Everything You Wanted to Know about Smart Healthcare

By Prabha Sundaravadivel, Elias Kougianos, Saraju P. Mohanty, and Madhavi Ganapathiraju

The Internet-of-Things (IoT) has taken over the business spectrum and its applications vary widely from agriculture, and healthcare, to transportation etc. A hospital environment can be very stressful, especially for senior citizens and children. With the ever-increasing world population, the conventional patient-doctor appointment has lost its effectiveness. Hence smart healthcare becomes very important. Smart healthcare can be implemented at all levels, starting from temperature monitoring for babies to monitoring vital signs in the elderly. The complexity and cost of implementation varies based on the required precision of the individual devices, functionalities and sophistication of the application for which they are used. Smart healthcare also falls under vertical areas such as VLSI, embedded systems, big data, machine learning, cloud computing and Artificial Intelligence. This article discusses the importance, requirements and applications of smart healthcare along with the current industry trends and products. It gives a deeper insight about the different platforms across which more research can be pursued in this dynamic domain.

1. INTRODUCTION

Traditional healthcare is unable to accommodate everyone's needs due to the tremendous increase in population. Despite having excellent infrastructure, and cutting-edge technologies, medical services are not approachable or affordable to everyone. One of the goals of smart healthcare is to help users by educating them about their medical status and keeping them health-aware. Smart healthcare empowers users to self-manage some emergency situations [1]. It provides an emphasis on improving the quality and experience of the user. Smart healthcare helps in utilizing available resources to their maximum potential. It aids remote monitoring of patients and helps in reducing the cost of the treatment for the user. It also helps medical practitioners to extend their services without any geographical barriers. With an increasing trend towards smart cities, an effective smart healthcare system assures a healthy living for its citizens.

Connected health in general refers to any digital healthcare solution that can operate remotely and is a collective term for subsets such as telemedicine and mobile-health, but with an additional component of continuous monitoring of health, emergency detection and alerting suitable individuals automatically. Connected health mainly focuses on the mission to improve the quality and efficiency of healthcare by enabling self-care and complementing it with remote-

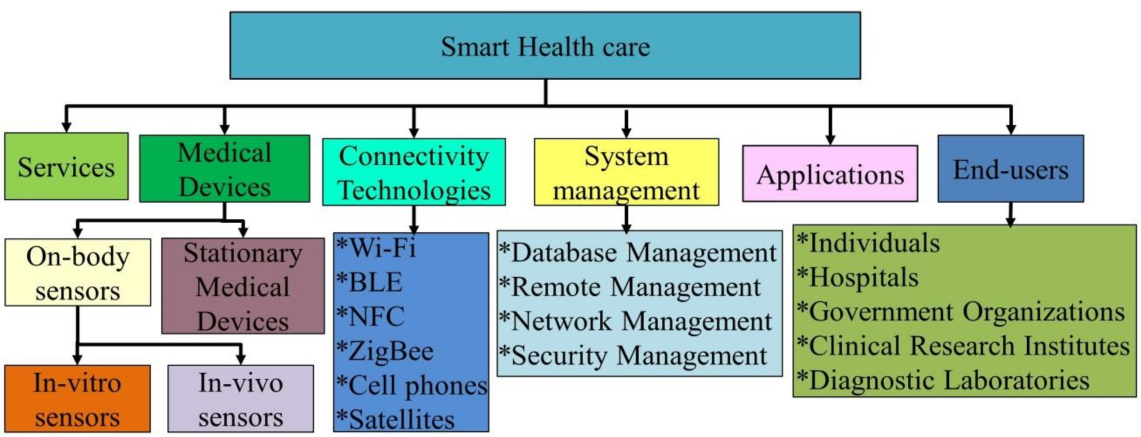

FIGURE 1. Classification of Smart Health Care.

care. It has its origin in the era of telemedicine, where the users are educated about their health and are given feedback whenever required. While smart healthcare refers to solutions which can operate completely autonomously, connected healthcare offers solutions for the users to receive feedback from clinicians. The most important classification, which redefines the economy of the smart healthcare, is the end user market. Depending upon whether the healthcare network is to be implemented for individuals or hospitals, the cost, power, and architecture varies widely.

