A Survey of Wireless Communication Technologies for IoT-based Health Care Systems

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ABSTRACT
Healthcare system is propelled by communications between integrated devices through wireless communication technologies. However, communication technologies are faced with numerous challenges, which could impede achieving affordable healthcare system through IoT. Thus, this paper examines the background of IoT, and its application within the health sector and the core area of communication media, through which healthcare devices interact with each other. Interaction between devices currently relies on Short Range Low Power Wireless Communication Technologies, Medium Range Low Power Communication Technologies, and Long Range Low Power Communication Technologies. The future communication appears to rely on 5G network, which mitigates issues such as security and privacy, low network mobility and coverage, and poor scalability. The study opines that the future of IoT application in the health sector relies on 5G network that overcomes the various challenges found in the existing networks. The network provides a very high capacity to carry data and information when compared to the legacy cellular networks and millimeter wave (mm-wave) bands that provides spectrum in the range of 30GHZ to 300GHZ range when compared to the conventional cellular frequencies.

Keywords: 5G, *IoT, wireless communication, ZigBee, healthcare, cellular technologies.*

African Journal of Computing & ICT Reference Format:

Ikenna Uzoma Ajere and Charles Ikerionwu (2019), A
Survey of Wireless Communication Technologies for IoT-based
Health Care Systems,
Afr. J. Comp. & ICT, Vol.12, No. 2, pp. 1 - 18.

I. INTRODUCTION

The Internet of Things (hereafter "IoT") is a paradigm with the potential to connect the global world by inter-connecting huge number of devices embedded with software using several technologies and seamless connectivity solutions [1]. The interconnection of smart devices to exchange data is not the main goal of IoT. Rather, its ultimate goal is to harness such data to generate information that will be beneficial to the users. The benefits of IoT are noticeable in its range of applications. From smart cities to smart grid systems, smart homes to smart offices, precision agriculture to healthcare systems, IoT has been applied to reduce traffic congestion in cities, provide efficient and accurate metering systems for utilities (water and electricity), generate soil data, and monitor patients' health status thereby making lives easier and improving the qualities of life for citizens.

In all the application domains, IoT can be actualized by combining several technologies [2], which include identification (RFID tags), sensing (sensors), communication (short range, medium range and long range) and intelligent information processing technologies.

One important area of IoT's application is in healthcare delivery as affirmed in [3] that health is the real wealth and not pieces of gold and silver. As the need to keep people safe and healthy rises, and the demand for solutions to lower healthcare costs increases, IoT has the potential to bring affordable and efficient healthcare solutions that will improve the quality of life of people [4]. IoT can help monitor patients' vital organs; track location of patients, medical personnel and medical equipment; alert care givers and healthcare professionals to identify issues before they become critical to allow for earlier diagnosis and intervention which can result to saving lives of patients with heart problems, diabetes or other conditions. Such application could be seen in heart, pulse, insulin monitors and biosensors.

The design and implementation of IoT hinges on the connectivity of devices and people. Thus, connectivity is a huge aspect of the IoT especially in its application in healthcare and several communication technologies abound for connecting the devices to one another as well as to the internet in the IoT ecosystem [5]. The connectivity requirements for healthcare applications vary and this variation is a reflection of the application's purpose. While some healthcare applications such as heart rate and blood pressure monitors for patients in serious conditions will require real time monitoring that necessitates the need for communication technologies with low latency, bi-directionality and high data rate, however, other situations may also arise where the use of such communication technologies may be unnecessary. In other words, the communication technology that best suits the application's purpose should be adopted.

Therefore, in this paper, we review the existing and potential wireless communication technologies for IoT-healthcare based systems. The unique thing about our review is in its comprehensiveness which appears to be lacking in all the literatures reviewed. Furthermore, we list and analyze some of the underlying mechanisms in these communication technologies which enable full implementation of IoT healthcare services and applications. The paper is divided into seven specific sections. Section one captures the introduction, while in section two, we briefly explain the IoT concept using a simple architecture to present our explanation from a healthcare delivery perspective. In section three, we discuss the proprietary low power (short, medium and long range) technologies while in section four, we review the newer cellular technologies for the IoT highlighting the legacy cellular technologies which are their building block. Section five reviews the future cellular technologies for the IoT-based healthcare systems while in section six, we mention some of the research challenges of IoT-healthcare implementation and finally, we present our concluding remarks in section seven.

II. INTERNET OF THINGS

2.1 What then is IoT

The Internet of Things (IoT) is a concept reflecting a connected set of any one, anything, anytime, anyplace, any service, and any network [6]. The term "IoT" in some sense is misleading. It is not a single unified network of connected devices but rather a set of different technologies – wireless, mobile communications, nanotechnology, Radio Frequency Identification (RFID), sensors and actuators working together with the aim of internetworking physical objects or things to monitor situations, learn and respond in real time with the ultimate goal of improving the lives of people [7]. From a general perspective, these "objects or things" can be mobile devices, vehicles and buildings which are embedded with electronics, software, sensors, actuators and network connectivity to enable them collect and exchange data. However, in a healthcare scenario, the "things" can be patients, medical personnel, medical equipment and systems which are integrated using network connectivity and the internet with the aim of exchanging vital data that will be used to perform tracking, monitoring, alerting, controlling and optimization functions [5]. Figure 1 illustrates the definition of the concept and vision of IoT as given in [6].

2.2 Architecture of the IoT

To further illustrate our definition in subsection I, we present a simple IoT architecture in figure 2 which captures in its layers all the key elements from a healthcare delivery perspective. The layers include the identification, sensing, network, middleware and application layers [5].

Using a device (insulin monitor) to explain this architecture, the identification layer consists of an RFID or Electronic Product Code (EPC) tag on the device; the sensing layer contains the insulin sensor chip implanted on the device to monitor the insulin level of the wearer (patient); the network layer transmits information from the device to the processing systems or other devices in the IoT system; the middleware layer connects all the devices (which could be blood pressure, glucose level monitors) in an IoT system and the application layer provides the service (which enables the patient or the health personnel interpret the information in a useful way).

2.3 IoT Healthcare Services and Applications

IoT-based healthcare systems can be used to care for children and elderly people, monitor chronic diseases from remote or close locations and support accurate diagnosis of patients' diseases [1]. In different scenarios, each IoT-based healthcare device performs the same function. An example is the glucose monitor which can be used to monitor the glucose level of an elderly diabetic or an accident victim. Building on that premise, we categorize IoT-based healthcare systems into services and applications. Each scenario represents a distinct service and the applications that are developed to cater for the service. In this paper, we briefly explain some of the services and applications of IoT in healthcare delivery as shown in table 1.

