Secured Cancer Care and Cloud Services in IoT/WSN Based Medical Systems

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Abstract. In recent years, the Internet of Things (IoT) has constituted a driving force of modern technological advancement, and it has become increasingly common as its impacts are seen in a variety of application domains, including healthcare. IoT is characterized by the interconnectivity of smart sensors, objects, devices, data, and applications. With the unprecedented use of IoT in industrial, commercial and domestic, it becomes very imperative to harness the benefits and functionalities associated with the IoT technology in (re)assessing the provision and positioning of healthcare to ensure efficient and improved healthcare delivery. In this research, we are focusing on two important services in healthcare systems, which are cancer care services and business analytics/cloud services. These services incorporate the implementation of an IoT that provides solution and framework for analyzing health data gathered from IoT through various sensor networks and other smart devices in order to improve healthcare delivery and to help health care providers in their decision-making process for enhanced and efficient cancer treatment. In addition, we discuss the wireless sensor network (WSN), WSN routing and data transmission in the healthcare environment. Finally, some operational challenges and security issues with IoT-based healthcare system are discussed.

Keywords: IoT · Smart health care system
(wireless) Sensor network · Cancer care services · Cloud services
Business analytics

1 Introduction

Internet of Things (IoT) technology presents promising technological, economic, and social benefits to the evolution of data communications and networking facilities due to the advanced connectivity of devices, systems, and services beyond machine-to-machine (M2M) communications. Interestingly, the IoT technology has contributed to and supported a wide range of services and applications, such as smart cities, waste management, home automation, transportation systems, and healthcare. It is also fuelling the development of "smart connected things" – televisions, thermostats, medical devices, cars, wearable technology – clothing and devices [7].

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This research considers two of the various services that are pertinent to healthcare delivery. Specifically, it is intended to propose the application and implementation of IoT technology in cancer care health delivery in the context of cancer care services along with the incorporation of business analytics and cloud services for cancer care treatments and diagnoses. The combination of these services proffers solution and framework for analyzing health data gathered from IoT through various sensor networks and other smart connected devices to help healthcare providers to turn a stream of data into actionable insights and evidence-based healthcare decision making about the health conditions of patients using appropriate analytics tools to improve and enhance cancer treatments.

1.1 Motivation and Related Work

The motivation for this research work has been triggered by the desire to improve the cancer care in healthcare delivery. Hence, this has prompted the need to (re)assess the provision and positioning of healthcare services to harness the benefits associated with the use of IoT technology. This relatively new trend in IoT technology will suffice in ensuring interconnectivity and interoperability among the health centres, clinics, and hospitals in various regions through network design that will facilitate health region-wide communications. As a result, it is argued that the use of IoT initiative will offer huge benefits such as increased workforce productivity, overall cost savings, enhanced Return on Investment (ROI), improved and new business models [12], and improved collaboration with health practitioners and patients in every service of healthcare delivery. It is also argued that by 2019, about 87% of healthcare organizations would have adopted IoT technology with about 76% in the healthcare industry [17]. The widespread application of IoT in healthcare domain has been successfully applied in a variety of services, including cancer care and business analytics/cloud services [8], medical system (such as clinical care – drug labelling and administration, blood transfusion, real-time ECG monitoring, etc.) [7,10], health and wellness monitoring, remote monitoring system [11], rehabilitation system [3], operational services system [2,4], emergency services system [4,9], just to mention a few. In the course of this research work, we found that most of the papers only mentioned some of the services listed above but none on the application of IoT in cancer care services until a brief version of our initial work [8] has been published. In essence, we have incorporated lots of details and proposed new frameworks, components, and benefits not previously covered in the implementation of IoT and cloud services in cancer care services in this research.