Figure 1 shows the broad classification of the smart healthcare market, based on the services, medical devices, technologies used, applications, system management and end users. Connectivity technologies used play a vital role in expanding the applications for which the healthcare system is designed. Efficient integration of small devices through wireless technologies can help in implementing remote health monitoring through the Internet of Things (IoT) [2]. If a personalized monitoring device such as a wrist band is used, a Bluetooth module, 6LowPAN or RFID can be used to connect the device to the internet. But in a hospital scenario where a healthcare network is maintained, Wi-Fi and ground cables are required to maintain constant internet connectivity and support heavy data traffic. The medical devices used to implement the smart healthcare can be classified into on-body sensors and stationary medical devices. On-body sensors are usually bio-sensors which are attached to the human body for physiological monitoring. These sensors can be further classified into in-vitro and in-vivo sensors. In-vitro sensors are attached externally to the human body which helps in reducing the involvement of lab or hospital facilities in healthcare. In-vivo sensors are implantable devices which are placed inside the body after fulfilling the regulations and standards on sterilization.

2. SMART HEALTHCARE ARCHITECTURES: REQUIREMENTS, COMPONENTS AND CHARACTERISTICS

Requirements of smart healthcare can be broadly classified into functional requirements and non-functional requirements, as shown in Figure 2. Functional requirements address specific requirements of a smart healthcare architecture. For example, if a temperature monitoring system is deployed, based on the application it is used for, the range of operation of the thermistor/thermometer, data collection mechanism, and frequency of operation might vary. Hence functional requirements are specific to each component used in that healthcare system based on their application.

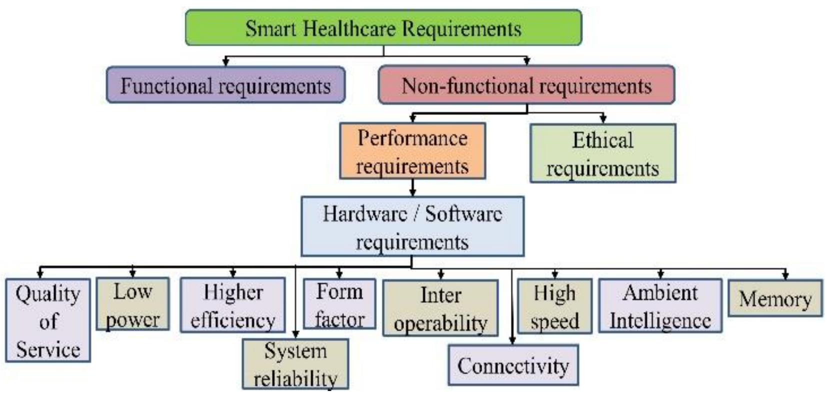

FIGURE 2. Requirements in Smart Health Care.

On the other hand, non-functional requirements are not very specific. Nonfunctional requirements refer to attributes based on which the quality of the healthcare system can be determined. On a broader perspective, non-functional requirements of smart healthcare can be classified into performance requirements and ethical requirements. Due to the large number of verticals involved in designing a complete smart healthcare system, performance requirements can be further classified into software and hardware requirements. Essential requirements for an efficient smart healthcare system are low power, small form factor, system reliability, quality of service, enriched user experience, higher efficiency, ability to interoperate across different platforms, ease of deployment, popularity of the smart healthcare system to offer continuous support, scalability of the system to upgrade to newer versions and technologies, and ample connectivity since the very prime motive of designing a smart healthcare is to ensure medical service promptly. In advanced applications, along with these requirements, the system also needs to have ambient intelligence to improve the quality of service.

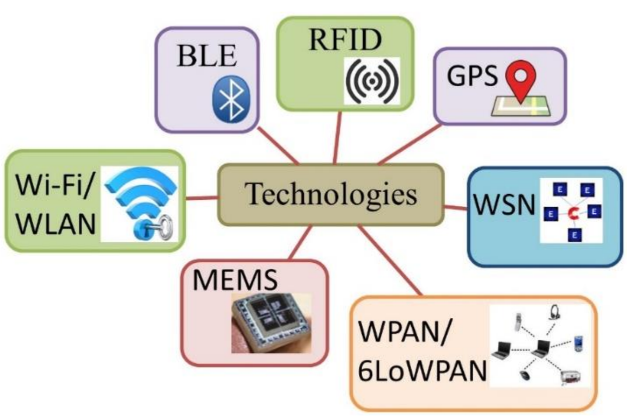

FIGURE 3. Different Technologies used to Deploy Smart Healthcare.

