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Implementing IoT/WSN based smart Saskatchewan Healthcare System

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Abstract

The Internet of Things (IoT) technology has recently experienced popularity and growth in every facet of life, and it has been applied to every industry in recent years. The healthcare system has not been left out of the equation, where various services are considered toward improved healthcare and patient delivery. It is important to emphasize that related literature on the applications of IoT in healthcare explored various services on an individual basis without considering the consolidated services as we have introduced. Here, the consolidation of those services proffers improved healthcare delivery, which impacts and collaborates in an IoT-based healthcare environment. In this paper, we have utilized the newly formed Saskatchewan Health Authority comprising of various healthcare regions as our case study. In essence, we have proposed a Smart Saskatchewan Healthcare System based on IoT technology in the context of four services, namely: business analytics and cloud services, cancer care services, emergency services, and operational services. Further, the paper highlights the design implementation of a smart healthcare system for the province of Saskatchewan for enhanced electronic medical record initiative and also to augment and support the existing healthcare delivery options to ensure the quality of life of patients by integrating IoT technology and other pertinent technologies in the contexts of those services. It also features IoT-based network mapping, designs, methodologies, frameworks, architectures, platforms, and applications for the IoT based solution for all connected things (network resources and sites) towards efficient healthcare delivery. We have combined all these services to foster faster and more efficient healthcare delivery. We have also alluded that the stream of patient health data generated by the IoT smart/connected devices will be helpful in decision making and gaining insights. The operational challenges and security concerns pertinent to the design of the smart healthcare system are discussed. Lastly, from the design network solutions, it is evident to admit that the solution arguments and delivers improved healthcare delivery using IoT/WSN technologies.

Keywords Business analytics · Cancer care services · Emergency services · Operational services · IoT · Healthcare system

1 Introduction

The term "Internet of things" (IoT) was first invented in 1999 and has been applied to shape the world of technology with smart connectivity, interconnectivity, and interoperability. We cannot talk about the future of the Internet without mentioning the Internet of Things. In essence, the Internet of Things is viewed as a complex business technology because it goes beyond just smart or connected devices instead, it is an extension of the internet into the physical world. Since the advent of IoT, it has generated interests among researchers in various fields of human endeavor, and the research is still ongoing at least for the next few decades. The IoT has been a very promising innovation for communicating, sensing, identifying, networking and integrating connected devices and services to provide immediate information interaction, communication and monitoring from network-connected devices in order to facilitate exchange and collection of data to and from remote systems (servers).

Unequivocally, sensors and smart connected devices have been predominantly utilized to observe and capture

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physical parameters in various environments for improving operational processes and services. It is possible to allude that most of the IoT-based solutions and deployments, especially in healthcare settings as we have proposed, comprise heterogeneous smart devices. Hence, in integrating and interacting those devices/sensors, it is paramount to take into account the communication criteria that describe the attributes to be considered when embedding the devices into the IoT-enabled network solutions coupled with the IoT access technologies [7, 16]. The attributes are as follows: range, power consumption, topology, frequency bands, constrained nodes/devices, and constrained networks. On this premise, [10] has argued and envisioned a framework for optimizing fault tolerance in virtualization in wireless sensor networks based on the heterogeneity and constraint of devices of the network requirement for IoT application. Note that this focused on communication failure. Therefore, this paper [10] points an approach that could be used to deal with the challenge of communication failure especially when running IoT services on virtual networks.

Also, sensor-enabled and smart connected devices are being utilized to monitor, interact, and respond to immediate physical environments and surroundings. Since the IoT devices have the capability of generating data in the form of texts, images, audios, and videos, [1] has demonstrated the use of multimedia-oriented IoT for pervasive and real-time vehicle communication. This involves smart enabled devices and IoT access technologies such as dedicated short range communication (DSRC) and 5G communication technologies for urban and highway traffic video streaming in vehicular IoT (VSV-IoT) environments. It is interesting to mention that [1] also delves into various metrics and simulation tools for vehicular video streaming communication.

On the other hand, smart/IoT-enabled devices are significantly for the generation of a massive amount of data as will be addressed subsequently. In this research, WSNs are utilized with a variety of heterogeneous smart/IoT devices/nodes that are interconnected across the network making up the proposed healthcare system solution with access and interaction from various geographical health regions and sites across the province. Considering the full-mesh network architecture or topology, we have perceived that energy consumption might be an issue to the solution, which needed to be addressed at one point or the other during the design implementation. The issue has been considered by [4] to ensure the sensor nodes are energy efficient, especially during transmitting and receiving of data packets. As a result, [4] argued and proposed a framework for reducing the energy consumption of the sensors in the WSN mesh-topology architecture/system through energy-oriented path selection and message scheduling approaches.

In the context of healthcare, IoT could be applied as a means of preventative care. In fact, it has been found to offer a wide range of benefits by means of connected devices, which include monitoring the patient's conditions/symptoms; alerting nurses and physicians of missed medications; monitoring pains and fever; monitoring haemoglobin; managing allergies; detecting illnesses; enhancing treatments and diagnoses; managing chronic illnesses; assisting with disabilities;just to mention a few. As a result, healthcare providers and those in the circle of care have continued to embrace the implementation of IoT technology in various services in healthcare [28]. Even, IoT has facilitated the next generation of the connected healthcare industry thereby causing drift from the traditional approaches to revolutionized technological approaches. Given this, we anticipate exploring this revolution in the manner in which healthcare delivery is provided using IoT connected devices, smart devices and sensors. However, there are various enabling technologies of IoT that enable communication and data collection. These technologies include but not limited to Wireless Sensor Networks (WSN), ZigBee wireless 802.15.4, cloud computing, 6LoWPAN, RFID, BT-LE, Wi-Fi, and Hadoop framework.

Typically, healthcare delivery delves into a variety of services such as cancer care services, business analytics/cloud services, operational services, emergency services (including ambulance services, vehicular accidents and patient emergency), patient tracking services, rehabilitation services, surgical services, infirmity and condition detecting/sensing services, laboratory and blood services, diagnostic imaging services, immunization services, etc. Typically, all these services and many more are expected to be carried out in any healthcare setting. However, the goal of this research paper is to propose four of those essential healthcare services, which will be modeled for the newly established Saskatchewan Health Authority IoT driven solution. Therefore, the focused services are cancer care services, business analytics/cloud services, operational services, and emergency services (including ambulance services, vehicular accidents, and patient emergency), respectively. In essence, this research can be perceived as a well-thought-out notion to augment the existing traditional service delivery approaches for those healthcare services by incorporating IoT/WSN technology.

Also, the proposed IoT driven healthcare solution presents interoperability and consolidation of various services in the form of consolidated services as against individual services being addressed in some related literature. Hence, we have consolidated those services for the following reasons:

- streamline workflows and processes across the entire health authority for various regions and sites in the province
- reduce the cost of healthcare delivery and medical treatment
- ensure quality care and safety of patients
- improve drug administration
- improve drug/medicine inventory management and procurement
- enhance control and monitoring of hospital assets and medical equipment/devices
- ensure prompt access to patient vital statistics and speed up healthcare delivery to emergency patients to reduce complications
- reduce errors and ensure the confidentiality and privacy of patient medical records
- access to patients' electronic charts rather than the use of paper charts

The notion of the paper is to implement IoT in Saskatchewan Health Authority (SHA). As observed, it can be viewed as a design of the implementation or better still design implementation as the consideration in the future is to implement it on a particular scale. On the other hand, it could be viewed or likened to pre-implementation based on the three phases of implementation: pre-implementation, actual implementation (go-live), and post-implementation. On the whole, it is highly essential to ensure a design implementation and/or architecture that define(s) the functions of various infrastructures within the overall network in meeting the fundamental network design goals of scalability, availability, performance, redundancy, maintainability, security, tolerance, and manageability that will ensure increased or enhanced interconnectivity, interoperability, and intercommunication as argued in [16]. This is intended to meet the various complexities regarding both the technical and non-technical requirements associated with the integrated healthcare system for the province based on the IoT technology to ensure a cost-effective network solution.

The remaining parts of this paper are organized as follows. Section 2 discusses the motivation, related work and background information leading to IoT based healthcare system regarding Saskatchewan Health Authority (SHA). Section 3 delves into the framework for IoT Smart Saskatchewan Healthcare System. Section 4 discusses the network basics and technologies as deemed necessary for the design of the smart healthcare solution. In Sect. 5, the proposed Smart Saskatchewan Healthcare System, along with some pertinent thoughts on various services being considered are introduced. Also, the comparison between our proposed healthcare system and some existing healthcare systems are summarized. In Sect. 6, the IoT-based operational challenges/issues and security concerns associated with the proposed smart healthcare solution are extensively discussed. Lastly, Sect. 7 discusses the concluding remarks, and recommendations for future research.

2 Motivation, related works and background

2.1 Motivation and related works

The motivation for this research work has been prompted by the need to improve healthcare delivery in the landscape of Saskatchewan. This is perceived will be useful to healthcare providers and those in the circle of care, especially as the province embarks on the consolidation of healthcare regions and agency in Saskatchewan under one umbrella, known as Saskatchewan Health Authority (SHA). With the relatively new hype in the world of technology as orchestrated by the IoT innovation, we have conceived that this will suffice in the consolidation to ensure interconnectivity and interoperability among the health regions through network designs that will facilitate health-region-wide communications. It is argued that the use of IoT initiative will offer huge benefits such as increased workforce productivity, overall cost savings, enhanced ROIs, improved and new business models [30], and improved collaboration with health practitioners and patients in every segment of healthcare delivery.

Next, we delve into some related works that have been done in this research domain. The impact of IoT has been seen in a variety of application domains, including healthcare. The widespread application of IoT in healthcare domain has been successfully applied in a variety of services, including emergency services and operational services [12], cancer care services and business analytics and cloud services [15–17], medical system (such as clinical care - drug labelling and administration, blood transfusion, real-time ECG monitoring, etc.) [8], health and wellness monitoring. Moreover, in remote monitoring system [11], rehabilitation services and system [3], ambulatory care services and system [5], patient healthcare monitoring [2], inventory management system [9], home care cancer monitoring [27], general perspectives in healthcare system [18], healthcare asset management system [13], patient heart ECG telemetry system [19], just to mention a few.

