing systems. Moreover, edge intelligence is a relatively new approach. It is the combination of edge computing and machine learning that collects, stores, and processes data. Its objective is to increase the quality of data, increase the data processing speed, better connectivity as well as security.

Combining NB-IoT and edge Intelligence will aid us in achieving real-time monitoring. NB-IoT provides us with huge coverage and better indoor penetration. On the other hand, edge intelligence has faster data processing. This helps us in achieving real-time monitoring.

There are existing systems for realtime health monitoring but they have their cons. Like, LoRa (Long Range), an LPWAN technology, consumes less power than NB-IoT, but it has longer latency and lower data rates. Sigfox, another LPWAN technology, has a broad coverage but it sends small data packages very slowly. However, one of the main reasons is the coverage. NB-IoT provides coverage per cell throughout a radius of 10 km for 66.67 μs time delay and 40 km for 266.7 μs time delay [45]. The radius of 10 km is not just enough to cover a medical facility but also a significant area around it. Also, NB-IoT devices are low-powered and have a remarkably high duty cycle which means that the nodes can work for a long time without maintenance.

The major contributions of this paper are given below:

- We have proposed a system for remotely monitoring patients in realtime
- The proposed system has migrated major computations to edge to reduce the burden on cloud and have faster local processing
- Our system is optimized as it avoids the round trip to the cloud for computation
- It avoids the dependency on centralized mechanism of cloud that elevates security
- The proposed system has used licensed bandwidth thus avoiding interference with other frequencies
- The proposed system covers remote areas in large scale since the architecture is based on NB-IoT

The following sections of this paper are organized as follows. Firstly, Chapter 2 begins with the related works, where multiple pieces of literature that are related to our topic have been reviewed to move forth with ideas being developed concurrently to the real-life application of the proposed works. Then in Chapter 3 where we gave a brief overview of Realtime Healthcare Monitoring, and in Chapter 4 we described the wireless technology that we used. In Chapter 5 we have discussed our system architecture. Moving on to the methodology in Chapter 6, which explains the implementation and software analysis. In the Chapter 7, we concluded our paper.

1.2 Motivation

The growing use of the Internet of Things (IoT), especially smart wearables, would play a significant role role in improving the quality of healthcare coverage, providing convenience for patients and growing levels of patient care. However, owing to the absence of connectivity protocols, there is a non-unified system that can link all intelligent facilities in smart hospitals, which is made feasible with the advancement of the Narrowband IoT (NB-IoT), which is why it is more acceptable and deemed a better integrated choice to shift more into real-time operations for specific treatment and examination. Synchronized sensor nodes would have dramatically enhanced assistance functions. IoT may have all of these standardized forms of assistance. Narrowband IoT (NBIoT) is a conservative and less technical adaptation of IoT that can deal with these industries efficiently. On the other hand, over the past few years, the Internet of Things (IoT) has appeared as the latest daunting innovation to change the society. In order to overcome its management and resource barriers, this field has gone to distributed computing.Despite the absence of small dormancy in cloud connectivity, though, this growth has lead to a massive increase of iot frameworks and data that would make current companies a bottleneck. Edge figuring has been created to tackle this test, taking the handling to the edge network of the business. In view of this, we suggest engineering to link shrewd stuff in genius NB-IoT-dependent clinics, and acquaintance edge figuring with handling the need for inertia in the clinical cycle and also to make measurement shift more towards the real-time.

1.3 Contribution

1.3.1 Problem Statement

Bangladesh had a demographic of 156.6 million in 2013, which is projected to grow to nearly 218 million by 2030 [19]. The country is experiencing major social and economic changes and there is a high rate of urbanization in the country.For example , the population of the capital city of Dhaka has increased from about 5.8 million in 1990 to nearly 10.2 million by 2000, and is projected to rise to about 16.8 million by 2015 [8]. Basic needs such as shelter, protection and access to critical facilities, including health , sanitation and desalinated water, are frequently inadequately-served by the expanding population of major cities. Bangladesh remains largely a rural region, despite such rapid urbanization, with more than 70% of the population currently living in rural areas[8]. Almost half of the world lives on less than 1.25 US dollars a day [18]. The population is relatively young, with just 4% being above the age of 65 or older. This is anticipated to change, though, with the number over 65 years of age or older rising to about 6.6 percent before 2025 [10]. While many health metrics have increased dramatically in recent years , the government faces substantial challenges with regard to its ability to manage and deliver a wide spectrum of health and social services [4]. A significant majority of people, especially the young, face a wide range of health issues related to socio-economic imbalance [5], [6], [9].As well as a low percentage of GDP spending on welfare, Bangladesh has low per capita healthcare costs. Public revenue per capita and GDP were US$745 and US$683 respectively in 2009-10 [16]. Public sector health care spending is estimated to account for just 34 percent of overall health care investment, which is insufficient to satisfy the population public demands [12]. Since the 1990s, private health care facilities in Bangladesh have grown rapidly. Several advanced private hospitals have been built so far, such as Square Hospital, Apollo Hospital, Lab Aid Hospital, Ad-din Hospital, etc., and all these hospitals are focused solely in Dhaka. Often, because of geographical isolation and transport issues, people who reside out of Dhaka do not get convenient access to these hospitals. And then when we checked the overall situation, we realized though as of 2015, there were around 8500 functional beds (both public and private) in the region, while there were 3000 registered private hospitals and clinics with 45,000 beds in 2013 (MOHFW, 2013). Despite the vast group of private hospitals, owing to high medical rates, millions and disadvantaged populations do not have access to health care from this sector (Schlossberg and Wong, 1990). Despite the cost of care, the most daunting issue for quality health facilities is disparity in building health service networks throughout the country. It is shown that the system for health care is not constructed uniformly across the entire population. In Dhaka, as well as in metropolitan areas, most of the tertiary and secondary hospitals are clustered, as well as a few hospitals are scattered far outside Dhaka. In countries such as Bangladesh, the effect on adequate primary health care in rural regions is far less in comparison to that of urban areas, relative to the population growth in high amounts . In locations like this, comprehensive hospital installations in geographic regions of remote areas, hiring surgeons, consultants or clinicians will become very costly. The need for appropriate and reliable disease detection as well as healthcare tracking will also increase government resources to drive further into the SDG's healthcare sectors where budgets which exceeds a benchmark.

1.3.2 Solution

The human race has significantly increased their living conditions with the advent of technology, and the application of technology in medical sector is rising as each day around the world. The healthcare industry is perhaps the most innovative market in the world of new technology. This field is well trained and capable of supplying customers with improved health care. Singapore, for example, is well advanced of health coverage than most third world nations, and better health facilities or well-equipped health infrastructure are not equally available worldwide. The ineptitude of medical devices in public health care leaves this field weak in third-world countries , including Bangladesh, and patients do not get sufficient diagnostic facilities. Between 1998 and 2003 It is reported that only 50% of the medical equipment supplied under the guidance of Health and Population Sector Program (HPSP)and was successfully used at its intended destination. Medical supplies were unused in the remaining half. In comparison, approximately 17% of medical instruments were in operating order but not in use, 16% were not mounted and 17% were out of service. World Bank report has expressed this issue by saying that public healthcare facilities in Bangladesh are poorly prepared with medical equipment, resources and resources (World Bank, 2012). On the other hand, there are state-of-the-art medical devices and services in the private health sector, are essentially over-expensive hospitals and facilities in particular .Owing to the shortage of technologists in running the testing facilities in public healthcare facilities, these diagnosis and care facilities are becoming unreachable causes for disadvantaged and poor patients.In this case, our proposed model plays a critical role as the infrastructure enabled by our framework, mainly: Edge intelligence and NB-IoT , the integration of these technologies and our proposed concept is made to provide real-time detection and tracking of health-related issues without making people migrate from rural areas to cities where they demand better care. Along with the additional advantages of real-time healthcare performance monitoring, the area scope of Edge technologies and NB-IoT is exceptional in such required situations, the expenses of such services is incredibly low, which is why locations such as rural regions are chosen for our implementation. As 3GPP-Release13 (NB-IoT) uses approved and licensed bandwidth it therefore comes to our benefit, because it will help us track patients without frequency interruption in some rural parts of the region outside of the cities.

Chapter 2

Related Work

For quite a time, the Internet of Things (IoT) sector has been there, with unimagined promise in the healthcare system area. In recent years, a large number of IoT applications were also built for various domains, but we need to keep up with innovative new frameworks and protocols, e.g. A broad range of mobile sensors and devices have been developed for the application of continuous personal domain control, healthcare and physical activity perception. Experts today are particularly involved in designing wearable healthcare applications for persistent tracking, supervision and healthcare access to the medical data of patients in patient monitoring system. Both of the publications below provide us some insight into which methodology will provide our thesis with a more productive layout.

In their model, A. Hande [7] suggested a proposal for wireless sensor node network utilizing Wifi and other wireless Local Area Network (LAN) technologies, utilizing wireless sensor networks (WSNs) consisting of very low-power consuming nodes that are incredibly small in number. These functionality make it easier to combine with non-invasive medical devices. However, this architecture is intended for a tiny packet of short-range applications that usually consist of a low-power processor with minimum capabilities and resources for the system. It also has a transmitter that can relay block of data of just a few bytes and has a moderate range of about 10 metres.This means that in a long-distance range application, there will be a chain of hop to hop communication for packets to reach the desired location. This adds up to time delay where the transmission rate is 4 μs per bit [50], the synchronization time for each hop to hop transmission is about 25 μs. But more importantly, the alarming issue is the loss of data packets. We find a directly proportional relationship not just between bandwidth and data rate but also an inverse relationship between bandwidth and indoor coverage. In [54] we see that NB-IoT has very low bandwidth compared to Wi-Fi (short-ranged), we can also see that data rate is low for NB-IoT [44] that compared to other Long Range (LoRa) wireless protocol alternatives, NB-IoT stands out as having the best coverage for both indoor and outdoor and also the failure of packet transmission probability is close to zero. Whereas [14] presents the difference in permeability of signal with context to different types of Wi-Fi used for [7] shows disappointing results and therefore a very high probability of loss of data packets compared to NB-IoT.

R. S. Sinha [42] in their research compares two of the leading LPWA technologies in the IoT market. It goes to show that NB-IoT provides benefits in terms of Quality of reliability, QoS, range, and latency. Now, latency would be an important factor to consider while designing a healthcare system as real-time is a desirable attribute. Reliability refers to the retainability of data packets while transmission where [44] shows the NB-IoT is the most reliable when it comes to that. And finally, when it comes to range, we see in [54] that NB-IoT has a range of 10 to 15km whereas LoRa has a suburban coverage of 15km and 2 to 5 km coverage in urban areas. This goes to show that indoor coverage for NB-IoT is very high compared to LoRa.

WSN was used by A. Darwish [11] for the wireless networking of sensors. The paper analyzes a concept using WSN for wearable and embedded body sensor networks to evaluate patients in their everyday lives. By offering medical services such as patient surveillance, memory enhancing right to home equipment to manage access to health information and connectivity in emergency cases, body sensor nodes systems can support users in real emergencies. Consistent surveillance of wearable and implantable body sensor networks may facilitate patient early warning of critical symptoms and illnesses, as well as provide a wide variety of health care to persons with varying forms of cognitive and physical disabilities. As we already mentioned, compared to NB-IoT, the WSN technology, which uses low-cost Wi-Fi(in this case), has a very low indoor coverage, high probability of data packet loss during transmission and also a very short range of 10 meters [7]. However, the fact that this application requires taking readings in day-to-day life makes NB-IoT as it does not support mobility.

S.Chang [30] discusses the importance of monitoring diabetes patients 24/7. Failure to manage the disease not only leads to long-term consequences such as visual impairment or paralysis, but patients may also be at immediate risk. Detecting the change in behavior for the attributes of the chronic patient is the most important precautionary measure. The paper presents an interactive mobile health system (ImHS) to establish two-way communication between patients and caregivers. This ImHS consists of three devices: a General Packet Radio Service (GPRS), Blood-Glucose Monitor (BGM), a telecare android and IOS application for caregivers, and a cloud server platform that integrates the system's main functions. The system has a local cloud server and uses Long Range (LoRa) GPRS protocol for communication. [54] provides an overview of the unique desired functionalities of NB-IoT that can be used for this application. However, NB-IoT does not support mobility and thus cannot transmit data packets on the run. In [44] however, we see a thorough comparison between GPRS and NB-IoT. We see that NB-IoT has drastically high indoor and outdoor coverage as it has the lowest percentage of outrage coverage as it has the lowest percentage of outage probability. Outrage probability is defined as the probability that the information rate is less than the required information rate i.e an outrage will occur within a specified period of time.

C.Pasluosta [27] talks about the treatment of chronic neurological disorders such as Parkinson's disease where symptoms start gradually, sometimes barely noticeable, causes progressive nervous system disorder. Using a laterally distributed framework such as IoT, real-time motion measurements are obtained by putting lightweight wearable sensors in the clothes of the patient and connecting them to the medical database through mobile devices like cellphones or tablets. Therefore huge amounts of medical data are not only collected during regular medical visits but also during activities in daily life. This means that physical defects can be discovered more accurately and medications can be adjusted based on that. The wireless connectivity protocol for this application was not explicitly mentioned, however, low-cost technology and optimized wireless protocols are preferred.

G.Angelov [56] presents an idea of remote healthcare monitoring which is based on non-invasive and wearable sensors, which convert various forms of vital signs into electrical signals. Such systems can be used for life supportive implants, preventive measures, long term monitoring of disabled or ill patients. The transmitter receives physical signals, processes the data and sends through Wi-Fi to the ZigBee Data is transferred by the receiver to the computer. The transmitter uses a microcontroller, gets the patient's physiological parameters and converts it to a voltage signal and then displayed. Wi-Fi and ZigBee have a limited range [54] and are, therefore, suitable for the short-ranged application.

Chapter 3

Realtime Healthcare Monitoring

3.1 Definition of Realtime Healthcare Monitoring

Real-time health monitoring devices help us in achieving patient's various criterions in realtime. Through these devices, doctors receive real-time data about their patients which help them to design a flexible healthcare routine. The IoMT greatly improves patients' healthcare conditions.

Due to the use of the IoT medical tools in the healthcare sector, it has become possible to track patient monitoring and drug management. The increase in aging population, rising medical costs, and a rise in chronic disease developments are causing medical shareholders to seriously monitor remote health management and patient monitoring.

3.2 Issues of Realtime Healthcare Monitoring

Good broadband connection is one of the primary requirements of real-time healthcare monitoring. Unfortunately, it is very difficult to ensure this on rural areas. Another thing to consider, smartphone is not accessible to everyone, and aged people find it difficult to get accustomed to this modern technologies.

One of the major issues that still remains is security and privacy. It prevents users from using Real-Time Healthcare Monitoring technology for medical purposes, as solutions for healthcare monitoring have the potential to be infringed or hacked. Chances are that dishonest interlopers will be able to access centralized systems and start realizing some cruel intentions. The leakage of confidential health data and location data of the patient and the interference with sensor data can have serious outcomes.

Hardware failure or bugs, or even power outage, can affect sensor performance. This puts the healthcare procedures at stake. Moreover, software updates cannot be skipped. It can turn out to be very hazardous for patient's health.