Perspectives of smart heath care widely vary amongst researchers and industries, based on the chosen goal to be achieved. Components of smart healthcare system can be classified based on the sensors or actuators, computing devices, data storage elements and networking components. A sensor is an analytical device which combines with a biological element that creates a recognition of events [3]. Sensors or actuators vary based on the monitoring systems. Temperature sensors, ECG, blood pressure, blood glucose, EMG, heart rate, SpO_2, gyroscope, motion sensors, and accelerometers, are the common sensors used in smart healthcare. Computing devices used in the present era range from smart phones, tablets, and PDAs to complex and advanced devices such as super computers and servers. Memories play a very important role in smart healthcare since storing the information is the most important function of these systems. Data storage components in the smart heath care network cover a broader spectrum starting from embedded memory on the sensing devices to big servers that are used to handle big data analytics. Networking components vary from link sensors to routers and base stations. Based on the severity of the problem addressed, the sophistication of the components varies. Wireless technologies are the backbone of the smart healthcare network. Different wireless technologies such as Wi-Fi, Bluetooth, 6LoWPAN, RFID etc., as shown in Figure 3, play a vital role in exchanging the information among different physical elements that are configured to form the healthcare network.

The most important characteristics required for smart healthcare system are shown in Figure 4. Characteristics of smart healthcare can be broadly classified based on three categories: App-oriented, Things-oriented and Semantics-oriented. App-oriented architectures need to ensure reliable transmission between the applications in smart phones and the sensors, establish a personalized network between the sensors and the user's computing device and secure the information. Things-oriented architectures need to be adaptive based on the application, real time monitoring, on-time delivery, higher sensitivity, maintain higher efficiency at lower power dissipation, and embark on intelligent processing. Semantic-oriented systems need to be able to develop behavioral patterns based on the previously acquired information, process natural language processing techniques to enrich user experience and have ubiquitous computing capabilities [4], [5].

Adding to this list, other significant characteristics include heterogeneous computing, spontaneous interaction across all the elements in the network, location-aware computing, dynamic networks which can accommodate a large number of devices as required, and resource constrained computing with higher efficiency.

3. SMART HEALTHCARE NETWORKS: CONFIGURATION, ORGANIZATION AND FRAMEWORK

Wireless sensor networks (WSNs) were the initial research effort for the IoT. Using WSNs in different applications led to efficient architectures for healthcare applications [6]. There are many dimensions to the architectures and platforms used to deploy smart healthcare. Research in healthcare networks, can be categorized into three major research dimensions: Configuration, Organization and Framework. Healthcare configuration refers to the assembly of different physical elements in appropriate applications which can be used to address key issues. By placing the right sensors/actuators in environments, heterogeneous computing grids can be configured to use such configurations in seamless healthcare computing environments [7]. On the other hand, the organization groups the specifications of the healthcare physical elements along with the hierarchy of the design. Smart healthcare architectures need to be interoperable across different technologies. For example, the sensors used in the body would communicate amongst each other through a personal area network or body area network. This information would be transferred to a smart phone through a Bluetooth or Wi-Fi technology and further will be processed across the network through IPV6 [8]. Thus, organization helps in discussing the working principles and techniques involved in the network architectures. Research on exploring

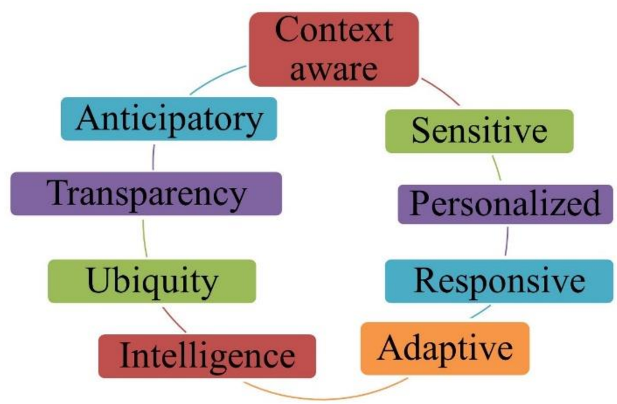

FIGURE 4. Characteristics of Smart Healthcare.

big data techniques in healthcare services, using cloud assistive architectures and integrating multiple technologies to assure quality of service has been constantly gaining more attention from researchers worldwide [9], [10].