1.2 Background of Smart Healthcare System

Adoption of IoT based healthcare systems in all the operations of health industry will facilitate enhanced diagnoses/treatments and monitoring, automatic infirmity and condition detecting and sensing, community health care, location-based health care, rehabilitation, surgery and recovery, imaging services, etc. The IoT devices will be used for communicating between patients and those in the circle of care, and for sharing and interconnecting healthcare network resources into the network as related to the delivery of IoT-based smart healthcare system. The healthcare resources include physicians, doctors, oncologists, health providers, nurses, other health personnel in the circle of care, patients, caregivers, human resources, ambulances, emergency units, medical devices, hospital sites, clinics, community health centres, workstation servers, smart devices or connected things (e.g. tablets), sensors, etc. This interconnection of resources can be achieved through various network industry communication standards such as wireless (short, medium and long), Ethernet with transmission control protocol/internet protocol (TCP/IP), unique identifier (UID) based identification, and GPS-based location technologies.

The remainder of the paper is organized as follows. Section 2 discusses the framework for IoT solution. Section 3 provides the methodology and analysis of the network, which includes design basics and hierarchical architecture based on the core, distribution, and access layouts, respectively. Also discussed is the WSN, its routing and data dissemination in the healthcare environment. Section 4 presents the network design solutions for healthcare services using mesh hierarchical topology. Section 5 discusses the concluding remarks and recommendations for future research.

2 IoT Based Healthcare System Framework

Fig. 1 represents an IoT based healthcare system framework for the proposed network that shows the interdependencies of various components that are impacted by the network design methodology. The framework captures some features and approaches to be adopted in presenting the design solution. It also defines the way we integrate, interface, network and transmit the network resources produced by those connected devices from one node to another within the system.

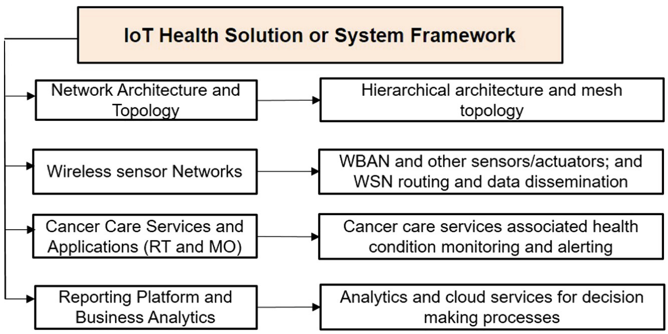

Fig. 1. IoT health solution/system framework.

3 Network Methodology and Analysis

3.1 Network Design Basics and Hierarchical Architecture

It should be noted that the success of any network design is crucial to its implementation. This is why we have paid a close attention to the network design to ensure flaws are eradicated, especially to project of this nature, in terms of the organization size and the number of healthcare network resources that are interconnected. Though, it might be difficult to design a network that is nearly 100% reliable. However, we have thoroughly determined the requirements (i.e. technical and non-technical) in the design of the smart healthcare system in order to decide what is considered a good design, thereby avoiding over complication of the network design.

In addition, two categories of network architecture are considered, namely, *flat architecture* and *hierarchical architecture*, but the focus here is on the hierarchical architecture. Hierarchical architecture is easier to manage and expand, and any inherent issues are more quickly solved with little or no disruption to operation. Typically, hierarchical architecture divides the network into three discrete layers: (1) Core Layout; (2) Distribution Layout; and (3) Access Layout. Each of these layers provides specific functions that define its role within the overall network, thereby resulting in a network that provides modularity with the design goals of scalability (i.e. to meet the demands for additional services), supportability, availability, performance, redundancy, maintainability, security, tolerance, and manageability [5]. The access layer interfaces and controls the end devices (such as sensors, actuators, and IoT connected/smart devices) and the rest of network resources that communicate on the network.

3.2 Wireless Sensor Networks

The combination of the Internet, network communications, information technology, and engineering advances have made provision for a new generation of inexpensive sensors and actuators, which are capable of achieving a high order of spatial and temporal resolution and accuracy. Currently, network sensor systems are seen as an important component of the IoT technology, which has experienced rapid growth in various applications [12,15]. According to [12], a sensor network is an infrastructure comprising of sensing (measuring), computing, and communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment, where the environment can be viewed as physical world, biological system, or an information technology system. The technology embedded in sensors constitutes a broad range of applications in health care, agriculture, energy, food safety, production processing, quality of life, and many other fields. All these applications involve sensing, collecting, and sharing data.