There seems to be no consensus on IoT standards and frameworks, therefore different manufacturers follow different protocols while producing their devices. This results in a high probability that the devices may not work properly together. The lack of uniformity prevents IoT from being fully integrated and thus limits its potential effectiveness.

Guidelines are already being provided by global health administrations. These guidelines must be followed tightly by governmental health institutions that integrate the IoT into their workflow. These can somewhat restrict potential capacities.

Although the IoT aims to reduce the cost of healthcare in the long haul, the cost of implementing it is very high in hospitals and staff training.

3.3 Benefits of Modern Healthcare System

Healthcare technologies have saved millions and continually improving our life. Not just that, but medical science has had a tremendous effect on the practices and activities of almost all healthcare professionals.

Health record digitalisation: Electronic health records (EHRs) has been a massive game changer in the world of healthcare. This has impacted almost every role related to healthcare.

It is the responsibility of nurses and technicians to input patient data into their digital recording systems. Medical billing and coding appointments update patient records with diagnostic codes (such as test results) and provide insurance companies with health claims. With only a click of a button patients can see their records and errors are recognized faster.

Enhancement of public health: EHRs provide health researchers with useful data to further develop knowledge of medicine and build therapy for common health conditions (such as viral epidemics). A standardized health IT system would provide transparency into how severe an epidemic is, permitting for much quicker implementation of preventive initiatives (such as increased production of flu shots).
Our proposed Workflow: Bureau of Labor Statistics said that , coders and medical billers are among the most impacted internal medicine employees, and growth for this industry is projected to rise by 15% from 2017 to 2027. For medical billers and coders, the advent of EHRs has just makes it straightforward.
Entering data into a software program is far less time intensive than methods based on paper, which eliminates the possibility of mistakes in medical accounts and various information. Virtual access to health information also enables medical coding specialists to operate from home, growing efficiency and productivity.
Telemedicine/Telehealth: E-health monitoring works on means of advancing electronic-dependent healthcare. Telemedicine services, for several reasons, is achieving recognition and popularity. Next, patient can connect directly with a physician via their smartphone in rural areas where there could be a shortage of access to hospitals as well as several other health-related services. Furthermore, there are major telemedicine services-related opportunities. Up to $100 per doctor's appointment can be saved via digital health systems in compliance with [63],

Another analysis showed that patients at an Intensive Care Unit equipped with healthcare organizations were moved 25 percent faster and had a 28 percent minimizes the probability than traditional ICUs. [62].
Remote Monitoring Tools: As patients monitor their health at home, they should save money in the long term costly doctor visits. As of the end of 2011, [62] was used by 2.2 million foreign patients by health care surveillance providers.
Electronic pace maeker pumps for people going through from the disease will transfer data to external care clinics directly. These instruments are useful for patients suffering from chronic illnesses and can enable structures to track the health of a patient from such distance.
Wearable Technology: For wearable medical devices, market is increasingly increasing. These technologies capture data that helps both patients and clinicians to track and assess the welfare of the person wearing.
Wearables, such as bands for the wrists and watches, are very popular, allowing consumers to play a bigger role in their own long-being, as well as gadgets that warn officials about urgent medical conditions. Per the Huffington Post, an unprecedented 160 million wearables will be shipped to clients by the beginning of 2020. [36].

Chapter 4

Narrowband Internet of Things

4.1 Definition of NB-IoT

Technological breakthrough over the last decade has anticipated IoT to scoop out the state of the art prospective in information and communication technology. IoT now is implementing the gigantic network of trillions of devices, moreover it provides the users with plenty of smart services. This would undoubtedly make our lives more innovative but at the expense of high energy consumption and carbon footprint. As a result, there is a elevated demand for green communication to minimizing energy consumption which needs optimum availability of resources and regulated levels of power.

Narrowband-Internet of Things (NB-IoT) is a Low Power Wide Area (LPWA) standards-based technology progress to enable a wide range of new IoT devices and services. NB-IoT remarkably enhances user device power consumption, system capacity, and spectrum efficiency, especially in deep coverage. For a wide range of uses, it is possible to support battery life of more than 10 years.

New physical layer signals and channels are designed to fulfill the demanding needs for prolonged coverage – rural and deep indoors – and the complexity of the ultra-low devices. The initial expense of the NB-IoT modules should be close to that of GSM / GPRS. However, the underlying technology is much simpler than the GSM / GPRS of today, and its cost is expected to decrease exponentially as demand grows.

Backed by all major mobile device makers, chipsets, and modules, NB-IoT will co-exist with 2G, 3G, and 4G mobile networks. It again has support from all mobile network security and privacy features, worthy mentions as support for the confidentiality of user identity, entity verification, confidentiality, the integrity of records, and the identification of mobile equipment.

4.2 History of NB-IoT

Over a long period of time, cellular mobile communication has assisted voice service and mobile broadband access that only human can utilize. From 2005, 3GPP has initiated Machine-Type Communication (MTC) services for deep cellular network research (which includes Global System for Mobile, Universal Mobile Telecommunications System, and Long Term Evolution). In accordance with the tradition of NB-IoT development and standardization course, that is addressed in [31], present feasibility and enhancement Study[13] aims to allow MTC to become a Major Factor of 5G networks[49]. The Empirical study of 3GPP (R8-R11) it concentrates primarily on major issues such as information overload, and congestion and aircraft signaling and the numbering and addressing of resource constraints during contemporaneous approach of multiple terminals to the network. This is based on MTC 's slightly earlier integration. After further sophistication and provisions of MTC service requirements[52] and features, GSM access network range, related to the MTC terminal's low cost design, security specifications, and network system architecture were declared in R12 3GPP. Ensured by non-3GPP LPWA technologies (such as LoRa and Sigfox), MTC set five R13 3GPP goals, which contains improved indoor range, supported large small-data terminals, few terminal complexity and expenses, higher energy delivery, and dissimilar latency characteristics supported. Furthermore, 3 kinds of new narrowband air-interfaces are taken care of by the R13.These are EC-GSM-IoT(GSM-compatible), eMTC(LTE-compatible) and NB-IoT. Huawei Technologies Co. leads NB-IoT in that respect. Ltd., an inovative Chinese private enterprise[49]. As a result software upgrade and core network reuse used in authorized frequency bands, the 3GPP LPWA technology (represented by NB-IoT) attracts increased interest from the industry compared to non-3GPP LPWA technology. Cost amortization and market promotion of the NB-IoT terminal chip is anticipated to take place steadily in 2017.

Chinese working group IMT2020 introduce truly relevant NB-IoT concepts in February 2015. Ever since, the IMT2020 has slowly reinforced the technical proposal research[32] and the development in factors of the sample computer and terminal chip[29] principle. R-13 being constriced by time, for a long-term NB-IoT viewpoint, it offers only an initial principle framework. So many features in 3GPP R14 still need to be improved. Based on the standard usage and the difference in service specs, the MTC services known by R14 can be divided into two groups, mMTC and uRLLC[60]. Furthermore, R14 proposes functional requirements based on the 5 objectives of R13. These requirements are in the areas of support for localisation, portability, multi-cast, higher data rates and linking adaptation. Aim of this R14 proposal is to render more complementing objects and application ranges for cellular IoT[35]. To be more specific, 3GPP is taking a dual idea to overcome the technical challenges that MTC services comes. The transition strategy is the first stairway which aims at using and optimizing the pre-existing network and technologies for the provision of MTC services[41]. Prolonged plan focusing on the development of a new NB-IoT air interface technology is the second step. This step is to support the large-scale development of MTC services and preserving its essential competitiveness in non-3GPP LPWA technology[25].

4.3 NB-IoT Features

NB-IoT's key features are briefly presented as follows:

4.3.1 Low Power Consumption

The Power Saving Mode (PSM) and the Expanded Discontinuous Reception (eDRX) both utilized by NB-IoT. Which assist NB-IoT to take care of longer standby times. In Rel-12, where the terminal is standby and registered online in power saving mode but can not be reached by signaling in VOLUME 5, 2017 20559 M, PSM technology is freshly included. Chen et al.: For prolonged power saving mode, the NB-IoT signals the terminal snoozes for a extended period. At the same time, in Rel-13, the eDRX is recently introduced. In idle mode, this further increases the terminal sleep cycle and eliminates needless start-up of the receiving cell. In comparison with PSM, eDRX favors downlink accessibility substantially. The process in which PSM and eDRX saves power is as shown in Fig. 4.1 [49].

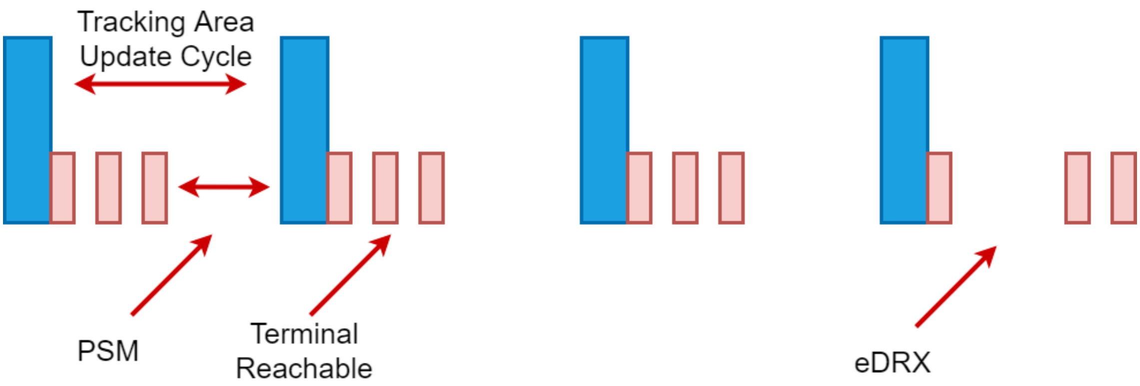

Figure 4.1: How PSM and eDRX saves power

There is great significance for NB-IoT that the terminal service life of a constant volume battery is 10 years for standard low-rate service at low pulsation.Whereas, simulated data by TR45.820, the service life of the 5-Wh battery may be 12.8 years(if a 200 byte message is sent by terminal once a day) for coupling loss of 164 dB and using both PSM and eDRX. It is shown in Table 2[48].

	Battery life / years		
Message size / interval	Coupliong loss = 144 dB	Coupliong loss = 154 dB	Coupliong loss = 154 dB
50 bytes / 2 hours	22.40	11.00	2.50
200 bytes / 2 hours	18.20	5.90	1.50
50 bytes / 1 day	36.00	31.60	17.50
200 bytes / 1 day	34.90	26.20	12.80

Table 4.1: Approximation on battery service life in integrated PA

4.3.2 Enhanced Coverage & Low Latency Sensitivity

It can be proved, in keeping in mind to the data simulated from TR45.820, In individualistic distribution mode, NB-IoT's covering power will hit 164 dB. There was a simulation analysis implementation included in both in-band deployment and guard band deployment. To satisfy coverage enhancement, NB-IoT processes numerous plans. This includes retransmission (200 times) and low frequency modulation.The 16QAM support for NB-IoT is currently still under discussion. If the coupling loss of 164 dB is preserved by a stable data transmission, the latency increases due to the retransmission of mass data. Simulations for TR45.820 demonstrate with 99% accuracy that the latency of the irregular reporting service scenario and various coupling losses (header compressing or not), Table 3[48].

Currently in 3GPP IoT, 10s is discussed as possible latency that is within tolerable range.In fact, furthermore it aids latency as low as of around 6s for maximum coupling losses. See NB-IoT simulation results for TR45.820 for extensive specifics.

4.3.3 Transmission Mode

The evolution of NB-IoT, as shown in table 4[38], is centralized on LTE. Amelioration is made solely on the basis of unique aspects of NB-IoT which is convenient to LTE technologies. The RF bandwidth of the NB-IoT physical layer is 200 kHz. NB-IoT satisfies the downlink OFDMA and QPSK modem technologies with a 15 KHz[20] subcarrier spacing. In uplink, including single subcarriers and many subcarriers, QPSK modem or BPSK and SC-FDMA technology has been introduced.When we consider IoT terminals with ultra-low rate and ultra-low power consumption, a single sub-carrier technology of 15 kHz and 3.75 kHz sub-carrier spacing is needed.

Due to the dissemination of the a frequency in range of 15kHz subcarriers, continuous subcarries of 12 are taken into account. Therefore, for the 3.75 kHz of the harmony of sub-carrier, constant sub-carriers of around 48 are detailed. Encouraging 15 kHz spacing of the sub-carrier, multiple sub-carrier communication classifies of around 12 continuous sub-carriers merged into 3 to 12 continuous sub-carriers. The range for 3.8 kHz spacing is higher than for 15 kHz spacing due to exponentially spectral power resolution. For 3.75-kHz spacing, the cell capacity for 15-kHz spacing is 92 percent, but the deploying performance and deploying complexity are preferable. Albeit the Narrow Physical Random Access Channel (NPRACH) would allow a standard 3.8 kHz spaced sub-carrier transmission, most machines ideally takes a single 3.8 kHz spaced sub-carrier transmission for uplink. As a result the implementation of single subcarrier transmission with a spacing of 15 kHz and transmission of multiple subcarrier, the inclination at the terminal is contrived correspond to the competence of the channel in an evolved manner. The Resource Block (RB) is the cramped Physical Downlink Shared Channel (NPDSCH) conveyance finite dispatch unit, and the Resource Unit (RU) is the Narrow Physical Uplink Shared Channel (NPUSCH) transmittal least possible dispatch unit. As per the realm of time, single sub-carrier transmission for which the resource unit is of 31 ms for 3.8 kHz sub-carrier spacing and 8 ms for 15 kHz sub-carrier spacing, as well as the resource unit is 1 ms for 12 sub-carrier, 2 ms for 6 sub-carrier spacing, and spacing for multiple sub-carrier transmission.

The lofty elevated protocol (the layer below network layer) of the NB-IoT is forged by developing some LTE functions, such as sub-connection, power utilization and low and little data. The NB-IoT core network is analogous through the S1 interface.