Table 1 consists of four specific services and applications, which explains where and how services could be applied using specific devices. To utilize Semantic Medical Access, Smartphone and iMed Package are found in greater use. According to [8], countless connected devices provide the use of semantic technology to analyze massive amount of data for IoT-based healthcare systems. In doing so, patients' profile is created, which would help in further treatment of the individual. Meanwhile, any drug to be taken by a patient is matched to this profile using the iMed Pack Application which performs the role of a pharmaceutical intelligent information system to sense whether the patient is compatible with the drug [9]. Furthermore, SMA provides medical researchers access to a broad spectrum of data for analysis. Figure 3 is a typical architecture of iMed Pack, which could be accessed from distant locations. It consists of specific components which include Biochip, Glucose sensor, Heart Rate Sensor, IoT Cloud and iMed Box, which communicates with other components.

For the elderly, Ambient Assisted Living (AAL) services provide the required succor that caters for their needs. AAL uses artificial intelligence technologies to assist this category of aged people live independent lives conveniently and in the safety of their homes [6]. It uses global positioning systems (GPS) enabled devices that help prevent wandering in people with dementia to insulin monitors that help elderly diabetics monitor and control their insulin levels, thereby
supporting their independence.

IoT also enables healthcare providers deliver basic emergency services to patients in their homes or on the road to hospitals using Emergency Healthcare system. This is supported by Intelligent Transport Systems (ITS), another application of IoT that offers support in emergency care delivery by providing the emergency crew with accurate real time traffic information that will enable them arrive at the hospital faster [10]. Using children Health Information, the mind status and general health of children with behavioral, emotional and mental health problems are closely monitored. An IoT system with a wireless connectivity and sensor could be adopted to monitor a child's activity [11]. The system enables the child to play android games that will make him to think and act dynamically. Other example is the proposed interactive totem which can be placed in a pediatric ward aimed at educating and amusing hospitalized children [12].

III. COMMUNICATIONS TECHNOLOGIES FOR IOT-BASED HEALTH CARE SYSTEMS

Successful implementations of IoT healthcare systems depends on the communication among devices and as shown in Table 2, which details connectivity requirements for IoT-based healthcare systems. Depending on the demands of the service, one or more communication technologies can enable efficient delivery of the service's applications. To achieve maximum return on investment (ROI), the perfect connectivity solution should be the one that consumes minimal power, covers the widest range and transmits the largest amount of data per second. Unfortunately, none of the existing wireless communications technologies can offer all those qualities as our review shows that each option exemplifies a compromise between power consumption, range and bandwidth. However, researchers are working towards developing that perfect solution in the future and 5G technology holds a lot of promise. The next section explains the current wireless communications technologies for IoT-based healthcare systems.

3.1 Short Range Low Power Wireless Communication Technologies

This range of connectivity support low power and high data rate communication over short distances. Typical examples include:

Near Field Communication

Near Field Communication (NFC) is a short-range half duplex wireless technology, which establishes contactless communication between two electronic devices that are within a range of about 20 cm. It is based on the ISO 13157 specification and operates in the 13.56 MHZ band [13]. Communication between devices is point-to-point with a data rate of about 424kbps. Each NFC device can operate in three modes – NFC card emulation where devices can act as smart cards and are used to perform transactions such as payment and ticketing; NFC reader/writer which enables devices to read information stored on inexpensive NFC tags embedded in labels or smart posters; NFC peer-to-peer which enables two NFC enabled devices to communicate with each other to exchange information in an ad hoc fashion. Applications can be found in allergy detection systems and storage of encrypted health data. It is compatible with Bluetooth and other short range technologies. However, it is not secure as information is sent over the air though the short range of about 20cm may pose difficulties for the attacker to eavesdrop the information within that short distance.

Z-Wave

This is a reliable wireless mesh network communications protocol that allows transmission of short messages from a control unit (master) to one or more nodes (slaves). It operates at the 900 MHz band and supports data rate of 40 kbps using Binary Frequency Shift Keying (BFSK) modulation. The recent Z-Wave 400 series chip can operate in the 2.4 GHz band and support data rate of about 200 kbps and a maximum range of about 100m (extendable using repeaters) in open air though obstacles on its path such as building materials can reduce the range [14]. The Media Access Control (MAC) layer exploits carrier sense multiple access with collision avoidance (CSMA/CA). CSMA allows the transmission of a frame when the channel is available but defers the transmission attempt for a random period of time when the channel is unavailable thereby minimizing collision and maximizing signal-to-interference ratio. It is applied in AAL systems to control lighting and open windows and doors without the aid of switches and knobs. Z-Wave allows interoperability among devices that are part of the Z-Wave Alliance. However, it shares a frequency range (900 MHz) used by some cellular phones and will be susceptible to interference from such phones.

ZigBee

A wireless technology that builds on the IEEE 802.15.4 - 2006 PHY and MAC standards. Globally, it operates at the 2.4 GHz Industrial Scientific and Medical (ISM) band with a data rate of about 250 Kbps and a maximum range of 75 meters. It provides communication for machine-to-machine and other IoT networks. The MAC layer exploits CSMA/CA as its channel access scheme while the PHY layer uses direct sequence spread spectrum (DSSS) technique to mitigate interference on the ISM band. ZigBee Healthcare under the auspices of ZigBee Alliance offers interoperable products that can be used in the monitoring and management of healthcare services such as AAL, chronic diseases, general health, wellness and fitness [15] and such products include glucometer, pulse oximeter and respirometer. ZigBee network topologies include star, cluster tree and mesh topologies. Zigbee has a robust AES-128 encryption standard that secures personal information. However, it suffers interference from other devices that operate in the ISM band. In addition, the transport layer uses User Datagram Protocol (UDP) which offers unreliable message delivery and this poses a huge risk for time critical IoT applications such as blood pressure and heart monitors.

Bluetooth Low Energy (BLE)

A "smart ready" new radio standard that adopts the star topology and offers universal wireless connectivity to smart devices [16] similar to what USB has been to desktop PCs. It operates in the 2.4 GHz band, offering a maximum data range of about 150 meters in open field as well as a data rate of 1mbps. By adopting adaptive frequency hopping at the PHY layer, BLE achieves interoperability with the classic Bluetooth and Wi-Fi standards. Typical applications can be found in home health monitoring services such as the blood pressure and heart rate monitors. It is highly scalable and can connect about 2 billion devices. In addition, its robust AES CCM – 128 encryption standard can provide adequate security for patients' personal health information. However, it is designed for sending small data chunks and does not support streaming.