Although the concept of IoT has been studied in the literature, most focused on the general healthcare-related experiences with no particular services being discussed. For examples, in [8], smart connected devices, and IoT access technologies through IoT are utilized in health monitoring and management but with no specific details about various healthcare services other than the general review in healthcare. Similarly, as per [2], the research considers wearable and implantable body area network systems for continuous monitoring of patients to minimize the costs associated with the use of caregivers while still being provided with quality care. In this case, no specific healthcare services are discussed but based on the general view. Similarly, in [19], a real-time signal quality-aware ECG system for healthcare monitoring based on IoT is considered. This provides IoT-enabled ECG monitoring framework using ECG sensors, Arduino, Android phone, Bluetooth, and cloud server. As with others, this is based on the general view of healthcare, no specific services are discussed.

On the other hand, [9] considers various measuring sensors based on IoT for ensuring or establishing a shared inventory management system for efficient managing of inventory of assets and stocks thereby eliminating unnecessary workforce and automating order placement. Also, it is interesting to point that the research work in [16] on application and implementation of IoT in cancer care services and business analytics and cloud services constitutes one of the few papers that discussed extensively on cancer care services. Equally important to mention that it has been argued by [4] that sensor-enabled devices consume energy, so the research work proposes a framework for reducing the energy consumption of the sensors in the WSN mesh-topology system through energy-oriented path selection and message scheduling approaches. We have considered this being very valuable to our research especially for the power consumption of sensors in WSN that we have considered in our proposed solution.

To this end, to demonstrate the novelty of this research, we have conducted a comparison between the proposed solution/system and some other existing solutions. The following actors/parameters are considered: IoT devices, IoT access technologies, GPS location tracking, routing protocols, services, analytics and cloud Services, operational challenges, security, scalability, reliability, and other relevant parameters, as outlined in Sect. 5.4. In essence, the proposed system covers a great deal to ensure the robustness of the solution as we move from reactive healthcare to proactive healthcare.

2.2 Background of Saskatchewan Healthcare System

In the face of changing nature of the healthcare landscape in Canada as initiated by the electronic health record (EMR) initiative (which has been traced back to at least 1997 as one of the first countries of the world to embrace eHealth record [25]) and with the advancing pace of technological changes, there is the need to (re)assess the provision and positioning of healthcare services across the country. It is anticipated that in years to come, many healthcare organizations in various countries would have embraced IoT technology, which will transform the healthcare industry for increased innovation, visibility, and interoperability across the healthcare organizations. However, there are numerous business drivers, which are needed to be addressed by the current healthcare systems but the focus of this research work centers on the possible adoption and implementation of Internet of Things (IoT) in healthcare, especially for the newly Saskatchewan Health Authority. Candidly, there is no better time to adopt IoT based healthcare systems in all the operations and services of health industry but now, and this suffices smart healthcare systems that will assist patients and health providers and personnel in the circle of care in the discharge of their responsibilities. This will, in turn, facilitate enhanced diagnoses/treatments, monitoring and maintenance, automatic infirmity and condition detecting and sensing, community health care, location-based health care, rehabilitation, surgery and recovery, imaging services, and so on.

On January 4, 2017, the Government of Saskatchewan announced a major move in the health care system for the province to a single health authority, named Saskatchewan Health Authority (SHA). The initiative was taken to reduce the existing health regions and agency (see Fig. 1) into a single entity, and the health ministry will still be committed to a health system that puts patients first by providing *better health*, *better care*, *better Value*, and *better teams* for Saskatchewan people [29]. With SHA as an entity, it creates an opportunity to consolidate all its services from diagnostic imaging, ambulance (emergency medical) to drug administration without disruption to the delivery of healthcare services to patients. This will ensure interoperability among the health regions under the new integrated healthcare system through centralizing, optimizing and integrating patient-centered care. In view of this, we have design considered the implementation of IoT in Saskatchewan with SHA as our case study for this research work. Table 1 depicts the list of all the 13 health regions and the agency that make up the Saskatchewan Health Authority. The map depicting the various health regions in Saskatchewan is as shown in Fig. 1, and the corresponding network node architecture for connecting and communicating with the health region locations and sites for the design of the Smart Saskatchewan Healthcare System (SSHS) is illustrated in Fig. 2. As mentioned, the smart healthcare system will assist patients and health providers in the discharge of their responsibilities. The IoT connected devices, such as sensors, body sensor networks (BSNs) and actuators, will be used for communicating between patients and those in the circle of care. Also, they will facilitate the sharing and interconnecting healthcare network resources

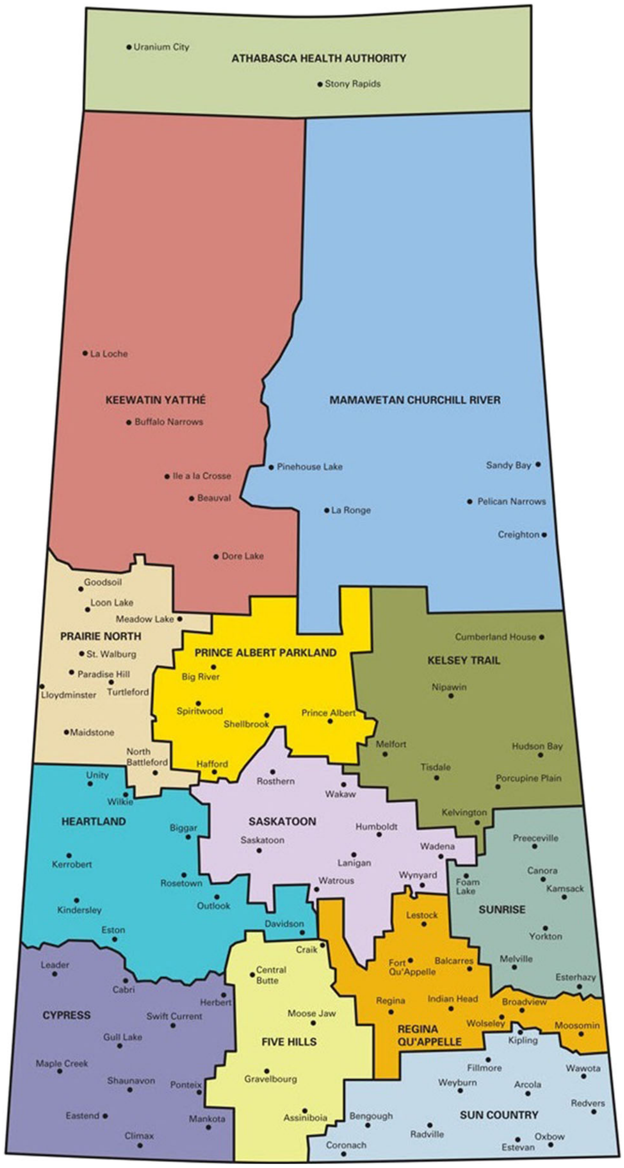

Fig. 1 Map of all health regions in Saskatchewan [31]

in the network as related to the delivery of IoT-based smart and integrated healthcare system for the province of Saskatchewan based on the four healthcare services we have identified above as summarized in Fig. 3. In wrapping up this section, it is necessary to mention that there is a possibility that the design methodology and framework for this research can be leveraged in other provinces, and in Canada, at large.

3 Smart Saskatchewan Healthcare System framework

The smart Saskatchewan Healthcare System framework comprises of the essential underlying and supporting components or elements that make up the entire and proposed system. It also shows the interdependencies of the various elements that are impacted by the network design methodology towards the desired solution. Through the framework, we are able to integrate the various capabilities and functionalities that the proposed system is capable of accomplishing in the context of IoT technology. In a way, for each of the element or component, there is an association with the methodology to generate an output as part of the requirements for the system to enhance healthcare delivery. The framework is instrumental in developing the full-mesh smart healthcare system for the consolidated healthcare services. The schematic representation of what constitutes the framework is depicted in Fig. 4. The figure inherently defines the way in which the network resources (i.e., communication and information produced by those connecting devices from one node to another within the system) will be interfaced, networked, and transmitted.

From the framework, we have the first component as "network mapping". In this case, it shows the association of the network mapping with various health regions or sites and agency within the province that constitutes the new Saskatchewan Health Authority. The agency is responsible for cancer care services, called Saskatchewan Cancer Agency (SCA). Being the only cancer agency for the province, there exists information sharing and exchanging with all the health regions. Hence, the network mapping facilitates the exchange of patient data and records. In addition, the "network architecture and topology" is used for the design of the communication network requirements and technologies. For the proposed healthcare solution, the use of hierarchical architecture is preferred to flat

Table 1 Saskatchewan health regions and agency

Cypress Health Region	Prince Albert Parkland Region
Five Hills Health Region	Regina Qu'Appelle Health Region
Heartland Health Region	Saskatoon Health Region
Keewatin Yatth Health Region	Sun Country Health Region
Kelsey Trail Health Region	Sunrise Health Region
Mamawetan Churchill River Region	Athabasca Health Authority
Prairie North Health Region	Saskatchewan Cancer Agency