3.3 WSN Routing and Data Dissemination in Healthcare

Predominantly, the use of wireless/smart sensors and connected devices plays a major part of IoT implementation. These devices are deployed for all the services (with a few exceptions) as they will be strategically attached to or implanted within human body or placed in a specific area to monitor patient under surveillance, treatment or diagnosis in order to collect objective measures/data. Once deployed, the sensor nodes form an autonomous wireless ad hoc network which is attached to the main network.

As the application of WSNs becomes apparently useful for various services in healthcare setting, data and information from sensors are being transmitted and routed within the networks from one site to another, then to the data center site through cloud services (as will be discussed in business analytics and cloud services section). In data dissemination through WSN, some characteristics have to be addressed such as routing protocols from one source to another. This is necessary to adopt appropriate routing strategy in WSNs that is capable of managing the trade-off between optimality and efficiency to ensure computation and communication capabilities [12]. In WSN routing, four strategies are proposed, namely: *flat or hierarchical network*, *structure on the network*, *data-centric network*, and *location network*. But in this research, we consider the location-based routing since it cuts across different locations where the position of the node within the geographical coverage of the network is relevant to query issued by the source node. This ensures cost effective routing approach geographically due to its low overhead and localized interaction [12], and it offers the possibility of including several routing algorithms for data dissemination. The geographical WSN routing and data transmission from WSNs in a clinical setting is illustrated in Fig. 2, where each node of the sensor forwards data to the destination located at the data center within the network.

3.4 Proposed IoT-Based Healthcare Services and Applications

In the design of network, there is a variety of network topologies for network communication. Since the desire is to identify the best solution that meets the needs of a smart healthcare system, a full mesh topology is proposed. In this, every node in the network has a connection to each of the other nodes (i.e. all nodes cooperate in the distribution of data thus allowing for most transmissions to be distributed, even if one of the connections goes down) [5]. The proposed IoT-based healthcare system comprises of services and an array of applications and conditions to patients administered by those in the circle of care. There exists an association between the services and applications/conditions for managing different types of diseases/infirmities, along with the broad categories of disease or infirmity conditions, as summarized in Fig. 3. The architectures for both services are discussed subsequently.