A framework for smart healthcare architecture includes the libraries and environments in which the healthcare architecture is used. Healthcare platforms can be widely classified into network platforms, computing platforms and service platforms. Network platforms refer to the networking libraries used to interconnect different architectures. Computing platforms can vary widely based on the technologies used. Due to diversity in the application environments of smart healthcare networks, the frameworks for computing platforms are usually an intersection of wider concepts such as database management, optimization, human-machine interface, machine learning algorithms and so on [11]. Service platform refers to the support layer which acts as a middleware between the technologies and the users. This support layer can either be agents or call center representatives or, in advanced applications, robots or algorithms with cognitive and behavioral perspective. A framework for processing health information using the IoT has been proposed in [12]. Figure 5 shows the various attributes which are to be considered before modeling the frameworks, organizations and platforms, specifically for smart healthcare.

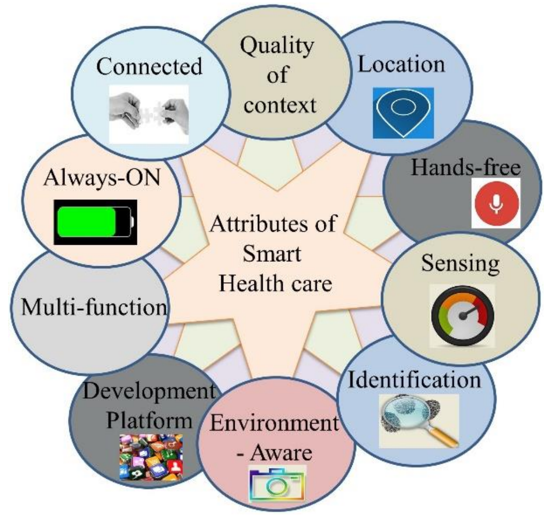

FIGURE 5. Attributes of Smart Healthcare.

4. SMART HEALTHCARE: SERVICES & APPLICATIONS

From the healthcare perspective, services can vary from push-notifications on the healthcare mobile App to cross-connectivity protocols required for connected devices, as shown in Figure 6. Modifications in already existing healthcare systems might help in integrating these systems in smart healthcare. In addition to being secure and fast, these services should also be easily accessible to the patient. Context-aware services use the current location of the user to provide additional services. This could be used in mobile or wearable sensors. For example, based on the information received from the sensor, the walking trail can be tracked to analyze the number of miles covered. In some cases where the user needs additional help to call an ambulance or a paramedic, the required assistance can be provided based on the geographical data obtained from the user. Embedded context prediction (ECP) provides a framework with appropriate mechanisms which can be used to build context aware system. Context aware systems can operate in ubiquitous environments [13].

Semantic processing is a behavior of the human brain to understand colors, patterns, objects etc. based on the context that helps in deeper processing. For example, when a familiar word is heard, the brain processes its meaning based on semantic memory which involves common knowledge. In smart healthcare, the use of semantics and ontologies has led to a service called semantic medical access (SMA). This helps in processing ubiquitous data available in the medical cloud and providing emergency services by integrating these services [14], [15].

FIGURE 6. Services Available Through Smart Healthcare.

Wireless Body Area Networks (WBANs) are the basic components of community healthcare monitoring. Community healthcare monitoring helps in creating a network around the local community. Multiple WBAN constitute a community healthcare network and multiple community healthcare networks constitute a cooperative network. A community healthcare network might include schools, residential areas, hospitals etc. which helps in providing energy efficient monitoring in rural area.