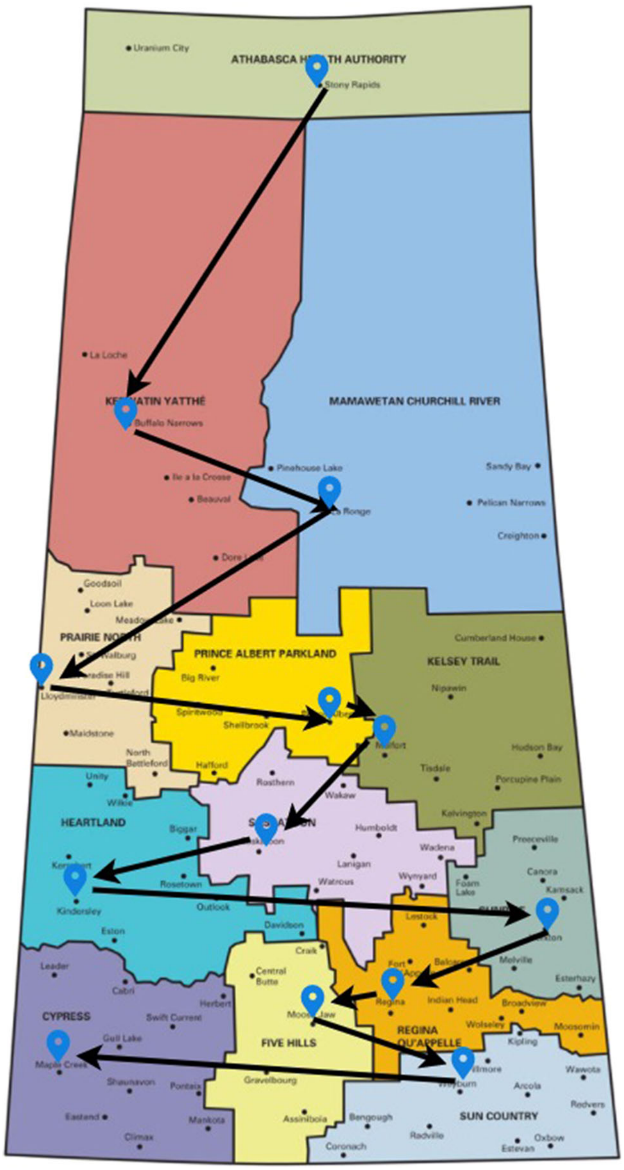

Fig. 2 Saskatchewan health region network nodes

architecture. The details of this are provided in Sect. 4. Aside from the architecture, mesh network topology is considered primarily for redundancy. Next, the "wireless sensor networks" form a major part of the IoT driven system that facilitates interconnection of spatially distributed autonomous and heterogeneous sensors for data packet transmission and exchange over geographical locations of the hospital clinics and centers using appropriate routing protocols and algorithms from various sources to the destination of the data center. The "emergency services" feature all emergency related services, such as ambulance (ambulatory) services, vehicular accidents, and patient emergencies. Similarly, the "operational services" associate and feature facility and operational related services. The "cancer care services and applications (RT and MO)", on the other hand, are associated with various cancer care related procedures, such as prevention, diagnosis, treatment, and patient monitoring. The "reporting platform and business analytics" associate with the analytics and computing services with the capability of aggregating data for decision making and actionable insights. On the final note, the "cloud services and cloud computing platforms" of the framework feature interaction with patient records and data by those in the circle of care using any of the services of cloud computing. Details about the incorporation of all these components and elements are discussed in the subsequent section. All these components are geared towards the augmentation of IoT-enabled healthcare solution.

4 Network design for services

4.1 Network design basics

The success of any network design is crucial to its implementation, and it should be borne in mind that if the network design is flawed or faulty, then the implementation suffers. This is why we have paid close attention to the network design to ensure necessary flaws are minimized and eliminated, especially to project of this nature. This is due to its complexity in terms of the organization size (comprising of those in the circle of care), health region sites, and network resources to be shared amongst others. Though, it might be difficult to build or design a network that is nearly 100 percent reliable. However, we strived to exercise due diligence in designing a network that addresses the needs of a smart healthcare system based on IoT technology. In conducting this design, both technical and non-technical requirements of the smart healthcare system involving various services across various health sites or remotes sites have to be examined to ensure a good network design that avoids complication in the network design. The networks should also ensure adjustability and scalability to the demands for additional services while at the same time ensuring security, manageability and supportability of the networks.

4.2 Hierarchical network architecture

In the design of the communication network for the smart solution, two categories of network architecture are normally considered, namely: *flat architecture* and *hierarchical architecture*. Here, we have adopted the hierarchical architecture as compared to the other one because we are more likely to have a reliable network considering the size of the organization and size of the network resources and facilities that will be interacting and interoperating on the

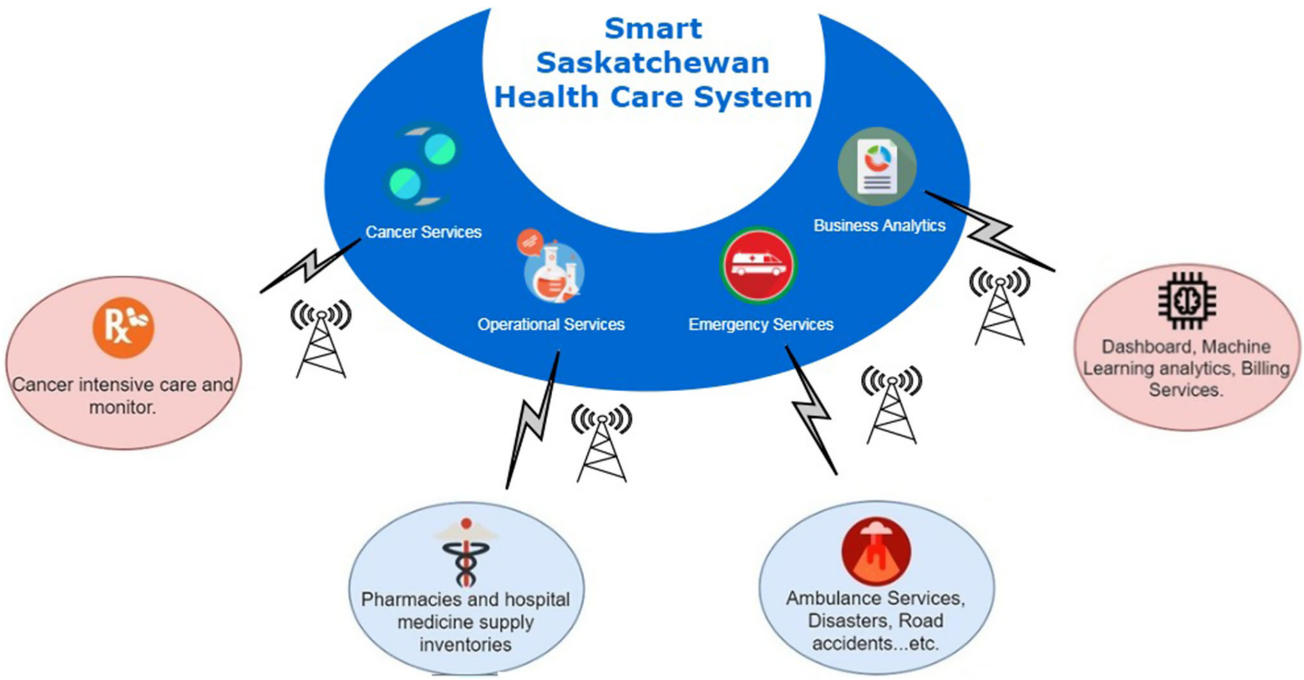

Fig. 3 Smart Saskatchewan Healthcare System architecture

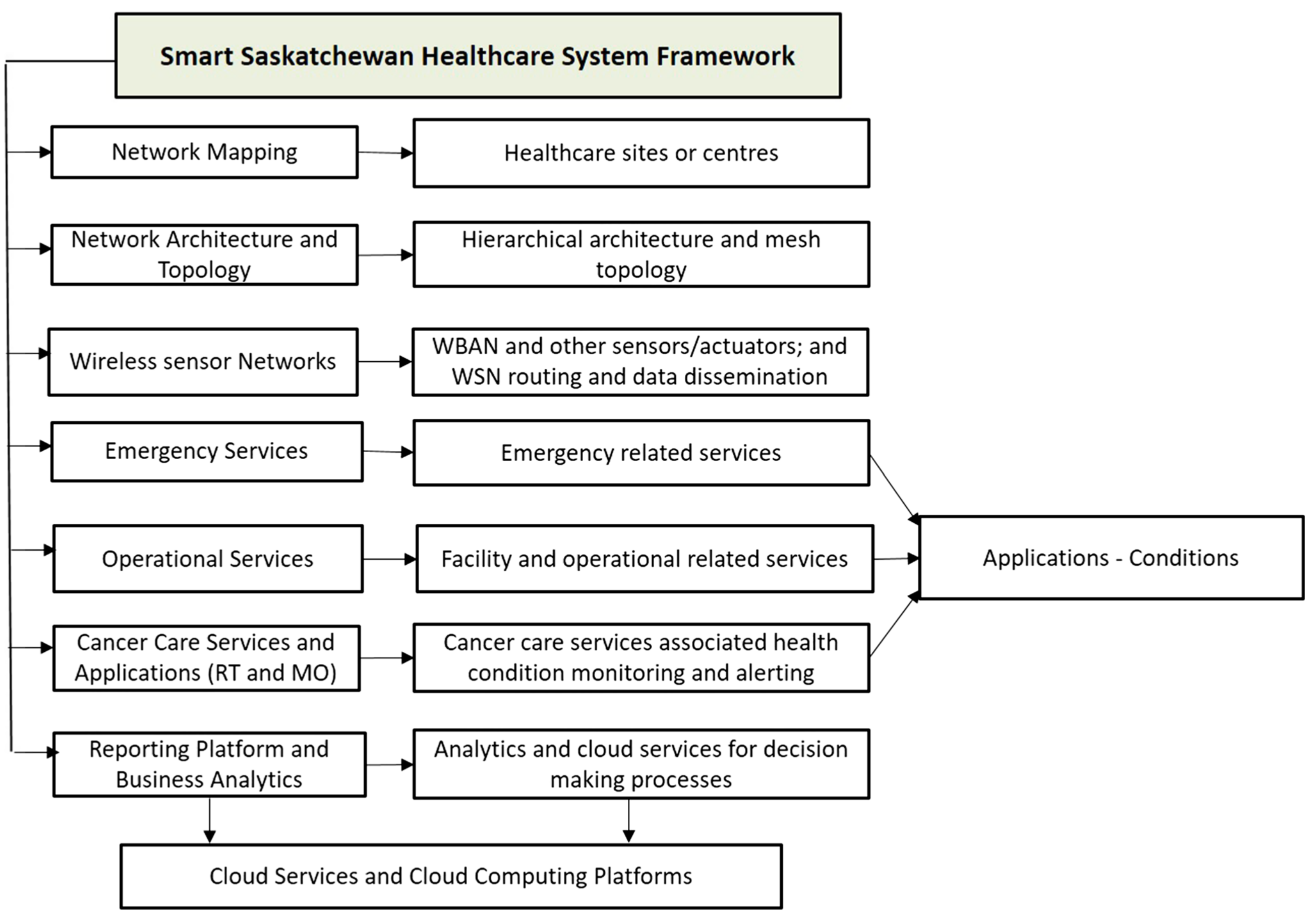

Fig. 4 IoT health solution/system framework

network. Also, the hierarchical network architecture is easier to manage and expand, and any inherent issues are more quickly solved with little or no disruption to operations and services. Typically, hierarchical network architecture involves three discrete layers: (1) Core Layout; (2) Distribution Layout; and (3) Access Layout. Each of these layouts provides specific functions that define its role within the overall network, thereby resulting in a network that provides modularity in order to meet the fundamental network design goals of scalability, availability, performance, redundancy, maintainability, security, tolerance, and manageability [14]. Brief descriptions of each layout are provided subsequently.

4.3 Hierarchical network architecture considerations

4.3.1 Core architecture layout

This layout constitutes the backbone of the network that enables transporting and transmitting of large amounts of data quickly and reliably between one section of the network and another. It this case, high-speed connectivity is required, which is intended to provide 100% uptime, maximize throughput and network growth. The core layout also establishes a connection between multiple buildings/sites to support the internet, virtual private networks (VPN), extranet, and WAN access.

