

# INTERNET OF THINGS APPLICATIONS IN HEALTHCARE

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## BACKGROUND OF IOT:

Internet of things also known as IOT is a revolutionary technology which connects devices or objects to the internet. Over the past decade with the advent of internet, IOT has become quite popular and is having a significant impact in our lives.

In the initial days of the internet, not many people were able to access the Internet due to high cost. But slowly, with the evolution in the Internet every year, it had a great impact in the communication industry. In the late 90's when mobile phones came into the market, they simply had basic features of sending a text message or calling a person and were commonly known as cell phones. But now with the easy access to the Internet, the cell phones are equipped with various smart features with Wi-Fi capability that are launched into the market very often and are famously known as smart phones. Due to smart phones, one can watch online videos or listen to any favourite music from anywhere or play games live online on the Internet.

Now-a-days we cannot imagine our lives without the Internet. Internet of Things which is a wonderful and emergent technology is a result of the revolution in the Internet. In simple words, Internet of Things is nothing but taking all the things and then trying to connect them to the internet. Due to the advancement in technology, the terminology of being connected is not only limited to the computers, mobile phones or tablets but this concept has also transformed into being connected and the ability to communicate with any object or any person. The dimensions of IOT as illustrated in Fig 1 span across from anybody to anyone, from any business to any service, from any network to any path, from any device to anything, from anywhere to any place and any context.

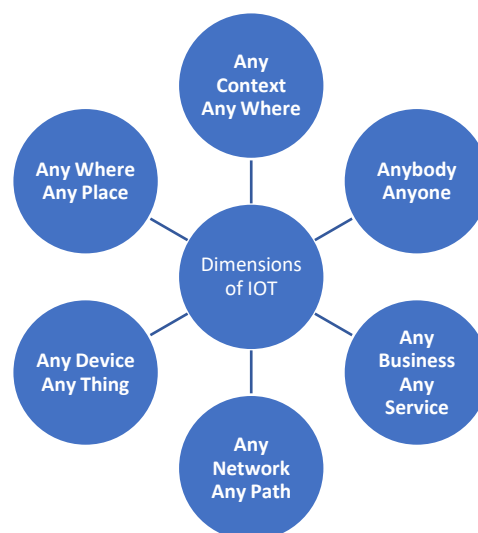
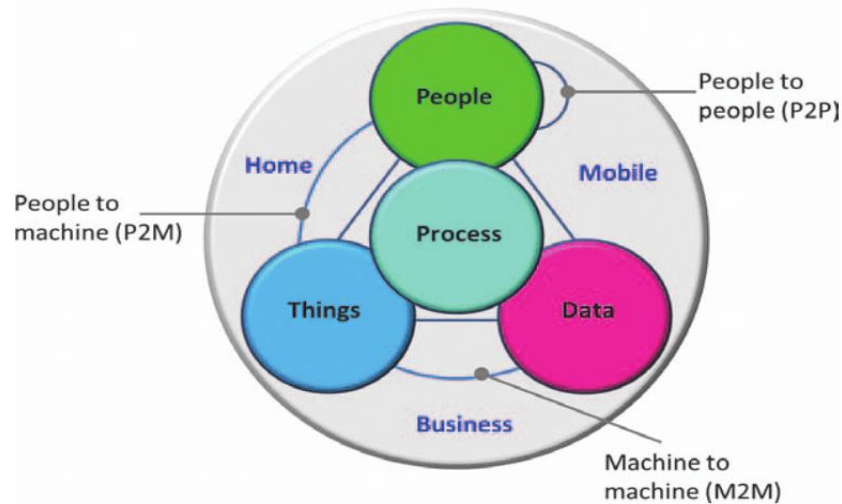


Figure 1 Several Dimensions of Internet of Things, Source [1]

Internet of Things can be defined as the network of the interrelated physical objects, computing devices, mechanical and digital machines, people or even animals that are

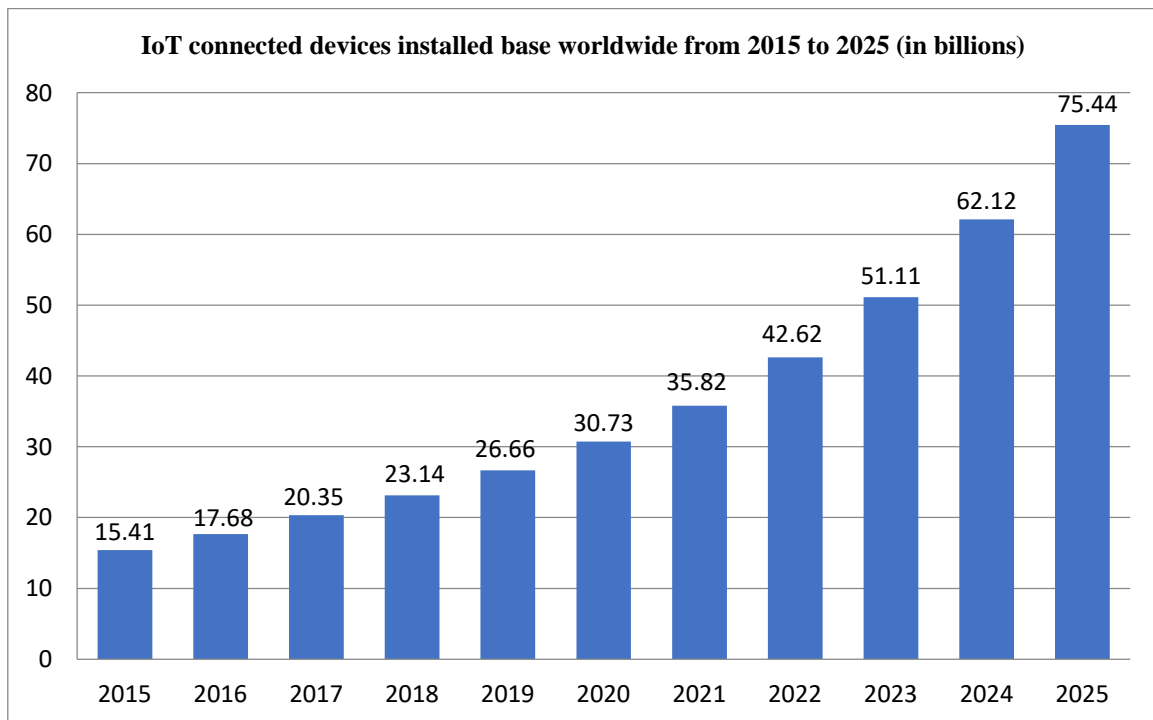
assigned a unique identifier and possess the ability to send or receive the data over a network without requiring human-to-human or human-to-computer interaction [2]

As described in the figure 2, Cisco defines IOT as Internet of everything which is a concept involving people, processes, data and things, bringing them together to establish networked connections would turn out to be more valuable than before and could unleash the power of the internet in achieving greater heights for businesses, individuals and countries [3].



**Figure 2 Internet of Everything, Source [3]**

As per study by Statista in 2018 in Fig 3, number of connected devices in 2015 were 15.4 billion and this number is expected to rise further to 30.7 billion by 2020 and 75.4 billion by 2025. [4]



**Figure 3: IOT connected devices worldwide from 2015 to 2025 (in billions), Source [4]**

According to statistics by Forbes, 90% of cars will be connected to the internet by 2020. Every other second, additional 127 devices are getting connected to the internet. This is happening due to rapid development in the internet availability. It is estimated that the IOT will have a global economic impact of \$11.1 trillion by 2025 which is huge. Even the IOT market at home is expected to rise to \$53.4 billion by 2022. There has been a growth in healthcare IOT expecting the growth rate of 12% annually from 2017 to 2023. Global IOT spends are estimated to reach \$1 trillion by 2022. Smart cities based on IOT would be worth \$2 trillion total by 2025. The top 600 smart cities would account for 60% of the world's GDP. [5]

With all the highlighted facts regarding IOT, it is clearly evident that the IOT market would continue to grow dramatically and is a door to infinite opportunities. Undoubtedly, IOT has a great potential in enhancing all the domains of life.

## **EVOLUTION OF IOT**

When the first electromagnetic telegraph was designed dating back to 1832, the concept of the connected devices was born. The electrical signals were a means of communication for transferring electrical signals between two machines.

However, the concept of the devices or the objects exchanging data without human to computer interaction became more prevalent since 1970's with the invention of Internet. This was then termed as pervasive computing or embedded internet. In the early 1980's Coca-Cola vending machine was the first connected device to the internet situated at Carnegie Mellon University. The local programmers integrated micro-switches into the machine with initial internet to notice if the drinks were kept cold and checking availability of coke cans. This paved a way towards further studies in the interconnected devices over entire world.

In 1990, a toaster was connected to the internet through TCP/IP protocol for the first time by John Romkey. The year 1999 marks a significant year in the history of the IOT when the term Internet of Things was first coined by scientist Kevin Ashton. This is when the IOT started becoming popular among the academics and industry.

In the beginning of the 21<sup>st</sup> century, the IOT technology was on the rise. A refrigerator by LG was connected to the internet in 2000 allowing users to shop online and make video calls. Interestingly, there was a small robot named Nabaztag created in 2005 which could tell latest news, weather forecast and stock market updates. In the year 2008, 1<sup>st</sup> International Conference on IOT was held in Switzerland, where RFID, short range wireless communications and sensor networks were discussed.[6]

In today's era, we are having more number of IOT connected devices than the number of humans on this planet. As per the CISCO IBSG report in the year 2011 represented in table 1, the number of devices connected to the internet surpassed the number of people long ago in year 2008 and ever since the numbers are on an increasing trend.