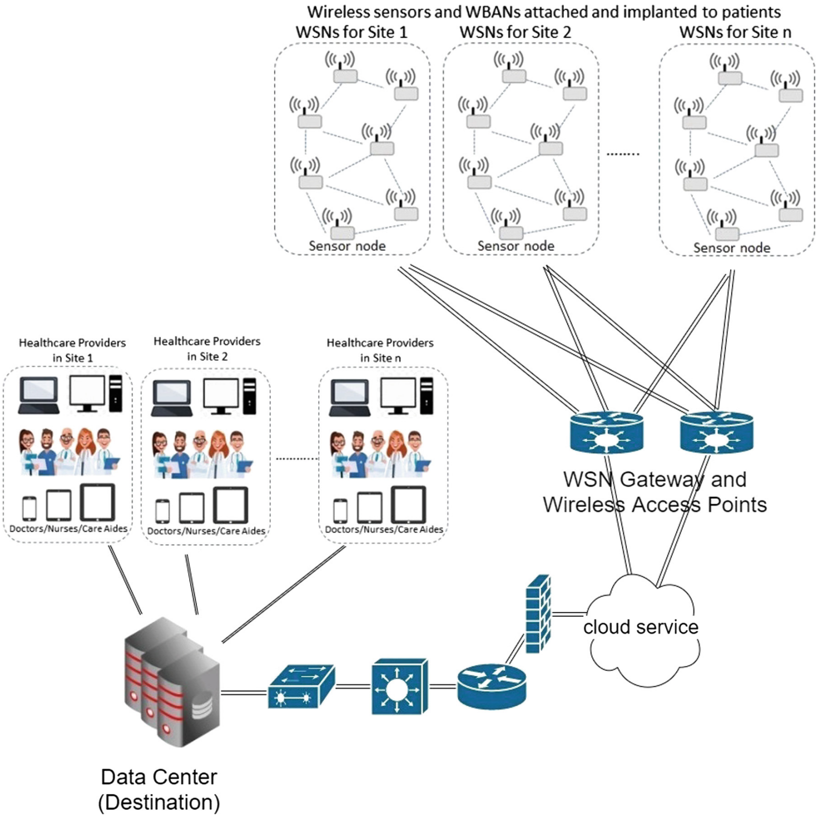

Fig. 2. WSN routing and data transmission.

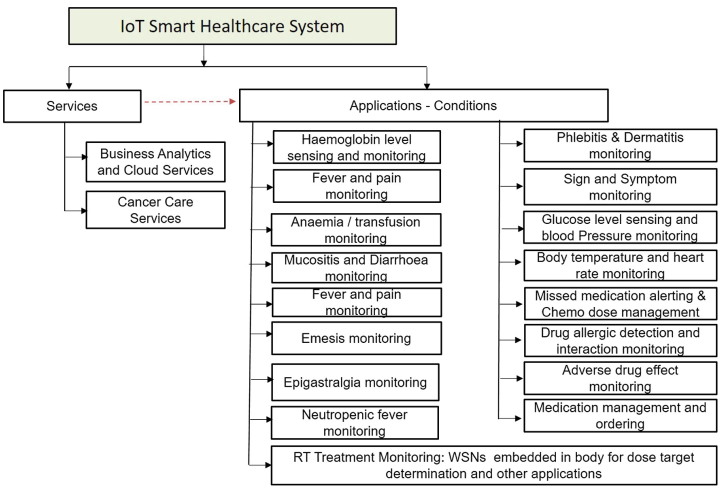

Fig. 3. IoT health care services and applications/conditions.

4 Network Design Solutions for Services

4.1 Cancer Care Services

Essentially, cancer care services comprise of two sub-services associated with the diagnosis and treatment of cancer, namely, chemotherapy and radiotherapy. The chemotherapy is associated with medical oncology (MO) while the radiotherapy (RT) is associated with radiation oncology (RO). The use of smart devices and wireless sensors can be applied towards improving the quality of cancer care services and patient care by seamless and secure integration of those devices in medical oncology and radiation oncology procedures. This is argued in [16] that patient care (i.e. monitoring, alerting, and following-up) for cancer patients undergoing chemotherapy can safely be moved into the home.

As pointed out in [8], attaching and embedding WSNs and smart devices to patients can enhance cancer treatments by allowing health practitioners/nurses to monitor and be alerted of any changes, complications, problems, signs, symptoms, adverse effects, allergies, pains, infections, toxic effects, neutropenic fever occurrences, missed medications, haemoglobin level issues, drug allergic detection, drug interaction, phlebitis, dermatitis, mucositis, diarrhoea, infection of upper respiratory tract, emesis, epigastralgia, neutropenic fever, etc. These issues can automatically be detected, subdued, and blocked, thereby influencing patient care and attention related to patient treatment and enforcing what controls to put in place to circumvent those changes, issues, effects, and symptoms.

Although, [1] claims that no perfect methodology for identifying the magnitude of the adverse effects and issues of chemotherapy, but as alluded by [8], the MO cancer care services can incorporate smart devices that provide assistance to cancer patients in the event of any issues/complications through process automation, remote monitoring, and alert communication. In essence, the IoT technologies through WSNs/smart devices can be programmed at certain level of precision to determine fairly reasonable magnitude deemed fit for the adverse effects of those characteristics on the body. With this innovation, the level of care to patients undergoing such issues can be monitored as shown in Fig. 3.