3.2 Medium Range Low Power Communication Technologies

This range of connectivity supports low power, high data rate communications over distances longer than that supported by technologies under the short range low power category. A typical example includes:

Low Power Wi-Fi (Wi-Fi HaLow)

It is based on the IEEE 802.11ah specification which extends the application area of Wi-Fi networks to meet the low power requirements of IoT. It operates at 900 MHz band and has the ability to travel long distances (about 1 km) and penetrate walls – an important requirement for monitoring patients in a hospital or care home complex. With Wi-F HaLow, data rates as low as 150 kbps are possible using a 1 MHz channel and high data rates of about 78 Mbps are possible with a 19 MHz channel. The technology is used to connect medical equipment in hospitals as well as to remotely control room signage for AAL systems. It is highly scalable and backward compatible with Wi-Fi products. However, it has low coverage due to lack of global standard for the 900 MHz band.

The short-range and medium-range low power communication technologies operate in the license-exempt frequency bands. Hence, they are used to support low cost IoT-based healthcare services. However, they have limited coverage capabilities and cannot support services over longer distances. To be able to support low cost services on the license-exempt bands but over longer distances, long range low power technologies were developed. Thus, the next subsection discusses the long-range communication technologies.

3.3 Long Range Low Power Communication Technologies

These technologies operate in the license-exempt frequency bands and therefore adhere to the regulatory specifications of the ISM band. They provide support for long range connectivity which make them suitable for implementing IoT services that span across large geographical space. These technologies include:

LoRa

A wireless technology which is designed to operate in the 169 MHz, 433 MHz, 915 MHz bands in the USA and in the 868 MHz band in Europe with a maximum data rate of 50Kbps. LoRa uses a proprietary physical layer standard derived from Chirp Spread Spectrum (CSS) **-** a modulation scheme with different bandwidths – 7.8KHz, 10.4KHz, 15.6KHz, 31.2KHz, 44.7KHz, 62.5KHz, 125KHz, 250KHz and 500KHz. CSS ensures phase continuity between different chirp symbols in the preamble part of the packet thus enabling a simpler and more accurate timing and frequency synchronization [17]. LoRa employs Frequency Hopping Spread Spectrum (FHSS) not only to enable access to the different channels but to also reduce the interference at the receiver for correct reception. It achieves the latter by using a longer sequence of bits to encode a symbol. While the physical layer exploits a proprietary standard, the rest of the protocol stack called LoRaWAN is kept open. The MAC layer protocol is based on ALOHA to accomplish the wide coverage requirement. With LoRa, a range of about 15km is possible. Figure 4 shows the LoRa systems architecture. As can be seen in the figure, the network is laid out in a star topology which consists of the end devices (body sensors), a LoRa gateway, and a LoRa Net Server. LoRa Alliance is in charge of standardizing and developing LoRa. It is used to remotely monitor medical fridges and track the location of patients with dementia or Alzheimer disease. The technology runs on an open standard making it affordable. It also has the capability to penetrate walls. However, the current version does not support roaming, quality of service and firmware upgrades over the air.

Sigfox

A lightweight protocol that uses the 915 MHz and the 868 MHz band in the USA and Europe respectively. It employs Binary Phase Shift Keying (BPSK) modulation scheme. The architecture consists of end devices (equipped with Sigfox technology), base stations (configured with cognitive software defined radios) and backend servers in the cloud. Data is sent by these end devices via the base stations to the cloud backend servers for processing after which the results are sent back to the end devices stations for visualization. Ranges of 30 – 50 km in rural areas or 3 – 10 km in urban areas as well as data rate of 100bps is obtainable with Sigfox. It is applied in fall detection systems and tracking systems to remotely monitor a patient's wellbeing. Sigfox signals can penetrate walls, travel longer distances and at the same time consume very low energy leading to longer battery lifetime. However, its low data rate is not feasible for low latency IoT applications.

Ingenu – RPMA
A proprietary low power wireless access technology that operates in the 2.4GHz band and exploits the Random Phase Multiple Access (RPMA) with DSSS for uplink communications. This allows multiple transmitters to share a single timeslot which is achieved by adding a random offset delay to each transmitter within the time slot thus reducing overlapping among the transmitters [14]. Downlink communications exploits CDMA with DSSS. RPMA is robust and devices using it can operate over long ranges of up to 15km under the most challenging radio frequency (RF) environments. Operating in the license exempt Industrial, Scientific and Medical (ISM) band makes it affordable. However, devices using the technology experience more interference and propagation loss due to the adopted frequency band.

Weightless: An open standard new wireless technology which was introduced by the Weightless Special Interest Group and operates in both licensed and unlicensed spectrum. It actually consists of three open LPWA standards – Weightless-N, Weightless-W and Weightless-P. Weightless-N operates in the licensed 470 MHz to 790 MHz bands and supports only one-way uplink communication using Differential BPSK (DBPSK) modulation scheme. It exploits cognitive radio technology which enables its end devices utilize unused spectrum as opportunistic users without causing interference to the primary users of the licensed spectrum. Weightless-W operates in the unlicensed band and supports DBPSK and 16 QAM modulation schemes which can achieve data rate of up to 10 mbps. Weightless-P operates in the licensed band and uses GMSK and QPSK modulations schemes. It achieves data rates of 100 kbps using narrow channels (12.5 KHz).

IV. CELLULAR TECHNOLOGIES FOR THE IOT

The legacy cellular network technologies (2G, 3G, LTE and 4G) were not designed bearing IoT in mind. Although they offer global reachability and high data rate communications, yet the high cost of devices, high device complexity and very low power efficiency make them unsuitable for IoT applications. Furthermore, it is expected that the projected number of connected devices in IoT will overwhelm these cellular networks. Therefore, to accommodate the interconnection of billions of low cost and low power devices over global ranges offered by these cellular networks, the third generation partnership project (3GPP) made efforts to redesign them.

Consequently, three new technologies which are generally referred to as cellular IoT were developed. In this section, we summarize the legacy cellular network technologies. The rationale behind providing this summary is twofold. The first is that some of these legacy cellular technologies (e.g. EGPRS) have been used for practical implementations of IoT applications. The second reason is that the summary will provide the basic background for understanding the cellular IoT technologies which we will discuss in subsection II of this section. However, our emphasis is on the 3GPP cellular IoT technologies and we highlight some of the mechanisms that enable them support the basic requirements of IoT. Finally, we review the future 5G networks which promises to provide a perfect connectivity solution for the IoT.

4.1 Legacy Cellular Technologies
2G digital cellular network has three standards namely: Global System for Mobile Communication (GSM), Japanese Digital Cellular (JDC) and the North American Interim Standard (IS-95). GSM, the most popular standard operates in 900 MHz and 1800 MHz bands around the world except in the USA where it operates in the 850 MHz and 1900 MHz bands. It achieves high network capacity by using a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) as its channel access scheme. FDMA breaks up the allocated frequency band into multiple bands while TDMA breaks up each band into different time slots to enable multiple users in each band. The modulation technique used is Gaussian Minimum Shift Keying (GMSK). Standard 2G networks support voice communications and therefore, are not suitable for IoT implementation.