	2003	2010	2015	2020
<b>World Population</b>	6.3 Billion	6.5 Billion	7.2 Billion	7.6 Billion
<b>Connected Devices</b>	500 Million	12.5 Billion	25 Billion	50 Billion
<b>Connected Devices Per Person</b>	0.08	1.84	3.47	6.58

**Table 1 Connected Devices by 2020 Data Source: Cisco IBSG, 2011 [7]**

Due to the rapid expansion of internet connectivity, increase in the smart phones and computing power, reduced cost of storage due to cloud solutions, and cost reduction in sensors are the determining factors towards exponential growth in IOT

## CHARACTERISTICS OF IOT

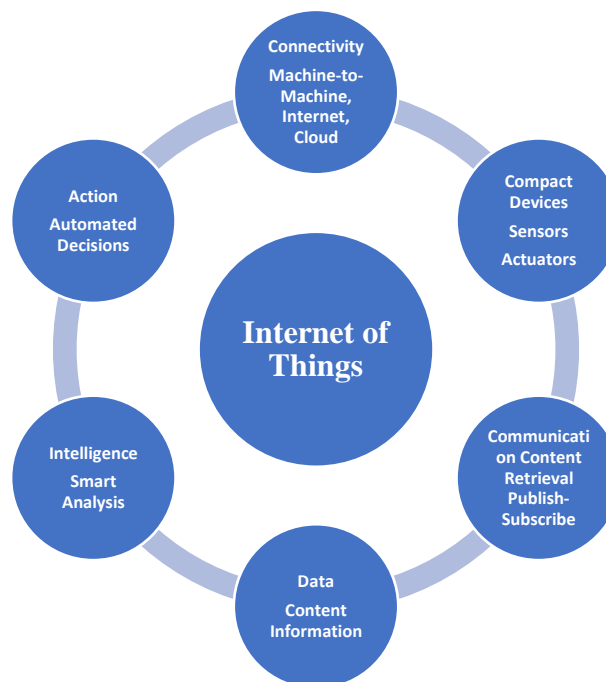
The basic concept behind IOT is to connect it to the internet and empower intelligence. Several technologies are integrated for sensors to sense and receive data, communicate, analyse and take intelligent decisions without human interaction. Fig 4 represents the IOT characteristics and benefits

The list of some fundamental characteristics of the IOT are as follows [8][9]

**Interconnectivity:** The basic principle of IOT is to interconnect anything with the information and the communication infrastructure, accessing the network with the ability to send and receive the information. Different technologies are used to establish the connectivity between the devices and with the internet

**Sensing:** The sensing feature plays a vital role in IOT as the sensors facilitate in collecting measurements, monitoring, and helps in communicating with the physical world and humans.

**Intelligence:** IOT devices collect the data through sensing. The device can also take intelligent decisions by analysing the data based on incorporating certain logic and algorithms



**Figure 4 IOT Characteristics & Benefits, Source [9]**

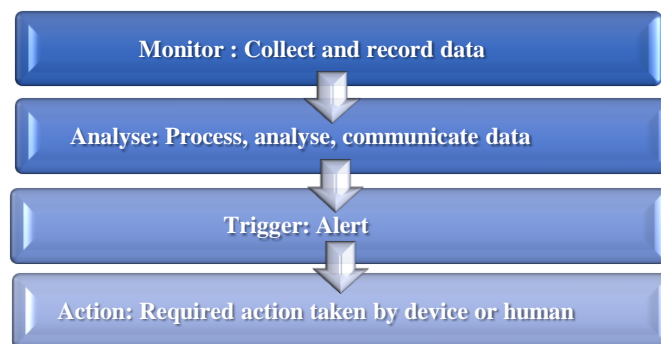
**Heterogeneity:** IOT have the characteristic of being heterogeneous depending on several hardware platforms and networks. These devices can communicate with the other devices or services through different network

**Dynamic changes:** The devices are dynamic as their statuses as well as context such as location and speed can change dynamically. The different states in which the IOT devices can be are sleep, waking up, connected, disconnected.

**Enormous scale:** Due to the huge number of devices connected to the interact and also that interacting with each other, the information and the relevance of the data to the application in use needs to be managed which requires effective data handling.

## IOT PROCESS

The IOT based devices go through different phases as shown in the Fig 5. The first phase is the Monitor Phase where the device collects the data and records it. In the next phase which is Analyse phase, it processes, analyses and communicates the data over the network. In the third phase which is Trigger phase, it generates the alert triggers upon reaching certain threshold vales. In the last phase which is the Action Phase, the necessary actions are taken either by the device itself or by a human.



**Figure 5 Phases of IOT process**

## APPLICATIONS OF IOT

The following are the real world applications of IOT, shown in Fig 6 [9] [10]

**Healthcare:** Connected healthcare is the hottest research areas in the fields of IOT which empowers well being of the patients as well as people in general. Examples include patient monitoring and surveillance, medical refrigerators that control the conditions inside the fridge for proper storage of the medicines, vaccinations, fall detection system for old age people.

**Wearables:** Wearable devices contain the sensors which can collect the information, and the software installed in the wearable device analyses and processes the data to provide the useful insights about the user. Examples include smart watch which track and monitor a person's fitness levels and other health parameters such as blood pressure, pulse rate etc.

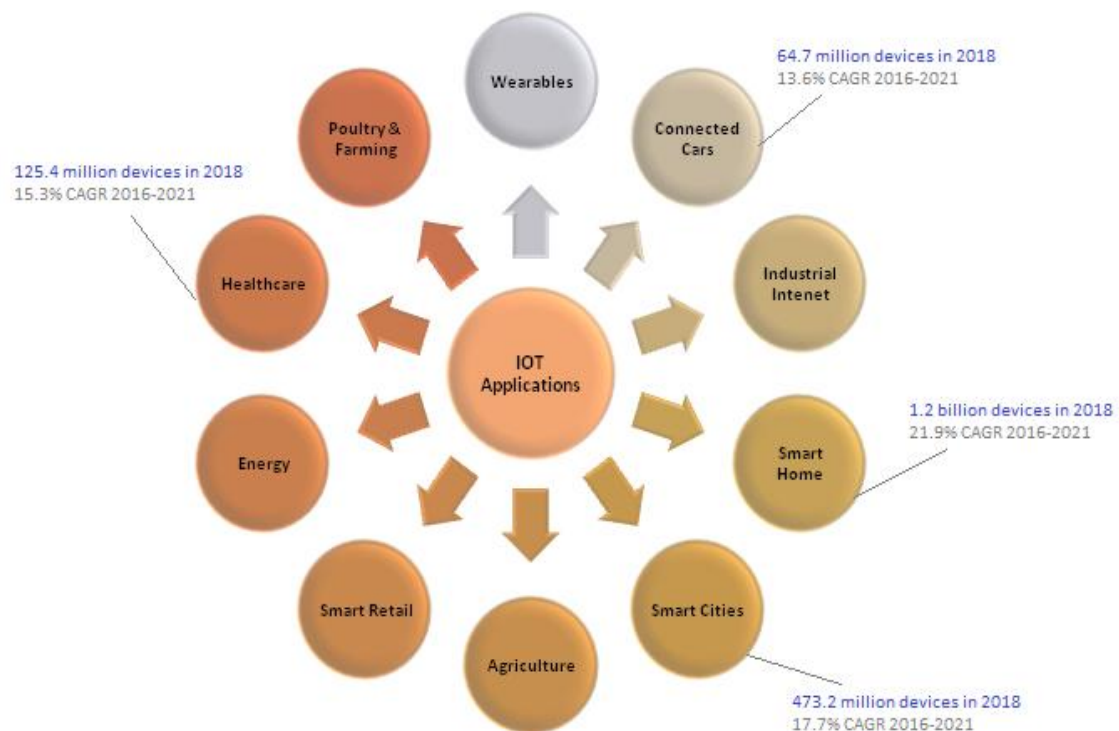
**Smart Home:** Smart home products aim to save time, energy and money at the residential areas. Examples include smart refrigerators telling about food items which are about to expire

and notifying about shortage of certain food items, cameras, home alarm systems, intrusion detection systems for ensuring safety

**Connected Cars:** With the help of IOT sensors and internet, cars can optimize their operations, maintenance along with the traveller's comfort.

**Industrial Internet:** Applications includes tracking of the goods, inventory and data exchange between the suppliers, retailers and providing automated delivery are on the rise due to great potential of IOT in the industrial sector.

**Smart Cities** IOT has the ability to enhance the life style of the people living in the cities by controlling the pollution, reducing the traffic congestion, effectively managing the energy supply. Examples include Structural health of the buildings, historical monuments, bridges, lighting adapted according to the weather, fire control management, smart transportation for preventing accidents and traffic congestion, real time monitoring of the parking space availability, effective waste management



**Figure 6 Various applications of IOT[10]**

**Agriculture** There is a high demand for the food supply due to the rise in the world population. IOT can contribute greatly towards the agricultural sector. Examples include Green Houses, Compost control, monitoring the farms for reducing crop wastage.

**Smart Retail** IOT brings the retailers to connect with the customers and thereby improving the in-store experience. Due to the smart phones, the retailers can remain connected with the customers even when out of store.

**Energy Engagement** Smart Grids or Power grids have gained popularity in terms of their ability to monitor energy consumption, wind turbines and power houses to analyse the energy consumption patterns and power supply controllers.

**Poultry and Farming** With the help of IOT applications, the health of the cattle can be monitored and preventive measures can be taken in case of sickness. Examples include livestock monitoring, off spring care

## **NEED FOR INTERNET OF THINGS IN HEALTHCARE**

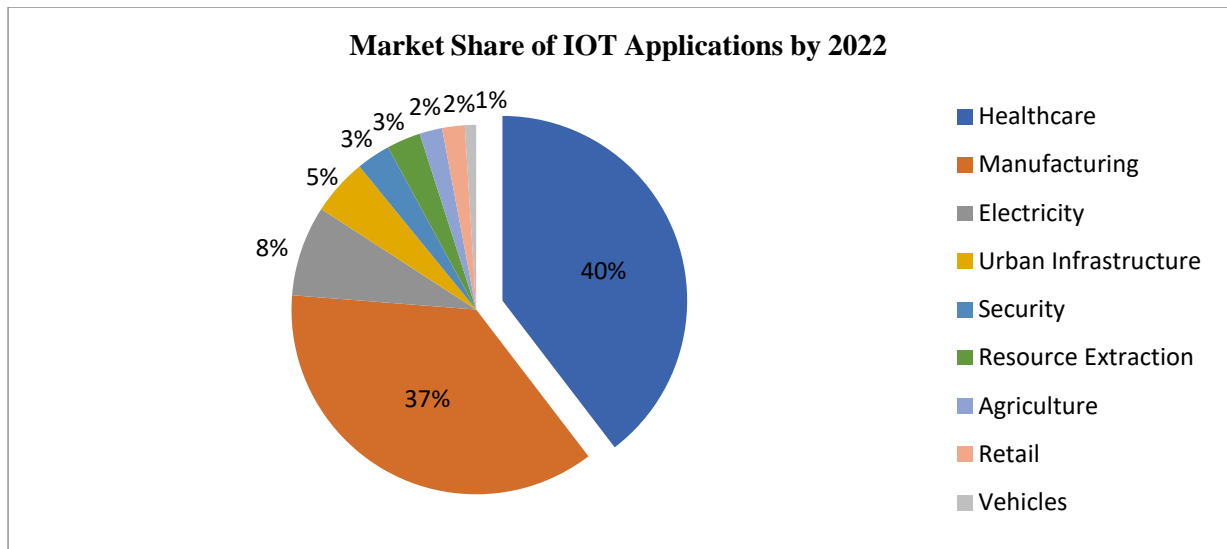
Change is the one thing which is constant in our society. There is an emerging need of change in the healthcare industry too as the world is changing. The healthcare industry is an ever growing industry.