On the other hand, the implementation of IoT and WSN devices in radiation oncology treatment or radiotherapy is different because of the manner the prescription doses are being administered to patients. Though the use of IoT connected devices can be applied as depicted in Fig. 4. Generally, prior to the DICOM communicating with the various pieces of software, a sequence of steps for the RT treatment starts with the generation of treatment plans in $Eclipse^{TM}$ by associating related files, namely computed tomography (CT) files, radiotherapy (RT) structure files and dose-volume as applicable to commercial treatment planning system, $Eclipse^{TM}$ with DICOM as interface [6]. This leads to the determination of prescription doses or final dose calculation for the targets or disease sites and the dose volume constraints for organ at risk (OAR). This is followed by the uploading of plan DICOM files back to Eclipse and recalculating the dose and dose volume history (DVHs), then finally doing the evaluation on Eclipse and also conducting patient QA for dosimetric analysis of internal anatomy because emphasis should be placed on the accurate definition for the targets to ensure precision of protons radiotherapy prior to administering of the doses to patients [6]. Having discussed above, we have to admit that the use of inherent smart devices and wireless sensor networks could help achieve intended results for patient treatment. Therefore, the use of IoT technology can be beneficial for administering radiotherapy to patients as it could help improve the margin, preciseness, and accuracy of the radiotherapy doses to ensure they hit the targets/disease sites thereby eliminating geometric uncertainties in setup, patient motion, and patient changes. In this case, WSNs or IoT devices can be implanted or embedded close to the targets, and this will ensure the doses from the linear accelerator do not miss their targets. WSNs are perceived to be useful in achieving better treatment planning results toward appropriate prescription doses.

From Fig. 4, the Health Level-7 (HL7) connectivity utilizes XML technology for interoperating two or more systems for data definition and message exchanging, sharing and reusing within and between lab centres and clinics. On the other hand, the Digital Imaging and Communications in Medicine (DICOM) connectivity communicates with the various pieces of software for transmission of diagnostic images while the embedded systems, such as Laboratory Interface System (LIS), Pathology Interface System (PIS) and Radiology Interface System (RIS), serve as access points for the healthcare providers to access patient information relating to lab results, malignancy or abnormal (pathology) results, and radiology results. In wrapping up, all these systems along with the pharmacy, medical oncology, and radiation oncology servers allow access to comprehensive patient chart information from any device (workstations, tablets, etc.) either at the clinical environment or via remote VPN access from outside the clinic(s). The underlying technologies being considered include: Bluetooth Low Energy (BT-LE), Near Field Communication (NFC), Radio Frequency Identification (RFID), and 6LoWPAN/WiFi/ZigBee [8]. Figure 4 illustrates the network architecture for the proposed cancer care services.

4.2 Business Analytics and Cloud Services

With the growing rate of patient data generated by means of the wireless sensor networks (i.e. WBANs, wearables, smart devices, and embedded systems), data, queries and physical characteristics as observed from these devices and equipment are gathered and collected for researching, analyzing and reporting purposes; gaining intelligence; formulating insights; streamlining operations; and gaining competitive business advantage.

The incorporation of business analytics and cloud services to cancer care services ensures availability and accessibility of patient data being streamed from various sources on a real-time and continuous basis. This, in turn, enables the ever-increasing data to be managed and shared across the healthcare network systems upon deployment into the cloud. Obviously, streams of data are relayed and generated about patients and for some medical devices (through sensors and other connected devices) as related to the patients. These data, in form