The IS-95 standard uses Code Division Multiple Access (CDMA) as its channel access mechanism whereby all the users transmit on the same frequency band. However, every user uses a unique code to transmit his message/packet. The modulation scheme used is Quadrature Phase Shift Keying (QPSK). CDMA offers higher capacity and lower battery consumption compared to GSM which are positives for IoT implementation. On the other hand, the technology does not enjoy wide coverage as it is used hugely only in the USA and some other countries in Europe.

Technologies referred to as 2.5G technologies include General Packet Radio Service (GPRS) and Wireless Access Protocol (WAP). Both technologies added packet data capabilities to the existing GSM network. GPRS is the first technology that enabled mobile devices to browse the internet. Using carrier aggregation, GPRS can achieve higher bandwidth and can support data rates of about 17.2 kbps [18]. WAP on the other hand determines the guidelines through which web pages are delivered over low bandwidth wireless channels to the screens of mobile devices.

The Enhanced Data Rate for GSM Evolution (EDGE) also known as the Enhanced GPRS (EGPRS) was developed to give GSM networks the capacity to handle 3G services. Using a higher order modulation scheme (Phase Shift Keying/8 known as 8-PSK) in addition to GMSK as well as efficient protocol handling schemes, it can support transmission of data at high data rates of about 130kbps. 3G was introduced to harmonize the various standards for mobile communication and to increase the voice quality, network capacity and data rate of mobile data services [19]. As a family of standards, it eases broadband connectivity of mobile users irrespective of their network provider. While the European standard - Universal Mobile Terrestrial System (UMTS) uses Wideband CDMA (WCDMA) as its air interface technology, its American equivalent - CDMA2000 uses CDMA. With 3G, it is possible to achieve data rates of up to 144Kbps for high mobility scenarios and 384kbps for low mobility scenarios [20]. UMTS also offers High Speed Packet Access (HSPA) data transmission capabilities and can deliver speeds up to 14.4 Mbps on the downlink and 5.8 Mbps on the uplink while the CDMA 2000 standard offers Evolution Data Optimized Revelation B (EV-DO Rev B) with a downlink speed of 15.67 Mbps. 3G's high coverage, high data rate and low latency offer positives for IoT healthcare services while its high battery consumption and inability to support multimedia services will not be favorable for some IoT applications.

The Long Term Evolution (LTE) is an evolution of the UMTS/HSPA technologies. Apart from the introduction of a different radio interface, improvements were also done on the core network to increase the capacity and speed of the 3G networks. LTE employs orthogonal frequency division multiple access (OFDMA) and single carrier-frequency division multiple access (SC-FDMA) as its channel access schemes in the downlink and uplink respectively. OFDMA provides resilience against selective fading and multipath interference at high transmission rates while SC-FDMA ensures lower power consumption for the mobile device as well as resilience against multipath interference. Multiple Input Multiple Output (MIMO) technology is also deployed to further improve data throughput and spectral efficiency above that obtained by OFDM. To increase network capacity, LTE adopted multiple channels for signal transmission and they include – 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz and the 20MHz channels. Depending on the prevailing signal strength, different modulation schemes - QPSK, 16QAM and 64QAM can be adopted to achieve an expected data rate.

4G is an all IP-based network which provides a single network standard (unlike 3G) making mobile roaming possible. It has the capability of supporting multimedia service on-the-go, high quality video and higher data rate and can be accessed using different platforms – mobile phones, laptops, PDAs etc. The dominant technology is WIMAX, the air interface technology is OFDMA and the modulation techniques are QPSK and 16QAM. 4G can support ubiquitous connectivity, high data rate (100 Mbps and 1 Gbps for high mobility and low mobility scenarios respectively), and low device cost which are positives for IoT.

4.2 Cellular Internet of Things

Extended Coverage for GSM IoT (EC-GSM-IoT)

EC-GSM-IoT is an enhancement of the GSM and EDGE technologies to support IoT's design objectives of low device complexity, cost, greater power efficiency, extended coverage and improved security. The architecture re-uses the basic physical layer design of the GSM network but introduces some new techniques to achieve the design requirements of IoT. Blind repetition or blind retransmission of the physical signals is used for extending the coverage while improving the signal-to-noise ratio (SNR) at the receiver. With this technique, a transmitter transmits up to 28 blocks or bursts of the physical signal without receiving any acknowledgement or feedback from the receiver about the status of the transmitted blocks. To increase SNR, the receiver accumulates the Inphase and Quadrature (IQ) components of the blindly transmitted bursts to a single burst before synchronizing to the burst and performing channel estimation [21].

Greater power efficiency is achieved by using the Extended Discontinuous Reception (eDRX) mechanism which enables the EC-GSM-IoT device extend its "Sleep Mode" duration or inactivity period by increasing the listening interval of the Physical Downlink Control Channel (PDCCH) from a few minutes (as is the case in DRX) to over an hour. By so doing, longer device battery lifetime is achieved. To improve on security which is a very important requirement for IoT health services, mutual authentication in which both the device and the network are authenticated during connection establishment is adopted. In addition, a 128-bit long encryption algorithm (GEA5) is defined and its use is compulsory for every device and network using the technology. Table 3 compares the performance objectives of the EC-GSM-IoT and EGPRS.

Long Term Evolution for Machine Type Communications (LTE-M)
LTE-M is an enhancement of the LTE technology with features to accommodate design requirements of IoT. To achieve a reduction in device complexity and cost, half duplex operation was employed. In addition, a single antenna (instead of two used in LTE) was used for the reception of signals at the receiver. Furthermore, the downlink bandwidth and the device power class of basic LTE were reduced from 20 MHz and 23 dBm respectively to 1.4 MHz and 20 dBm. Repetition of physical signal was used to achieve extended coverage while eDRX and Power Saving Mode (PSM) mechanisms helped in achieving longer device battery lifetime. With PSM, the device is dormant during the PSM window and utilizes very minimal power thereby extending its battery lifetime. Finally support for massive number of devices was achieved by introducing Radio Resource Control (RRC) Suspend/Resume mechanism. This mechanism reduces the amount of signaling required when resuming an RRC connection after a period of inactivity as long as the device has not left the cell in the meantime.

Narrow Band IoT (NB-IoT)
NB-IoT is an enhancement of the LTE-M to further achieve design requirements of the IoT. To reduce device complexity and cost, NB-IoT adopted techniques such as half duplex operation, LTE Tail Biting Convolution Coding scheme (TBCC) as well as the use of one receive and one transmit antenna. Devices using half duplex are not required to listen to the downlink while transmitting or the uplink while receiving. Coverage enhancement was achieved by using retransmissions or repetitions of the physical signal. In addition, NB-IoT used a close to constant waveform in the uplink to minimize the need to back off the output power from the maximum configurable level. Long device battery lifetime was achieved by using PSM, eDRX and Connected mode DRX (CDRX) mechanisms. In CDRX, the device goes into DRX mode when there is no data transmission in either the downlink or the uplink channels.