As the saying goes, “*The greatest wealth is health*” coined by roman poet Virgil over 2000 years ago, healthcare is definitely an important aspect for healthy life and well being. A stage has reached where the basic healthcare is getting expensive and not affordable for most of the people. As there is an increase in the number of old age people, this section of the society would be prone to more chronic ailments. Huge bills are incurred on the medical diagnostics for undergoing medical tests which are costly. There is no of real time data available for the hospitals which results in the delays of the proper diagnosis and treatments. Sometimes delays occur in the proper treatment given to the patients in case of emergencies, this demands for the major need of IOT in healthcare. Due to the lack of smart care devices, one cannot monitor or keep track of one’s health on a regular basis. The smart care devices can allow the patients to do certain routine check-ups at the convenience of being at home. The standard analytics on the medical data could be inaccurate sometimes as it is prone to human errors. A slightest of mistake in the medical data can lead to serious consequences which should be avoided. [11]

Also, in the developing nations there are high number of deaths due to the lack of real time data and in-time medical treatments when compared to the developed nations. A majority of these deaths can be prevented with timely and proper care. IOT based healthcare devices allows the patients to directly schedule the appointment with the doctors and avoid delays. This also enables the doctors to view the patient’s information at from anywhere and anytime on their smart phones[12]

Although the technology cannot control people from ageing or eradicating the severe diseases completely, but the technology can at least make the healthcare a bit cheaper. It is now become the need of the hour to have better healthcare through better technology.

The below Fig 7 illustrates the market share of the IOT applications by year 2022 as per Forbes. The healthcare industry would dominate the potential economic impact among all the other IOT applications holding largest share of 40 %. The next is the Manufactory industry would have the next best IOT market share of around 37% followed by Electricity 8 %, Urban Infrastructure at 5 %, Security and Resource extraction at 3% each, agriculture and retail 2 % each, Vehicles industry having 1% of market share.



**Figure 7 Potential Economic Impact of IOT applications by 2022. Source [13]**

## **RESEARCH WORK IN IOT IN HEALTHCARE INDUSTRY**

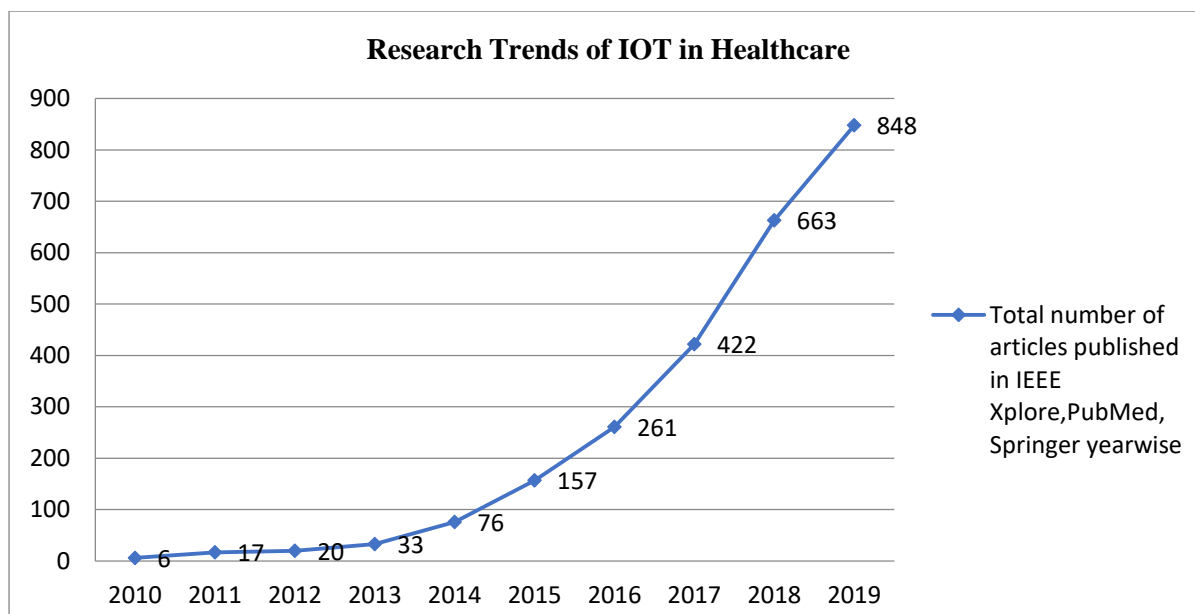
In this section, we would explore the research work conducted in this domain. We would look at the IOT popularity in the healthcare sector and then go through the literature search and taxonomy which is used to as a reference to explain the research carried out in IOT in healthcare domain, different research methodologies used, current challenges and future scope.

### **Popularity of IOT healthcare in research area:**

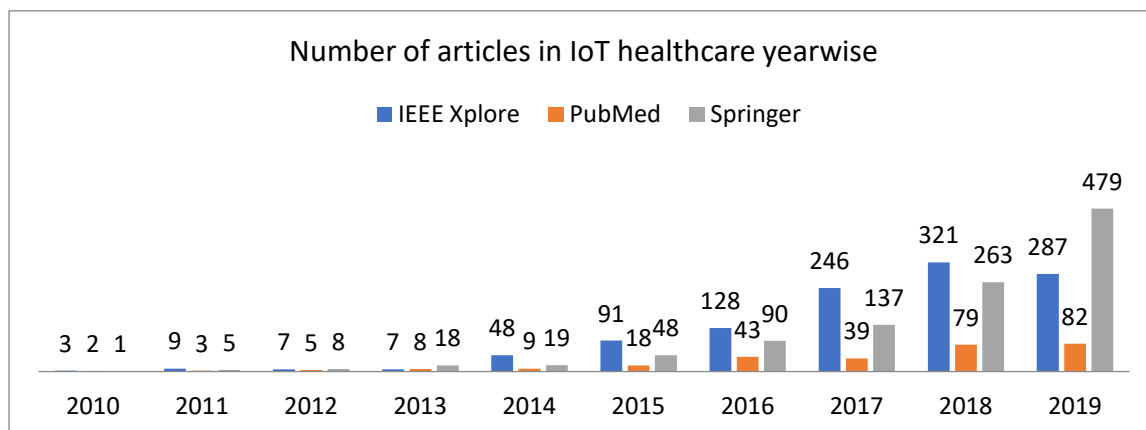
To understand the popularity of IOT in healthcare sector, we searched through IEEE Explore Digital Library, PubMed and Springer for IOT healthcare articles and publications. The article was categorized as relevant to the topic was that it has mentioning of the words such as “Internet of Things”, ”IOT”, “Healthcare”.

There has been lot of research work carried out in the area especially since the past decade in IOT in Healthcare. Various researchers have addressed applications, use cases, challenges and future scope for IOT in healthcare. As depicted in figures 8 and 9 below, research in IOT healthcare had a slow start with very few published articles in the initial years, but it gained momentum since the past 5 years where the numbers of the published articles have increased tremendously. Although IOT came into existence in the year 1999, but the researchers have started exploring extensively in the domains of healthcare industry only since past 5 years.





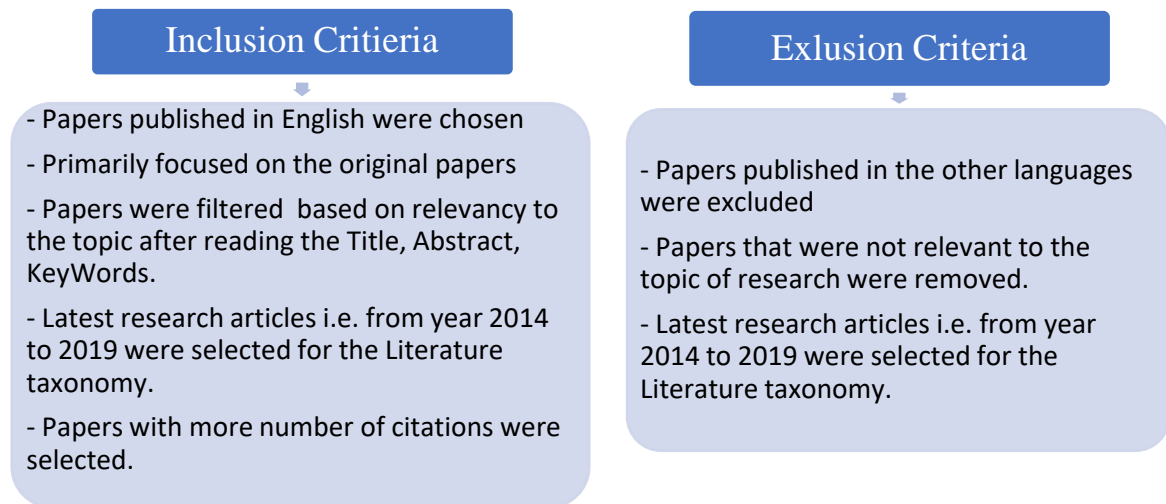
**Figure 8 Research Trends of IOT in Healthcare**



**Figure 9 Number of articles in IOT healthcare published year wise**

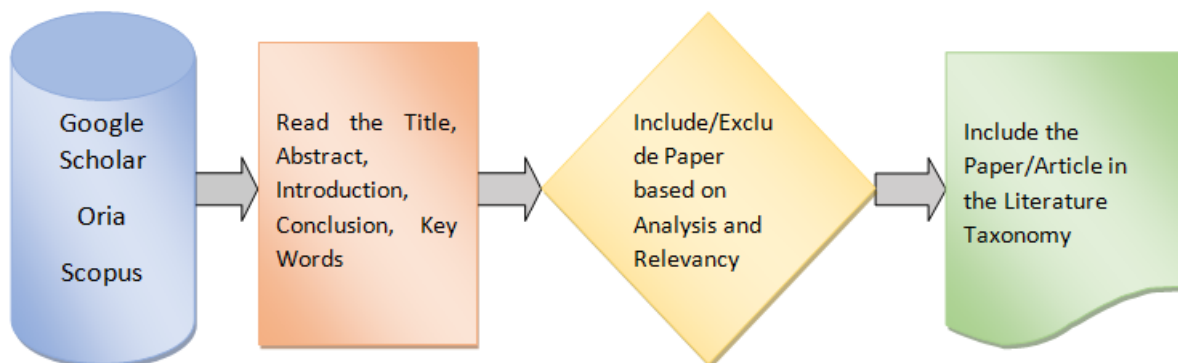
### Literature Survey:

In order to gather the literature survey we performed an intensive search on the Internet with the keywords relating to the field such as “*Internet of things, IOT, IOT in Healthcare, IOT and AI in Healthcare*”. We particularly searched in the databases and search engines namely Google Scholar (Google’s search engine for academic literature), Oria (University access page to informative sources) and Scopus (Database on variety of subject fields).