4.3.4 Spectrum Resource

The IoT is the fundamental service that will draw a extended neighborhood of patrons to the preeminent telecommunications service sector in the millennium, hence the formulation of NB-IoT, as outlined in [38], has marvelous backing from four colossal telecommunications

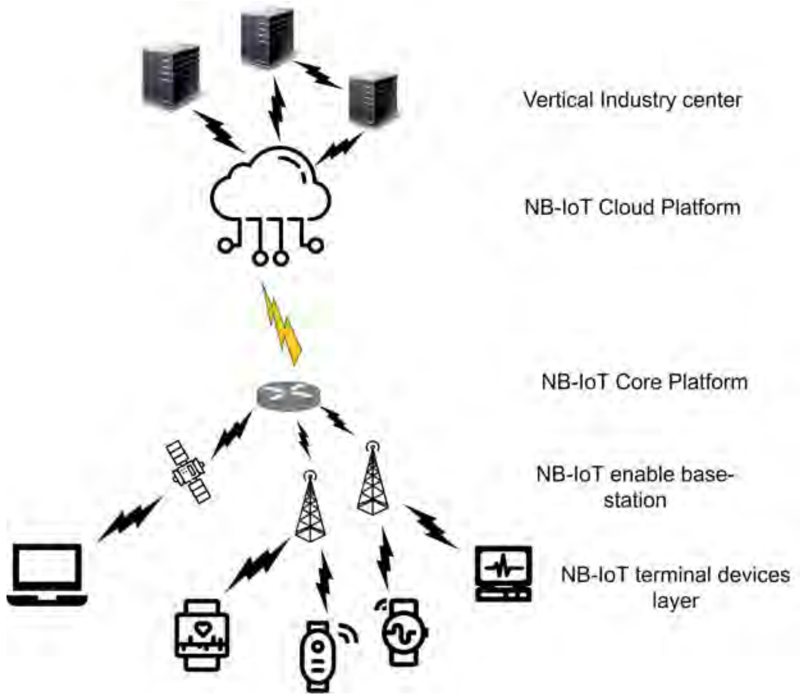

Figure 4.2: Narrowband Internet of Things

enterprise in China who retain all the auspicious spectrum assets of NB-IoT.China Unicom has opened the NB-IoT commercial grid in that respect. As NB-IoT RP-151621 articulate that NB-IoT rumored only relys FDD transmission mode of 180 kHz bandwidth and deployment scenes of 3 ensuing forms seen in the figure. 4.2 and [38] [59]: [59]:

- Stand-alone mode inaugurate, applying a split frequency band that does not impede with the frequency band of LTE ;
- The deployment of guard bands is also known as the guard band mode, which uses the LTE edge frequency band.;
- In-band deployment that utilizes the LTE frequency band for formation and allows frequency band support of 1 PRB for deployment.

4.3.5 Frame Structure

Previously observed [58] the downlink of NB-IoT eNodeB aids E-Utran Wireless Frame Structure 1 (FS1) . In addition, the uplink supports FS1 for 15 kHz sub-carrier spacing. For 3.75 kHz sub-carrier spacing, although, a modern mode of framework architecture is specified as [58].

4.3.6 NB-IoT Network

This display the NB-IoT network in [38] in which it can be identified that it consists of five categories:

- NB-IoT terminal: IoT gear in total corporation have entry to the NB-IoT chain as long as they have equipped the analogous SIM card;
- NB-IoT base station: primarily states to the fact that the base station already set up by the telecommunication driver. NB-IoT to network. And it assistance to all three aforementioned deployment modes;
- NB-IoT core network: The NB-IoT base station will link via the NB-IoT core network to the NB-IoT cloud.;
- NB-IoT cloud platform: The NB-IoT cloud portal can employ diverse accounts and send data to the vertical business center or NB-IoT terminal.;
- Vertical business center: It will gather data from its own center's NB-IoT service and take charge of the NB-IoT terminal.

4.3.7 Semi-static Link Adaptation

Mini-packet communication are much of the objective assistance scenes of NB-IoT and longstanding and persistent gestures of a variation in the effectiveness of a channel are problematic for NB-IoT to afford.[26]. For this debate, instead of the dynamic link adaptation scheme, NB-IoT enforce coverage level[21]. Three class of coverage categories can be found which consist of traditional coverage(correspond to the minimum coupling loss (MCL) of 144 dB), robust coverage(correspond to the minimum coupling loss (MCL) of 158 dB) and extreme coverage(correspond to the minimum coupling loss (MCL) of 164 dB). Confide in on the terminal coverage classification, modulation, coding mode and reiteration data transmission times can be preferential. This is how the semi-static link adaptation is achieved[21].One RSPP agenda accommodate two RSPP threshold values is composed by the NB-IoT base station to differentiate the distinctive coverage standards.

4.3.8 Data Retransmission

The NB-IoT adopts data retransmission system to procure low-order modulation and time diversification improvement, that outcomes in heightens coverage and demodulation efficacy [1], [15]. All the medium sponsor retransmission of the data. Moreover, The retransmission comprise for individual channel and the reciprocal modulation mode are also construe by 3GPP, as shown in Table 6[58].

4.4 NB-IoT and other Wireless Protocols

In the industry, as a result of the accelerated growth of smart low-data IoT services, LPWA technology is frequently regarded and market share is increasingly rising. Smart IoT apps can be categorized into three groups based on data rate transmission criteria in 2019.

4.4.1 High Data Transmission Rate

The High Data Transfer Rate is called a transfer rate that reaches 10 Mbps. 3G,4G,Wi-Fi are the access technologies that are available. Any of its main uses are direct media transmission, automotive navigation, automotive entertainment and automated healthcare systems. The total market share for IoT applications of this sort is 9%.

4.4.2 Medium Data Transmission Rate

The rate of transmission of below 1 Mbps is considered to be Medium Data Transmission Rate. 2G, and MTC / eMTC are the available access technologies. These applications include a smart home, a POS machine, and a return connection to M2M. For this form of IoT application, the estimated market share is 30%. However, in the course of time, MTC / eMTC technology will eventually replace the 2G M2M.

4.4.3 Low Data Transmission Rate

It is known that a transfer rate below 100Kbps is a poor transmitting data rate. LoRa, SigFox, NB-IoT , and short-range wireless networking are among the available connectivity technologies. These are mainly used in LPWA technologies, like sensors ,logistics, smart metering, monitoring of goods, parking, and smart farming.The estimated market share for this form of iot system is 55%. In the related sector, however, there have been plenty of opportunities. Thus, there will be a bright future for NB-IoT.

The differentiation between the LPWAN represented by NB-IoT and many other channels of technology from different perspectives is explored in depth in In [54]. It was distinguished by characteristics of the network coverage and the rate of transmission of information. For short-range and high-bandwidth networking systems such as Wi-Fi, the coverage in general can go up to 110 m and the data transmission rate can go up to 100Mbps. This type of communication technologies is suitable for use where narrow-range and bandwidth efficiency are required. For applications with a close range and poor data transfer rate, such as Zigbee and Bluetooth, the maximum coverage area is also 110 m. Their data transfer rate will go as high as 150Kbps. But in the other hand, an overall coverage area of 11 km is provided by GSM and its data transfer rate would be as high as 110 Kbps. LPWA is a platform of long-range and low data connectivity. It can occupy an 11 km area and transmit data at a high capacity of 110Kbps.

Also featured in [54] is the NB-IoT technology exchange architecture. The strengths of 5G or 4G connectivity and low-power consumption systems are all taken from this connectivity. Peak pace, reliability, and client-experienced data transfer rate is

taken from 5G or 4G technologies. It took cheap and intensive transmitting from low power consumption wireless networking technologies.
we compare the many success parameters from [54]. This requires I) energy consumption , (ii)rate of data transfer, (iii) availability, (iv) security, (v)latency , (vi) price, (vii) efficiency of the NB-IoT bandwidth and (vii) range of coverage, short range connectivity and communication and private technology . There will be their own strengths and weaknesses of short-distance networking technologies and also private technologies, as seen in [54]. Yet NB-IoT does well. For instance , in terms of high security, decreased latency, high data transfer rate , high efficiency, larger coverage area and higher spectral performance, NB-IoT is better compared to other innovations. Moreover, in terms of low cost and low energy consumption, the reliability of NB-IoT lies between short-distance networking technology success and private technologies.In brief, [54] explains how NB-IoT can have a superior communication channel relative to the other technologies.
It was carried out in relation to WAN technologies and indicates NB-IoT 's potential prosperity in the operating company-level network. Furthermore, the NB-IoT to provide us with many network solutions that provides a wide range of coverage, a service effectively of connections and limited IoT costs. In addition, leading to fast and responsive deployment, LoRa might also be recognized throughout smart cities, unique production and company applications. Yet we should guarantee that these LPWA innovations are complementary to the industrial use of.
eFrom many aspects: peak data rate, user-experienced data rate, mobility, spectrum quality,energy efficiency, link density,spectrum quality and flow capacity, we correlated LPWAN and mobile communications system output (portrayed by 4 G and 5 G) beginning with the growth of mobile telecommunications. LPWAN is comparable to the 5G or 4G network in link density, but not as strong in other ways.The dominance of the 5 G network is particularly prominent. In comparison, the energy savings of LPWAN is greater than the energy savings of the 4 G lte, yet lower than the energy efficiency of the 5 G technology. Implementations that involve low power consumption, low data transfer and high link capacity can be added to LPWAN. The low cost that is not marked in the illustration is another major benefit of LPWAN. In the IoT region, however, LPWAN, expressed by NB-IoT, has huge potential.

In comparison to that of the previous generation of technologies, the efficiency of LTE Evolution for Machines or LTE-M has also been improved significantly relative to the established LTE IoT technology. A bandwidth of just 0.9-MHz is occupied by the LTE-M whereas NB-IoT does best with a bandwidth of 210kHz. Throughout the past, furthermore, both NB-IoT and LTE-M have lowered the 25-MHz spectrum used, but their data transfer rate has dropped from 1.5 Mbps to 210 kbps.

Low power consumption and broad coverage can also be achieved by NB-IoT, whose service area stands today at up to 22 km. In order to reach the desired coverage, it is typically assumed that NB-IoT must be recognized at the specific frequency, at 700-900 MHz or other bandwidth below 1.2 GHz. In addition, we must remember that coverage requires not just to range, but also penetration. In that regard, it is emphasised that NB-IoT is more penetrable than 2G. Its input signal is 25 dB greater than that. We can therefore achieve good-quality connectivity even in in-

door spaces.
The present IEEE 802.11ah channel frequency, similar to the LTE-M frequency, is 1 to 16 MHz. Usually, 20570 of VOLUME 5, 2017 of M. Chen et al.: Internet of Things Narrow-Band requires around 1to 5MHz channel bandwidth. The exception would be Zigbee at 870 MHz in the Western Europe zone, which has a bandwidth smaller than the NB-IoT throughput of 850 kHz. The 12 Ah transmitting distance, however, has yet to be checked. The present distance of 1.5km
Huawei claims that the costs of the NB-IoT chipset and modules of the chipset should be around $1 to $3, overall, as far as cost is comes to concernation. Furthermore, because of the power usage requirement, the cells must have continuity of service for 10 years without substitution.
According to existing plans, LTE-M2M or LTE base stations must be capable of serving around 150,000 terminals, or to at least 60,000 terminals. In reality, 5G has also observed positive targets. At the current level, the minimum for 5G is 1 million terminals per sq.km, i.e. one terminal per square meter. By reference, the NB-IoT criterion is not yet static.
Furthermore, for specific implementations, we analyzed three techniques. Class 0 proposed in 3GPP's R12 is mostly used for portable electronics and power storage or, more precisely, for fitness watches and domestic electricity usage regulation.However, for object detection (such loosing a pet, bicycles being stoken and many more cases), energy calibration, digital patient diagnosis and control, and local service building (which include street lamp and parking maintenance), the LTE-M of 1-MHz bandwidth is intended for use. However, NB-IoT is part of corporate application areas, such as environmental tracking and smart city.

Almost all of the existing and potential networking systems will potentially deal with NB-IoT. In comparison, microchip companies drive the Sub-1GHz transmitting plans; for instance, the Zigbee-based smart grid and charging station for electric vehicles with NAN (Neighborhood Area Network) as position technology[39].

4.5 Security Requirements of NB-IoT

Protection criteria for NB-IoT are similar to those of conventional IoT, Fig. 4.3 [38]. However, there are several other differences that primarily apply to IoT physical hardware with low energy consumption, channel medium of communication, and real service specifications. The typical IoT gateway device, for example , typically has heavy computing capacity, complicated network communication configuration, and embraces an enhanced security contractions; energy consumption is typically high, too, and regular charging becomes required. But in the other hand,IoT systems of low power are distinguished by consumption of low power , low processing power and semi-frequent charging, which mostly means that terminals are more likely to be affected by security threats. Moreover, state of denial of service triggers basic resource depletion. Moreover, the number of IoT terminal devices with low energy consumption is much higher in real implementation than in conventional IoT [51]. As a consequence, some minor data protection failure will lead to much higher security incidents because of the simpler and lighter terminal's embedded system, so it is much simpler for attackers to grasp system level data..

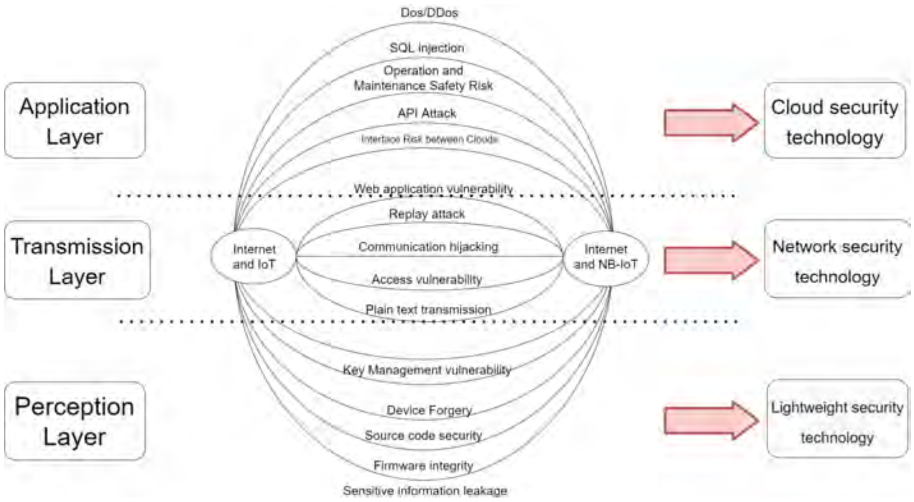

Figure 4.3: Narrowband Internet of Things Security Requirements

4.6 Benefits of Edge Computing based on IoT

In this next section, we analyze the advantages of combining IoT with edge computing.

4.6.1 Transmission

The transmitting time is affected by network quality, which, amongst others, can be measured through bandwidth, packet delay and latency. Quick transmitting speed, which can satisfy the Quality of Service of time-sensitive applications, such as the 'Live Video Analytics' of Microsoft'[2] project, is one of the notable benefits of edge computing, as addressed before.The aim of this project is to examine live videos obtained from all available cameras in a real-time open environment. This framework would run through a distributed of geo [3] structure with large clouds and intelligent edges. One of the tasks of this proposal is the estimation of automotive flow of traffic, which is clearly time-sensitive. The hierarchical architecture of edge computing ensures shorter propagation time than every other channel [23].
In the meantime, edge computing was also developed to solve the gating factor issue of network resources in IoT. Through discharging the data measurement and processing to end users, the response time and traffic flow would be substantially decreased. The distributed heirarchy edge nodes, such as "Live Video Analytics" [2], "Human Behavior Classification" [17], "Motion Prediction" [24], etc., will satisfy the conditions of time-sensitive applications.

4.6.2 Storage

Composed of groups of data centers and disk drives, cloud computing-based storage is typically tightly controlled and executed as complex , multi-layer systems. It is assembled on top of the program, which is the core values of the network topology.

Comparably, certain edge cells are placed for serving data needs, however, in contrast to the conventional cloud, edge computing-based data is spread at the edge of the network system.

To satisfy QoS parameters, Edge computing-based storage can exploit load balancing and loss recovery techniques to recognize the requisite reliability and speed. These load balancing approaches are able to unload the storage capacity to separate edge devices, decreasing the congestion of network communication connections.