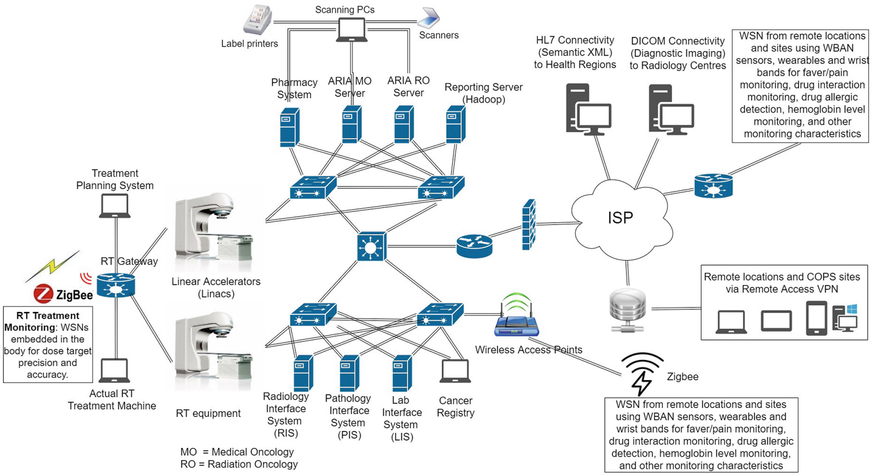

Fig. 4. Cancer care services network architecture.

of multimedia, textual and visual formats, are transmitted through the cloud services to remote servers (data center). As a result, the volume, velocity, and variety of health data and information of patients have continually increased significantly, which puts challenges for analysis and interpretation of data for decision-making purposes using appropriate data analytical tools [8,14].

This architecture also offers reporting capabilities for immediate dashboards that facilitate treatment decisions as we will be able to discover patterns from all the data from various services in order to analyze the quality of care and risk, disease and epidemic pattern, patient/facility monitoring and optimization, etc. This, indeed, will be beneficial to healthcare providers to turn a stream of data into actionable insights and evidence-based healthcare decisions about the health conditions of patients, and also for helping the clinical experts and research groups to keep up to date with the latest trends and breakthroughs in clinical oncology practices. The architecture uses the Picture Archiving Communication System (PACS), which comprises of secure computer systems for storage, retrieval, and display of diagnostic images such as X-rays, CT scans, Magnetic Resonance Imaging (MRIs), etc. The PACS constitutes an important component, where the diagnostic images are being retrieved and accessed through the business analytics and cloud services as made available on the cloud. In view of this, we have proposed an appropriate strategy to gather and analyze data as collected across the network fabric and communications infrastructure through secure transmissions from one end to the other. The details of the network architecture for the business analytics/cloud services are as depicted in Fig. 5, where the initial figure in [8] has been modified to include PACS component.

Hadoop Deployment in Business Analytics and Cloud Services. Based on the huge volume of data involved for those services, the Hadoop cluster or framework is viewed as an ideal solution for processing and solving the workloads associated with massive amounts of data storage, which ensure transformations between source systems and data warehouses. Hadoop cluster is used for predictive analytics through its own machine learning and data mining capabilities. With Hadoop cluster, crucial single point(s) of failure that could bring down the entire Hadoop cluster can be eliminated, and it makes provision for data to be normally triple replicated to ensure availability in the event of failures and disasters [10]. Other benefits of Hadoop include its low response time and real time alert capability. In summary, Hadoop is considered for the following features and characteristics, as follows [13]: *data value*; *schema*; *workload*; *data sources*; *availability*; *security*; and *scalability*. The NoSQL databases and Hadoop cluster components are suggested for the business analytics and cloud services basically for conducting disease, genomics and epidemic pattern research; patient-disease tracking and monitoring; patient sentiment analysis; risk and quality of care analysis; etc. (as shown in Fig. 5).

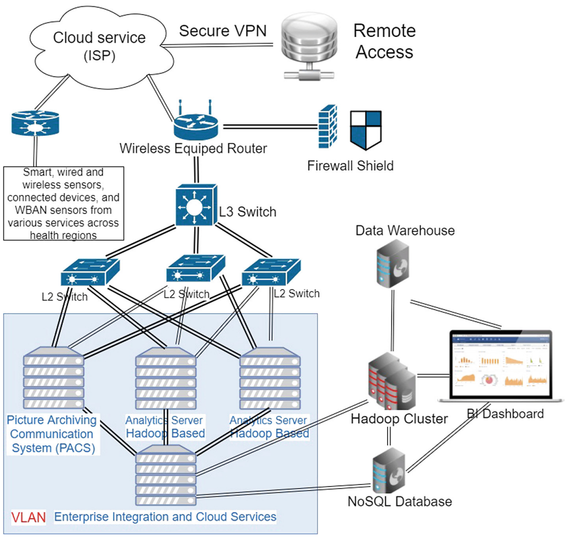

Fig. 5. Business analytics and cloud services network architecture [8].