4.3.2 Distribution architecture layout

The distribution layer, on the other hand, constitutes a communication point between the core layer and access layer, and this layer is responsible for routing, managing and filtering traffic flows. It also serves as a connection point between remote sites and core layer by complementing the needs of the other two layers. In essence, it controls the flow of network traffic using policies and allocates broadcast domains by performing routing between VLANs defined at the access layer. Typically, the distribution layer is built using layer three devices.

4.3.3 Access architecture layout

The access layer interfaces and controls the end devices and the rest of network resources that communicate on the network. It is at this layer where all the sensors, actuators, and IoT connected/smart devices are placed. The control of users and network resources is important to ensure that that layer is not speedily overwhelmed with traffic which could cause less-than-acceptable performance for the end users. Typically, the access layer is built using layer two switching technology, and access to the network can either be through a wired infrastructure or wireless access points (WAPs). In managing and improving access layout, the VLAN architecture and traffic patterns are considered for improved connectivity [22]. Typically, the sensors and IoT connected devices are attached to the access layout through gateway devices. In essence, the access layer interfaces and controls the end devices and the rest of network resources that communicate on the network.

4.4 Wireless sensor networks and WSN routing in Healthcare settings

The wireless sensor networks (WSNs) have been a revolutionary and prevalent trend in every field, and they have played an important role in IoT based solutions or systems that allow a number of spatially distributed autonomous sensors to be linked to the network fabric to facilitate data transmission and exchange. In healthcare, for instance, the wireless sensor networks in the form of wireless body area sensor networks (WBANs) are implanted or attached within the human body or placed in a specific area because of their capability to compute and communicate physical characteristics and parameters. Hence, it is worth mentioning to explain how wireless sensor network technology, their applications, and communication standards are included in our network methodology and architectures. In supporting the proposed smart IoT based healthcare system, the use of wireless sensors/actuators cannot be overemphasized because they ensure the actualization of the so-called IoT solution. As alluded in [15–17], WSNs are an important component of IoT implementation and application. A sensor network is an infrastructure comprising of sensing (measuring), computing and communicating elements that give the ability to instrument, observe, and react to events and phenomena in a specified environment, where the environment can be viewed as the physical world, biological system, or an information technology system [21]. Typically, a sensor network comprises four basic components [21]: (1) an assembly of distributed or localized sensors; (2) an interconnecting network (usually, but not always, wireless-based); (3) a central point of information clustering; and (4) a set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining. The technology embedded in sensors constitutes a broad range of applications in infrastructure protection and security, health care, agriculture, energy, food safety, production processing, quality of life, economy, medical telemetry, radiation activation and nuclear-threat detection systems, "over the-horizon" weapon sensors for ships, biomedical applications, habitat sensing, seismic monitoring, air traffic control & surveillance, video surveillance, industrial and manufacturing automation, process control, inventory management, distributed robotics, weather sensing, environment monitoring, national border monitoring, etc. [21].

Other applications range from remote monitoring of physiological data; tracking and monitoring doctors and patients inside a hospital; drug administration; elderly assistance, and national security applications using networked biological and chemical sensors. In essence, the sensors and actuators ensure the actualization of the smart healthcare system that provides communication (using sensing, collecting, exchanging, sharing, monitoring, observing and interacting to changes in the states of the body) with the network gateway devices attached to the network. The reader is referred to the details of wireless sensor networks as presented in [16].

Subsequently, we will be discussing the importance of WSN routing and data dissemination in a healthcare environment. In the proposed healthcare solution, WSN comprises a significant number of sensors nodes that are interconnected based on the geographical locations of the clinics and hospital sites. Once wireless sensor networks are deployed, the sensor nodes form autonomous wireless ad hoc networks, which are embedded in the main network for all the services. Through these ad hoc networks, the sensor nodes collaborate to perform the required, such as processing, transmission, and aggregation data from various sources, which are used to determine the nature of the illness in order for those in the circle of care to determine the nature of treatments and diagnoses to offer. These ad hoc networks are referred to as "WSN for sites" since we are dealing with the integration and interaction of hospital sites and clinics in the course of the design implementation of the smart IoT based solution.

As already known, data and information from sensors are transmitted or routed from various health care sites within the network to the data center through cloud services. This facilitates the exchange of data and information within the healthcare regions/agency. Hence, in maintaining the node routes for data dissemination within the stated network fabric, the use of appropriate routing protocols is required to ensure appropriateness, optimality, and efficiency of the protocol to handle the capabilities and application requirements of the nodes, especially with the increasing number of sensor modes, as alluded in [15–17]. There are different types of routing protocols, namely: Location-based routing protocols; data-centric routing protocols; hierarchical routing protocols; mobility-based routing protocols; multipath-based routing protocols; heterogeneity-based routing protocols; and QoS-based routing protocols. As related to fulfilling the criteria for the smart healthcare system, a combination of hierarchical routing and geographical or location-based routing protocols will be ideal. The reason being that the hierarchical routing protocol reduces energy consumption by classifying nodes into clusters, where nodes behave in the inter and intra-cluster domain. Also, hierarchical routing is also significant due to its feature of collision avoidance coupled with low latency and uniformity in energy dissipation. On the other hand, in geographic-based or location-based routing protocol utilizes the location information to ensure routing techniques more efficient [20]. Also, the "location-based routing" protocol technique or strategy involves to node location and a type of sensor that is used in identifying the final destination by using an appropriate algorithm (such as Distance Routing Effect Algorithm for Mobility (DREAM) to prevent intrusion and to conduct analysis on the packet sent by sensor node) as deemed necessary for this research work. The illustration of the hierarchical and location-based WSN routing is as depicted in Fig. 5.

Some of the location-based protocols being considered are Minimum Energy Communication Network (MECN), Small Minimum Energy Communication Network (SMECN), Geographic and Energy Aware Routing (GEAR), Greedy Perimeter Stateless Routing (GPSR), Location-Aided Routing (LAR), Geographic Adaptive Fidelity (GAF), just to mention a few. Lastly, in this approach, the broadcast server (BS) helps in the data transmission from the sensors to the broadcast server with the aim of reducing energy consumption and enhancing efficiency.

4.5 Clinical environment interaction in smart system

In a clinical setting based on IoT, we can briefly describe the processes that are prevalent that enable interactions of clinical or healthcare environments with the various patient environments along with the health regions closest to any of patient environments, as depicted in Fig. 6. This is intended to define how the services are integrated especially as related to the use of IoT on patients through the WBANs on patients thereby leading to transmission of data and information across the health regions through the data center located at the SHA head office. This obviously facilitates interaction between the patients and those in the circle of care especially during patient treatment and recovery processes which in most cases happen in the rehabilitation center, home care, and the patients home. Those constitute the environments to access data about patients.

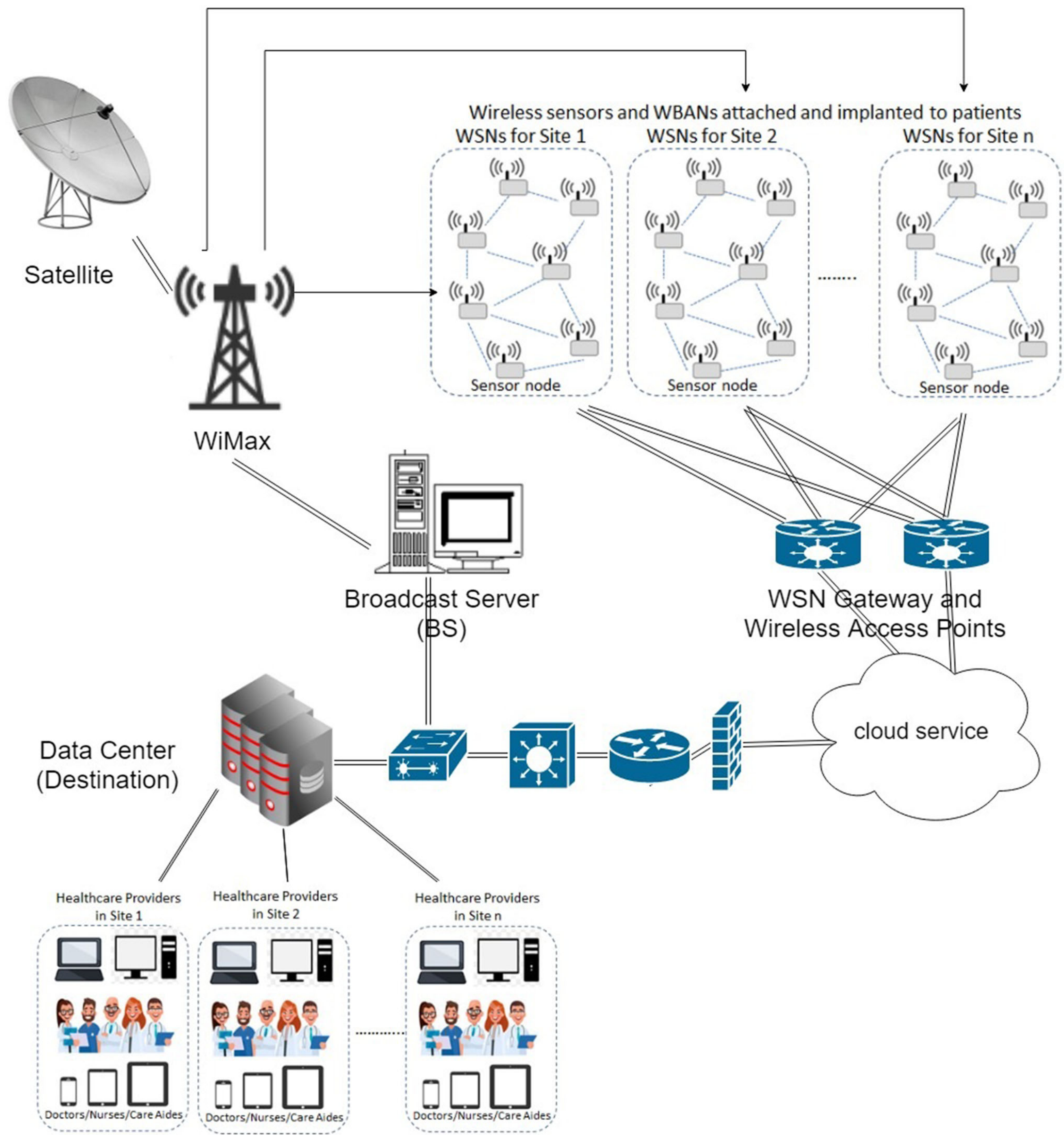

Fig. 5 Hierarchical and location-based WSN routing

5 Integrated services for smart Saskatchewan Healthcare System

5.1 Mesh hierarchical network topology

In the design of the network, there is a variety of network topologies for network communications. As noted earlier, the success of any network design is crucial to its implementation, so the desire to identify network requirements and select the best solution that meets the needs of a smart healthcare system is of great concern in this research. A mesh topology is proposed, in which each node and network device is interconnected with one another such that each node relays data for the network. Typically, a mesh topology can either be a full mesh or a partial mesh. In a full mesh topology, every node in the network has a