4.6.3 Computation

Compared to the availability of resources in cloud each of the nodes consists of less processing power. Consequently, to meet the same criteria, the processing activities need to be allocated to multiple network edge. If we remind ourselves about taking the storage and computing activities to the network edge then , the requirement of the end user can therefore be satisfied, and the task execution time scheduling scheme turns into a key component for computation on the edge. Generally or in common Task scheduling planning can be developed based on the targets. we kept in mind about the implementation of scheduled tasks for different methods for this section in edge intelligence.

Chapter 5

System Architecture

5.1 Perception Layer Architecture

In Figure 5.1 we have proposed an architecture using NB-IoT for our healthcare application for remote monitoring. In this figure each clinic within a particular area is considered to be a node for the NB-IoT. The diagnostic data of patients are fed into and stored inside the memories of the Nucleo processors. The data after following the NB-IoT is then sent to the BS (Base Station) where it is sent to the Edge servers for the automated computational process to take place. Taking a closer look at the architecture, having the local diagnostic or medical monitoring devices safely integrated with an ultra-low-power enabled Nucleo boards of STM32-based(L476RG (Cortex M4)) or L073RZ (Cortex M0+) together with Quectel based BG96 chipset-based boards(also known as Avnet Silica NB-IoT shield or the EVB Kit of GSM/NB-IoT) where the entire set is powered by an external power source like 20000mAh BP15 BLOW battery. As the units for processing for the ST32-based Nucleo boards, and

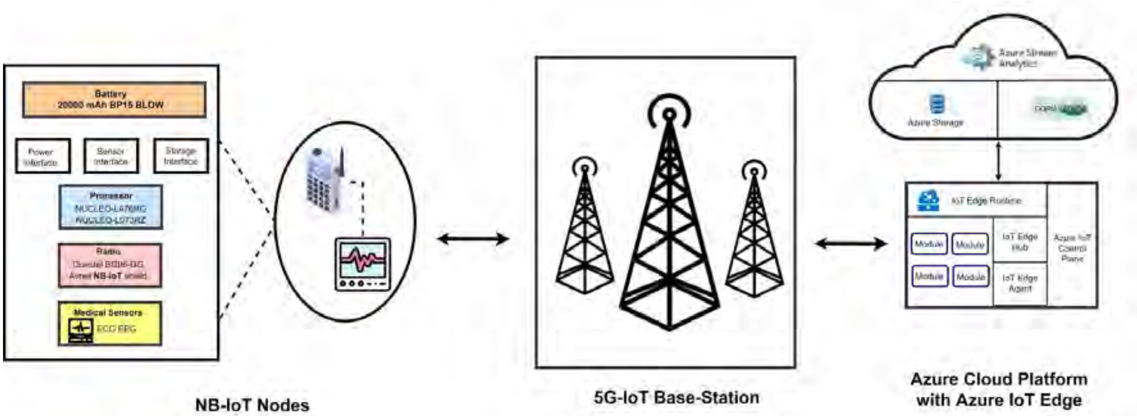

Figure 5.1: Perception Layer Architecture

therefore are utilized as it can be stretched out to be used with countless additional items to work with a wide range and scope of sensors. Referring to Figure 5.1 the Quectel BG96 radio chipset which highlightslow-power utilization and which also supports LTE Cat NB1(i.e. 3GPP Release 13 NB-IoT), together with sets of interfaces which maintains industrial standards like ((like USB/UART/I2C/Status Indicator)) which is applicable for a number of applications of the IoT platforms.

Within our NB-IoT nodes, the sensor device data is passed on to the STM32 microcontroller through dedicated interfaces where it is then enfolded into UDP packets and sent through the interface of UART to the BG96 module. Initially the BG96 module sets up a safe association with both the Base-Station and therefore sends the information to the NB-IoT empowered base-station then later to the IoT-Edge which places the fundamental preparation of the information arriving.

5.2 Network Layer Architecture

Large number of NB-IoT base-stations are set in the BS layer, where the need of routing, clog controlling, planning of traffic, controlling traffic congestion, bottlenecks and guarantee of security together with incorporate and securing transmission of information and data. At the point of where the BS receives the information from the detecting layer, the requirement of designing sensible way of transmission is therefore essential which is therefore provided by our design. In smart clinics for whether it is for monitoring purpose or not an enormous amount of terminal devices are accessed. Due to the sending of a huge amount of information it can trigger blockage or loss of information. These issues therefore raises the need for congestion controlling and the need of guaranteeing the progress of information with the high need to away from falling flat of monitoring of patients or hardware because of the event of system blockage. Likewise the need of plan of traffic of the BS rises when congestion occurs. Identity validation and the identification of interruption can therefore be utilized to ensure information security in the BS layer. The validation, which is a cycle that surveys the client's character and decides if the client has the consent to access. Furthermore the BS is susceptible to being attacked or hacked so the need arises for an interruption recognition instrument, which can gather and examine, arrange practices, logs of security, reviewing of information and other key data check to keep check whether there are any lack of following security protocols and an infringement to the security strategy. The forestalling of the BS layer is occurred to keep the BS layer from being devastated through the use of Interruption recognition.

5.3 Cloud Layer Architecture

The technology and services of Azure IoT Edge has been chosen as it analyzes the information and data it receives to send less information to the cloud, taking the pressure of computation off from the cloud, responding to occasions more rapidly, working offline and most importantly avoid the round-trip directly to the cloud in order to do the computation more towards the real-time. According to Microsoft's Official Azure Edge Documentation, the Edge shifts the Cloud Analytics and Custom logic of business towards the Edge servers with the objective that we revolve around more on the business logic than the information of management of data. Our scaled out IoT arrangement lead to the bundling of our business logic in to standard containers, where at that point we can convey those containers to any of the servers and screen everything from the cloud. The cycle starts by gathering and preparing of data as soon as the information is gathered from the base-stations inside a 300 mile sweep to the IoT –Edge server.In mane different cases, particularly for our situation the information should be gathered from the NB-IoT device and stored in the cloud. The groundwork of machine learning is required for the gathering of the crude information from the sensors.The key off occurs when the progression which includes the tidying up of information reformatting or preprocessing to infuse extra data for machine learning. After the preprocessing of the information, the readied data is then collected where we would be able to explore the different areas or avenues regarding the diverse machine learning calculations and definitions for preparation of models and then contrast the outcomes with another. As suggested in the proposed architecture of Edge Computing in An Edge Computing architecture of Internet Of Things that the prepared Random Forest Algorithm fulfills our prosperity standards and hence compute in real-time, after which we are all set for the deployment. It includes the model that we have utilized here into a web administration application that can be taken care of with information using REST calls and return investigation results. The web administration application is bundled into a docker holder, which thus can be sent either in the cloud or as an IoT Edge module where concerning our model we focused on arrangement to the IoT Edge. When the model we are utilizing is affirmed much of the time is spent on gathering the information and intermittently transfer these information to the cloud. We would then be able to use and utilize this information to keep refining our model which we will be redeploying to the Edge for better accuracy.The business logic of our code for the Random Forest Classifier Algorithm is run on the IoT Edge module executed as viable Docker holders, all on the network's Edge Node, for the improved maintainability of our business logic. In order for them to interact with one another, various modules should be arranged in different orientations to create a data processing pipeline.It makes custom and cloud logic on IoT Edge devices for the IoT-Edge runtime. Microsoft Official Azure Edge Literature Referencing the runtime executes many tasks, such as:

- Launches and upgrades the server system workloads
- Maintenance Development of security requirements for Azure IoT Edge on a server
- Helps to ensure that there are still up and working IoT Edge modules
- Tracking the cloud for module health for remote controlling and for monitoring purposes
- Communication management between downstream leaf devices and the IoT Edge Device between IoT Edge Server and Cloud modules

When the data is sent to the cloud at this point for the additional preparation and breaking down in order to prepare the model in order to manage the exceptions, extremes of points and outliers. The Function set 's task is to only send upstream messages to the IoT-Hub if the disturbances or even deviations cross a certain limits. As the information arrives in the cloud from the NB-IoT devices the Analytic administration will be utilized in order to pickup experiences about the information as it arrives. With the Azure Stream Analytics we are shifting the logic onto the device itself. Because of the handling of the information from the facility focused at the Edge we can decrease the measure of information transferred and also reduce the time it takes in order to respond to the actionable insights present. Normally in a framework of IoT, in order to deliver a precise feedback to the client(application) the cloud examines all the information traffic that comes from the hubs of the IoT through a passage system. In order of decoding and breaking down the anticipated potential results thorough investigation of data-mining could be used. The cloud administration likewise would ensure the QoS(Quality of Service) and security capacities where the information should be kept sheltered and secured for the needs in the future. For the distributed computing layer enormous information investigation, information combination and Machine Learning is being utilized by the cloud center. Where furthermore security review,access control and information reinforcement part of our algorithm is being done and likewise with the guarantee of information security.

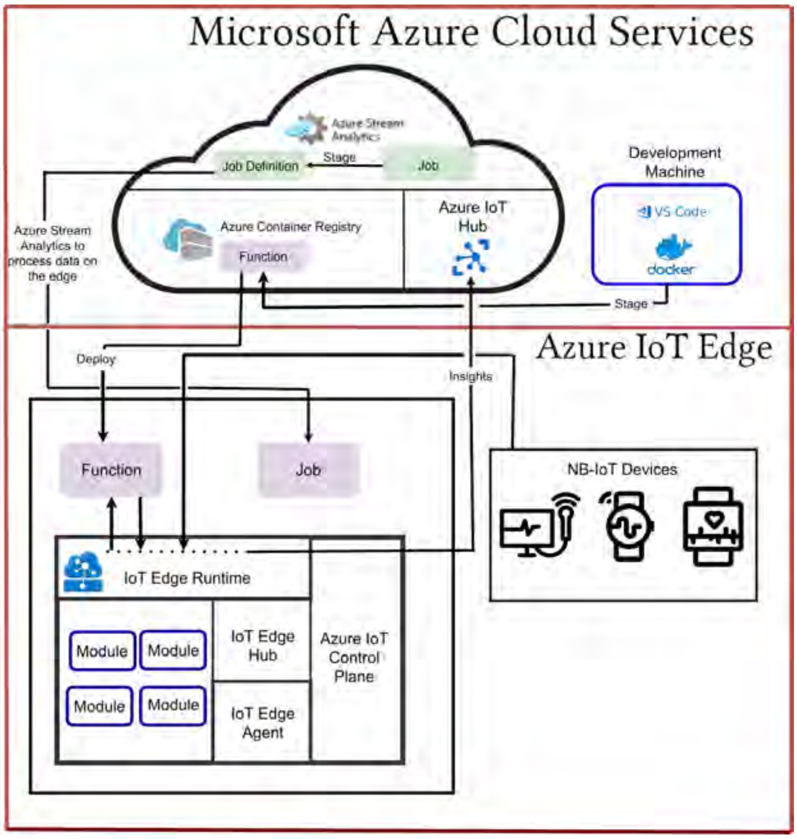

Figure 5.2: Cloud and Edge Architecture

Big Data techniques can be used in the cloud center to handle its own information or the information recovered from the edge's processing server and utilized these information combinations procedure in order to relate and orchestrate various types of data and information, and using Machine Learning algorithms like Random Forest Classifier, Bayesian system, neural system shrouded Markov model to move away information and rules from authentic information in order to do smart finding. The issue of Cloud security is additionally significant which went up against cloud center. The most significant issue of security is the access control. To guarantee the security of cloud center security review additionally adds up to the procedure together records, system activities and client activities to examine the environment and together exercises of working occasions to find the system vulnerabilities, weaknesses and interruptions.

Referring to the Figure 5.2 depending on NB-IoT we have formalized the design in order to interface insightful intels to the smart clinics which leverages the benefit of higher limit. More extensive inclusion, low cost and low power utilization of NB-IoT. For the NB-IoT application for clinical use the latency was the primary challenge for those healthcare monitoring devices with higher continuous prerequisites. For the solutions to these problems we introduces the services of Edge devices to our aid inside our proposed architecture.

The Azure IoT Edge of our design goes about as a straightforward passage that may decipher the conventions and information designs utilized by these leaf-level nodes. Every server has a relating module enrolled with the Edge Layer. The runtime specialist oversees the module which starts up as compartments inside the Edge server. The modules in our Edge-engineering are plain Vanilla Docker holders that are ordinarily planned to a device.

For instance, if there are two nodes associated with the edge, a normal temperature sensor and a bulb, they are basically displaced as two separate Modules containing correspondence component and the logic or rationale to speak with the server. These Modules are pushed to an open or private vault from standard Dockerfile. They cant be treated as independent holders due to the reliance on the runtime and context. Through an all around characterized interface which is built-up at runtime the modules can communicate with one another keeping in mind that not every module should be planned to a device. Rather for the latter issue it is daisy chained to a camera module that catches the frame which are passed onto the following module. Azure IoT Edge considers the module which are approximately coupled as independent components. Just like UNIX pipes the yield of one module is fed to another. This plan choice there makes it conceivable to characterize modern pipelines that are secluded and extensible.

The IoT Edge Agent is the main part of IoT Edge Runtime that runs as a compartment. It bootstraps itself each time the edge device is controlled on. The other part of Azure IoT Edge runtime is Edge Hub that mirrors the IoT Hub in the open cloud. It basically gives capacities of an IoT Hub its offline features by uncovering validation and correspondence administrations to the leaf nodes.

A module speaking to one of the monitoring device has logics to be made sure of with the local hub. Likewise, it can send telemetery data or information to the cloud center that will advance it to the upstream of the segments which are different modules which are categorized according to its task. Edge Hub uncovered similar API as its cloud counterpart This plan decreases the exertion needed to refactor devices for the edge. Since it stores the qualifications after the runtime gets validated during the handshake with IoT Hub in the cloud. Edge Hub goes about as a communication broker encouraging nearby device communication. It also underpins standard conventions of IoT Hub including AMQP, MQTT, and HTTP. Notwithstanding, HTTP isn't accessible in the current form of Edge Hub.

5.4 Edge Layer Architecture

At the Azure IoT Edge Layer the Edge servers are low-level electronic devices deployed in that layer which operates for the goal of task completion like data-processing, major processing tasks that takes the load from the cloud does it on the edge, sensing actuating and controlling and other security checks for better reliability. Each servers of the edge is logically manipulated or controlled using

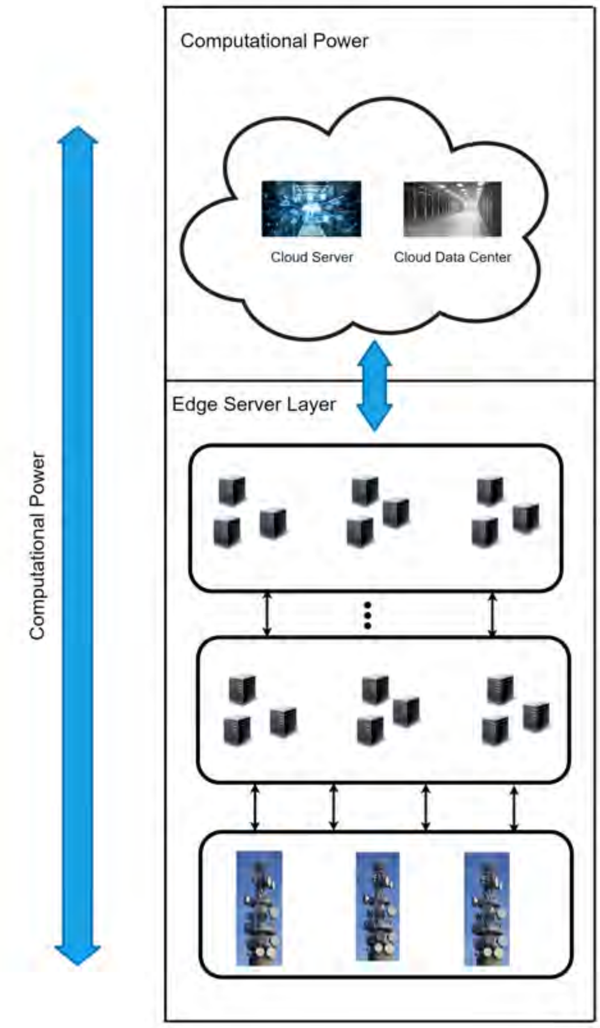

Figure 5.3: Edge Layer Architecture

microcontroller (MCU's), with a small computer being run on a single integrated circuit in each of them. The firmware is basically referred to as the programmed software interface at the low-level that provides a form of control of the device's hardware. Controlling, sensing, computing together with all other functions are therefore encoded inside the firmware which is then taken control by the MCU.