4.3 Operational Challenges and Security Issues

In [8], we have outlined the analysis of the operational challenges and security issues to cancer care services based on IoT, which we will suggest to the reader to read it though additional information is provided here. While using business analytics on patient data, the issues of confidentiality and privacy have been a concern without exposing the patient demographic information to the research group and business experts. As a result, we will ultimately ensure that patient-sensitive information is protected and encrypted as this may be a major threat and barrier in realizing the potential benefits of business analytics services in healthcare environment, which could deter business improvements, if not addressed.

Since there are various nodes, wireless devices and sensors in the proposed solutions, then we have to ensure that those devices conform to industry standard (i.e. meeting the service- and operational-level agreements) that guarantee reliability and security. In addition, the reliability of the network system is very paramount especially due to the nature of the healthcare environment coupled with the sensitivity of patient information/data. This is one of the reasons why mesh topology is proposed, especially at the distribution layer such that every data transmitted from the source is accepted at the destination within a reasonable time. It is also to ensure high availability with minimal equipment failure and human intervention.

4.4 Securing IoT Services and Devices

Knowing that the security of patient medical data cannot be underestimated and jeopardized, then it becomes imperative to talk about securing the various devices and services being made available during the design of the IoT based medical system in order to avoid leakage of patient information. Hence, some feasible security mechanisms as related to this research include but not limited to: *security for communication in IoT*. For the communication in IoT devices from one layer to another in the network architecture, the three layouts: core, distribution, and access, should be an utmost consideration in terms of security and protection due to the nature of the healthcare environment; *security approaches or mechanisms for WSN, smart connected and remote (RFID) devices*. It is equally paramount to ensure security mechanisms for the WSNs that characterize the IoT solution through securing the routing protocols to prevent attacks that could affect the entire network. In addition, the security mechanisms can be extended to prevent illegal node access, while at the same introduce trust management and distribution mechanism for the WSN routing for data privacy and location privacy of patients within and outside the clinical environment, more so that a large number of nodes is required coupled with the generation/dissemination of a large amount of data; *security for IPv6 (6LoWPAN)*. The use of low power consumption devices and sensors should be considered especially with long-term device or sensory operation coupled with the involvement of human lives (as for devices that are embedded in the human body or with contact with the human body). This will certainly mandate the use of low power IPv6 architecture in the design of the IoT based solution with low power consumption for secured integration; and *security, privacy, and encryption of actuators/sensors, remote devices are equally important*.

5 Conclusions and Future Work

We have proposed the implementation of the IoT based medical system, with reference to cancer care services and business analytics/cloud services, for enhanced treatment, diagnosis, and monitoring of cancer patients. The healthcare solution has been accomplished through the use of WSNs and smart connected devices. This is because WSN plays an important role that allows a number of spatially distributed autonomous sensors to be linked to the network fabric based on geographical routing from source to destination, which facilitate data transmission/exchange. We have also delved into business analytics/cloud services that ensure the availability of patient data stream for actionable insights and evidence-based healthcare decisions. Also addressed are the operational and security challenges associated with the deployment of IoT based medical system due to the nature of the environment and the sensitivity of patient information. This is necessary prior to the go-live phase of the IoT based solution implementation to avoid failure to the entire system and breach of patient data.

In wrapping up, it is worth mentioning that there are various services being delivered in healthcare settings but we have only covered the cancer care and business analytics/cloud services. Hence, we will be considering and integrating more services in our future research work in the same research domain.

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