To achieve spectral efficiency with a view to providing support for massive number of devices, NB-IoT can be deployed in one of three modes - stand-alone, in-band or guard-band. Stand-alone mode of operation can be achieved in the GSM band by re-farming part of the GSM spectrum to accommodate NB-IoT. In-band mode of operation involves using a Physical Resource Block (PRB) in an LTE carrier to deploy NB-IoT while guard band mode involves deploying NB-IoT in an unused LTE carrier's guard band. All the deployment modes are shown in figure 5.

V. FUTURE COMMUNICATION TECHNOLOGIES FOR IOT-BASED HEALTHCARE SYSTEMS

5.I Fifth Generation Cellular Network (5G)
5G next generation network has the potential to accommodate more massive deployment of interconnected heterogeneous devices and at the same time support the basic requirements of IoT for healthcare provision [22]. In addition, it promises to improve the perceived user's quality of service as well as quality of experience while using the service. We briefly discuss some of the emerging technologies that will enable 5G meet some of the design objectives (spectral efficiency, network capacity, energy efficiency and support for heterogeneous devices and services) of IoT healthcare service requirements.

Software-Defined Networking (SDN)
Software Defined Networking (SDN) is a new paradigm aimed at improving programmability of the network by

decoupling the network data plane from the network control plane [23]. This simplifies network management and makes network configuration of the massive number of devices projected in IoT easier to handle, thereby facilitating the introduction of new services. Other key features of SDN are:

i. The Open Standards and Vendor-neutral Application Programming Interfaces (APIs) which will support the heterogeneity of networks and devices in the IoT;
ii. The SDN Controllers where network intelligence or the network control logic is domiciled. Its role is similar to that of the Network Operating System (NOS) in legacy networks.
iii. Flow Programming which controls and implements forwarding decisions and enables network operators to dynamically adjust traffic flows to meet changing network needs [24].

Network Function Virtualization (NFV)
NFV promises to support massive deployment of devices envisaged in IoT by virtualizing certain network functions (routing, switching, load balancing etc.) which will further be implemented into software packages with the aim of providing same services as their counterparts in the existing network infrastructure. The concept borrows the idea of a virtual machine (VM) which can be configured to run on different operating systems in one server. By virtualizing network functions, NFV promises to ease network management, reduce network rollout and maintenance costs, increase device scalability as well as reduce energy consumption.

Cognitive Radio
The huge number of devices that 5G will support and the high bandwidth nature of some of its services and applications will certainly lead to overloading the existing available spectrum. Previous research which showed that a deficit in broadband spectrum was likely to have approached 300 MHz in 2014 [25] supports that fact. To avert the above from happening, one option was to purchase more spectrum for 5G services. However, the huge cost involved will trickle down and increase the cost incurred by users of these services. Hence a need to introduce a technology that will enable efficient use of the available spectrum to support IoT service requirements. Cognitive Radio (CR) technology enables 5G network users to share the licensed spectrum of the cellular networks with the primary users in an opportunistic manner.

It offers mobile devices in IoT the capability to identify available free spectrum or free portions of a spectrum in use, detect the presence of licensed users in a system (spectrum sensing), select the best available channel from a set of available channels in a spectrum (spectrum management), coordinate the accessibility of the available channels with licensed users (spectrum sharing) depending on the bandwidth requirements of the service as well as to exit the accessed channel on the arrival of the primary user (spectrum mobility) if the bandwidth requirements of the licensed service will not allow for spectrum sharing. CR technology can help extend IoT services to rural and remote areas where network operators do not have presence due to the low population density that characterizes these regions with its negative impact on generated revenue. By accessing "TV White Spaces" which are unused portions of the TV broadcast band released by the Federal Communications Communication (FCC) and made available for unlicensed operation [26], extension of cost effective IoT services to remote regions is feasible without incurring the additional cost of purchasing more spectrum.

5.2 IPv$_6$ over Low-Power Wireless Personal Area Network (6LoWPAN)
The Low Power Wireless Area Network (LPWA) technologies discussed in section three are proprietary solutions. Achieving interoperability of these technologies to enable IoT implementation is a huge task for researchers as they are yet to come up with feasible solutions. In addition, these technologies are not IP-based which makes integrating them into the larger internet to enable IoT an onerous task. With IP, device connection to the internet and system management are easier as there are existing and readily available tools for commissioning, configuring, managing and debugging IP networks [27], [28]. However, traditional IP-based (IPv4) protocols are not efficient for IoT services because of the following reasons: low energy efficiency, poor security, and low reliability. The main objective of 6LoWPAN which is to enable the efficient transmission of IPv6 packets over low power and lossy networks was achieved through some of its features which include: header compression, multiple security schemes and the use of Routing Protocol for Low-Power and Lossy networks (RPL) – a reliable routing protocol standardized by the Internet Engineering Task Force (IETF) and the Routing over Low-Power and Lossy networks (RoLL) working

group. With RPL, as shown in figure 6, nodes which are beyond the coverage area of the root node (such as node 3) can still join the destination-oriented directed acyclic graph (DODAG) path by proactively sending DODAG Information Solicitation (DIS) messages to their closest node (node 2) which is within the coverage area of the root node to solicit DODAG Information Object (DIO) messages. On receiving the DIO messages, the out-of-range node (node 3) sends an acknowledgment – Destination Advertisement Object (DAO) back to the sending node which forwards same to the root node. In this way, the out-of-range node joins the DODAG and can send and receive packets from other nodes in other networks through the root node. In order to achieve reliable packet delivery, each RPL node can have multiple parent nodes. RPL uses the TrickleTimer algorithm to control DIO messages in order to reduce network congestion. This algorithm also ensures shorter convergence times (of about 4 seconds) [29] after link failures. Different quality of service (QoS) for different flows can be achieved by using multiple RPL instances which provide different routes with different QoS.

VI. CHALLENGES

Available communication technologies are confronted with numerous challenges, which impedes achieving the goals of IoT in the health sector. Thus, this section presents the challenges identified with the current literature:

Security and Privacy

The sensitive data that will be conveyed in communication networks of IoT-based healthcare systems makes the issue of security and privacy a serious challenge. As the number of connected IoT healthcare devices increase, the surface area of attack continues to increase. Research indicates that attacks such as man-in-the middle and denial of service could have fatal consequences on the users of these IoT services and applications. Imagine a scenario where an attacker hacks into the log of a heart rate monitor and sends false data about a patient's heart condition to the medical personnel resulting to the death of the patient. The existing internet security schemes – Advanced Encryption Standard (AES), Diffie Hellman (DH) and Rivest–Shamir-Adleman (RSA) though robust in their performance were developed for high performance platforms and cannot be adapted to the resource constrained environment of IoT. Hence, there is need for robust and lightweight authentication and encryption schemes for the resource-constrained IoT environment.