Referring to our proposed architecture the Edge devices can be classified as mobile or IoT devices. They are lightweight electronic devices which are interconnected to the Edge servers in the Edge Server layer of our architecture through various protocols for instance Wi-Fi, 4G/5G and Bluetooth. It usually runs on ultra-lightweight cooperative real-time operating systems for instance: RT Thread and FreeRTOS.

Once an RTOS is installed into the IoT device chip, further programming interfaces are not needed.

As seen in Figure 5.3 , The server layer of the Edge has a pyramid relationship of numerous different layers with several edge servers of rising computational capabilities from bottom - up approach. NB-IoT enabled base stations and the Access Points also known as AP in short , which are basically used for the purpose of communicaton in order to receive information from the edge servers situated at the sublayer in the lower layers, which are primarily implemented to collect data from both the edge of the network for connectivity purposes and transmit control the flows right to them through the various wireless networks.The NB-IoT enabled base stations or the Access Points brings forth the data towards the edge servers situated in the top sublayers after getting signals from edge computers, which have been predominantly responsible for performing computing activities. Upon getting signals transferred to the deeper lower layers through Base Stations or servers of the edge, the edge servers execute acceptable calculation and analysis functions around their own. If a function size and complexity approaches the technical constraints of the existing edge server, it will unload the work to the upper sublayer server computers that have more accurate mathematical capability. Then these processing servers finish with a set of defined flows and return them to the APs that forward it to the edge.

5.5 Use-case Architecture

Considering the wide coverage range in suburban areas, one clinic per village can be considered to be a node with embedded healthcare monitor device unit and NB-IoT powered modules, as they serve as clients as each node is connected to the core which is the Edge Computing Layer.

The Edge devices have the functionality of collecting data and hence processing of the data. Furthermore, the plan of the security and the energy utilization ought to be considered for the betterment of the managing of the supply of the energy and therefore the security of the terminal devices. Because of the added constraints of the resources, the monitoring devices on the node layers are susceptible and powerless against third-party attacks. For the security and protection purposes the layer underlying raises the requirement of such security mechanisms like for instance information encryption, access verification and lastly Data checking. The verification of the accessing requires two-side assurance among the devices and the base station. We can manage the packet error and packet loss in the remote transmission cycle utilizing the Data check system in order to guarantee the integrity of data transmission.As the data is sent to the BS the wide-are coverage process proves to be an advantage and contrasting the current system in NB-IoT which expands a 20db+ connection This significantly increases the entry potential and allows it to be best equipped for the hardware association of facilities.

Following the transfer of information from both the diagnostic testing unit and NB-IoT hub and the BS, the safety and authentication mechanism is monitored to decrease the risk of being targeted. The Edge Server gathers the information received from the BS into the system core and begins the operational loop.The edge processor is usually close to the nodes, the data's round trip time is comparatively small and decreases the congestion considerably. This will tremendously help the surveillance with the high latency constraint such as real-time critical care surveillance as shown in An embedded edge computing system on the connected devices..Because Big Data is conventionally found and processed in the cloud environment. This focused knowledge planning would reveal its characteristic problems in the architecture of clinical IoT because it interfaces a large range of devices processing information at a massive level and the explicit creation of remote computing resources can not organize the peripheral blast of data. Any NB-IoT base station can also connect up to 50000+ computers, which increases the transmission speed and idleness of the machine. In the other hand, some data in smart clinics such as the UCL heart data sets we use have high requirements to resolve latency, that the need for edge computing servers in the infrastructure is crucial to minimize latency and carry out data collection and calculation in real time.

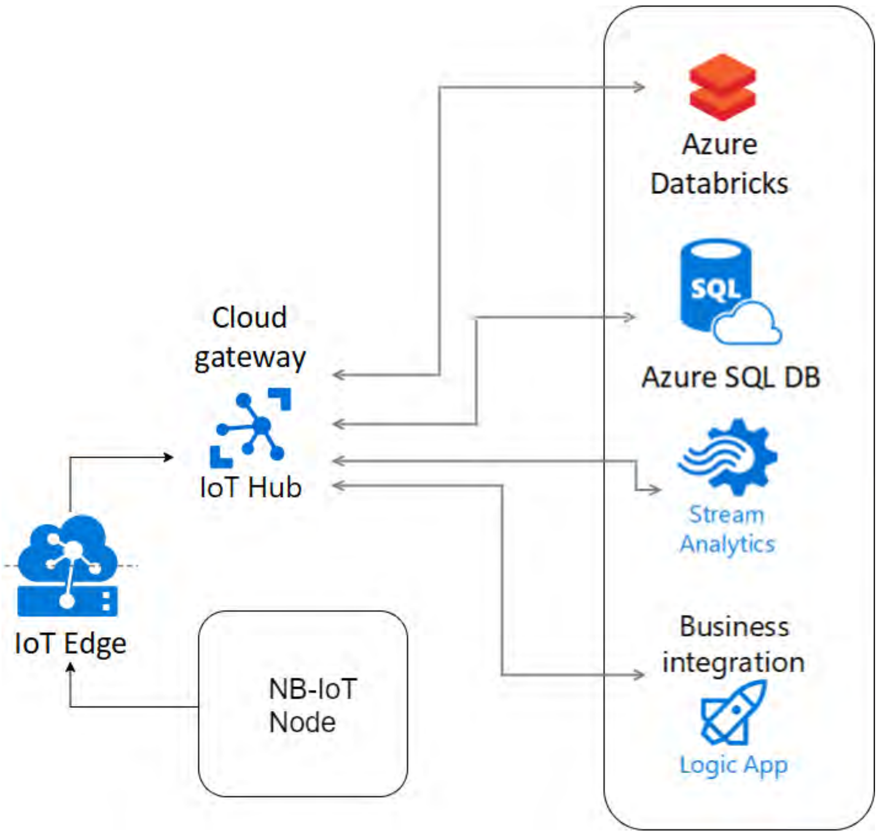

Figure 5.4: Use-case Architecture

After the significant measurement and the complex loop on the ground, the information can be shared via the cloud entry as seen in Figure 5.4 below the database server to be securely processed where knowledge researchers and software architects can use Azure Databricks in Azure Cloud Platform without too much of a push of workspaces. Further analyze them by using the integrated Azure Machine Learning to easily discern rational estimates as alluded to in Azure Databricks Documentation with sophisticated advanced machine learning capability. Where administrators administer the servers via the Azure SQL API in the back-end. On the other hand, Azure Stream Analytics on both the IoT Edge and the cloud helps engineers to bring near, constant analytical insights near to IoT users so that they can leverage up the maximum benefit of device-generated data provided with low inactivity and low latency capacity, effective utilization of transfer speed, and consistency.

Chapter 6

Methodology

By building a Linux virtual machine that is designed to be an IoT Edge system, the following design section guides us. Then, we launch a module to our device from an Azure portal. A virtual sensor that produces heart data and blood pressure data in the module used in this segment.

6.1 Implementation

For the following implementation we use the official Microsoft Azure Edge Services to deploy our business logic to the Edge from the Cloud so that the Machine Learning computation takes place at the Edge of the network so that the calculation can happen in real time with the concept of virtualization. We begin by installing container - based code on a Linux IoT Edge virtual system. In order to send more of the workloads to the edge, the IoT Edge helps us to handle code remotely on our computers. We will use an Azure virtual machine for our IoT Edge computer, which aids us in building a machine for test easily with the IoT Edge service installed. Azure hosts an immersive shell environment called Azure Cloud Shell that we could use from our browser. With Cloud Shell, we could either use Bash or PowerShell to interact with resources from Azure. As mentioned in the documentation, we could use Cloud Shell preinstalled commands to execute the program without needing to install something in your local environment.

By clicking the Cloud Shell button in the upper-right toolbar of the Azure portal under "https:/shell.azure.com", the Azure Command Line Interface (CLI) command is selected and referring to the code in Figure 6.1 below makes the Cloud Shell instance of the Azure IoT extension.

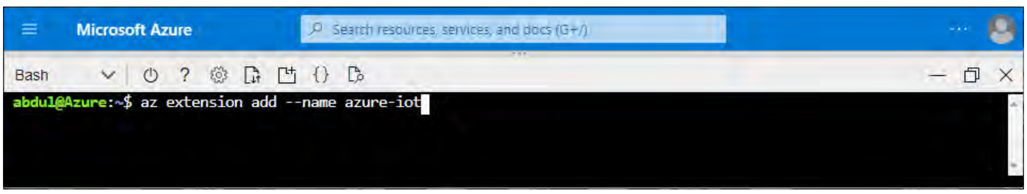

Figure 6.1: Creating Extension

We built the IoT-Hub or a portal for the next steps, but for that, we needed a cloud resource group to handle all the services we needed in this implementation.

By entering the following command from Figure 6.2, we built a resource category.

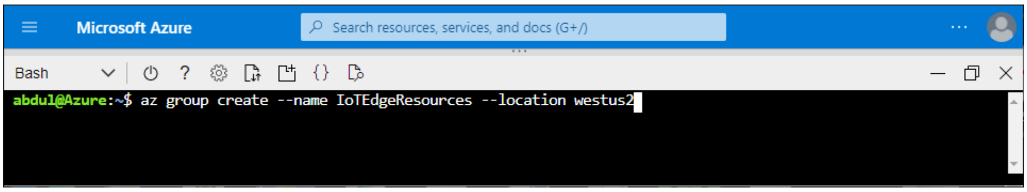

Figure 6.2: Creating Resource Group

To finally build the IoT-Hub for our gateway, we used the command in Figure 6.3 with the specific name that we gave our IoT-Hub

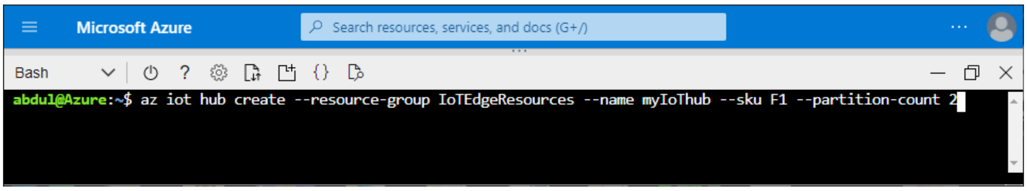

Figure 6.3: Creating IoT Hub

We created a user identity for our IoT Edge device so it can communicate with our IoT center. The user identity exists in the cloud so we use a connection string for the device to associate a physical object with an object identity. We have declared this identification with the edge-enabled flag for an IoT Edge device, since Edge devices work and can be treated differently than standard iot nodes.

We type the following command from Figure 6.4 into the Azure Cloud Shell.

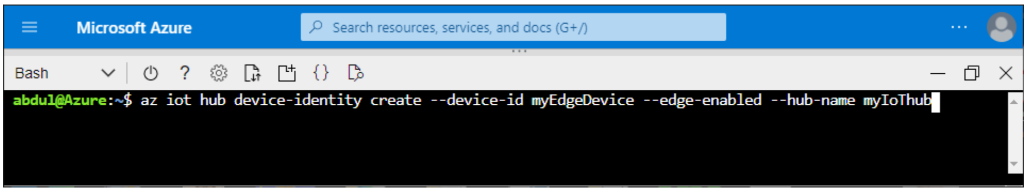

Figure 6.4: Registering an Edge Device

A device reference string that connects our device to its IoT Hub. It included the name of our IoT hub, the name of our system, and then a general key which verifies the links between both the two. We take account of the relation string as we would like to establish our Edge System with the aid of this connection string. By running the following command in Figure 6.5, we created the relation string.

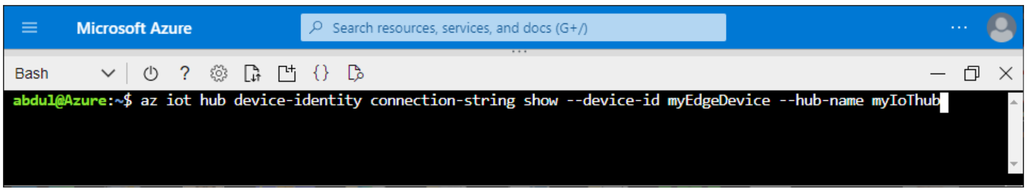

Figure 6.5: Generating Connection String

Now that we finished building both the IoT-Hub and the connection string created for the Edge-Device configuration, we went forward to configuring our Edge Device. On all IoT Edge computers, the IoT Edge runtime is implemented. There are three components of it:

- When the IoT Edge Edge device booted and integrated in the device by launching the IoT Edge agent, each IoT Edge protection daemon started.
- The IoT Edge agent allows the deployment and monitoring of modules also on IoT Edge unit simple, including that of the IoT Edge base.
- The IoT Edge hub manages connectivity between such modules upon this IoT Edge Edge system and between the system and the IoT Hub.

We supply the interface connection string during the runtime initialization. It was the string we obtained from the Azure CLI. This string identifies the IoT Edge identity of the device in Azure with our physical device.

In Figure 6.6 Using the following CLI command we created our IoT Edge device:

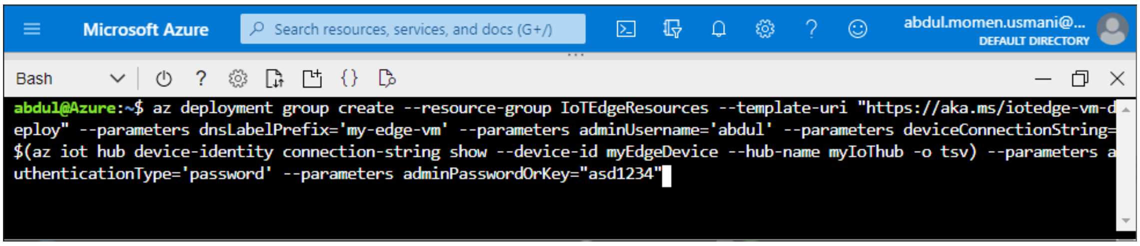

Figure 6.6: Deploying the Resource Group to Edge

After the setup is completed safely, we receive JSON-formatted output in the CLI that includes the SSH information to connect to the virtual world. We copy the value of that same public SSH entry section of the output layer. On the IoT Edge device itself, the majority of the commands take place, so we can see what's going on the device. Since we're using a virtual computer, we're now connected to that computer using the administrator credentials we set up and the DNS name that the deployment command gave us. To connect to the virtual machine, we use the following command from the console. Referring to Figure 6.7:

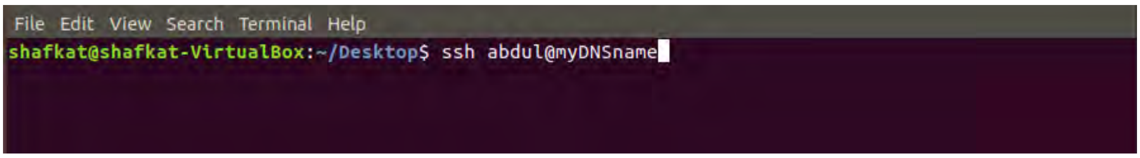

Figure 6.7: Connecting to Virtual Machine on the Edge

To check whether the runtime was successfully installed and configured we enter the following command in Bash from Figure 6.8 where it returns the status of active running.