**Figure 10 Inclusion and Exclusion criteria for articles**

To enable an effective search, we initially started the research survey with the recent literature from the past 6 years i.e. from 2014 to 2019. We focussed on the Title/Abstract/Keyword searches for our search words in the articles rather than searching it in the entire article and selected those which were relevant to the topic. Also, we found some research articles in order to support the background information about the topic.



**Figure 11 Flowchart of Literature search process**

### Observations and Findings:

This indicates that although Internet of Things has been around since 1999 since its inception, however the researchers have realized the usage and tremendous potential of Internet of Things in the healthcare industry since past 5-6 years. This demonstrates the fact that Internet of Things has been a hot topic of investigation especially in the healthcare industry lately. We filtered around 32 articles related to this topic in the last 6 years which were most relevant.

We prepared a literature taxonomy spreadsheet based on the articles which were relevant to topic of IOT applications in Healthcare. We collected 25 articles which spanned across articles from the Journal Paper, Conference Papers and Review Papers. We also identified 7 articles from the other non scientific sources such as Blog Posts and White Papers which were relevant. The count of 32 articles would sufficiently provide us the necessary information to analyse and figure out any particular characteristics. We created the taxonomy report where each row corresponded to the details and a brief snapshot about the articles. We

also included the feature/field description columns such as Title, Year of the Publication, Authors, Venue, Research Methods, Sentiments, Problem addressed, Reasons for Problem Consideration, Outcome, Conclusion in the taxonomy spreadsheet.

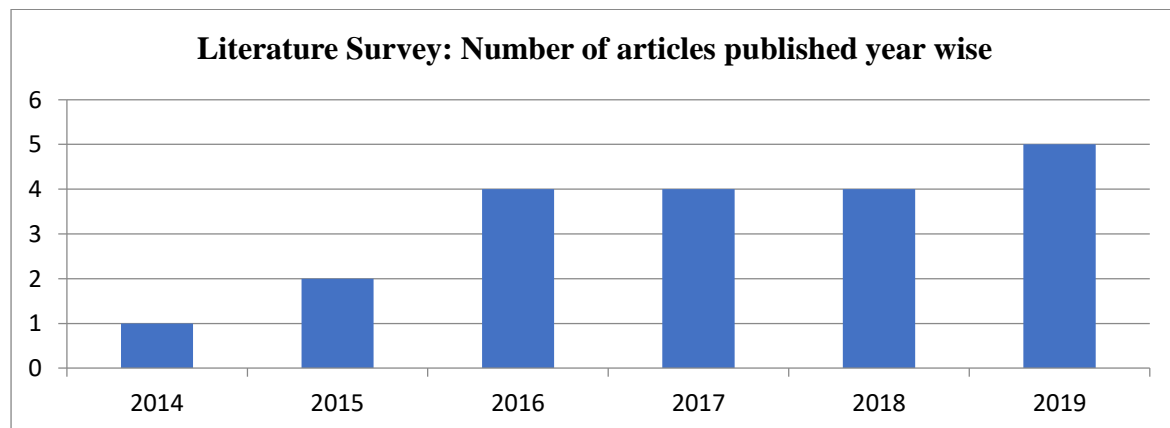
For some of the columns, we also have pre-defined categories in order to sort the literature. For instance, for the Venue Column, we have the categories like Journal, Conference or Workshop.

Categorization of the information obtained from the Articles surveyed in the Taxonomy.

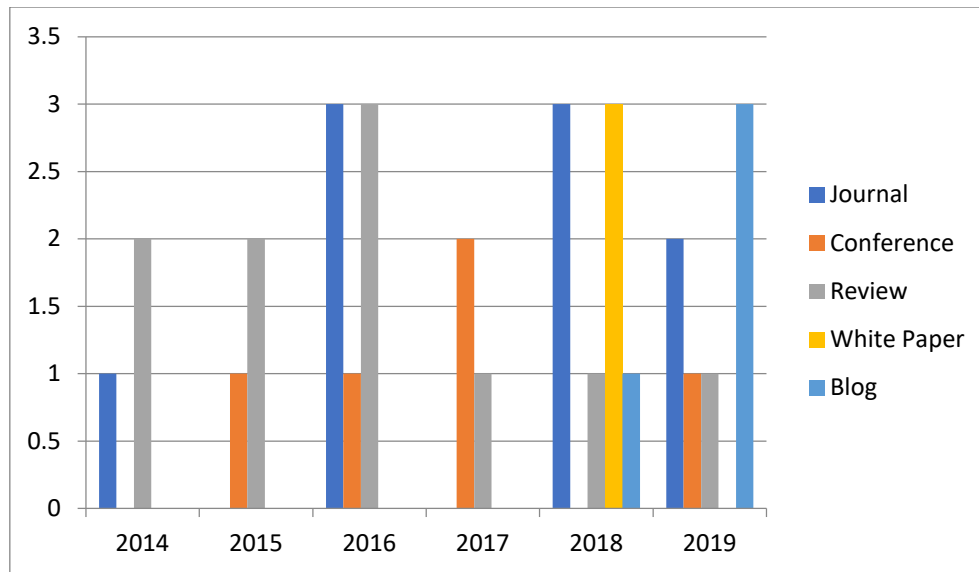
<b>TAXONOMY</b>	
Category	Classification of the Information
Year	Publication year of the article
Title	Title of the article
Authors	List of the all the authors
Approach/Methods	Observations, Simulation, Surveys, Experiments, Analysis
Features	Technology, Information Delivery, Communication, Sensors, Security, Concerns
Venue	Conference, Journal, Review, Work Shop
Sentiments	Enthusiastic, Skeptical, Favourable, Arguable, Curious
Problem addressed	What is the problem the paper addresses?
Reasons for Problem Consideration	Why should we care about the problem?
Outcome of the Paper	What did the authors do?
Conclusion	Conclusions, discussions and future scope

**Table 2 Literature Taxonomy Categorization**

The search and sorting of the literature survey into a taxonomy report with this approach helped us to gain a general understanding of the research techniques used and numerous works carried out in IOT Healthcare. The taxonomy provided a platform to navigate through the various aspects of the articles by filtering on the specific categories. This aided in identifying typical patterns in the research articles for example: Frequency of articles published in every year, Kind of research methodology or approaches usually implemented to address the problem or Venues of the article publication. These observations are useful in terms of discovering interesting and valuable information about the topic.



**Figure 12 Number of articles published year wise in literature survey**

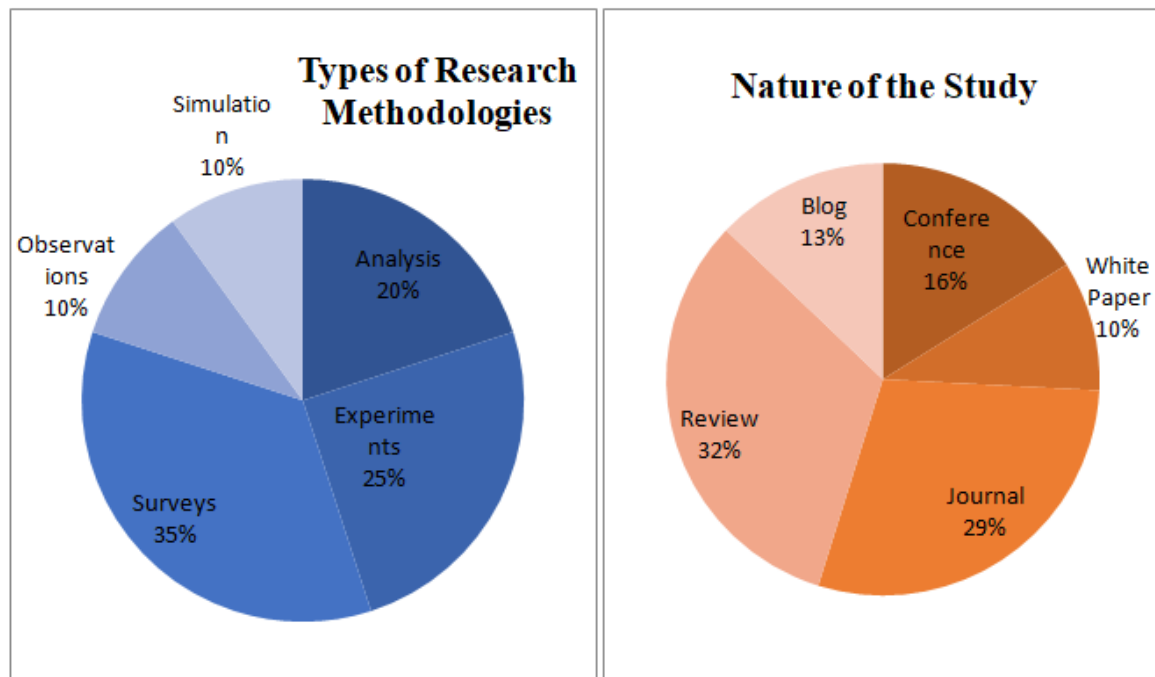


**Figure 13 Distribution of different types of published articles year wise**

Fig 12 demonstrates the frequency of the published articles in this literature survey year wise which shows an upward trend. As in the Fig 13, there is an equal mix of articles in terms of publication type.

### Research Methodologies:

We have classified the Research papers in the Literature Taxonomy in the field of IOT in Healthcare broadly into 5 main categories of Research methodologies applied. They are Observations, Analysis, Simulation, Experiments, Surveys based on how the researchers are addressing the problems in the papers. The Fig 14 displays the distribution of articles percentage wise across research methods and according to nature of studies



**Figure 14 Distribution of papers in type of research methodologies and nature of study**

## ***Internet of Things: An interconnected network of Enabling Technologies***

The papers discuss the various enabling technologies for IOT and below is the list of the key technologies.[25][26]

Identification Technology: An IOT working model could have huge number of nodes. The nodes which are authorized would be allowed to access the data or generate the data from any location. For achieving this it becomes necessary to identify the nodes. The identification process assigns every individual node or resource in the system for example doctors, nurses, staff members with a unique identification number (UID) in a digital domain for exchange of information. Open Software Foundation has developed a standard for uniquely identifying resources i.e. universally unique identifier (UUID) in the digital domain.