Figure 7 demonstrates the applications of smart healthcare, which start from fitness monitoring on one end of the spectrum to vital sign monitoring in hospitals. Based on the application, the quality of health care systems is improved with additional machine learning algorithms and artificial intelligence. The wide range of applications can be grouped into inter-body sensing, intra-body sensing and environmental management [16], [17]. Intra body sensing applications refer to those which help in monitoring multiple vital signs. For example, in fitness tracking through a smart watch, along with parameters such as number of calories burned, steps taken, active hours etc., it is also important to track the ph sensitivity of the sweat, oxygen intake of the body, heart rate monitoring, etc. In order to meet the competitive smart healthcare market, companies are trying to incorporate as many sensors as possible to offer ubiquitous sensing. Heart rate monitoring and remote ECG monitoring through wearables, have offered cost effective solutions in smart healthcare [18]. In smart watches, it is also necessary to keep a track of the previous monitoring analysis. Algorithms that incorporate cognitive and behavioral processes are being deployed in these sensors to discover patterns. Such patterns from various users can help researchers and industries to develop models that can be used in treating a condition better. Examples for this group of applications can be again found in fitness monitoring through smart watches where, with emergence of virtual reality, these applications are used to set a walking or hiking trail. Along with providing features such as localization and tracking, they help in tracking the fitness of the user. Creating sensitive and responsive digital environments has made the smart healthcare domain a multi and inter-disciplinary research area [19]. Mobile applications that are associated with wearables learn from the users, reason about their intensions of using the device and help them plan in achieving their fitness goals [20]. Environmental management applications help in establishing communication between the hospital and the patient. Monitoring the first responder's health status in an endemic or epidemic outbreak, getting ambulance assistance in case of emergency, developing evacuation schemes for disaster management in hospitals, maintaining active databases to ensure correct delivery of organs/blood to the users in need, accurate billing of surgical procedures through RFID tags are some of the significant applications in environmental management.

FIGURE 7. Application Domains in Smart Healthcare.

5. THE IoT IN SMART HEALTHCARE

The IoT is a combination of ubiquitous communication, connectivity and computing along with ambient intelligence. It refers to a cyber physical paradigm, where all the real-world components can stay connected. The IoT gives users the ability to plan every day and it integrates real physical world elements such as electronic devices, smart phones and tablets which can communicate both physically and wirelessly. The IoT helps in managing virtually any number of devices. It aims in extending the benefits of internet such as remote access, data sharing and connectivity to various other application domains such as healthcare, transportation, parking activities, agriculture, surveillance [21], etc. With enormous benefits and attributes such as identification, location, sensing and connectivity, attached to the IoT, it is the integral component of smart healthcare, as shown in Figure 8. In implementing a smart healthcare system, the IoT can be broadly implemented in a wide range starting from calibrating medical equipment to personalized monitoring system. The IoT plays a significant role in healthcare applications, from managing chronic diseases at one end of the spectrum to monitoring day-to-day physical activities which could help in maintaining one's fitness goals [22]. The IoT can be used to monitor the process of production and tracing of medical equipment delivery. IoT-based architectures can be used to collect medical information from the user. The IoT functions as a bridge between the doctor and the patient by providing remote access, which can help the doctor continuously monitor the patient and give remote consultation. Combining sensors, actuators, microcontrollers, processors, along with cloud computing, the IoT helps in getting accurate results and makes healthcare attainable to everyone.

Using the IoT in healthcare has led researchers worldwide to design promising frameworks and technologies which can provide at-ease medical assistance to everyone. In addition to enriching the user experience, the IoT also urges the industry to automate, providing more research across different cross platforms. The integral components of the IoT in smart healthcare are a sensor/actuator, a local area network or in some case a body area network, the internet and the cloud. Depending upon the application and the requirements of the specific healthcare system, the specifications of each of these 4 integral components can vary widely.

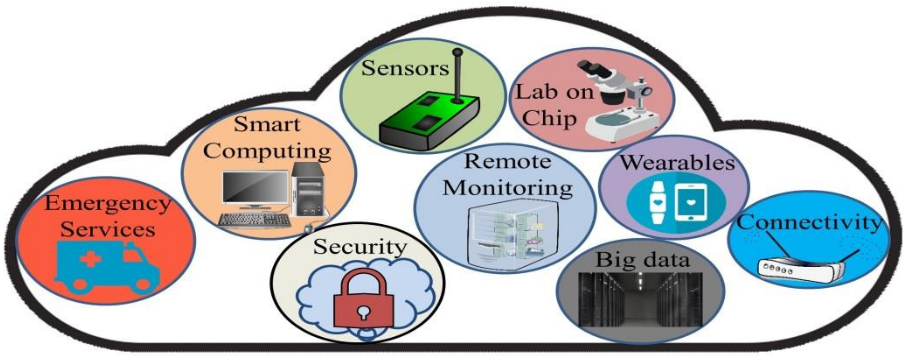

FIGURE 8. The IoT in Smart Healthcare.