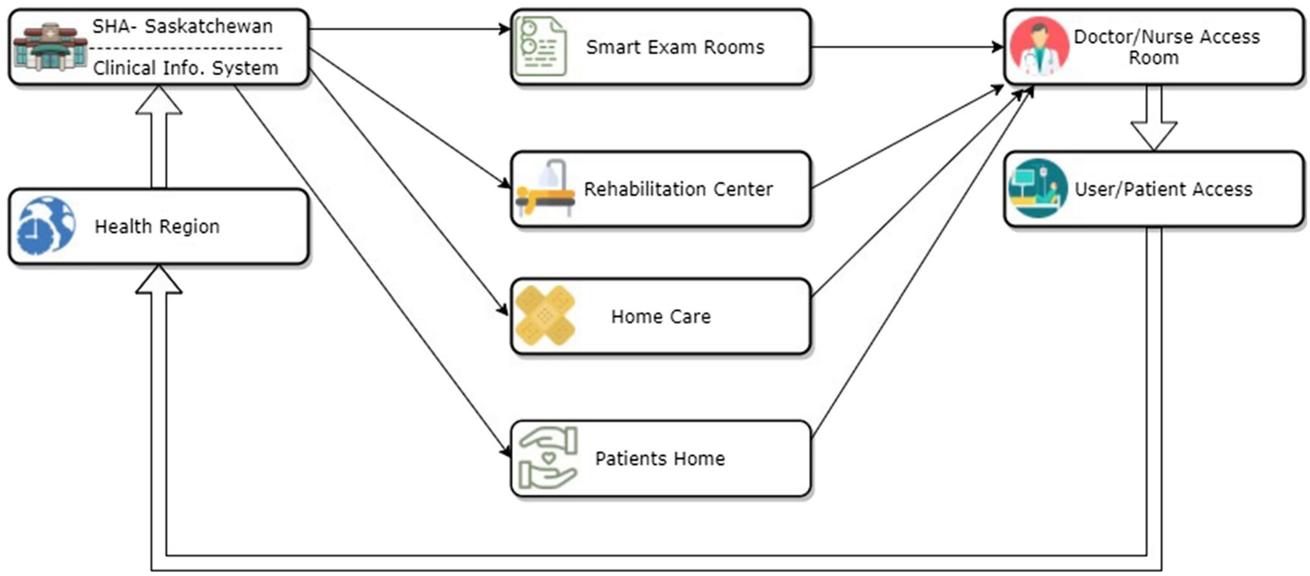

Fig. 6 Clinical environment interaction in smart system

connection to each of the other nodes in that network (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) [14]. The number of connections in this network is computed using the following formula: $n(n-1)/2$, where n is the number of connected devices like routers or switches in the network. The partial mesh topology, on the other hand, has at least two of the nodes in the network have connections to multiple other computers in that network. It is an inexpensive way to implement redundancy in a network. The partial mesh creates redundancy without the complexity of a full mesh. If one of the primary nodes or connections in the network fails, the rest of the network continues to operate normally, which is similar to the full mesh topology [14, 22].

5.2 IoT-based healthcare services and applications/conditions

With the IoT enabled devices, there poses a shift from a reactive healthcare system to a preventative one, where illnesses and disease will not only be better treated but will be avoidable [26]. These IoT connected devices proffer different application areas where they are being applied to different health conditions to foster and enhance better health because they provide immediate support of various forms. For examples, elderly patients will be able to stay at home alone with IoT connected devices being embedded in them, and both physicians and patients will have complete access to medical information. Also, a glucometer smart device is used for blood-glucose level monitoring, especially for diabetic patients.

In essence, our proposed IoT-based healthcare system comprises of services and an array of applications and conditions to facilitate the generation of several medical characteristics and parameters about patients being administered by those in the circle of care. It is obvious to see that there exists an association between those services and applications/conditions for managing different types of diseases and infirmities, as summarized in Fig. 7 along with the broad categories of disease or infirmity conditions—single or clustered. The subsequent subsections delve into the detailed network designs and methodologies for the healthcare services being considered.

Although, not all services in healthcare are covered in this research work, so we will be restricted to four (4) major services that are essential to initiate the SHA smart solution. Therefore, we will be focusing on the following:

- Operational Services
- Emergency Services (including ambulance services, vehicular accidents, and patient emergency)
- Cancer Care Services
- Business Analytics and Cloud Services

Business Analytics and Cloud Services (BA/CS) are important services that are not directly related to healthcare, but they serve as enablers for other services. The BA/CS are responsible for actionable insights, decision making, data transmission, and reporting.

5.2.1 Operational services

In this case, the focus is on medical tool/asset control and monitoring; and drug/medicine inventory management in the hospitals and clinics in collaboration with the pharmacy

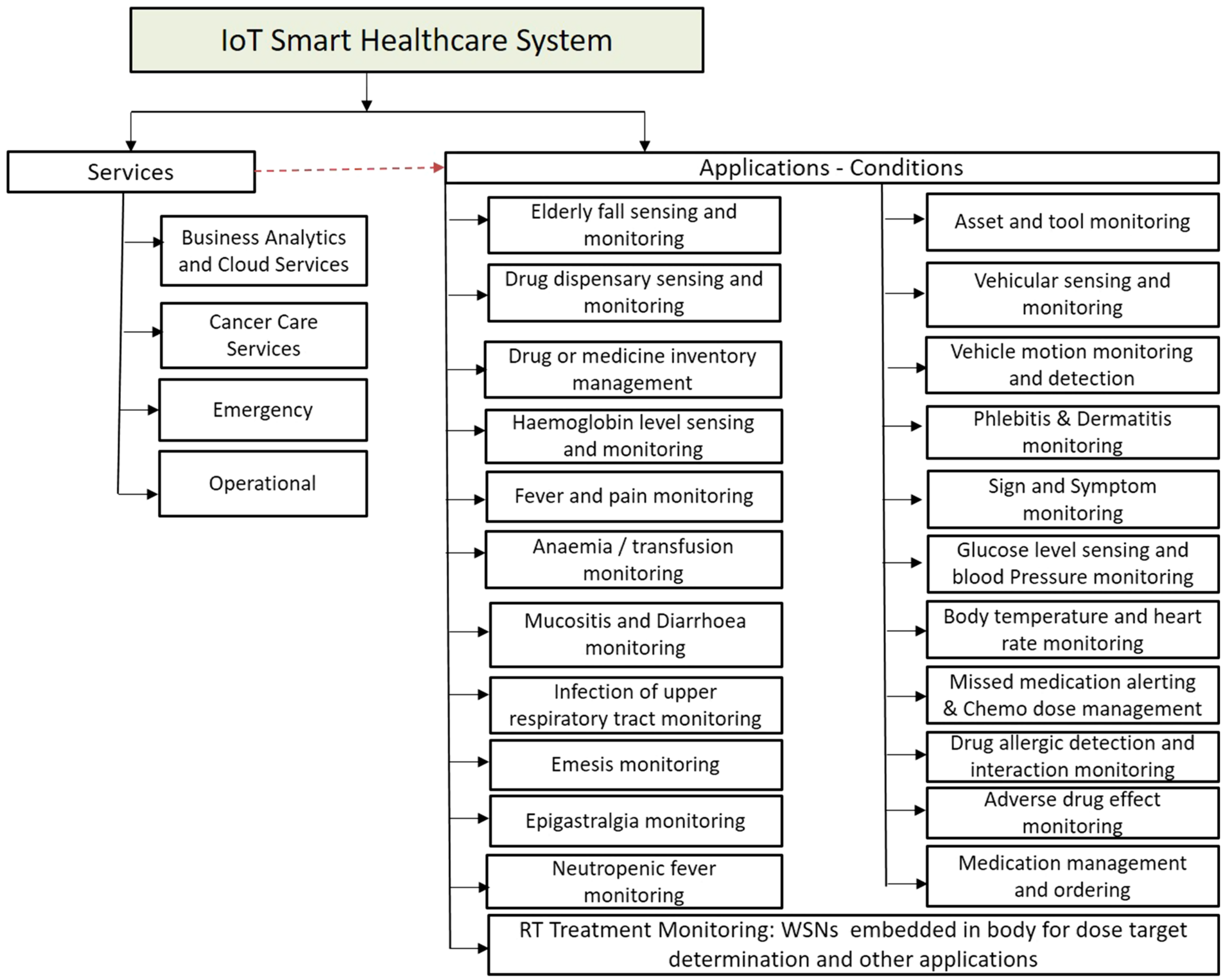

Fig. 7 IoT smart Saskatchewan healthcare services and applications

unit for drug/medicine procurement, placement, prescription administration, and dispensary. In a way, the operational services function in ensuring assets control and monitoring in hospitals using different sensors to track down how the inventory contents are operated and utilized. Through this, there are triggers for finding and purchasing drugs, which eases and fulfills drug prescriptions using sensors. Having examined the manners in which the operational services currently perform its functions, integrating and using the IoT connected devices, actuators, sensors and RFID devices are perceived to enhance automation while at the same time result in healthcare operation improvement with an enhanced, cost-effective approach. On that premise, the smart devices embedded on those assets and drugs will use a variety of IoT devices to enable information sharing and collaboration among assets and drugs for real-time and automation to enable replenishment and dispensary. The illustration of these services is seen in the integrated smart solution.

5.2.2 Emergency services

The emergency services comprise of the ambulance (ambulatory) service, vehicular accidents, and patient emergency. With the idea of the emergency services, we will delve into how IoT connected devices are applied to these categories of services from the site of the accident or accident to the point of administering diagnosis and treatment. Knowing the roles of the emergency services in healthcare, it will be beneficial for the emergency medical team (EMT) to be equipped with information about their patients or patients being cared for, but unfortunately, they are unable to receive such required information to initiate the necessary health care to be administered. This is because of limited access to information, and the only information available to them are the ones gathered from their family members or possibly from the emergency patients, who have been restrained from providing all the necessary and required information due to their state of condition. Even though the patients might have their information resident in the clinics or hospitals but unfortunately, the EMT is unable to access them. With the proposed design implementation of the smart healthcare system based on the IoT initiative, it will enable the EMT to use the IoT connected devices to informed or alerted of or about the health conditions of patients, such as chronic illnesses, allergies, medications, medical challenges/complications, and so on. In essence, the IoT based healthcare system could benefit significantly in the contexts of speedy health care delivery to emergency patients and situations thereby reducing complications and enhancing overall diagnosis and treatment experience. On that note, it is deemed important for IoT initiative to be embedded in the emergency services, so it makes provisions for necessary relevant healthcare records and information required by the EMT to communicated automatically to ensure better and faster services being delivered.