Communication Technology: The communication technologies play an important role to enable the network infrastructure. The IOT networks rely on the heterogeneous frequencies, standards and transmission rates for transferring the information. The communication technologies are categorized further into long distance and short distance technologies.

Long distance communication technologies deal with the means of communication like mobile phone or internet. Short distance communication enable the transmission of data over a short distance, which utilize the wireless technologies such as Bluetooth, IrDA (Infrared Data Association), Wi-Fi, ultra-wideband (UWB), RFID and others. The technology features may vary based on the several aspects such as installation cost, distance, transmission rates, power consumption, maintenance cost, number of entities, radio frequencies, security standards and so on.

Location Technology: The GPS (global positioning system) is regarded as the most important real time location systems (RTLS) in order to locate the objects. This is a navigation system which relies on the satellite and can locate objects in different weather conditions. GPS can accurately determine the location of the ambulances, patients, doctors and others. But these systems like GPS or BDS (China's Beidou system) are not effective indoors because of the construction which affects the transmission signals of the satellite. To address this, there is need to develop LPS (local positioning system) which can provide precise results even indoors. LPS measures the radio signals that travel between an object and an array of receivers aimed to locate it [28]. In future, the GPS or the BDS can be combined LPS to develop a smart indoor positioning system

Sensing Technology: Sensors forms the core element of the IOT based system as they do the critical function of monitoring the process, collecting the measurements and data. Due to technology advancements in sensors, data can be obtained continuously from objects or humans. For instance, the pulse oximeter device invented in the 1970s is extensively used for diagnosis [27]. It is used to monitor critical health parameters of the patient such as the health rate (HR) and blood oxygen saturation (SpO<sub>2</sub>) levels during emergency. There are other types of sensors such as temperature sensor, pressure sensor, water quality sensor and smoke sensor. In order to analyse motion, the devices are incorporated with different sensors such as accelerometers, gyroscopes, surface electrodes, and others [27]. The wireless sensors has enabled people to wear portable sensors which have the ability to collect and transfer data automatically

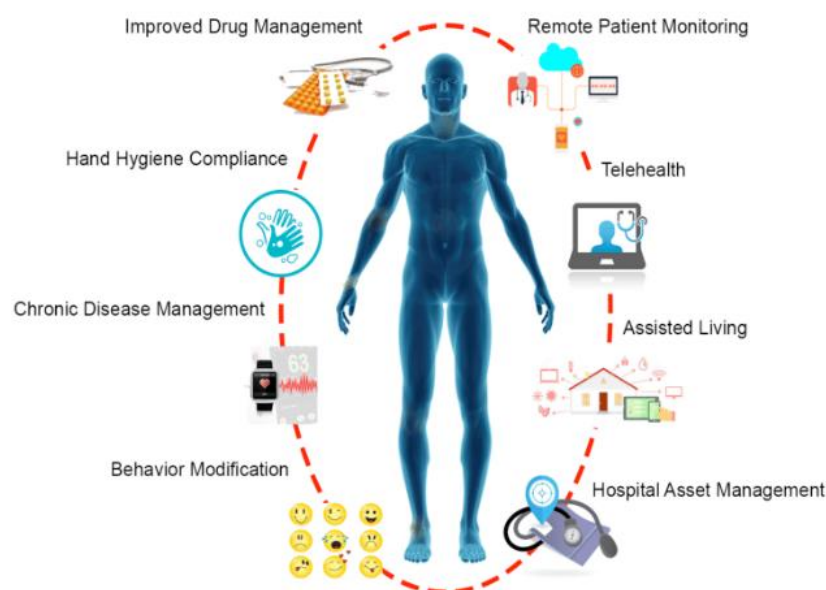
Cloud Computing: A huge data has to be stored, analysed and distributed in the IOT system operations[29]. Cloud computing provides large storage capacity and processing of the huge data generated in IOT systems .The cloud data centers retrieve information from each device in IOT system and send the data with other devices in network. Depending on the need, the cloud data centers can increase or decrease the computational capacity. As per research, cloud computing would benefit disabled people [29]. The future IOT systems would be moving to cloud. IOT devices can be configured again with less effort. Setting up cloud data centers in hospitals would lead to data sharing along with reliable monitoring and management systems [30]

### ***IOT Healthcare Services: A Building Block for set of applications or health solutions***

IOT offers wide range of healthcare services in which each service offers a set of healthcare solutions. However, in few cases, one cannot completely distinguish a service from a solution or an application. [37] Below are some of the main IOT healthcare services:

Ambient Assisted Living Ambient Assisted Living (AAL) as the name suggests is to primarily focussed on the support for elderly people as well as people with physical problems. There is an emerging need to develop such a system which can track and monitor the daily routine tasks of the elders or physically disabled people who are stay in such a smart environment. The AAL system comprises of multiple sensors for measuring body temperature, blood pressure levels, glucose, oxygen and weight. This system is for patients with diabetes and cardiac arrhythmia. It also allows doctors and family to remotely monitor patients health [48]

Authors in paper [49] have presented a living assistance for the elderly people based on the IOT solution which can monitor and store patients's vital health information and also can trigger alerts in case of emergency situations. A solution consisting of a wrist band connected to the cloud server to assist elderly people is proposed, this turns out to be low power and cost with the ability of Wireless communication. Due to the recent developments in Healthcare using IOT, AAL has turned to be dream come true.



**Figure 15 Illustration of an ambient Assisted Living, source [61]**

The Internet of m-health Things (m-IOT): Due to the technological advancements in the IOT technology, it has now become possible to monitor and diagnose the patients remotely instead of the patients physically visiting the hospitals. The patient with sensors collect the health data and send them through the internet to the medical data centers for taking further decisions.[50]



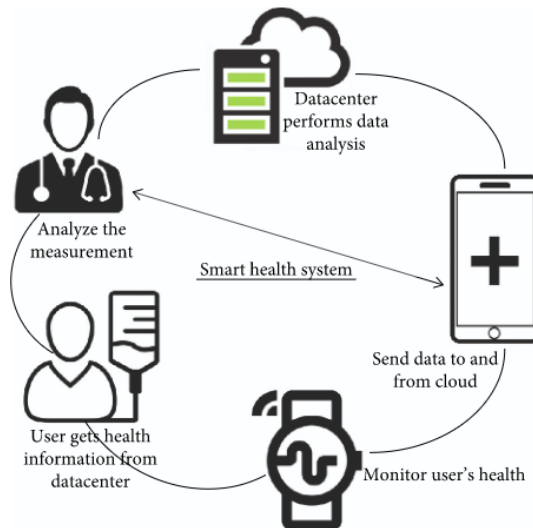
**Figure 16 m-Health Things, Source [62]**

Community Healthcare (CH) This system establishes a network system to cover a locality area. Examples of this could be any residential area or a rural community or a municipal hospital. The structure can be seen as a Virtual Health center operating on the IOT based network. [51]

Children Health Information (CHI) This system is for the children to focus on their health and inculcate good eating habits when they are staying away from their parents and have to eat outside. The children using the mobile phones get the information regarding the necessary food habits from their parents, guardians or doctors. This stored information is used by the health educator to give the feedback to the children and also helps to notify their parents and thereby promote a healthy food eating habits among the children [52]

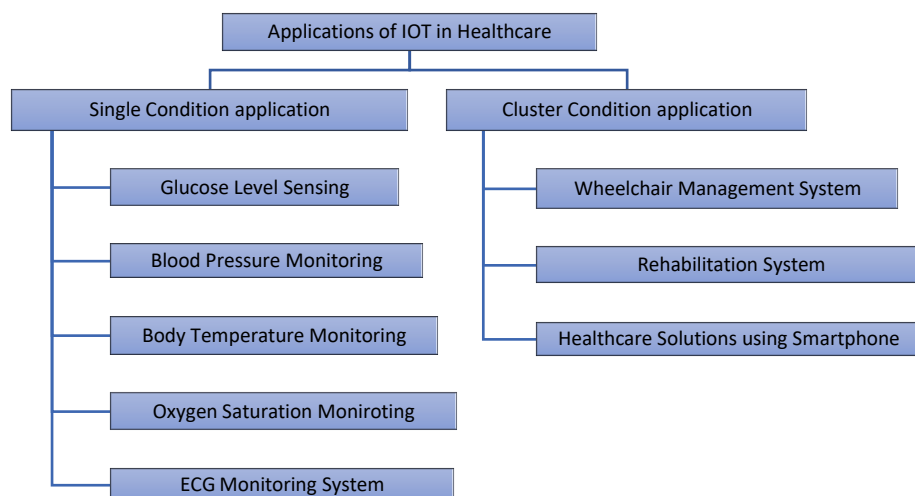
### ***Internet of Things Applications: A real game changer in the healthcare industry***

With the use of health applications, the life of the patients has become much easier as they can now continuously monitor and keep track of their health parameters on a regular basis. This has reduced the need to visit doctor substantially also resulting in a better quality life.



**Figure 17 Smart Health System, source [57]**

Let us discuss various application of IOT in Healthcare services. IOT based healthcare applications are widely classified into two categories namely: Single Condition Applications and Clustered Condition Applications as shown in the Fig 18 below



**Figure 18 Classification of Application in IOT based healthcare, Source [53]**

Single Condition Applications deal with a specific disease or a health condition. Clustered Condition Applications refer to multiple diseases or a several health conditions put together. IOT Applications are directly for the patients and the users. Along with the applications discussed here, there are also numerous other devices, gadgets and applications which are also presently available in the industry. We would discuss both the Single Condition applications and the clustered condition applications



## Single Condition Applications:

Glucose Level Sensing: Diabetes is a disease in which there is imbalance with the generation of hormone called Insulin which is made by pancreas. Insulin helps to regulate the glucose level (sugar) in the blood. The glucose level monitoring helps in providing any changes in the glucose levels either increase or decrease in the levels, thereby aids in proper planning of the meals, doing suitable exercises, and taking medicines accordingly. An m-IOT based configuration method for non-invasive glucose level monitoring on a live-basis is proposed.