6. BIG DATA AND ARTIFICIAL INTELLIGENCE IN SMART HEALTHCARE

In healthcare data, three main challenges need to be addressed: quantity, variety and velocity. There are enormous applications and services which require the storage of patient information and each time a service is used or the patient visits the healthcare facility, the information needs to be updated. Currently, with the increase in smart sensors, social networks, and web services, mobile devices are estimated to be generating more than 2.5 quintillion bytes per day [1]. Hence traditional databases and data storage mechanisms might not prove efficient in handling such large amounts of data. To address these challenges, a mix of non-relational and relational databases need to be used to store clinical data that are present in electronic format. Data collected by the smart healthcare systems need to be consistent. A high-level of semi-structured databases enabling multitude of queries are required. Cloud computing technology makes on-demand services scalable to large amounts of users. It has many features such as virtualization, scalability, pay-per-use and multitenancy. Cloud assistive treatment can help medical professionals offer services to users irrespective of the geographical location. Combining big data techniques with cloud computing, helps in achieving better analysis.
Assisted living, especially for the elderly, has been a primary research area involving Artificial Intelligence in smart healthcare. With intelligent systems that have ambient intelligence, the system increases the quality of life and ensures safety of elderly people. Along with the benefits it offers for the individual, it also helps in providing higher effectiveness of limited resources and improves the living standards.

7. SMART HEALTHCARE: INDUSTRY TRENDS AND PRODUCTS

The scope of smart healthcare products has expanded its horizons and has been predicted by Frost & Sullivan to be a 348.5 Billion USD market by 2025. With a lot of ongoing research and a scope to address new issues, entrepreneurs and well-established industries are competing at their best with remarkable creativity. Smart syringes, smart pills and smart RFID cabinets are gaining everyone’s interest in the smart healthcare domain. RFID has been widely used for infection safety, radiology and control of infections such as TB [23]. Electronic health records are the most significant products of smart healthcare which has given an altogether new perspective for addressing big data issues. These products fall across different verticals such as health data and storage, monitoring and treatment and inventory management.

In the present digital health revolution, Intel is leading the list with their Digital Health Foundation [24]. The company is constantly coming up with innovative technologies for data analytics, assistive technology and improving the home environment for the elderly population. IBM's Watson, an artificially intelligent computer system, can look at the content of the patient's health record and considers the medical information faster, to provide better health care models. IBM has partnered with Apple, Johnson & Johnson and Medtronic to continue their digital health research in a large scale. Google has a dedicated life sciences division to develop and research new technologies in digital health. Qualcomm Life helps in capturing the medical device data and integrates it to the nearby database partner through a wireless medical device and secures the information. This platform offered by Qualcomm provides high range of system interoperability and security. Microsoft's "Connected Health Platform", helps in offering digital health services through desktop frameworks. Microsoft Lync is used by Doctor's to offer medical services to patients in rural areas. Samsung has a $50 million investment in digital health through their Digital Health Initiative which is a collaboration of smart sensors, algorithms and data processing techniques through open source hardware and software platforms. Apple has an open source framework, ResearchKit, which aids researchers to develop apps that can facilitate medical research.

FIGURE 9. Features of a Smart Watch.

On the retail front, Amazon offers a unified healthcare platform where the users can access healthcare information, availability of latest products, health insurance and "on-demand" services. Wearables, especially in the form of smart watches or bands, have been revolutionizing the market. Notable products include Fitbit, moov, Proteus, Pebble Time, Withings AliveCor Health monitor, Beddit and so on. Significant amongst the healthcare products are smart watches. Smart watches are becoming more ubiquitous, as shown in Figure 9. The projected annualized rate is expected to reach 70 million units at a growth of 18% annualized rate by 2021. Apple is expected to have a hold of the larger share in the market, however, Android wear devices are continuously emerging. Apple's iWatch offers a package of built-in GPS, and heart rate sensors with a fast dual-core processor.

8. SMART HEALTHCARE: CHALLENGES, VULNERABILTIES AND OPPORTUNITIES

Though smart healthcare helps in providing better healthcare to everyone in the world, it also becomes more vulnerable to threats. Due to the dynamic nature and smaller form factors, the security requirements in smart healthcare systems vary from the traditional security techniques [25]. Figure 10 shows the key security requirements or challenges in maintaining a secured smart healthcare system. Healthcare networks contain personal information which can be easily tampered with. In order to reduce the cost of the design, the processors used in smart healthcare systems are low speed processors and have low on-device memory, which cannot accommodate additional security mechanisms [26]. Health care devices are mobile, which leads the user to connect to different networks such as home networks, office networks, and public networks. This increases the chance of attacks on the device. Due to the increase in the number of IoT devices in the healthcare network, it is a very challenging task for developers to provide dynamic security updates or a sound solution for multi-protocol information. Smart healthcare systems are vulnerable for security attacks at various levels of the system. By maintaining data freshness in the healthcare network, the passwords and keys need to be updated frequently. Attacks targeting data transmitted in the network can include interruption of the service availability, modification of original data, forging the messages and replaying the messages to disrupt the flow of data and create a false impression. Attacks can also tamper the hardware i.e. the interconnected physical devices or the software, namely the operating systems and applications.