Network Mobility and Coverage

Service interruption due to user mobility and limited network reachability poses a serious challenge to IoT-based healthcare systems. Most LPWA technologies are proprietary and have coverage limitations. Achieving interoperability among these technologies poses huge challenges for researchers. Considering the huge number of devices that will be involved, there will be a need for more base stations which will result to having more handoff procedures compared to the legacy cellular networks. In view of the above, a mobility management mechanism that will manage the huge number of heterogeneous devices across heterogeneous networks is needed.

Scalability

Performance degradation of the IoT communication technologies as the number of devices and applications that run on those devices increases is another challenge worth mentioning. There is need to develop mechanisms that will enable service quality improvement for devices at the cell edges (furthest from the base station) and fog computing holds a lot of promise in this regard. In addition, most of the cellular and LPWA technologies are based on IPV4 addressing scheme which cannot support the huge number of devices in IoT. However, the deployment of 6LoWPAN which is based on IPV6 promises to erase this challenge. In addition, efforts are ongoing to make it backward compatible with the LPWA technologies. However, one major drawback of 6LoWPAN is that it does not support mobile IPv6. However, a protocol for exchanging messages between mobile nodes, base networks and visited networks has been proposed in [30].

Lack of Channel Access Scheme for 5G Millimeter Wave Propagation

Millimeter wave bands have been proposed for use in 5G networks to provide the enormous capacity required as they offer orders of magnitude of more spectrum in the 30GHZ to 300GHZ range. However, this band is susceptible to path loss, path blocking and delay spread in outdoor scenarios and till today, no suitable channel model can be used to perceive the effect of path loss, angular spread, delay spread and path blocking in mm-wave propagation. This has delayed the development of a suitable channel access scheme for 5G mm-wave propagation.

VII. CONCLUSION

The application of IoT in healthcare promises to help in realizing the goal of keeping billions of people healthy at affordable cost, thereby making our world a safer and better place to live in. Despite the many potential benefits, some visible challenges also militate against its effective implementation. This paper reviewed the present and future wireless communication technologies for IoT in health from the perspective of technologies that can support short range, medium range and long range services. It is worthy to mention that massive deployment of devices in the IoT-Health ecosystem will be achieved using the cellular-based LPWA technologies (EC-GSM-IoT, NB-IoT, LTE-M) and the 5G networks. However, effective implementation will be realized if the different stakeholders – government, industries and academia pull resources to combat the confronting challenges which include security and privacy, coverage, scalability and network mobility issues.

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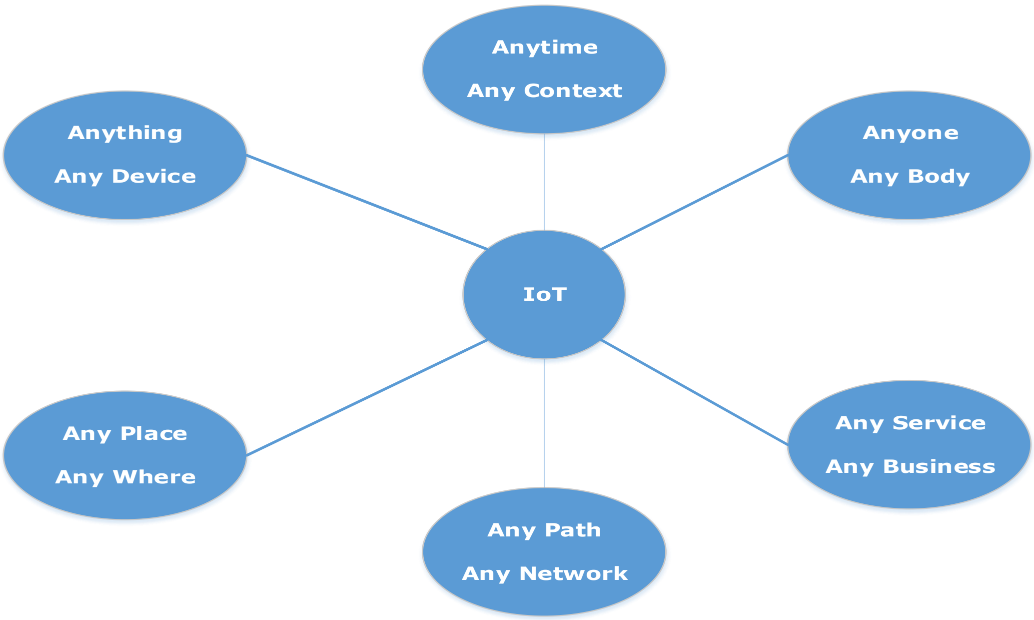

Figure 1: Conceptual Illustration of IoT [6].