As per this method, the sensors from the patients are connected through IPv6 connectivity to the relevant healthcare providers. As per utility model as mentioned in [53], it reveals a transmission device which transmits the blood sample results data on the blood glucose levels of the patient on the basis of the IOT networks. This device consists of a blood glucose collector, computer or smart phone and a processor. Along with this, a general IOT based medical acquisition detector for glucose level monitoring is also proposed. [53]

ElectroCardiogram Monitoring Electrocardiogram also known as ECG is measurement of the electric signals of the heart. This is recorded by the Electrocardiography. It is used to measure the heart rate and normal rhythm of the heart beats. In addition, it is also used to detect any cardiac rhythm disorder (multifaceted arrhythmias), inadequate coronary artery blood flow (myocardial ischemia) and prolonged QT intervals. This device has the capability to generate a medical report of the patient. The IOT system applies the algorithms for monitoring ECG continuously.[39] Also, a low power wearable electrocardiogram remote monitoring system is proposed in [54] in based on Internet of Things for home health monitoring.

Body Temperature Monitoring Body temperature measurement and monitoring forms an important basis for any healthcare related application. The homeostasis maintenance varies with the body temperature as per m-IOT perception. The sensors to monitor the body temperature are fixed with TelosBmote to give accurate results in processing. The system is based on the home gateway over the IOT mechanism to measure and monitor the temperature of the body. [55]

Oxygen Saturation Monitoring System Pulse oximeter instrument in medicine is used for continuous monitoring of oxygen saturation in the blood. For technology based medical applications, IOT usage with pulse oximetry proves to be beneficial. The pulse oximeter Wrist OX2 device which is proposed for monitoring the patients is based on IOT and is having low power and lost cost. It can monitor the patients health through IOT network and also has the connectivity to Bluetooth.[53]

Blood Pressure Monitoring The pressure at which the heart circulates the blood in the body is known as blood pressure. A supportive IOT based approach is proposed for monitoring the health parameters such as blood pressure (BP), haemoglobin levels (HB), glucose blood sugar level and abnormal cellular development. In addition, a IOT based healthcare service is proposed to measure blood pressure, glucose levels and obesity [56]

## Cluster Condition Applications:

Wheelchair Management System Smart wheelchairs with full automation is proposed by researchers with regards to the health of the elderly and disabled people. IOT has great capability to further make significant progress in this work. A medical support system through peer-to-peer P2P and IOT technology is implemented. The smart wheelchairs contain sensors which monitor the vitals of a patient / user sitting on the chair, track the wheelchair movements and can also collect the nearby data also track the status of the patient/user.[56]

Rehabilitation System As the human population is growing, there are several population growth related problems and lack of health expertise. Body Sensor network is proposed to design the rehabilitation system using IOT [56]. IOT can be more effective and reliable for actual information interactions using otology based automating design. There are several Rehabilitation system based on IOT like language training for childhood, smart city medical rehabilitation and an integrated application system for prisons.[53]

Healthcare Applications using Smart Phones Now-a-days, smart phones are equipped with controlled sensors. This shows that the increase in smart phones is contributing to the rise of IOT. A plethora of software and hardware products have been designed to enable the smart phones work as a useful healthcare gadget.[53]

*Several research works have been carried out on Wearable Devices that are means to a better and quality personal healthcare*

The wearable devices serve the purpose of monitoring the physical health and activities continuously. These devices are effective for elderly people which monitor their vital signs.

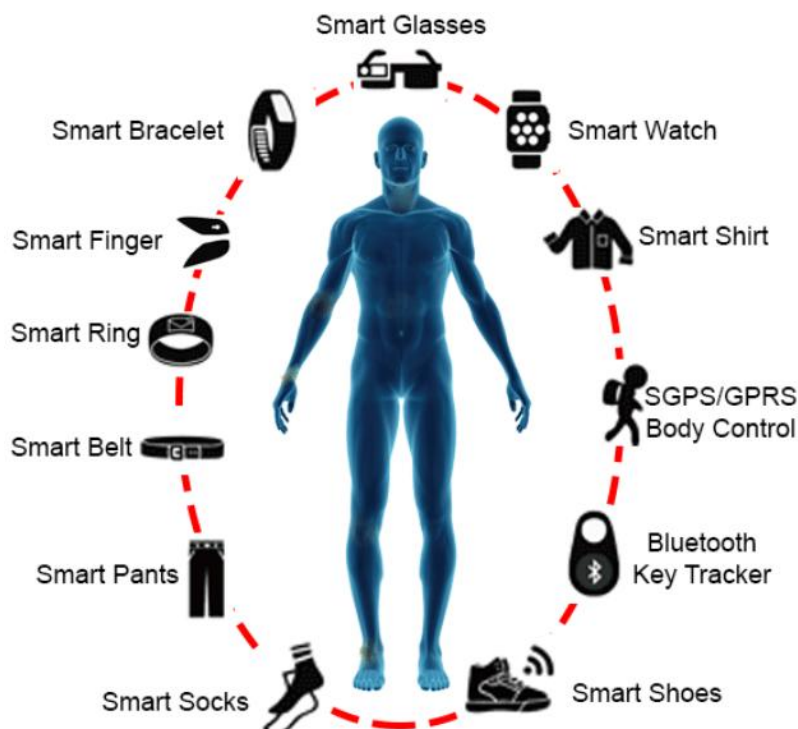


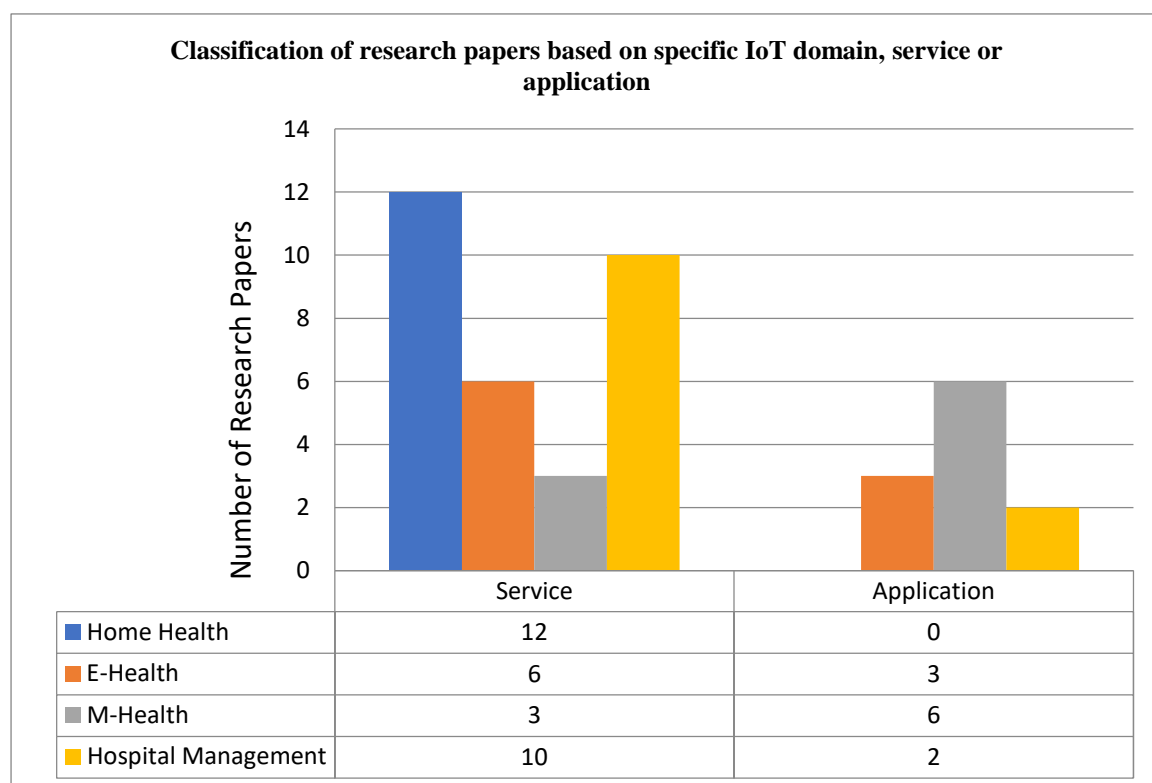
Figure 19 Different Applications of wearable Technology, Source [60]

Various researchers have proposed and developed systems which monitors blood pressure, temperature, ECG, and oxygen saturation levels in the body. The data is collected through the sensors in the IOT devices and analysed. The authors in [63] have proposed a solution for wearable device to monitor ECG integrated with cloud solutions. The paper [58] proposed a methodology based on IOT and Fog concepts which can detect and monitor the outbreak of chikungunya virus based. The Fuzzy C means algorithm helps for diagnosing the infected patients and generate emergency notifications from the fog layer.

Wearable devices are a great boon to remotely monitor health which results in better quality and also cheaper on pockets.

***Research work in Home health and Hospital Management are leading the Healthcare Services, whereas research in M-health is leading Healthcare Applications in IOT domain***

A review paper published in the year 2018 [23], classifies the 40 different research papers in IOT healthcare based on the Architecture domain such as Home Health, E-Health, M-Health, Hospital Management, Service or Application and type of the diseases.



**Figure 20 Classification of research papers based on domain and service/application Ref[23]**

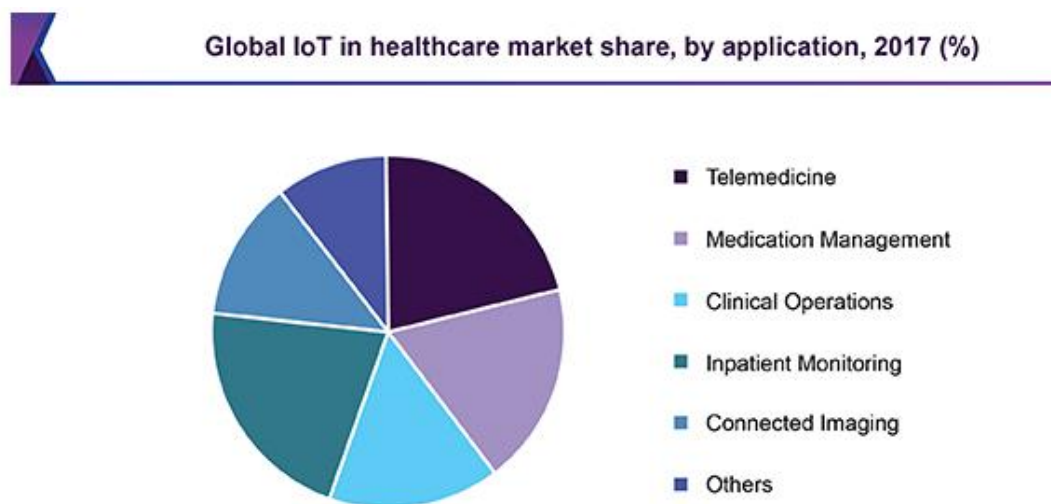
The papers in the Services are majorly focused on home health and hospital management. Among 12 papers under home health, majority were related to the elderly people, and others were regarding chronic diseases, bed sores, AAL, physical disabilities and children monitoring. Under the Hospital management, 10 papers were included, among which papers were addressing emergency management, elderly people, device and patient monitoring and

health information system. In the Applications, 6 papers out of 11 are related to the M-health application and these are mainly focussed on medication management, diabetes, ECG and patient monitoring.