For setting up the development environment on our local computer the following:

- Chocolatey
- Docker Desktop for Windows
- Git for Windows
- Git Credential Manager for Windows
- .NET Core SDK
- Python 3
- Visual Studio Code
- Azure Powershell
- Visual Studio Extension for Python, Docker and Powershell

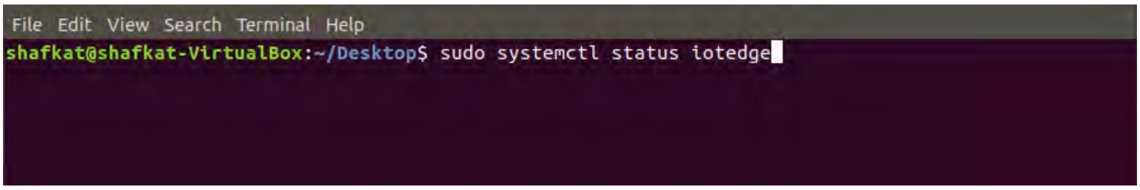

Figure 6.8: Checking Status of Connection

It manages safe communication amongst IoT devices and the cloud, since our Azure IoT Hub is the heart of every IoT function. It is the main coordination point for the operation of the IoT Edge machine learning solution. IoT Hub uses routes to direct incoming data from IoT devices to other downstream services. We will take advantage of IoT Hub routes to send device data to Azure Storage. In Azure Storage, the device data is consumed by Random Forest Classifier for detecting heart-diseases in our patients.

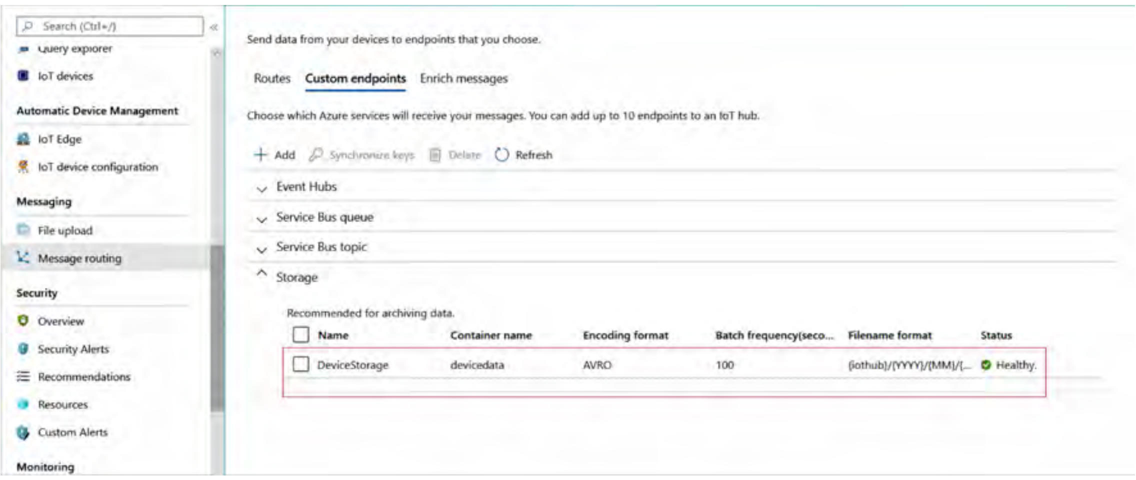

Figure 6.9: Creating a Custom Endpoint

You configure a route that forwards data received by the hub to an Azure Storage container. To begin the creation of IoT Storage we run the Powershell extension file given by Microsoft Azure. We run the creation script. We will be prompted to link our Azure account and after completion of the credentials our Azure Storage account would be created.

As part of running the script, a custom endpoint and a route were created. IoT Hub routes consist of a query expression and an endpoint. If a message matches the expression, the data is sent along the route to the associated endpoint. Endpoints can be Event Hubs, Service Bus Queues, and Topics. In this case, the endpoint is a blob container in a storage account. The Figure 6.9 reviews the storage created where DeviceStorage points to the blob storage container we created named DeviceData as indicated by Container name.

We then navigate to the Routes tab where we select the route name DeviceDataToStorage over here we see that the route's endpoint is the DeviceStorage as shown in Figure 6.10.

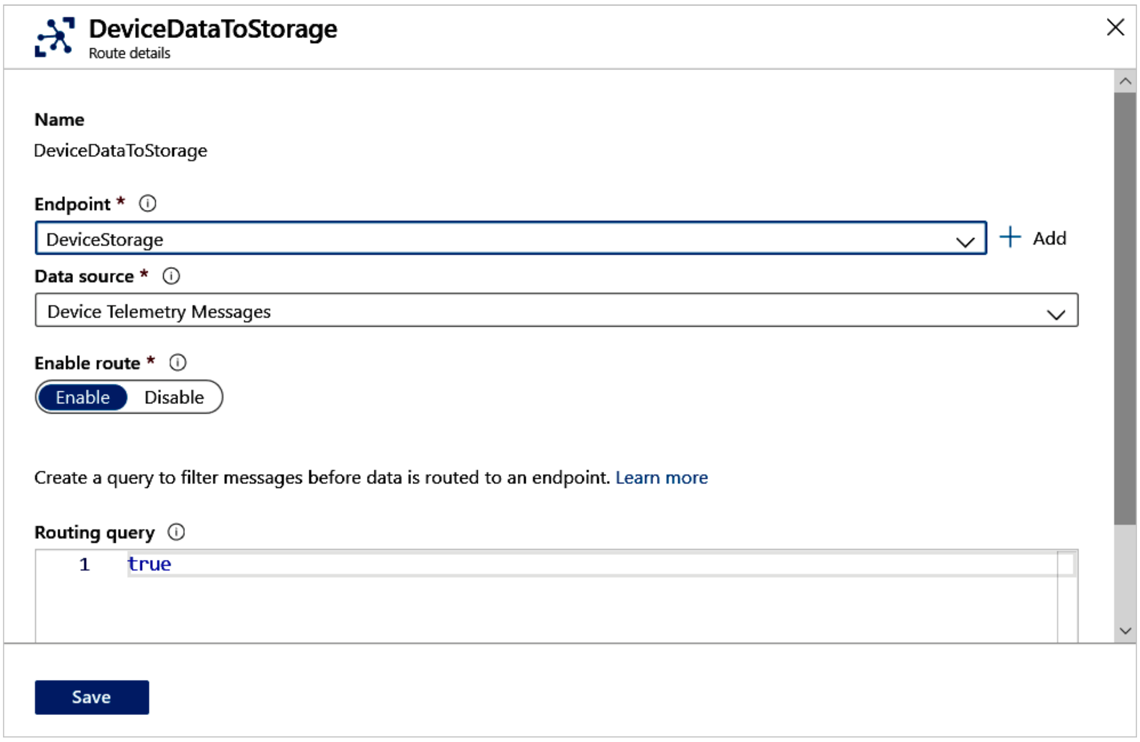

Figure 6.10: Creating a Route

The Routing query, which is set to true. This setting means that all device telemetry messages will match this route; and therefore all messages will be sent to the DeviceStorage endpoint.

In the next step we use machine learning training data to simulate a device sending telemetry to Azure IoT Hub, where the virtual simulated device in this part is considered to be the NB-IoT nodes that are situated in the endpoint Clinics located in the rural areas.

The simulator is a C# program that uses the IoT Hub APIs to programmatically register virtual devices with IoT Hub. We then read the data for each device from the provided data subset and send it to the IoT hub using a simulated IoT Device. We then use Visual Studio Code extensions to synchronize the virtual devices inside the SensorDevices folder.We validate that our environment is properly set up by triggering the build. After which we move forward to connecting IoT Hub and run SensorDevices. We sign in from our VS code to our Azure account and expand the AzureIoTHub frame and select our registered IoT-Hub and then we select the Copy IoT Hub connection string to copy the connection string.

When we run the SensorDevices project when prompted for the IoT Hub Connection String, we paste the connection string copied in the previous section. After refreshing in the Azure IoT Hub devices frame we see the list of virtual devices that are considered to be sensors in our case as referred to Figure 6.11

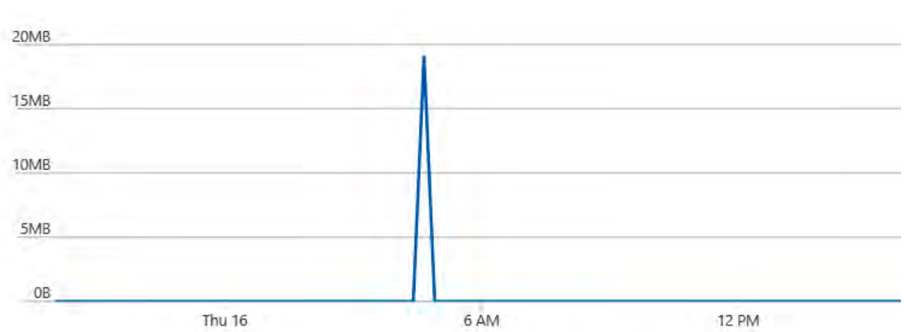

Figure 6.11: IoT Hub metrics chart

We viewed messages sent to the hub by right-clicking on any device and selected Start Monitoring Built-in Event Endpoint. The messages showed in the output pane in Visual Studio Code. We then navigated to our IoT-Hub in our Azure portal and selected Metric under the Monitoring pane and viewed the chart referred to Figure 6.12 below.

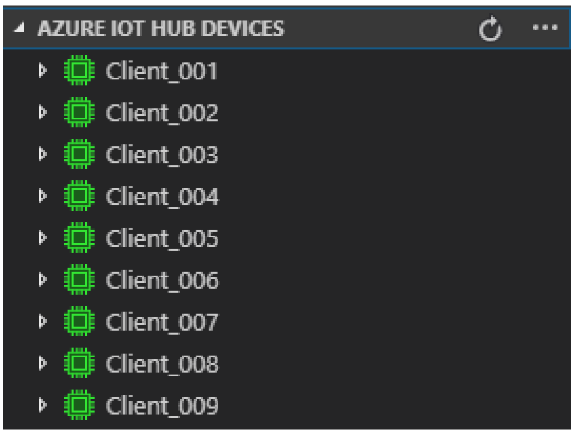

Figure 6.12: List of Devices connected to Hub

The data that was sent to the IoT hub was routed to the storage container that we created previously. Once enough data is collected, we used it to train models that predict heart-diseases for the patients.

In this next step we set up Azure Notebooks. We use Azure Notebooks to host the two Jupyter Notebooks and supporting files. Here we created and configured an Azure Notebooks project. For reviewing the files uploaded in the Azure Notebooks project:

- **train.ipynb**
  - Extracts data from Azure Storage that was extracted from our Virtual Devices (NB-IoT nodes)
  - Pre-processing is performed on the data and it is split for testing and training purposes
  - Utilizes selected classifier model to the machine learning service workspace
- **deploy.ipynb:** This notebook takes the model created in the previous notebook and uses it to create a container image ready to be deployed to an Azure IoT Edge device.
  - Creates a scoring script for the model.
  - Produces a container image using the classifier model that was saved in the Machine Learning service workspace.
  - Deploys the image as a web service on Azure Container Instance

Uses the web service to validate the model and the image work as expected.
When we ran the Azure Notebooks, in the cell previous to Workspace details the snippet of the code asks for authentication to visit the given line to sign in and provide the given code This sign-in procedure authenticates the Jupyter notebook to access Azure resources using the Microsoft Azure Cross-Platform Command Line Interface. We open model2.ipynb and run each cell. We will need to sign-into to authenticate in the cell that follows Configure workspace and hence return to our project page. Hence we created a container image, and to deploy and test the image as a web service. We build three IoT Edge modules in this portion that collect messages from leaf IoT sensors, operate the information through your machine learning model, and then forward IoT Hub insights. The IoT Edge hub allows correspondence from module to module. Using the IoT Edge hub as a message broker manages to hold modules independent of each other. Modules only need to determine the inputs for which messages are accepted and the outputs for which messages are written. We want the IoT Edge device to accomplish four things for us:

- Receive data from the leaf devices
- Predict heart disease for the device that sent the data.
- Deliver a message from the system to the IoT-Hub with the heart disease prediction model deployed as an image. Only if the prediction result is positive can this function be modified to send data.
- Saving the leaf device data to a local IoT Edge device file. To develop the machine learning model's training, this data file is routinely updated to IoT-Hub. It is more cost efficient to use file transfer instead of continuous message transmission.

For the completion of these tasks we made three custom modules:

- **Random-Forest Classifier module:** A standard machine learning module, which exposes an "amlInput" as input and "amlOutput" as output hence the module we developed in Train and implement as an Azure Machine Learning model.

- **Avro-writer module:** This module accepts messages at the input of model input of Avro writer and the message in Avro format resides on the disk for eventual upload to the IoT Hub.

- **Router module:** The router module accepts messages from the leaf modules of the downstream sensors in the network, formats them and transfers them to the classifier section. Then the module collects the messages from the section of the classifier and forwards the message to the writer module of Avro. Finally, only the Heart Disease Prediction is sent to the IoT Hub by the module.

  1. Inputs
     - **deviceInput:** receives messages from leaf-devices
     - **hdinput:** receives messages from "amlOutput"
  2. Outputs
     - **classify**: sends input to "amlOutput"
     - **writeAvro**: sends messages to "avroModuleInput"
     - **toIotHub**: send messages to $upstream, which passes the messages to the connected IoT Hub

Using the "Azure Machine Learning" module, we created a solution for the Azure IoT Edge and pointed the module to the published image using Notebooks from Azure. Next, our solution was linked by the Router module where the Router module manages many responsibilities for the solution:

- **Receives messages from leaf devices**: The Router module receives the message and continues to coordinate the message routing as messages come from downstream devices to the IoT Edge node. Sending messages to the Random-Forest Classifier module:the Router module converts the message into the structure that the Random-Forest Classifier module requires when a new message is sent from a downstream computer. The Router starts sending the heart-disease classification message to the Random-Forest Classifier. Once a prediction has been made by the classifier, the Route models gets the message sent by the classifier.

- **Send heart-disease classifying to IoT Hub**: When the classifier sends the message to the router the message is transformed to comprise only the necessary information and forwarded to the IoT hub for a shortened message. A further improvement that we've not done here is that when a certain threshold is reached for the Heart-disease prediction only then to send message to the IoT Hub. In this way, filtering would reduce the volume of messages and bring down the cost of the IoT hub.