On the other hand, knowing that the ambulatory services begin from the occurrence of the emergency situation [12] especially in the event of a vehicular emergency, it becomes necessary for the EMT to accurately and precisely recognize the point of occurrence of the emergency. With the state of the art IoT connected devices, the EMT is easily and accurately provided with the exact location and the shortest and fastest direction of travel to the location of the accident. On the vehicular side of the emergency services, the use of crash sensing connected devices should be installed and then link all the WSNs from the sensors to the central emergency repository system within the jurisdiction to ensure the EMT is alerted in the event of fatal accidents. In the vehicular accidents system, the sensor in the vehicle will also sense and apply brakes as needed to avoid collision with other vehicle or pedestrians, where mobile ad hoc network (MANET) is used to relay information from one vehicle to the other. Another form of emergency services is the prevention or reduction of occurrence of emergencies, especially for seniors or patients with disabilities through the use of IoT sensors that detect fall. This sensor provides support to the affected people where the sensors are being embedded or implanted.

5.2.3 Cancer care services

The use of IoT technology has been found to be implemented in cancer care services for diagnosis and treatment by seemingly integrating wireless and sensor technologies, such as IoT connected devices, to both medical oncology (chemotherapy) and radiation oncology (radiotherapy) procedures [16]. These connected devices enhance treatments and care both in the clinics and homes (by means of remote monitoring by caregivers and families) such that monitoring, alerting, following up, interacting, sensing, and detecting of any changes, complications, and problems with the patients are ensured. For example, for home care, the patients can be closely monitored to ensure quality care even after leaving the hospital. This is based on the fact that the IoT connected devices can provide feedbacks and critical care responses to those in the circle of health care as patient information and data can be shared and transmitted remotely by secured VPN connection. Basically, the cancer services incorporate smart clinical devices in assisting patients in the course of treatments and diagnosis. These services are divided into two (2) categories as discussed below.

- **Chemotherapy—Medical Oncology**
  According to [16], the proposed smart healthcare system can incorporate IoT-enabled devices to assist cancer patients in the event of missed drug management, complications, monitoring, dose management, drug allergic detection, drug ordering, and so on through process or procedure automation, remote monitoring and alert communications. It is equally important to mention that WSN and smart devices, sensors and actuators can be applied to reduce or eliminate side effects and complications associated with treatments. In essence, those smart devices can enhance cancer treatment and any changes due to complications, signs, symptoms, allergies, pains, missed medications, hemoglobin level, and other issues, all through the chemotherapy procedures to enhance communications and patient treatments.
- **Radiotherapy - Radiation Oncology**
  IoT and WSN technologies can be utilized in cancer diagnoses and treatments with respect to radiation oncology. Although, the application of IoT connected devices in the case differs from that of the medical oncology due to the manner in which the radiotherapy and prescription doses are being administered to patients, as argued in [15–17].

  In radiotherapy or RT treatment, four (4) sequential steps are usually employed before communicating with various aspects of the *Eclipse*™ (which is a commercial planning treatment software system with DICOM interface) by the Diagnostic Imaging and Communications in Medicine (DICOM). The steps are [16]:

  – generation of treatment plans in *Eclipse*™ by associating related files, such as computed tomography (CT), radiotherapy (RT), and dose volume (DV),

- determination of prescription doses for the disease sites along with the dose volume constraints for organ at risk,
- uploading of plan DICOM file back to *Eclipse*^{TM}, and recalculating the prescription doses and dose-volume history (DVH),
- lastly, conducting an evaluation on *Eclipse*^{TM} and patient QA for dosimetric analysis of internal anatomy to ensure precision of proton radiotherapy.

This has been argued that the use of IoT connected devices and WSN sensor and actuators could assist in patient treatment following the steps described above. Most importantly, the IoT connected devices when embedded close to the disease sites will help in margin improvement, preciseness, and accuracy to ensure the disease sites are being hit by the linear accelerator which will get rid of geometric uncertainties associated with setup, patient motion, and patient body changes for enhanced treatment results.

In wrapping up, the IoT technology in cancer care services could be done through passive communications (using technologies such as Bluetooth-Low Energy (BT-LE), Near Field Communication (NFC) and Radio Frequency Identification (RFID)) and through active communications (using technologies such as 6LoWPAN, Wi-FI, ZigBee). On the whole, the incorporation of these two aspects of cancer care services are demonstrated in the smart or integrated healthcare system presented in the next section.

5.2.4 Business analytics and cloud services

The IoT connected devices offer the capability of transmitting data and information, which ensure the availability of real-time data to treatments and diagnoses. Similarly, in WSN, the sensor nodes have the capability of data aggregation, which ensure the availability of data. In essence, these connected devices when deployed in the healthcare environment for diagnoses and treatments result in an exchange of data where a huge amount of data is being generated, collected, and shared. This, in turn, places a high demand for data to be analyzed in order to detect and observe valuable and actionable insights and decisions to be made by healthcare providers to help improve healthcare delivery.

Interestingly, through the use of Business Analytics and Cloud Services, the healthcare providers and research experts can engage in-depth data and business/data analytics in making sense of data collected using IoT connected devices and sensors. With the unprecedented growth rate and availability of patient healthcare data through the use of IoT and WSN connected devices from various network sources in the healthcare system, there is certainly some sense of urgency to analyze, interpret, aggregate, mine, manipulate, cluster and classify those data using appropriate analytics tools [24] and algorithms for analytics, reporting, and decision making, in order to gain actionable insights and intelligence to assist in disease diagnosis and treatment.

The cloud services are adopted to facilitate communications and data exchanges across the entire healthcare services from various healthcare sites to data and reporting center. Since data are stored via cloud services for processing, some pertinent cloud services are being utilized as discussed below. The growing use of the internet of things (IoT) and wireless sensor networks have generated data, queries and physical characteristics as observed from them. Due to the nature of the proposed smart solution being considered, we decided on using cloud computing services to overcome the following challenges that might likely impact the implementation of the solution. The challenges are: ownership of data collected and stored; how data will be used, shared, consented; loss of signals and connectivity; strength and security of the communication channels; power capacity of the connected devices; frequency of charging sensors or connected devices; and wireless technologies that support low energy for prolong use. In order to circumvent the challenges, we consider the following pertinent services of cloud computing, namely:

- Cloud Software as a Service (SaaS) by using providers enabled applications over a network
- Cloud Platform as a Service (PaaS) by deploying customer-created applications to a cloud
- Cloud Infrastructure as a Service (IaaS) by renting processing, storage, network capacity, and other fundamental computing resources.

The following advantages have prompted and triggered the adoption of services of cloud computing in our smart healthcare solution by leveraging on:

- Massive scale: Huge number of nodes (Medical Field)
- Heterogeneity: Different Heterogeneous devices will be under one system
- Virtualization: Anywhere, Anytime.
- Resilient computing: Similar to honey-pot technology.
- Low-cost software: No need to maintain software.
- Geographic distribution: Works well with distributed areas.
- Advanced security technologies: ensures authentication and privacy.
- Data Encryption (at-rest, in-flight), Key Management

Although there are some disadvantages associated with the deployment of cloud computing services, these include but not limited to:

- Centralization of control, where all data will be saved at the same place in one central location.
- If the central service is breached, then all your data is at risk.

In addition, due to the vast volume of data from various services involved, in terms of volume, velocity, and variety. The use of Hadoop cluster or framework has been suggested to be implemented for processing and solving various types of workloads associated with massive amounts of data due to the enormous benefits of Hadoop framework as stated in [16]. Finally, these have justified why the Business Analytics and Cloud Services serve as enablers for the various services in the healthcare system, especially for the IoT-enabled healthcare solution.

5.3 Proposed smart Saskatchewan Healthcare System

The proposed integrated smart healthcare system forms the core of this research work. Noting that the discussions in the previous sections coupled with our research work in [12] and [15–17] (where we surveyed and designed the implementation of the individual services that are being combined for this research work) are all targeted towards the development and design of this solution. In view of this, the resultant work is the combination of those services, which highlight how we have managed to put all the services as a whole as will be illustrated in our design architecture based on hierarchical network design and full-mesh topology. In this smart solution, some notions of network design goals are considered; namely, manageability, availability, performance, security, adaptability, scalability, and affordability to accommodate an expansion of the healthcare solution, especially as we anticipate the inclusion of additional services in the future.

It is pertinent to state that in the course of the integration of the various services, the following requirements are considered to ensure smooth operation of the entire healthcare system. These include but not limited to: viable assumptions on the use of network devices; viable network configurations; appropriate WSN routing protocols; determination of the number of network devices (i.e. layer 2 devices, layer 3 devices, routers, etc.); cabling options (cat5, cat6, and fiber optic cables); wireless accessibility options; routers for internet access (ISP); firewalls for internal and data center; virtual LAN (VLAN) requirements and configurations; HSRP for routers and firewalls; DHCP server for assigning IP addresses; DNS server for domain resolution; Data Servers for databases in the data center; NTP for time synchronization; remote virtual private network (VPN) for users from outside of the healthcare network; site-to-site VPN for clinics and healthcare community centres (sites); considerations for IoT devices, WSNs, sensors, actuators, workstations, smart devices, tablets, phones, etc.), just to mention a few.

The detailed and resultant smart healthcare system that has been proposed for the province of Saskatchewan for the integration and consolidation of services for the various healthcare regions and agency is as depicted in Fig. 8. This provides a complicated though manageable system that is able to handle all those services that we have considered. We will have to affirm that in the course of the design of the proposed smart healthcare system that we perceive to be scalable, reliable, adaptable, maintainable, and highly very resilient to handle intended loads due to the various technical and non-technical requirements being considered. These include but not limited to: network design architecture, IoT-based access technologies, IoT-based communication criteria, various computing infrastructures and services, network virtualization options, and heterogeneity of smart connected devices. The communication criteria include range, power consumption, topology, frequency bands, constrained nodes/devices, and constrained networks. As for the IoT-based access technologies, a variety of technologies is being considered especially with the heterogeneity of the WSN/smart connected devices in the implementation design, such as: NFC; Bluetooth Low Energy (BLE); ZigBee; 6LoWPAN; WirelessHART; Ethernet/IEEE 802.11 standards; Wireless cellular - 2G, 3G, LTE, 4G, 5G, Wi-Max, GSM, WCDMA, GPRS; LoRaWAN; Low Power Wide Area (LPWA); IEEE 802.15.4, 802.15.4e, 802.15.4g, 1901.2a standards; etc. Lastly, the routing protocols are also instrumental in fulfilling the design notions and goals of autonomy, energy consumption, scalability, resilience, mobility adaptability, heterogeneity, and so on.