Reduced cost, quality care from the convenience of home, real time data monitoring in hospitals, effective medicine management of dose intake are the factors towards majority of research contribution in these segments.

### ***Telemedicine and Medical Management have dominated the Global IOT healthcare application revenue market***

According to the market report of grandreviewresearch [16], the largest revenue was generated by Telemedicine in 2017 as shown in Fig 21. The growing need for patient monitoring remotely as well the increase in the chronic diseases are the reasons for the largest revenue share held. Telemedicine technological advancements are a driving force towards providing IOT solutions. The increase usage of smart wearable devices for remote monitoring will contribute towards further growth in Telemedicine. Some of the major providers of IOT solutions for telemedicine are Doctor On Demand, MyTelemedicine, Teladoc, The Bottom Line and iCliniq



**Figure 21 Global IOT in healthcare Market Share by application, Source [16]**

### ***IOT Healthcare is gaining popularity among the renowned Technology Firms***

The paper [40] highlights the IOT healthcare work carried out in some of the renowned technology firms.

Google has opened its code for an open source physical web standard for IOT which is a way to connect with medical devices [41] Microsoft has focussed on using the intelligent system to unveil the tremendous potential of IOT based healthcare solutions. [42]

*Intel* has a vision for providing the IOT based healthcare solutions anytime, anywhere through real time synchronous communication systems and health data streaming [43].

*IBM* has focussed on the many healthcare solutions such as connected home health, data governance in health, data analytics for healthcare providers through partnerships with other companies [44]

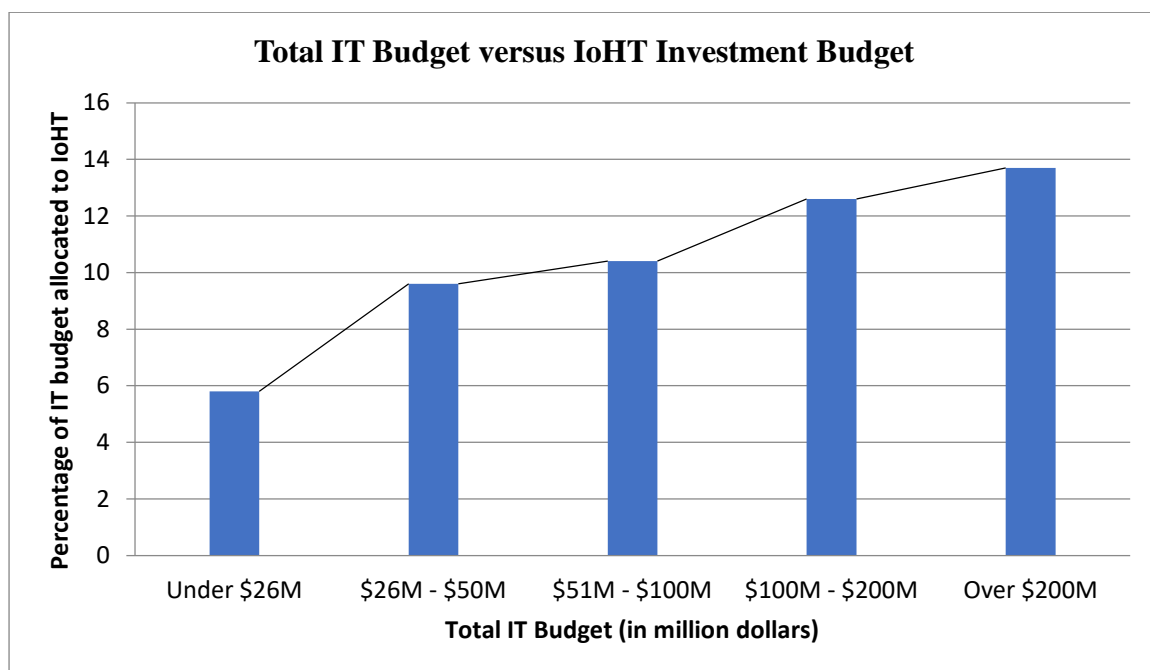
*Apple* have claimed that IOT is a revolutionizing technology for the future. The Apple watch which has smart features like fitness tracker or heart monitor. The Memorial Hermann healthcare system is dependent on Apple to provide solutions which can provide better and connected healthcare services with secure access.[45]

*CISCO* in cooperation with the leading healthcare firms is trying to develop a medical grade network architecture.[46]

*Qualcomm* has a set of wireless health solutions which can transmit the health data from wireless medical devices of the users to the integrated portals and databases. Qualcomm is building intelligent and innovative solutions to advance IOT healthcare solutions. [47]

***Budget allocated on the Internet of health things solutions varies directly with the Total IT budget***

Not only technology departments but also the R&D divisions are investing money in IoHT (Internet of Health Things). In a survey of healthcare organizations, 57% say that IT department contribute towards IoHT solutions whereas 26% mention that their R&D departments are driving efforts towards IoHT solutions. At present, healthcare organizations allocate on average 10% of their yearly IT budget for investing in IoHT solutions. The Fig 22 depicts that percentage contribution increases as there is increase in the size of the IT budgets [38]



**Figure 22 Percentage of IT budget allocated to Internet of Health Things [38]**

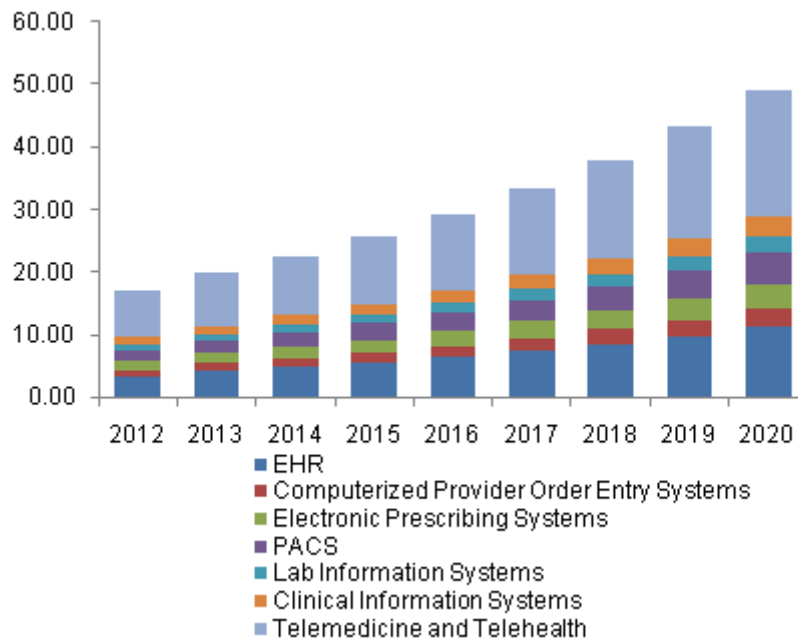
***Both IOT and E-Health have tailored its policies towards providing IOT based healthcare services in many countries***

Across the globe, there are major efforts undertaken for thriving technology such as IOT into the healthcare policies for technology driven healthcare. Along with IOT, even E-health i.e. healthcare services provided through internet also has remarkably entered into the healthcare policies in various countries.

Asian Countries In the early years of last decade, India took a major step to boost the health sector industry by leveraging the usage of IT infrastructure in the healthcare field. Current Indian government has set aside nearly 990 million dollars to develop 100 smart cities. India has a vision to create 15 billion-dollar IOT industry by 2020. To put things in perspective, a substantial increase in number of connected devices from existing 200 million to over 2.7 billion. Similarly, in early 2010, China's Ministry of Industry and Information Technology (MIIT) took a major decision to promote IOT. MIIT created a framework to develop goals, timetables and a road map to introduce the IOT and facilitate R&D and commercialization of IOT by leveraging existing foundational technologies and network connections in use. These measures are expected to stimulate the development of the IOT in major Asian countries.

Australia In the later years of previous decade, Australia embraced IOT and the Australian health ministry council came up with a strategic framework to have a coordinated and collaborated initiative in eHealth after consulting professionals from varied backgrounds like commonwealth, state and territory governments, general practitioners, medical specialists, nursing, pharmacy sectors, health information specialists, health service managers, researchers, scholars, and consumers. As per the latest report, currently IOT in Australia is worth \$13 billion and is expected to contribute over \$83 billion to Australian economy by 2025[17]

North and South American Countries: In the current decade, the evolution of IOT and its extension into healthcare, known as Internet of Medical Things (IoMT), has brought a revolution within the health industry. IoMT has enabled the transition from a reactive to preventive patient-centered care system by bridging the gap between inter connected medical devices, health systems, software & hardware applications and services. As per the latest report, in USA, IoMT will save nearly \$300 billion in healthcare industry and the resultant revenue is predicted to be over \$135 billion by 2025. As per the current trends, telemedicine market is expected to reach \$22 billion in 2022 from existing \$13.5 billion.[18]



**Figure 23 US Healthcare IT Market By Application, from 2012-2020 (USD Billion) Source [22]**

According to a report in US healthcare IT market [22], telemedicine and telehealth held over 40% of the market shares due to the high adoption to the technologies in 2013. The development in this segment due to Teleimmersive Environment for Everybody (TEEVE) and Session Initiation Protocol (SIP) are also key contributing elements of progress in this sector. Electronic Health Records (EHR) is expected to hit USD 26.72 billion in 2020. Due to the rising technological demands and urge to reduce maintenance expenses, the EHR systems are contributing immensely in faster growth.