FIGURE 10. Security requirements of Smart Healthcare

A specific example of tampering with a personal medical device, an insulin delivery system, is now discussed [27]. In this system, a personal digital device (such as a cell phone), an insulin pump, a continuous glucose sensor, and a remote-control device are all connected through a wireless Personal Area Network (PAN), as illustrated in Figure 11(a). Possible security attacks on this system can be active, passive, or both, as depicted in Figure 11(b). An example of a passive attack is to intercept the communications in the PAN between the remote control to the insulin pump with the objective of reverse engineering the communication protocol. On the other hand, an active attack is to use this reverse-engineered protocol to attach an impersonating remote-control device to the insulin pump. This allows the attacker full control of the insulin pump with potentially lethal consequences for the patient. Two different defenses for these attacks are rolling code protocols, and body-coupled communication. The rolling code encoder, as presented in Figure 11(c), generates rolling codes which avoids the system's dependency on a fixed device PIN every time. Since the rolling sequence is random (but known to the receiver and synchronized with it), a security breach is nearly impossible. This approach is equivalent to the use of one-time pad cryptography, universally considered as the strongest possible cryptographic protocol. As illustrated in Figure 11(d), the data are decrypted in the insulin pump using the shared key. The decrypted sequence number is then compared to the receiver's counter. If the difference between the two is within a certain range, to allow for small timing differences, then the insulin system validates the received control code, synchronizes the sequence counter, and performs its task. On the other hand, a security model based on body-coupled communication as defense reduces the signal strength, which makes passive attacks very difficult unless the attacker is in physical contact with the patient, which is normally not possible.