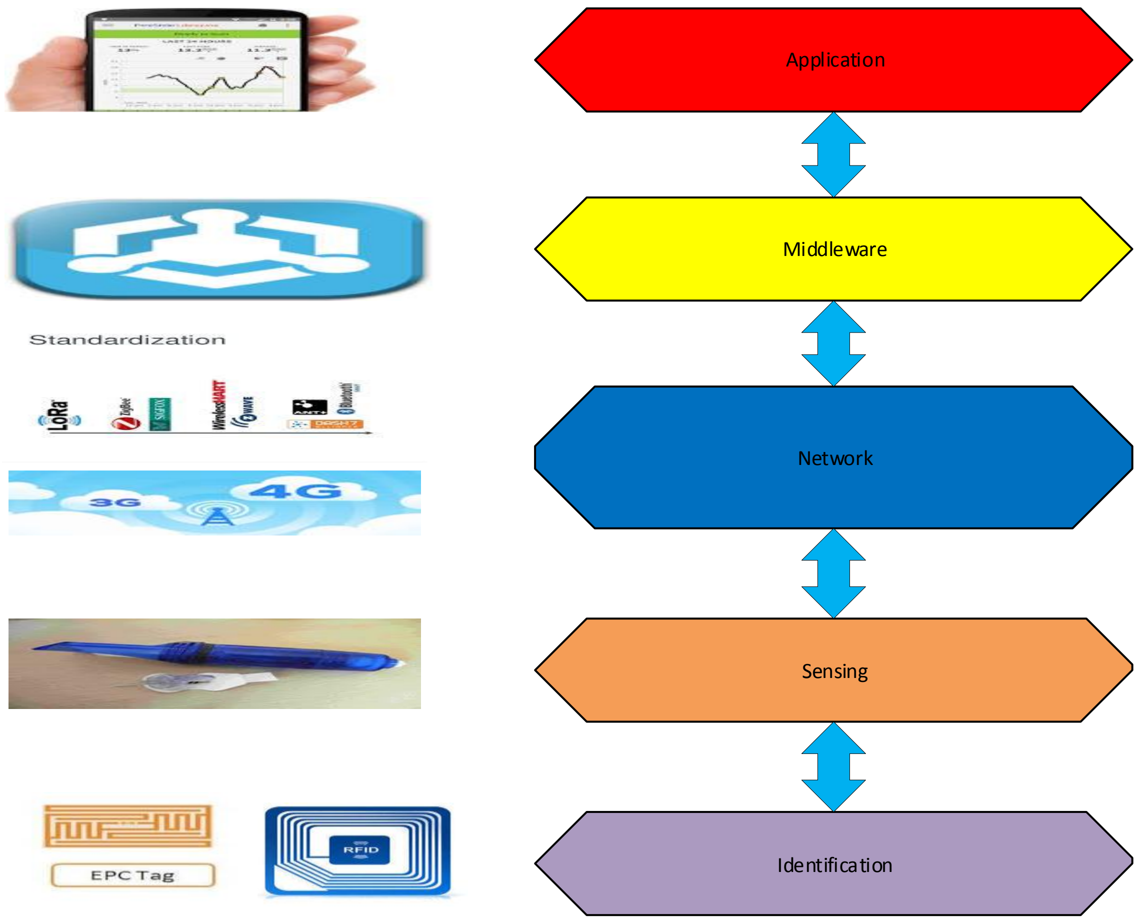

Figure 2: IoT architecture from a healthcare delivery perspective [5].

Table 1: IoT healthcare services and applications

Service	Application
Semantic Medical Access (SMA)	Smartphone applications, iMed Package
Ambient Assisted Living (AAL)	Glucose Level Sensing
Emergency Healthcare	Heart rate monitoring
Children Health Information	Smartphone applications, interactive totem.

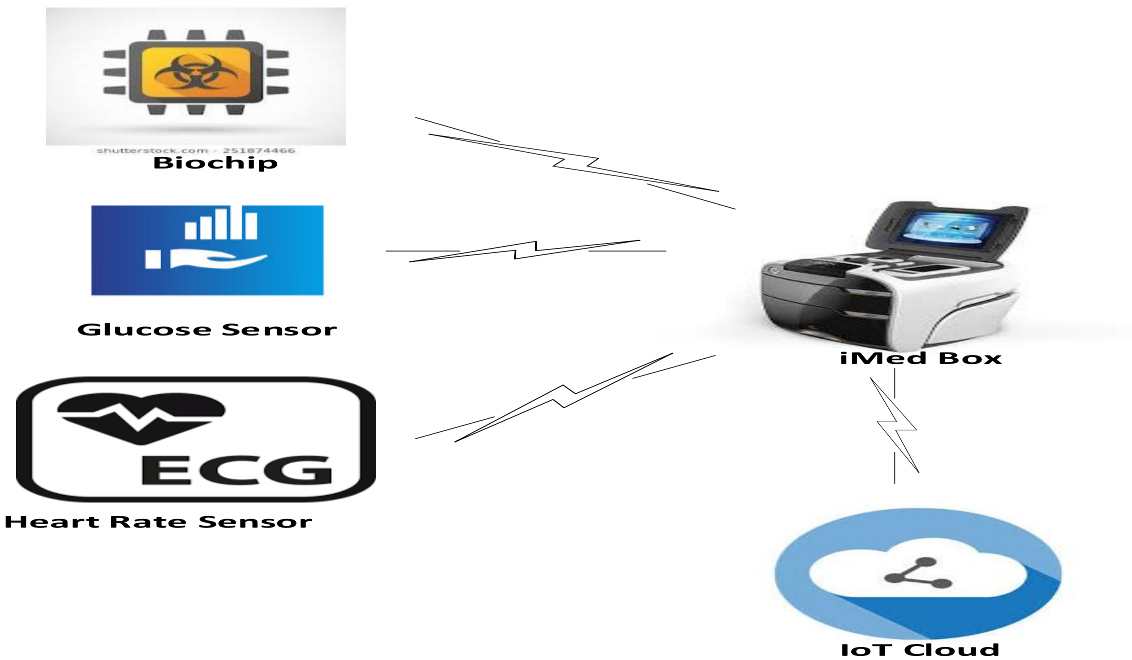

Figure 3: The iMed Pack [9]

Table 2: Connectivity Requirements of IoT Healthcare Services

Service	**Application**	**Connectivity Requirements**											
		Bi-directionality		**Security**		**Coverage**		**Cost**		**Data Rate**	**Energy Consumption**		
		NBD	**BD**	**L**	**H**	**L**	**H**	**L**	**H**	**L**	**H**	**L**	**H**
SMA	iMed Pack		✓		✓	✓	✓	✓			✓	✓	
AAL	Glucose Level Sensing	✓			✓		✓	✓			✓	✓	
EH	Heart rate monitor	✓	✓		✓		✓	✓			✓	✓	
CHI	Interactive Totem		✓		✓	✓		✓			✓	✓	

(L – Low, H – High, NBD – Non-Bi-directional, BD – Bi-directional)