Nordics Countries: IOT has been part of Nordic healthcare systems since the early 2010. As per the statistic report on the market size of the IOT in the Nordic countries in 2012, Sweden leads the list with nearly 515 million euros followed by Finland with nearly 400 million euros closely followed by Norway nearly 390 million and Denmark at nearly 380 million. As per the trends, Sweden was forecasted to enjoy the steepest growth with predicted size of the Internet of Things exceeding two billion in 2017. IOT In Finland, Norway and Denmark was expected to reach roughly 1.3 billion in each country in the same year.[19][20]

Rest of Europe: IOT has been central to Healthcare systems throughout Europe since the early 2000. But advancements were made in later years of previous decade nearly by almost all the leading Countries. In 2008, the French government supported the creation of an object-naming service (ONS) root server for the country to enable the advancement of the IOT. Registered with GS1 France, every product is uniquely identified using global standards. In this way, consumers become convinced that product data are accurate, authentic, and uniform across the country. In 2003, Germany enshrined its core eHealth activities in the legislation governing the healthcare sector. Germany has an ambitious plan to play a leadership role in the engineering and manufacturing sector, including in the IOT domain. According to High-Tech Strategy 2020 action plan, INDUSTRIE 4.0 is a strategic initiative in achieving this goal.[21]

### ***IOT coupled with several other technologies would transform Healthcare and Medicine***

There are several advantages of Internet of Things which are transforming the healthcare industry benefiting both the patients and health care providers. IOT has surely secured a larger presence in healthcare. Many researchers are studying the benefits of applying IOT with other trending technologies such as cloud computing, grid computing, big data, network, Augmented Reality, AI and Machine Learning, Robotics that can result in enormous healthcare benefits.

Cloud Computing: The IOT and cloud computing integration offers facilities with access to the shared resources from anywhere, huge data storage and receiving the services on demand. The researchers in the paper[24] describes a cloud-integrated Health IOT monitoring framework, where healthcare data are watermarked before sending to the cloud for secure, safe and high quality health monitoring

Edge Computing: Edge Computing has become a hot topic for the researchers in healthcare domain. In the year 2017, researchers in [33], have surveyed the state of art of Mobile Edge Computing (MEC) with focus on enabling technologies, and in [34] on network and resource management for computations. Also the research work in [35] in the same year discusses numerous benefits of Edge computing coupled with IOT in healthcare. This paper explores and compares the various edge computing models namely Mobile Edge Computing, Fog Computing and Cloudlet. The research[36] proposed methods in 2017 aims on determining characteristics from Brain Computer Interface using sensors like Electroencephalography (EEG) and resting state-functional magnetic resonance imaging (rs-fMRI) together with Diffusion Tensor Imaging for collecting information from epileptic brain. The solution was proposed with the edge computing methods for monitoring, analysing and regulating an epileptic brain using invasive and non-invasive techniques. The main focus of this research is to predict “Ictal onset”

Grid Computing: The concept of Grid Computing of non-invasive sensing and low power wireless communication can be utilized for continuously monitoring patients through sensors. The devices with small memory, energy and computational abilities can track and monitor critical health parameters like BP, temperature, ECG and oxygen levels of the patients.

Big Data For effective analysis of the medical data provided through the medical sensors, big data tools are useful for improving efficiency in medical diagnosis. [16]

Networks play an important role to support the communication for IOT-based healthcare through short-range communications namely WPANs, WBANs, WLANs, 6LoWPANs and long-range communications WSNs. The usage of ultra-wideband (UWB), BLE, NFC, and RFID technologies and communication protocols can be applied [16]

Ambient Intelligence This technology becomes extremely useful as the end customers of the IOT based healthcare systems are humans. Human Computer Interaction HCI is one of the fields of Ambient Intelligence. [16].



Augmented Reality There are various uses of this technology in healthcare such as assistance during surgeries and medical training enhancements. Augmented reality can transform the existing healthcare processes to make them more efficient.

AI and Machine Learning: These are trending technologies in the market which are researched in the fields of medicine to analyse medical data and intelligently classify medical symptoms and diagnose disease accordingly and propose treatment plans. It is estimated that there would be huge medical data which would double every 73 days by 2020. According to McKinsey [67], owing to AI, Machine learning along with Big data can save \$100 billion annually in medicine and pharma. AI and ML algorithms can assist doctors in predicting the diseases with certain probabilities and these systems get better with more analytical result data to further improve the accuracy.

Robotics Presently, the da Vinci surgical robot is assisting doctors with various tasks in the operation room[64]. There is a prediction that the medical robotics is estimated to reach \$20 billion by year 2023[65]. Robotics are also supporting doctors by treating patients in rural areas through telepresence[66], packaging and transporting medical things, helping patients with rehabilitation, automated laboratories and cleansing of bacterias in hospital rooms. Robotics together with IOT in medical domain can bring innovative health solutions.

Wearable Technology Wearables help the consumers to proactively take care of their health. These devices such as smart watches can not only tell the number of steps taken in a day but can also give results for the heart rhythms, amount of sleep taken. There are other wearable devices which are ECG monitors, monitor body temperatures, measure heart rates and so on. More than 80% of the population is willing to use the wearable technology there is a big opportunity for using wearables in healthcare.

5G Telemedicine is on the rise to provide the quality care in the remote areas. To facilitate this, good quality and high speed of the network are essential to provide efficient service. 5G can support in healthcare providers by allowing transmission of big imaging files to the doctors for viewing and provide appropriate medical care. Also allows the use of AI and IOT enhancing the quality to deliver right treatments through Augmented Reality, Virtual Reality and mixed reality supporting patient care remotely.

The incredible potential of these technologies provide opportunities to render better healthcare facilities to the people to meet the ever growing demands.

## **BENEFITS OF IOT IN HEALTHCARE**

IOT has brought lots of advantages to humankind especially in the walks of medical health. Major benefits include reduced medical cost, improved and proactive treatment, remote patient monitoring and reduced scope of errors. [14]

**Lower Expenses:** Due to several wearable devices available, doctors can view the real time data of the patients and suggest appropriate treatment even when the patient is located at home. This reduces frequent visits to doctors and thereby reduces the medical costs significantly. Doctors can remotely monitor the patient's health through telemedicine.

**Better treatment results.** As doctors can see the real time data of the patients due to cloud computing and connectivity with the help of IOT based health monitoring system due, it helps in the faster diagnosis and aids in timely treatment. This leads to quality health care and better treatment results.

**Better disease control.** Due to the IOT technology, based on the medical information received everyday, doctors can continuously monitor the patient data which helps to detect the disease at an early stage and give appropriate treatment.

**Fewer mistakes.** The automated processes like receiving information, decision based on the information analysis help in reducing mistakes.



Figure 24 Benefits of IOT in Healthcare, Source [14]

**More trust towards doctors.** Due to IOT the patients can easily connect and communicate with the doctors and receive the timely treatment. This improves patient's trust towards doctors.

**Medicine Control:** The medicine control IOT devices also assist in supervising the supply and intake of the medicines which result in few errors.

**Remote patient care** Remote patient care has become quite popular in some countries such as Singapore due to telemedicine technology. Doctors can see their patients situated remotely from anywhere and anytime through the technology.

**Maintenance of medical devices** Medical equipments are costly and they need proper maintenance. IOT can determine any issues beforehand which can prevent the damage to the medical devices

According to the Aruba report [15], majority of the people in the survey responded that the future benefits of IOT are increased workforce productivity (57%) and saved costs (57%)

## CHALLENGES IOT IN HEALTHCARE

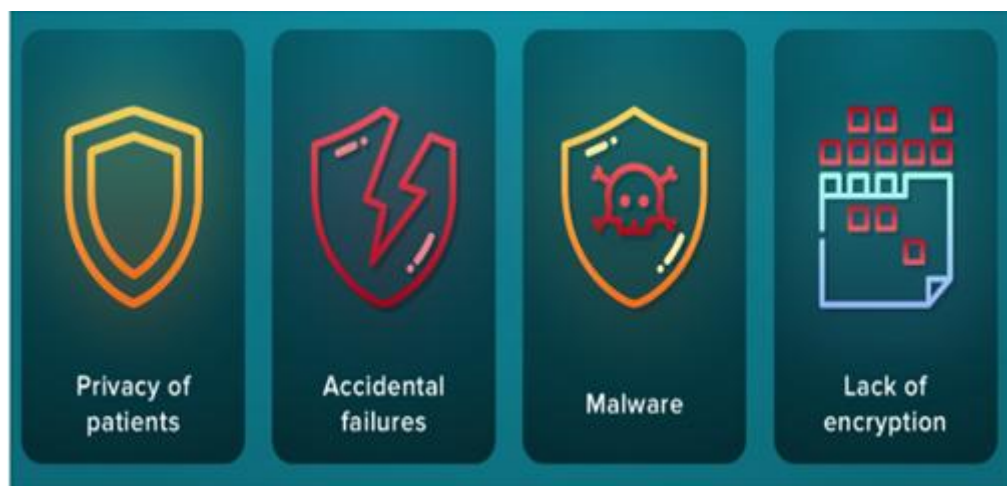
Although IOT technology has brought several advantages but with every technology there are always certain challenges and always room for improving further.

**Privacy** The personal information of the patient's data is confidential and should always remain private. Unfortunately, the IOT systems can be hacked and the personal data can be leaked.

**Security:** Security is of paramount importance especially when it comes to the healthcare data as slightest of the security breach can become life threatening. It is necessary to have apt policies and security measures to enable sharing of the data among authorized users and health organizations. The IOT based healthcare system must compulsorily have features such as confidentiality, integrity and availability of the patient's data [26]

According to a study published [15], security issues were commonly reported across several IOT deployments. As per the study, around 84% of organizations have experienced IOT security breach. More than 50% respondents to the survey are of the opinion that external attacks are hampering to embrace IOT technology. This shows that robust IOT security mechanism built on strong network access control and policies would be beneficial in protecting the healthcare data.

**Accidental Failures** Medical data is very sensitive and slightest error can be dangerous for patient's life. Therefore it is essential to consider every aspect diligently in development and hardware manufacturing.



**Figure 25 Challenges of IOT in Healthcare, Source [14]**

**Malware** Any device connected to the internet is prone to malware and viruses attack. It is necessary to safeguard the information during the transmission of data. Therefore, a good antivirus and firewall mechanism should be installed in IOT devices to prevent such attacks.

**Lack of encryption** Another way to protect IOT based system is to have encryption system. However, not all systems have good encryption mechanism so everyone has access to the system.

**Scalability:** As there are billions of interconnected IOT devices, there is enormous data generated to process and store. Therefore, the IOT based system should be scalable to handle such huge amounts of data. This large data is stored on the cloud using big data.

## CONCLUSION

The internet gave us the opportunity to connect in a way which we never thought. The next revolution of internet of things would take us beyond the connection to become a part of our living which would today seem like a Fantasy world. IOT has profoundly made a remarkable impact in all walks of life. The future scope of IOT in healthcare for research is addressing the challenges such as security, privacy and scalability issues, and integrating different other innovative technologies would radically further enhance human life.

With regards to healthcare, one can visualize the foreseeable future of completely connected healthcare in the years to come. Sky is the limit for IOT application in healthcare. We have just reached the tip of the iceberg and there are infinite opportunities for exploring and making this world a better place to live in.

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