- **Send message to the Avro Writer module**:The Router module sends the whole message sent from the classifier to the Avro Writer module, which survives and uploads the data using the IoT Hub file upload, to retain all the data submitted by the downstream unit.

The development of the Router module is initiated by trying to replace the authentication from the tasks.json file provided by the Azure Edge Computing Documentation. We studied how to set up the router module routes which we referred to in Figure 6.13. We continue to incorporate the Avro Writer module after the previous implementation of the mission. The Avro Writer module has two roles in our system: to upload files and store messages.

- **Store messages**: After receiving messages in the Avro Writer it writes the message in Avro format to the local file system. We used bind mounts that mounts a directory to a module container path. This mount allows the module to write and make certain files accessing directly from the IoT Edge system to a local route.

- **Upload files**: Using the Azure IoT Hub file upload functionality, the Avro Writer module uploads data to an Azure storage account. When a file has been correctly uploaded, the module erases the file from the device.

Figure 6.13: Routing commands for to initiate Router Module

Two Python modules, PyYAML and fastavro, are based on the author writer module. On our development machine, we need to load the dependencies and direct the Docker build method to load them in the image of our module.
We also modified our assumptions about what data will be sent to the hub and for what reason by adding the IoT Edge interface and modules to the system. In order to tackle our present situation, we need to reconfigure the routing in the hub. We plan to receive daily updates containing only the system ID and the Heart-Disease forecast for the system with the router and classification algorithm in place. We want the Heart-Disease data to be routed to its own storage location where the device status can be monitored, generate reports and engage alerts as needed.At just about the same time, we wanted to begin routing to the existing storage location any user details that is still being transmitted directly by a leaf device that has not been connected to our IoT Edge device yet. We are able to create the images and upload them to our Azure container registry now that we have made the configuration improvements. The process for build uses the necessary components that need to be designed. First, the development process runs a Docker development on the Dockerfiles, matching the current configuration found to generate an image in the

module.json package. It then began publishing the image from the module .json file to the registry with a release(version) tag that fits the one in the module.json file. Ultimately, a setup-specific deployment manifest is generated, which we deploy on the IoT Edge device.The IoT Edge system receives the information from the deployment manifest, and installs the components, configures paths, and sets any desirable properties depending on the directions. This method of implementation has two side effects that we should hear about:

- **Deployment lag:** Since the IoT Edge runtime should understand the adjustment to its desirable characteristics before it begins reconfiguring, it will take a bit of time to execute the modules before they can be picked up by the runtime and the IoT Edge system begins to upgrade.
- **Module versions matter:** If we are using the same release tags as the previous module to roll out a new new version of a module's container to the container registry, the new version of the module will not be updated during runtime. It compares the local image version tag and the expected image from the deployment manifest. If such versions fit, no action is taken in the runtime.And so it is necessary to increase the edition of our module any time we want new updates to be deployed. Increasing the version by the modification of the properties in the module .json file underneath the tag property for the module we're modifying. Create and post the module then after.

So we'll be able to use the Azure portal to check our published modules until the development is provides a complete view after publishing and building.
In our approach, we designed and installed the modules, and then we deploy the modules to the IoT Edge system.

We built three modules in for IoT Edge solution in Visual Studio Code which is a router, a classifier and a file writer/uploader. The route system was hence setup in order for the modules on the edge to communicate with each other. We changed the edge system configuration and updated Dockerfiles to load dependencies and apply connecting mounts to the containers of the devices modules. Where the predicted results were uploaded to the IoT-Hub and then finally to the Cloud Storage over the last phase.

6.2 Comparison of Architectures

6.2.1 LPWA Radio Technology Comparison

Different factors should be considered, such as spectrum (license), implementation, and end-device costs. [43] addresses Sigfox, NB-IoT, and LoRaWAN, offering a brief overview of the technologies for cellular LPWAN IoT deployment. NB-IoT minimizes the LTE protocol features and, as needed, enhances them for IoT applications. As an example, the LTE backend method is used to relay information that is true for all end devices inside a cell. As the broadcasting of the backend system requires energy and induces battery usage for each end unit, it is kept to a minimum in its scale as well as in its incidence. It was intended for small and unusual data messages, and abstained from features not needed for IoT purposes (e.g. radio

quality measurements, grouping, etc.). The end-devices can therefore be held at an reasonable cost and only require a limited amount of electricity.
Figure 6.14 indicates that while Sigfox and LoRaWAN have a cost advantage over NB-IoT, it is suggested that NB-Iot should be extended to applications needing higher service quality (QoS).
NB-IoT uses a licensed spectrum and LTE-based synchronous protocol (i.e. LTE frequency band auctions are over EUR 500 million per MHz [42]) that is cost-effective and suitable for QoS. NB-IoT is chosen for applications that require assured service efficiency due to QoS and cost tradeoffs, whereas LoRaWAN or Sigfox can be selected for applications that do not have this restriction.
NB-IoT has the advantage of very high scalability as opposed to Sigfox and LoRaWAN. NB-IoT allows networking of more than 100K devices per base station, compared to 50 K per cell for Sigfox and LoRaWAN [33].
On the other hand, the value of the full payload duration is also provided by NB-IoT. The NB-IoT supports up to 1600 bytes of data transfer. LoRaWAN has a maximum of up to 243 bytes to send. On the other hand, Sigfox recommends the lowest 12-byte payload length that limits its use on various IoT apps that need to send huge data sizes.

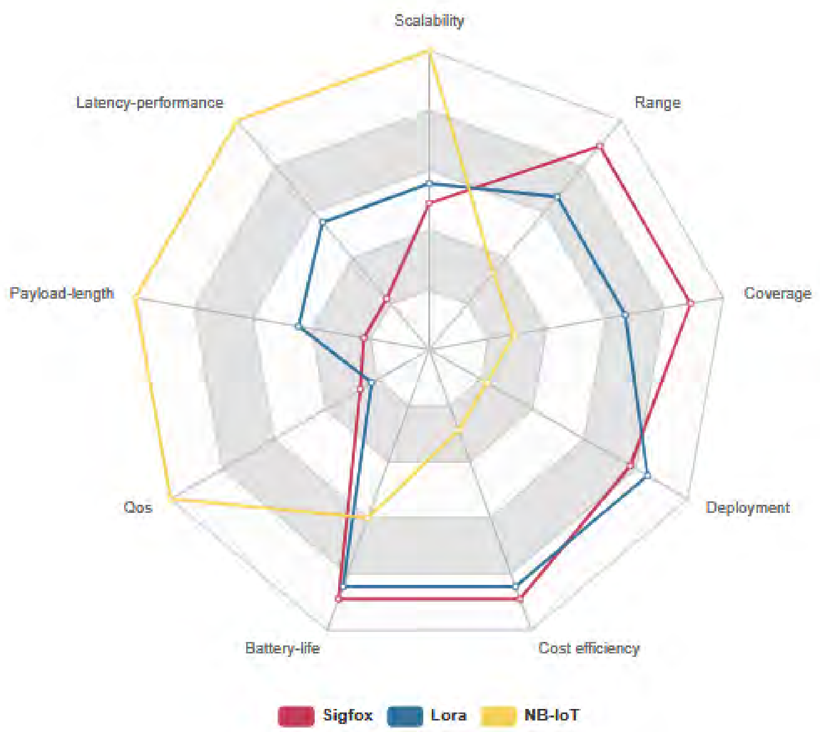

Figure 6.14: Comparison of Sigfox, NB-IoT, and LoRaWAN

Furthermore, NB-IoT has low IoT latency connectivity. Unlike Sigfox, at the expense of higher energy usage, LoRaWAN provides class C to accommodate even low bidirectional latency. For latency-insensitive applications, Sigfox and LoRaWAN Class-A are therefore the optimal solutions. For IoT applications with low latency communication, NB-IoT is the better option.

6.2.2 Edge and Realtime

An additional research path or the approach is the cross-design of the broadband network for intelligence computation of the edge. The requirement of the latency of all these sensor nodes are, in general, solved by installing edges data-processing nodes near IoT devices from two or more points. Furthermore, data-processing nodes of the edge devices directly capture and respond to certain data. Additionally, at edge process control nodes, some raw data from iot nodes is post - processed because only the usable component will be redirected to the Base Stations that are NB-IoT enabled. A hierarchical IoT network forms the BS, edge data-processing nodes, and IoT computers, in which the disturbance is dynamic and needs to be constantly handled. Edge computing is an emerging model of computing that places computer processing energy and space closer to end just at network edge. [55] provides intelligent capabilities through its integration with cloud technology. It is thus possible to define a more regional variant of cloud and fog computing as edge computing. Referring to [40], Edge computing is based on the fog nodes idea that was first introduced in the beginning of 2010. The philosophy behind cloud users is focused on computational "zones," and is analogous to the Wi-Fi hotspot since it delivers cloud computing also without low powered short ranged internet access.
The only limitation to the placement of the fog nodes is that it can be centered at or close to the end user's boundary of the network [53]. Per the [53], there are two results to the edge framework; it decreases the lag of connectivity amongst downstream devices and the network, and it combines local network devices and cloud resources effectively, as devices serve both as data providers and data compellers in edge computing. This implies that requests across end services and devices are uni - directional, such as in the figure 6.14. In response to extracting data from the current repository in the data center and distributing it to the customer, clusters also at edge of networks perform multiple processing functions, such info replication, IoT maintenance, device discharging and privacy security.
In addition, the cloud infrastructure is an unique benefit of this paradigm, as edges computing powers the Internet of Everything which is also known as (IoE). As the IoT focuses on the interface amongst systems and IoT objects, logical contact amongst individuals, processes, entities and data is the primary subject of IoE. Another of the key reasons for intelligence and computation at the edge of the network is that, as connectivity is more closer to the users, it's far more capable of satisfying IoE specifications as it has a smaller risk of privacy leakage.

6.3 Software Analysis

6.3.1 Dataset

For our research, we utilize the openly accessible UCI heart dataset in [61]. This information base contains 76 characteristics, yet we will utilize a portion of 14 of them. Specifically, the Cleveland information base is the one in particular that has been utilized to recognize the coronary illness presence in the patient. It is integer esteemed from 0 (no nearness) to 4. Analyses with the Cleveland information base have focused on basically endeavoring to recognize presence (values 1,2,3,4) from absence (esteem 0). These 14 attributes are as follows:

- Age: numeric
- Gender: 2 values (0, 1)
- Chest pain type: 4 values (1, 2, 3, 4)
- Trest Blood Pressure: numeric
- Serum Cholesterol: numeric
- Blood Sugar: 2 values (0, 1)
- Restecg: 3 values (0, 1, 2)
- Thalach: numeric
- Exang: 2 values (0, 1)
- Oldpeak: numeric
- Slope: 3 values (1, 2, 3)
- CA: 4 values (0, 1, 2, 3)
- Thal: 3 values (3, 6, 7)
- The class attribute: (sick type: 1, 2, 3, and 4).

6.3.2 Heart disease data pre-processing

Before the actual calculation or computation can begin, the pre-processing of the data should be initiated given the fact that the data index of the heart disease consists of a handful of information for example: area with chest pain, patient's unique identification, chest pain types, serum cholesterol, blood pressure while resting, criteria of smoking, beta blocker, ECG results, channel of calcium, fasting glucose, usage of nitrates, exercise convention, etc.

In conjuction with the collected heart disease datasets, informational index may include a number of unexpected and undesirable information with few of them even missing which lead to the decreasing of the classification measure of the heart disease. At this point the disturbance occurring in the dataset should be removed by the application of z-score and average standardization measure as it looks carefully without much difficulty at the noisy data in the dataset. Firstly the values that are missing must be replaced by computing the average value that is done as follows:

$$Average\,value = \frac{\sum_{i=0}^{\infty} x_i}{n} \tag{6.1}$$

In the above equation (6.1), x_i constitutes as heart disease data information in the row.

After examining the missing key-points and values in the heart disease dataset the entire information according to the standard deviation and mean must be normalized for most of the part also known as zero standardization measure which is process as follows:

$$d' = \frac{d \, - \, mean(X)}{std(X)} \tag{6.2}$$

In the equation (6.2), d' in the dataset is the normalized data. With the help of the equation (6.1) the mean vale for the particular data is calculated and the standard deviation of the attribute is reckoned as follows:

$$\sigma = \sqrt{\frac{1}{(n-1)} \sum_{i=0}^{\infty} (v_i \, - \, average\, value)^2} \tag{6.3}$$

In equation (6.3), σ is specified as the value standard deviation of attributes. The cycle above is continuously performed in order to remove the surplus data from the dataset regarding heart illness.In parallel to removing the dataset noise, various statistical measures like mean, correlation, variance, standard deviation, maximum, minimum and vitality together with other measures are found from the collection of the dataset for performing the measure of diabetic characterization.

The features that has been derived are massive in measurement and has been found difficult to measure by the use of classification process since it consumes the additional processing time to anticipate the specific heart disease highlights. The proportionality of these highlights are reduced by the application of operational optimized advanced features procedural choice known as the Random Forest.

6.3.3 Random Forest Algorithm

Random Forest is likewise a Machine Learning algorithm which is prevalently managed. This procedure can be utilized for assignments of classification and regression yet by and large performs better in classification tasks. As per what it is called, Random Forest method considers different trees of choices before providing a yield. Along these lines, it is essentially a troupe of choice trees. This method depends on the conviction that more number of trees would join to the correct choice or decision. For the classification, it utilizes a voting framework and afterward chooses the class while in regression it takes the average of the considerable number of outputs of every one of the decision trees shown in figure 6.15.

It functions admirably with enormous dataset with high dimensionality. In [47], random forest performs especially well. In Cleveland dataset, random forest has an essentially higher exactness of 0.916 than the various strategies. In People's Hospital dataset, it accomplishes an exactness of 0.97. In [28] random forest has accomplished a f-score of 0.86. In [22], random forest is utilized to foresee cardiac illness and it acquires an exactness of 0.977%.