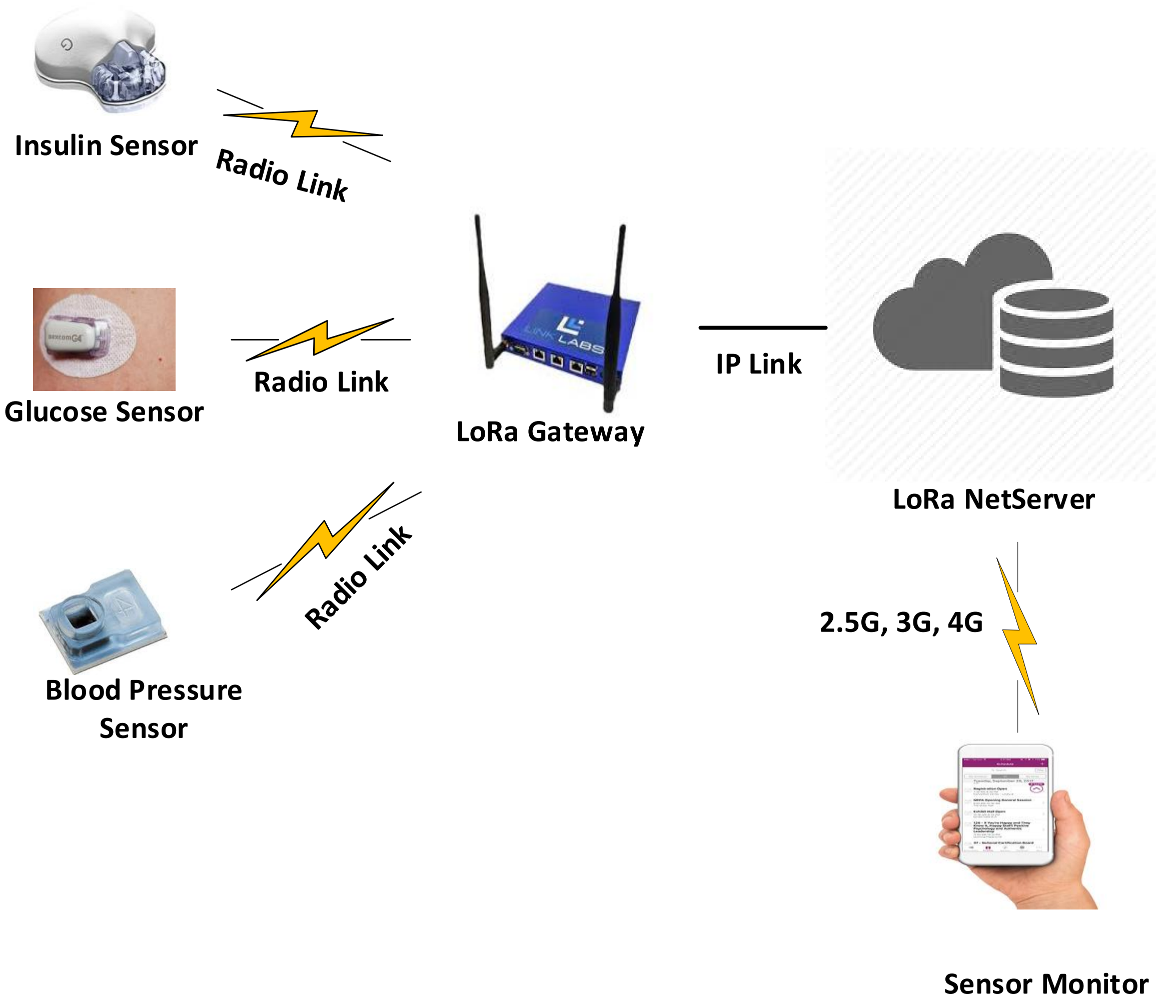

Figure 4: LoRa Systems Architecture [16]

Table 3: Comparison of performance objectives of EGPRS and EC-GSM-IoT [21]

Performance Metric	**EGPRS**	**EC-GSM-IoT**
Coverage	144 dB	164 dB
Maximum data rate	384 kbps	160 bps
End-to-end latency	Below 100 ms	10 s
Power Efficiency	Low	10 years/5wh (Very high)
Device Complexity	High	Ultra-low

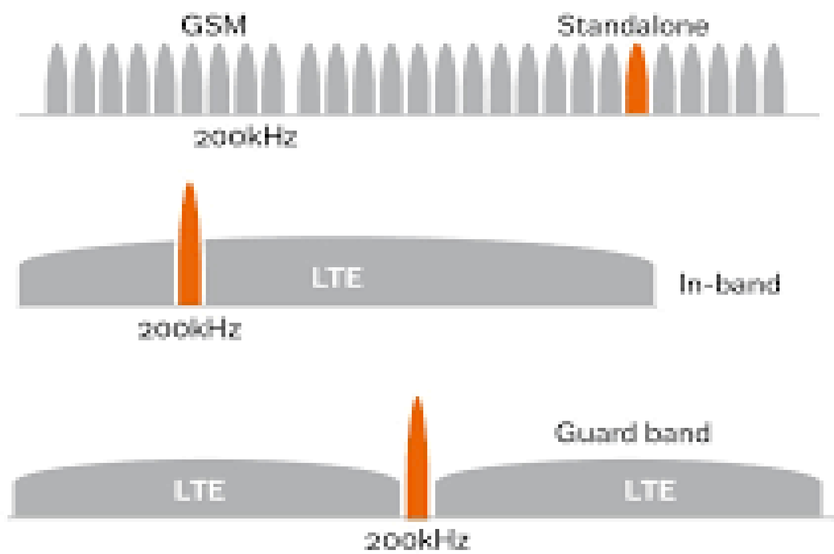

Figure 5: NB-IoT deployment modes [21]

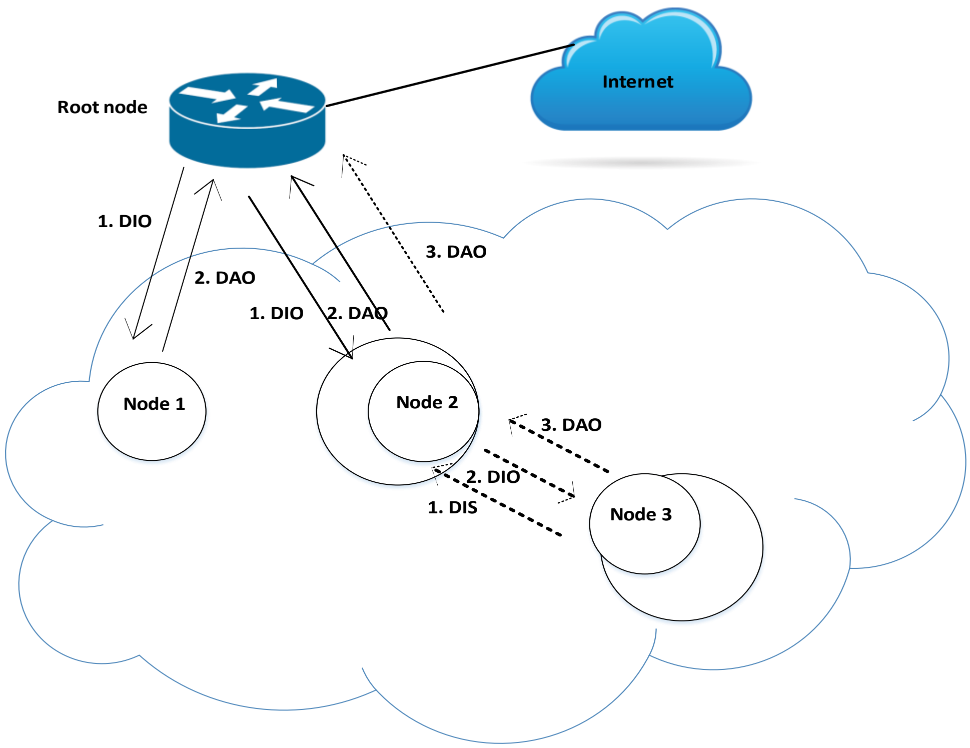

Figure 6: Basic operation scenario of RPL [29]