In addition, the ease of maintainability and disaster recovery are equally crucial to the design implementation of the smart healthcare system with the use if hierarchical architecture instead of flat architecture. Also, we will state that not all the number ports in the Layer 2 (L2) switches and Layer 3 (L3) switches are being utilized. In most cases, we will ensure that about 80% of the total ports on the switches is used for all the switches that will be implemented in the healthcare solution. This is intended to accommodate contingencies and also to ease maintainability. On the final note, a full mesh architecture is considered rather than partial mesh to ensure the robustness of the solution.

No doubt, the proposed smart Saskatchewan Healthcare System is a complex and innovative healthcare solution, which comprises of four (4) of the services being made available in the newly formed Saskatchewan Health Authority. As stated earlier, these services are integrated to facilitate enhanced electronic medical initiative and also to

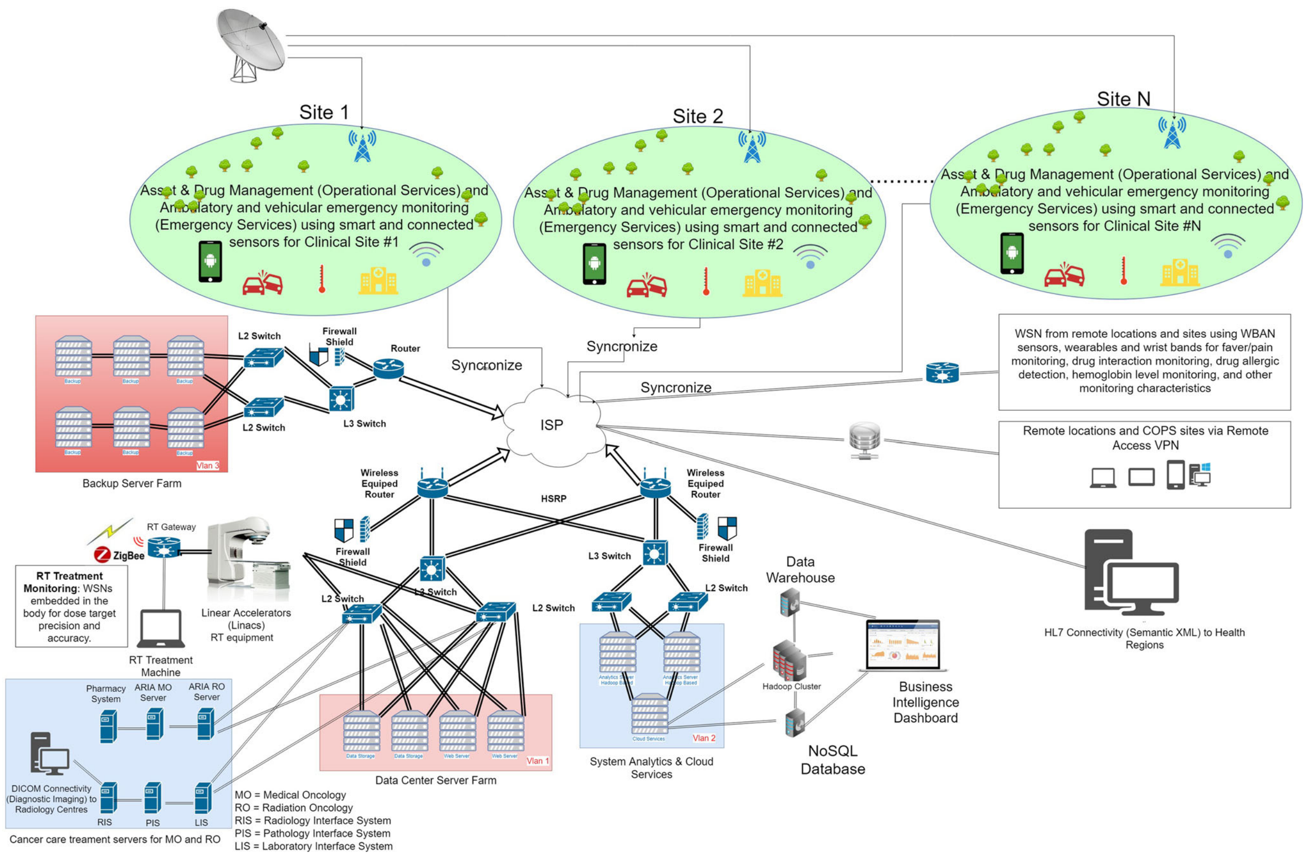

Fig. 8 Full mesh smart Saskatchewan Healthcare System

augment the delivery of healthcare. From the figure, there is an interconnection and synchronization of various healthcare regions, as denoted as *site*1, 2,..., *N*. Interestingly, all the services occur in all the sites/regions except for the cancer care service, which is provided only at the cancer care agency. The treatment options associated with the cancer care services are only available at two central locations or cities of the province (i.e., Regina and Saskatoon). Although, there exist provisions that allow those in the circle of care and physicians to have access to cancer patient information for follow-up treatments at any of the health regions through the use of secure remote access VPN and HL7 connectivity. The Health Level Seven International (HL7) is crucial due to its encryption for data transfer in healthcare services. In a way, it is a standardized healthcare framework developed in XML for the exchange, integration, sharing, and retrieval of health data or information in supporting clinical practice and management, and also for delivering health services across clinics and health sites.

The business analytics and cloud services are located at the data center in one of the sites of the health regions, while a backup/disaster recovery center is located in located in a different site in another city. The patient data/information is being replicated on a daily basis to the recovery/backup site to safeguard the clinical or medical information assets of the entire health authority. However, at every point in time, patient information or data are being accessed, exchanged, and shared by clinicians (those in the circle of care) and health regions through the data center through cloud services and cloud computing platforms. The business analytics and cloud services have been considered to be an essential component of the design implementation of the IoT-based smart healthcare system. Through this, the IoT data are being integrated to allow the value of the IoT implementation to be optimized, so that we could make use of the massive volume of data collected and generated from the IoT/smart devices. This, in turn, enables to analyze the collected data using Hadoop Deployment framework as a data repository and processing engine coupled with appropriate business intelligence dashboard to ensure actionable business intelligence and insights. Also, through business analytics, opportunities for further research and treatment option enhancements are realized, which will lead to improved quality of life of patients.

Importantly, the use of smart connected devices/sensors has been instrumental to all the healthcare services across the health regions and agency that enable monitoring and detection of healthcare characteristics about patients. On the other hand, the use of IoT in cancer care is discussed as shown in Fig. 8. Basically, the medical oncology treatment option is called chemotherapy, where ARIA MO and pharmacy system as associated together as linked to the architecture using the L2 switches. Also, the ARIA RO server, RIS, LIS, PIS, and PACS are being connected using L2 switches, which are associated with radiotherapy. We have subsequently demonstrated the adoption of IoT/WSN devices in radiotherapy for dose target precision while using linear accelerators for administering radiation doses/ protons to cancer patient using DICOM interface for connectivity.

5.4 Comparison between proposed system and existing healthcare systems

In the course of the research, we have made some comparison between our proposed IoT-enabled healthcare system and some other existing IoT-enabled healthcare systems in some of the related works as mentioned previously in Sect. 2. We have focused on the following recent papers:

- Paper #1: IoT-Based Smart Rehabilitation System [3];
- Paper #2: Health Monitoring and Management Using Internet-of-Things (IoT) Sensing with Cloud-based Processing: Opportunities and Challenges [8];
- Paper #3: Real-Time Signal Quality-Aware ECG Telemetry System for IoT-Based Health Care Monitoring [19].

The following factors or parameters have been considered for the comparison: IoT devices, IoT access technologies, GPS location tracking, Routing protocols, Services, Analytics and Cloud Services, Operational challenges, Security, Scalability, Reliability, and other relevant parameters, as outlined below.

Based on our proposed system and the papers listed above, we have presented the differences between them as tabulated below in Table 2. The table demonstrates the novelty of this research, especially with the level of complexity, security, reliability, stability, challenges, and service-consolidation addressed. We are able to state that the design architectural view of the smart Saskatchewan healthcare solution has been a promising one as we move from reactive healthcare to proactive healthcare. Interestingly, all the papers focus on the applications of IoT in healthcare. Although Paper #1 [3] utilized patient data as obtained from 21 hospitals and 18 rehabilitation centers but in our proposed solution, the use of patient data is intended to be considered during the actual implementation. In addition, Paper #2 [8] highlights several challenges as related to data acquisition, sensing, analytics, and visualization but we focused on operational challenges as related to the entire smart healthcare system. In Paper #3 [19], signal quality-aware (SQAw) paradigm has been considered for improving resource utilization efficiency and network utilization while the proposed solution delves into the implementation that enhances the augmentation of treatment in order to improve patients quality of life.

Although the notion of each paper varies despite using IoT technology, however, we can readily affirm that the proposed system utilizes a variety of IoT-enabled devices primarily because of the number of heterogeneous devices that we have focused on. This, in turns, contributes to the complexity of the system. Due to the diversity of locations of various healthcare regions, the proposed system utilizes a variety of access technologies and communication criteria to ensure delivery of robust services, which are partially or not in existence in other papers. As per the GPS location tracking and routing protocols, this paper and one other paper are the ones that utilized these criteria. For the healthcare services, the proposed system seems to cover the most while others cover either one or just a general view of healthcare services. Also, all the papers cover the analytics parameter except for one paper.

With respect to the operational services, this paper and one other paper cover it, though a detailed explanation is provided in this paper. Also, the security, reliability, and scalability parameters are not discussed in any other papers except in our proposed solution. Lastly, another relevant parameter is relatively an inconclusive parameter as we only highlight what is considered key points or illustrations in all the respective papers as illustrated in the table.

6 Operational challenges and security issues with smart Healthcare Solution

Undoubtedly, the IoT initiative in healthcare poses promising benefits to patients and those in the circle of care as alluded previously. However, despite these benefits associated with the implementation of the IoT-enabled healthcare system to support healthcare delivery, some inherent challenges and issues are critical to the services, devices, patients, and even those in the circle of care as related to operations and security. In essence, we cannot conclude on the proposed smart healthcare system without discussing the operational challenges and security concerns that may impact the design of the system, and they are broken into two main layers as will be discussed subsequently.