6.3.4 Comparative Algorithm Evaluation

To some point, any model we select are likely to be incorrect. This implies that searching for the absolutely correct model is impossible. Therefore, instead of

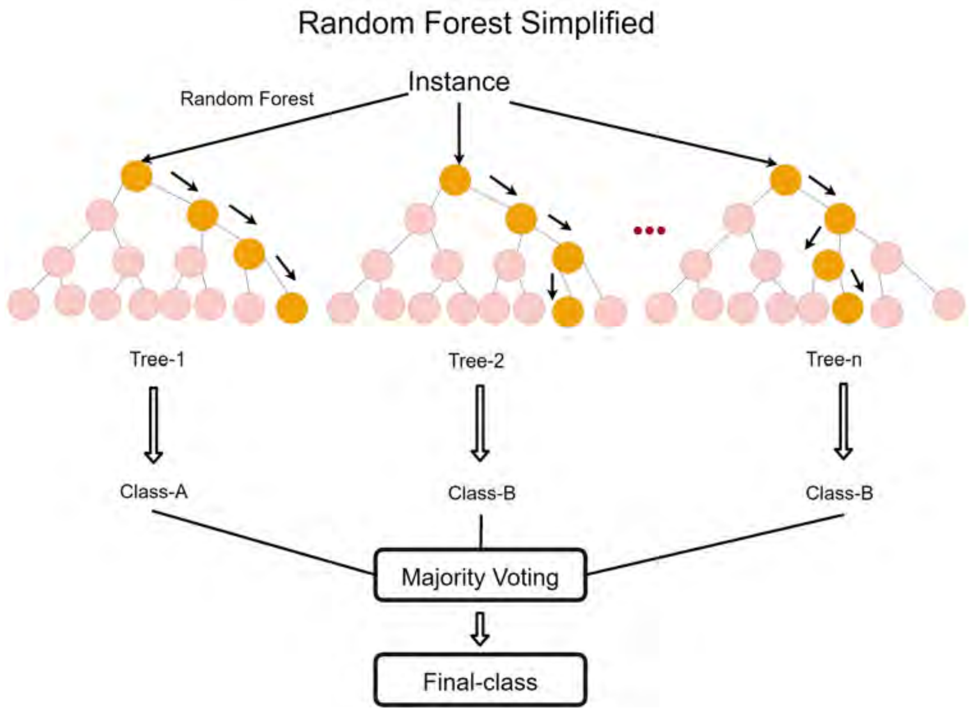

Figure 6.15: Nodes, features and branches for Random Forest

searching for a nonexistent right model, we can aim for a model that is a realistic approximation to actuality and provides insight.
The algorithms that we chose for relative analysis with our chosen random forest machine learning model are given as follows:

- **Logistic Regression**
  The performance is the approximate likelihood of the hypothesis. This is used to evaluate the quality of the expected value when an input is given real value, i which is a potential value for a particular domain. If we have the predicted probability of being p, there is $(p*100)\%$ chance that i will occur which explains the name 'logistic regression'. Data fits into the model of linear regression, which is then acted upon by a logistic function that predicts the dependent objective categorical variable.

- **Decision Tree**
  For classification problems, the decision tree approach is more efficient. On the other hand, the graphical representation of the data is the decision tree and it is also the type of machine learning algorithms that are supervised. In this method, there are two steps.: building a tree annd then the dataset is applied to the tree.

- **K-Nearest neighbor (KNN)**
  It is a non-parametric classifier, simple , lazy and non-parametric classification algorithm. KNN is preferred because all the attributes are constant. Recognition is performed by the detection of the nearest neighbor to establish the status of a sample that is unknown. KNN is preferred over many other classification methods, owing to its high simplicity and convergence speed.As it takes a lot longer to train data before classification data is being used, KNN is a

supervised lazy learning algorithm. It is a technique to assess the information using the training sets provided in the feature vectors.

- **Naive Bayes**
  A naive bayes is a basic probabilistic classification algorithm on that, with clear implications of independant naive, which relies on Bayes' theorem. In general terms, naïve bayes assumes that perhaps a class-specific feature's presence (or complete lack) is not related to the amount (or absence) of any such feature. Naive Bayes classification techniques are instructed to work through supervised instruction. It is specifically related when the dimention of the inputs is high. In particular,predictive capabilities is constructed with the help of Naïve Bayes.

After data mining classification techniques were applied, confusion matrix is obtained in order to determine the classification accuracy. A confusion matrix indicates how many instances in each class have been allocated. We have two groups in this example, and so we have a 2x2 confusion matrix. The possible classes are:

- Class a directs to being YES (cardiac disease to be true)
- Class b directs to being NO (cardiac disease to be false)

	Prediction	
	a (yes cardiac disease)	b (no cardiac disease)
a (yes cardiac disease)	TP	FN
b (no cardiac disease)	FP	TN

Table 6.1: A confusion matrix

- **TP (True Positive):**If they'd been valid, it signifies the set of records listed as valid.
- **FN (False Negative):** If they were technically valid, it denotes the set of records listed as false.
- **FP (False Positive):** Although they were simply incorrect, it signifies the set of records listed as valid.
- **TN (True Negative):** Although they were simply wrong, it represents the set of records listed as invalild.

Per method splits a given array into few different sets, equivalent to the real and false negatives and positives. While, the individual countsTN,FP,P and FN Per method splits a given array into few different sets, equivalent to the real and false negatives and positives.
While, the individual countsTN,FP,P and FN In Figure 6.16, Figure 6.17, Figure 6.18, Figure 6.19 and Figure 6.20, the uncertainty matrix multiplication for Logistic Regression, Decision Tree , Random Forest, Naive Bayes and K Nearest Neighbors

as stated. The values of the TP, FN, FP and TN obtained from the confusion matrices are used to calculate performance values to compare and contrast between the different learning techniques used on our chosen dataset.

Results obtained with 14 attributes are shown below:

Figure 6.16: Confusion matrix for Logistic Regression

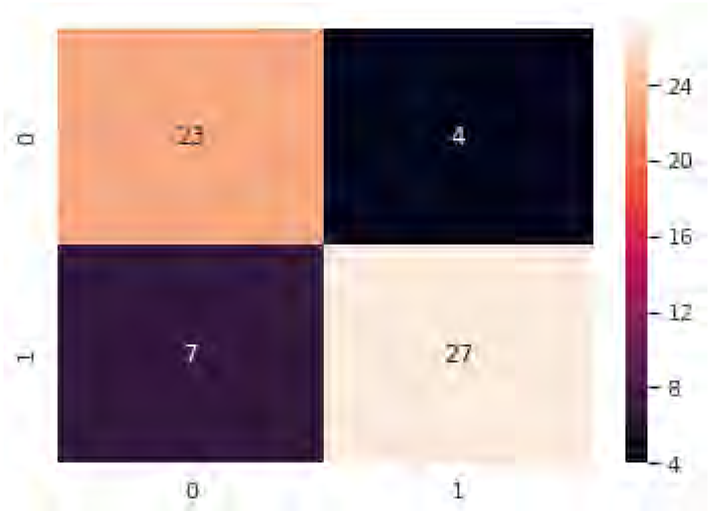

Figure 6.17: Confusion matrix for Decision Tree

We then use these values from the generated confusion matrices to calculate Precision, Recall and F-Score to compare the performance of the different learning models. In terms of probability, both precision and recall have a natural interpretation. Indeed, accuracy can be characterized as the likelihood that an object is important, provided that it is returned by the system, while a reminder is the likelihood that an object is returned. Recall is a statistic that out of all positive predictions that may have been made quantifies the number of accurate positive predictions made.

$$precision = \frac{TP}{TP + FP} \tag{6.4}$$

Figure 6.18: Confusion matrix for Random Forest

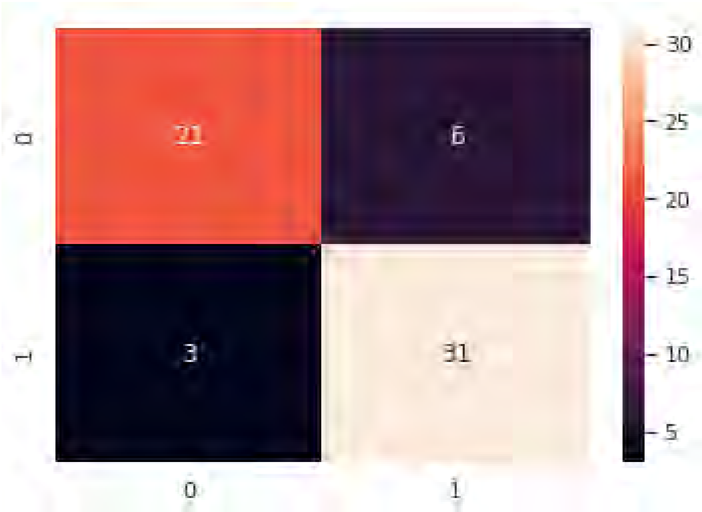

Figure 6.19: Confusion matrix for Naive Bayes

Figure 6.20: Confusion matrix for K Nearest Neighbors

The above equation (6.4) is used to calculate the value precision score ($precision$). Recall offers an indication of missing positive predictions, unlike precision that only comments on the right positive predictions out of all positive predictions i.e. the probability that a relevant object is returned.

$$recall = \frac{TP}{TP + FN} \tag{6.5}$$

The equation (6.5) above is used to calculate the value recall score ($recall$).
Both accuracy and recall are considered by F1 Score. It is the harmonic mean (average) of accuracy and reminder. If there is some kind of compromise between accuracy & recall in the method, the F1 Score is best. Conversely, if one measure is strengthened at the expense of the other, the F1 score is not so high.

$$F_1 = \frac{2 * (recall * precision)}{recall + precision} \tag{6.6}$$

The equation (6.7) above is used to calculate the value of F_1 score (F_1).
Table 6.2 shows the different performance values that we get when we apply Logistic Regression, Decision Tree, Random Forest, Naive Bayes and K Nearest Neighbors.

	Recall Score	Precision Score	F1 Score
Logistic Regression	0.8823529	0.8571429	0.8695652
Decision Tree	0.7941176	0.8709677	0.8307692
Random Forest	0.9117647	0.8611111	0.8857143
Naive Bayes	0.9117647	0.8378378	0.8732394
K Nearest Neighbors	0.6764706	0.7419355	0.7076923

Table 6.2: Performance Scores of the different Algorithms

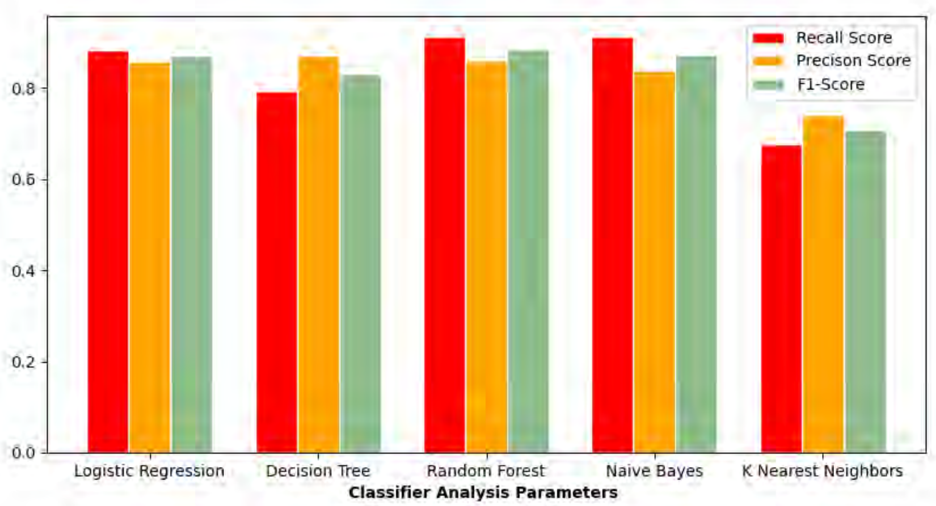

Figure 6.21: Performance Evaluation of the Algorithms

Figure 6.21 shows that Random Forest algorithm provides the best score values in all the aspects of performance evaluation.

We then use the correctness of the results generated by the learning models by calculating the accuracy score which is calculated using the values of the TP, FN, FP and TN obtained from the confusion matrices. Accuracy is the ratio between the number of correct predictions and total number of predictions i.e. ration of correct predictions to total predictions.

$$acc = \frac{TP + TN}{TP + TN + FP + FN} \tag{6.7}$$

The above equation (6.4) is used to calculate the value accuracy score (acc).
Table 6.3 shows the different performance values that we get when we use the different learning models.

	Accuracy
Logistic Regression	0.852459
Decision Tree	0.819672
Random Forest	0.885246
Naive Bayes	0.852459
K Nearest Neighbors	0.688525

Table 6.3: Accuracy Scores of the different Algorithms

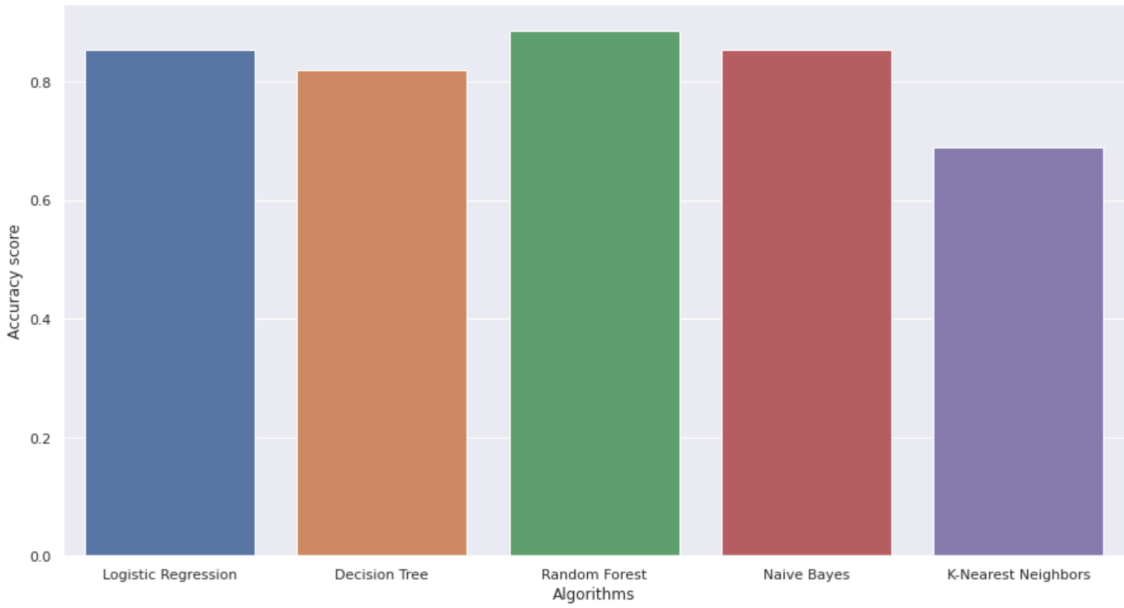

Figure 6.22: Accuracy Comparison of the Algorithms

Figure 6.22 the value representation on a bar chart which shows us that Random Forest algorithm provides the best accuracy score compared to the other machine learning models.

Chapter 7

Conclusions

In order to link intelligent devices utilizing the proposed architecture for potential needs, it is expected that the framework would be implemented on a broader scale as NB-IoT guarantees broad coverage, although with this benefit the corresponding downside is the lack of data protection as medical data will be accessible, as addressing the safety of the patient's wellbeing, security and preservation of privacy are a significant challenge. To reinforce authentication, we need to enhance the encryption process or methodology of the terminal devices, formulating protocols of encryption and managing key schemes. We may also use the wireless charging mechanism. The charging cable is loaded with defects, claim for example while a patient is tested by any other therapeutic equipment, the charging cable will impede the patient's activities exceptionally. We may also use the conversion strategy to further develop our tracking framework. In the event that the system is outdoors, sun-based or wind energy may be converted into fuel, certain piezoelectric components may absorb the mechanical energy generated by the individual's activity and turn it to electricity.

The idea of NB-IoT together with the computation power of Edge Intelligence for solving real-world medical scenarios problems is vital as it requires the use of real-time monitoring, which this architecture provides. Disease diagnosis require realtime observation which might not be easily manageable. In case of rural areas, as population keeps on increasing emergency monitoring is not that available. Thankfully for our proposed architecture leads to a more optimal way of dealing with cases which require realtime observation and monitoring for diseases other than coronary.

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