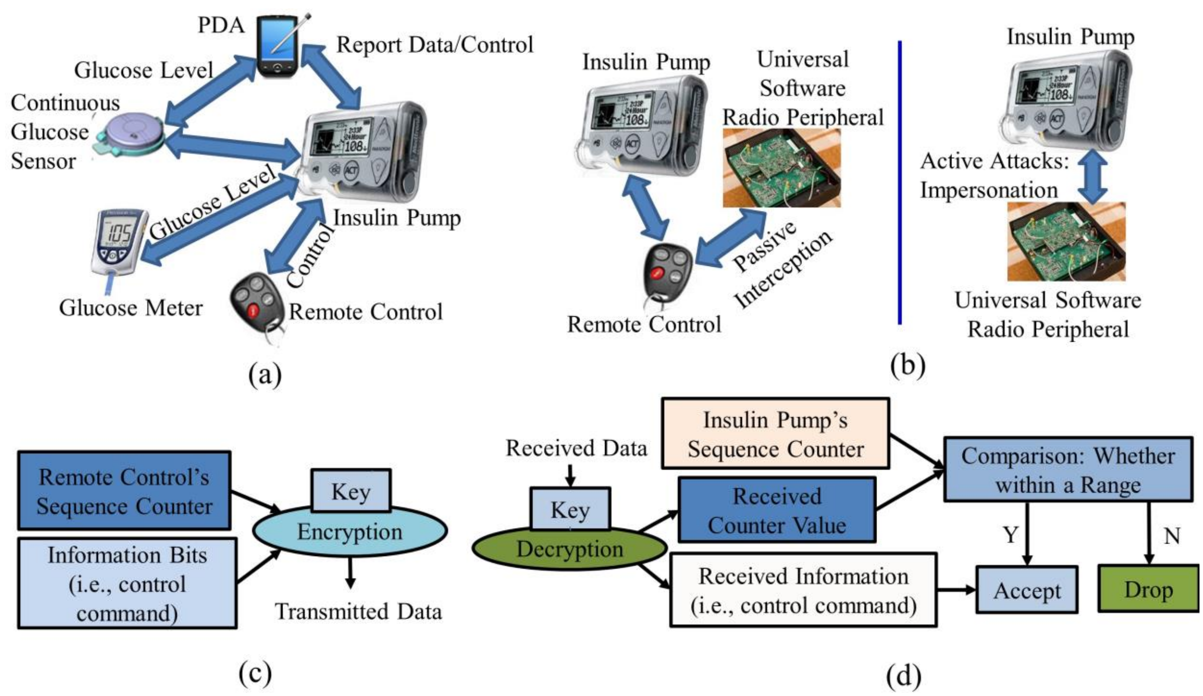

FIGURE 11. A specific example of security attack on a medical device. (a) an insulin delivery system, (b) passive and active security attacks on the insulin delivery system, (c) the rolling-code encoder in the remote control, and (d) the rolling-code decoder in the insulin pump.

Confidentiality is a key security requirement in smart healthcare. Data, which includes private information about the user, needs to be shared only with authorized users. Only authorized nodes and users should have access to the services or resources. At least two-level authentication needs to be implemented to ensure the identity of the peer.

Integrity needs to be maintained in the healthcare network, assuring the users that the data which are transmitted and received are not altered or compromised. If the interconnected device is compromised, the security system should ensure that there is no attack on the information or device in the healthcare network. The interconnected devices need to be self-healing to some degree, which ensures that if a device fails, it has minimum impact on the healthcare network.

9. NANO-SMART HEALTHCARE

Consumer electronics empowered with the latest wireless technologies and seamless architectures help in improving the quality of life through smart healthcare. One such example is the pill camera. Endoscopy or colonoscopy are procedures which are generally used by doctors for monitoring the internal organs for any gastrointestinal infections [28]. It is generally prescribed for patients with colon cancer, irritable bowel syndrome, stomach ulcers, tumors, piles and so on. These procedures are not just expensive; they also make the patient uncomfortable as a long tube is put inside a person. A pill camera makes the job easier for both the patient and the doctor. It is as simple as swallowing a pill and getting high resolution pictures of the internal organs. Figure 12 shows the overall architecture of the pill camera. The pill camera is a light device with image sensors to capture the footage, and an RF transmitter and antenna to wirelessly transmit this acquired data in real time to the data recorder which is a waist belt or a shoulder strap. The magnetic strips help in activating the camera as and when required. The LEDs are timed in such a way that when the camera reaches the appropriate position, they are turned ON to monitor the exact location and obtain better images. This camera is either powered by a small battery or through induction charging with the help of the data recorder strap. As there is no on board memory in the pill camera, it makes it very light to navigate through the intestine. Though pill cameras have been around for almost a decade, the latest advancements can produce over 800,000 images in 8 hours, with the camera turning at around 60 degrees every 12 seconds.

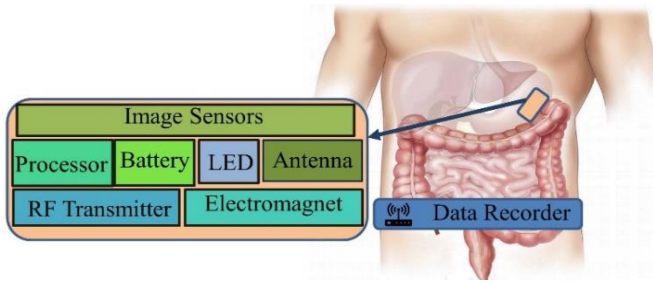

FIGURE 12. Pill Camera.

10. CONCLUSIONS AND FUTURE

This paper provides an extensive survey on the current research trends along with the challenges and opportunities available in smart healthcare. Needle-less and cost-effective healthcare solutions have always been on great demand. With enormous funding and increasing attention towards the smart healthcare domain, there are numerous products and applications available for users. As smart healthcare has multi-dimensional applications, it offers a lot of scope for researchers to constantly innovate new products and improve the already existing architectures. The transition towards smart healthcare services, is a slow and steady process. This is mainly because healthcare professionals need to be constantly educated and convinced to adapt to the digital era. By bridging the gap between researchers and healthcare professionals, more research problems and diseases can be addressed and smarter lifestyles can be adapted. Though the smart healthcare solutions backed by the IoT can improve revenue, and increase quality of life, the benefits can be easily overshadowed, if security is compromised. Additional measures need to be taken to handle threats and securing the potential information at both the customer and developer ends. Thus, the vision and long-term success of this dynamically growing industry lays in the synergy of researchers, healthcare professionals and the public.

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