Table 2 Comparison between proposed system and other similar IoT systems

#	Parameter	Proposed paper	Paper #1 [3]	Paper #2 [8]	Paper #3 [19]
1	IoT devices	WBAN, WSNs, sensors, actuators, IoT-medical devices, RFID, wearables, wrist bands, etc.	RFID	Wearable devices and sensors	Wearable devices, sensors, WBAN, Android Smart Phone
2	IoT access technologies	NFC, BLE, ZigBee, 6LoWPAN, WirelessHART, Wireless cellular, LoRaWAN, LPWA, IEEE 802.15.4, etc.	Not specified	BLE, Wi-Fi, and ZigBee	Bluetooth and cellular
3	GPS location tracking	Utilized	None	None	Utilized
4	Routing protocols	Utilized	None	None	Utilized
5	Services	Four services—cancer care, business analytics and cloud, emergency, and operational	Only rehabilitation service	General review of healthcare services	Not specific—other than ECG Telemetry
6	Analytics and cloud services	Business and data analytics, Hadoop Development framework, cloud computing, cloud platforms, etc.	Mentioned about storage, analytics, and visualization	None	Emphasized on Cloud server
7	Operational challenges	Govt. policies, network resources, device diversity and heterogeneity, vulnerability of security and devices, security breaches, etc.	None	Challenges in sensing, analytics, and visualization are discussed	None
8	Security	Security for communications in IoT; WSN, smart devices; IPv6; privacy and encryption for devices and sensors; patient records and services, etc.	Not addressed	Not addressed	Not addressed
9	Scalability	Using hierarchical architecture in core, distribution, and access layers	None	None	None
10	Reliability	By the use of hierarchical and full mesh architectures	None	None	None
11	Other relevant parameter	IoT Health system framework, WSN routing; Network topology, etc.	Focused on IoT-based smart rehabilitation using ontology-based automating design methodology (ADM). Clinical trials were conducted due to availability of data	Emphasized on the opportunities and challenges of healthcare monitoring and management using IoT sensing with cloud-based processing	Signal quality index was computed for accessing the clinical adaptability of ECG signals

6.1 Operational challenges

Candidly, the proposed IoT-based smart healthcare solution has a great tendency to optimize the value of operational processes to improve healthcare delivery. However, it presents some operational challenges, especially where highly sensitive data and information coupled with a variety of smart connected devices are involved due to the various services and healthcare regions/agency for the province of Saskatchewan. These challenges need to be thoroughly addressed as we move into the implementation. In essence, the considerations for the operational challenges include but not limited to: government regulatory policies; rules, regulations and policies on compatible interfaces, network resources, standards, and protocols across various devices, equipment, and platforms; interoperability issues; device diversity and heterogeneity; vulnerability of security and devices; security breaches; interests of various stakeholders of various health organizations and authorities; device compliance; cost of devices and operations; processes of transition; data management and ownership; data consent, sharing, and utilization; data confidentiality; data consistency, duplication and quality; data preparation and analysis/analytics; incomplete and huge data sources; difficulty and management of external data and data sources; and data lifecycle management [12, 15–17].

Other operational challenges that can be inherent from the integrated smart solution that could impact performance as related to IoT connected devices, wireless sensors, actuators, and other network devices are: loss of signals and connectivity; strength and security of the communication channels; power generation and power capacity of the connected devices; frequency of charging sensors and connected devices; wireless technologies and standards that support low energy consumption for prolong usage, etc. It is necessary to allude that each of these challenges and concerns could cause serious setback or failure, and even to the entire healthcare system with impact on the quality of operations, if not properly considered and managed. Hence, they should be handled appropriately and circumvented during the pre-implementation phase to ensure a resilient province-wide system that meets the complexity of the services involved.

In view of all these challenges and issues, we have proposed the following approaches to mitigate against them, which must be handled critically to avoid any loopholes. These are: ensure due diligence with all stakeholders, vendors, and government representatives to ensure compliance and adherence to all sorts of policies and legislation; ensure user privacy such that authentication and security are strictly adhered to; ensure reliable and secure network communications void of interruption, interference, phishing, and latency; ensure network that is able to accommodate different sensors and connected devices; ensure the use of low power consumption for the sensors such that the frequency of charging them is minimal; ensure avoidance of signal loss in communication from one end to the other; and ensure provisions for adaptability, adjustability, scalability, manageability, and supportability of the network for additional devices and services for future growth.

6.1.1 Effects of heterogeneity of IoT devices and WSN operation

The integration of increasing number and the heterogeneity of IoT connected devices in healthcare settings could pose some problems in their operation and function as intended. This could be caused by lack of agreement on the device set of protocols and standards from various device manufacturers as argued by [26]. In essence, the implementation of IoT-based healthcare systems could be impacted thereby causing a reduction in functionality due to the lack of homogeneity among various IoT connected medical devices. In proffering a solution, we have to ensure that those devices conform to industry standards (i.e., meeting the service and operational-level agreements) that guarantee reliability and security. In addition, we will incorporate the approach in paper [10] as alluded in the introduction section.

On the other hand, the wireless sensor networks could pose constraints due to reduced computing, radio and battery resources of the sensors. These constraints could hinder the sensors from fulfilling their routing protocol expectations [23]. According to [23], we should ensure the WSN fulfill some requirements such as: autonomy to attack on the WSN; energy efficiency to prolong lifetime to maintain reasonable connectivity; resilience to cope with unpredictability; scalability to work with an increasing number of nodes; device heterogeneity to the introduction of different types of sensors; and mobility adaptability to render appropriate support to any form of mobility. Also, power consumption in sensors for WSNs could cause operational challenge. The way out of this is to ensure a reduction in power consumption in those sensors and or engage sensors with low power consumption.

Finally, while the sensor nodes of WSN are in operation, there is a possibility of them doing to a sink phase (i.e., where sensor nodes go down due to deficiency). In WSN, the operation and utilization of the sensor nodes should be consistently maintained to ensure avoidance of sink phase. The reason being that the cost of downlink communication (i.e., in the sink phase when the sensors go down) is found to be significantly more expensive and higher than that of the uplink communication [6].

6.2 Security issues in IoT devices and services

With the increasing number of sensors and IoT connected devices, there is a corresponding increase in the number of risks and vulnerabilities being introduced in the IoT based system. A perceivable thought to this increase in risks and vulnerabilities could be the heterogeneity of the devices and the complexity of the services where those devices are being incorporated as they form the network fabric. This is, no doubt, has impacted or could impact the breach of patient and medical records. It is important to avoid any comprise or breach to patient records, IoT devices, and services as we conclude this research work. Therefore, some feasible security mechanisms have been discussed as follows:

6.2.1 Security for communications in IoT

Due to the nature of the network communication of the IoT connected devices within the healthcare environment from one layer to another in the architecture, there should be ab utmost consideration given to security improvement for the three layers core, distribution, and access.

6.2.2 Security for WSN, smart connected and remote devices

Securing the routing protocols for the WSNs that characterizes the IoT-enabled solution should also be taken seriously. This is important to prevent attacks that cause the entire network to collapse. Also, the security mechanisms should prevent any illegal intrusion and access to the sensor nodes. It is equally important to introduce trust management and distribution mechanism for the WSN touting for data and location privacy for patients within and outside of the clinical environment since a large number of sensors is involved coupled with a large amount of data being generated and disseminated.

6.2.3 Security for IPv6 and devices

In the design of the IoT based healthcare system, considerations should be given to the use of low power IPv6 (6LowPAN) architecture and low power consumption for the devices to ensure secure integration. This is necessary due to the involvement of human beings where the connected devices are being embedded or implanted. Also, low power devices consume less power that avoids circuit overloading in the long run.

6.2.4 Security, privacy and encryption for devices and sensors

In addition, we should attach great importance to the security, privacy and encryption to the connected devices, remote equipment, and sensors in the design of the network architecture to safeguard patient and medical records.

6.2.5 Security for patient records and services

Knowing that the increasing manners in which medical data will be shared within the healthcare centers and sites could make them susceptible to potential hazards and risks, so security issues need to be addressed to eliminate the menaces. A way around this is for the healthcare authority to safeguard the patient or sensitive data by means of secure and encrypted formats, and to enforce controls on how data are transmitted through the cloud services and within the network. These controls will prevent threats from hackers.

7 Conclusions and future work

7.1 Concluding remarks

In conclusion, a solution of this nature, especially in the healthcare industry has constituted a revolutionized transformation from traditional healthcare delivery to a smart healthcare delivery due to the vast and endless opportunities it renders. Therefore, we have proposed the design implementation of the IoT based healthcare system which aligns with the newly formed SHA resulting from the consolidation of various health regions. The smart solution has been accomplished by focusing on four (4) healthcare services business analytics/cloud services, cancer care services, emergency services, and operational services, through the Internet of Things (IoT) technologies especially with the use of wireless sensor networks and other connected devices by means of full-mesh hierarchical network topology.

The integrated system developed in this paper has been considered to be more robust and efficient to facilitate interoperability, interconnectivity, and intercommunication of those services. Presumably, it has offered huge benefits, especially to assist those in the circle of care to be able to interact and collaborate more proactively due to the availability of data from various applications and conditions of services that will enhance healthcare decisions. Other benefits being perceived in the long run are increased workforce productivity; prompt and speedy responses to emergency situations; speedy treatments in a real-time manner; enhanced return on investments; improved drug dispensary and management; and improved asset management. We have also covered cloud computing services for data streaming, exchanging, and transmitting from sensors and connected devices and network resources. We have also compared the proposed healthcare system and some other existing healthcare systems to justify the novelty of our research contribution.

On the final note, there is no doubt that the design implementation of this IoT-enabled solution will proffer considerable benefits to the go-live phase, as alluded earlier. However, all the pertinent operational challenges and security identified in this solution have to be circumvented. This is because failure to meet the required quality of operation could cause severe failure to the entire system, which may result in the breach of patient data, services, and devices.

7.2 Future work

The IoT-based smart Saskatchewan healthcare solution addressed in this paper considered only four services of several services. However, there are still many services that we have not been able to address in our research but are equally important. These include but not limited to: immunization services, mental health, and addictions services, acquired brain injuries services, long-term disabilities and illnesses services, patient tracking services, rehabilitation services, surgical services, infirmity and condition detecting/sensing services, laboratory and blood services, and diagnostic imaging services. Therefore, we will be considering the consolidation of these other services in the future research work that will enable a full-fledged IoT based healthcare system for the province.

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