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EVOLVING FRAMEWORK FOR IOT-BASED ENERGY EFFICIENT WIRELESS SENSOR NETWORKS FOR HEALTHCARE SERVICES

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Abstract **- The Internet-of-Things (IoT) is a system of interrelated computing devices having unique identifiers that enables to transfer data over a network without requiring human-to-computer or human-to-human interaction. With the rapid growth in embedded wireless computing devices with high-speed internet connectivity, the Wireless Sensor Networks (WSNs) for healthcare applications comprises of interconnected several tiny-powered, wearable, wireless bio-sensors to provide an effective way of collecting vital health-related data. The emerging paradigm of IoT in smart healthcare system requires a specialized secure framework in order to enable real-time health monitoring, reliable diagnostics, effective treatment processes, and many other related aspects of healthcare system. In this paper, various aspects of energy consumption in IoT-based framework of WSNs for healthcare services are discussed. The framework for IoT-based healthcare network cater to upgraded microcontrollers, IoT gateway devices, various wireless and web technologies for IoT, variety of bio-sensors and data collectors, and secure communication protocols. Techniques to optimize the energy consumption in WSNs have been presented leading to energy efficient framework for WSNs suitable for healthcare systems.**

Keywords **- Energy Efficiency, Internet of Things (IoT), Routing protocols, Wireless Sensor Networks (WSNs), Healthcare.**

I. INTRODUCTION

The first principle of IoT (Internet-of-Things) is to connect smart objects (wireless sensors) to the Internet in a transparent way. This leads to an exchange of data between all connected things, and brings information to intended users in a secure way. One of the most attractive application areas for IoT is the healthcare, giving us the possibility of several medical applications including remote health monitoring, chronic diseases, body fitness and elderly care. In fact, healthcare is an amalgam of multiple services rendered to individuals and communities by healthcare professionals responsible for delivery of medical care services. The overall healthcare sector includes various entities such as health parameters and diseases, diagnostic techniques, healthcare centers and hospitals, and trained healthcare staff and clinical experts. These entities support, control and interact with each other to make a complete healthcare system.

There are several issues in healthcare services that IoT can address and combat in the most effective way. For example, health management and the incapability of responding to emergency; shortage of trained healthcare manpower and medical facilities especially in rural areas, inaccessibility to diagnostic services in rural areas, shortage or absence of infrastructure for specialty healthcare; inadequate disease prevention and early detection capability, etc. With the development of Information and Communication Technology (ICT) based technologies such as IoT, Machine Learning, Artificial Intelligence, continuous efforts are being made to develop a framework which will overcome these issues and challenges. Table 1 depicts a brief account of IoT applications suitable for various healthcare services.

TABLE I
IoT Applications for Healthcare Services

Healthcare Service Type	**IoT Application**
Preventive alerts	Routine checkup and medication reminder, Immunization, guidelines for secondary prevention from diseases (pop-up alert, SMS, email, task list, detailed preventive

	guidelines)
Diagnosis	Suggested investigation report of clinical tests, information on patient condition, trigger notes/alerts in case of medical emergency
Treatment Plan	Treatment/medication plan based on diagnosis reports and using knowledge based on treatment of similar patients in the past, dosage recommendation, guidelines on possible drug reaction as per patient's medical history
Patient follow-up	Alerts/reminders for follow-up checkup or immediate consultation in case of emergency, monitoring of medication plan
In-patient management	Healthcare management through previous records, planning for duration of hospitalization through estimation of patient's recovery rate, avoidance of redundant tests, responding to actions taken by care giver

IoT based framework for healthcare is one such solution which is based on a layered architecture and supports several domains of healthcare service sector [1]. Deployment of an IoT framework in integration with existing healthcare system can provide features of smart healthcare. Starting from telemedicine to e-health and m-health, utilization of ICT is increasing and offering more and more services to the healthcare sector. Devices have been developed to offer IoT based services such as Ambient Assisted Living (AAL) [2], remote monitoring for chronic diseases [3], smart ambulance to provide patient monitoring during mobility [4], [5], [6] and many more. Most of these applications are based on the wireless sensors which record bio-signals from the human body and transmit them to a data aggregating unit. The data is then processed at the same unit or sent to a separate centralized data processing unit to generate clinical inferences regarding health state of the patient.

Wearable bio-sensors can acquire physiological data with high degree of accuracy without any direct intervention of human beings. This data varies from simple case of body temperature and pulse rate to capturing ECG and EEG signals. The data from these sensors is stored locally in a data aggregator or in remote database. This transfer of data from the sensors and access to this data is provided to the users through different network access techniques depending upon the type of application or user devices. Thus, wireless sensor network has a vital role in overall functioning of an IoT-based healthcare service system. Due to wide diversity in the type of data and random in the placement, mobility and ambient conditions of both the sensors or their bearers and the end users, the desired characteristics for such networks is quite different from many other commonly used communication systems. Similar to any other IoT system, the amount of data to be processed in healthcare systems is extremely large because large number of users whose health status and clinical treatment act as source of data. Moreover, unlike many other IoT systems which generate text or numeric data (except those including imaging devices), the healthcare data includes high resolution images made from pathological sample slides and radiology equipments. Also, the data such as ECG or EEG is continuously generated and needs to be transmitted seamlessly in case of remote monitoring system of IoT enabled intensive or critical care units (ICU/CCU). The quality of service (QoS) or performance parameters are much more demanding in terms of network resources with stringent accuracy and security. The two most crucial network resources are bandwidth and energy.

The IoT networks are intelligent networks and require sensors and network devices which should not only be energy-smart but low cost also. These devices are continuously engaged in computation, processing and transmission of data which is a high power consumption activity. On the contrary, most of these devices being battery driven, there is a strong requirement to minimize the consumption of power, thus making it an energy efficient network. The demand for seamless connectivity with best possible QoS in case of healthcare applications restricts the network and application planners to put the devices in sleep mode or adopt energy efficient methods which are more common in several other not-so-critical applications.

The frameworks for the IoT-enabled healthcare systems have to continuously evolve to meet the challenges related to low-cost of deployment, providing for consistent as well as secure data collection using the small energy reserves at their disposal. This paper elaborates on the various aspects related to energy efficient operation of the network and is organized as follows way. Section 2 discusses the related work to extract the current status of the frameworks used for healthcare applications. Section 3 presents the requirements for the energy-efficient framework at different layers of the network. A comparative analysis of the energy efficient routing protocols is given in Section 4. Finally, the energy efficient framework strategies are discussed in Section 5, followed by conclusions in Section

6 to aid in the evolution of new frameworks for healthcare applications of IoT-enabled WSNs.

II. RELATED WORK

The wireless sensor network usually follows either a static client-server based architecture, or dynamic adhoc architecture for static/mobile devices and users. A 3-layered architecture for IoT framework which is a common approach followed in many IoT based healthcare systems was discussed in [7]. It mainly comprises of data acquisition sensors, data aggregator and cloud resources. The network of data acquisition devices, known as Body Sensor Network (BSN) was deliberated in [8]. Bio-sensors connect with data aggregator as smart phone via WiFi/Bluetooth, ZigBee, or RFID. Based on 7-layered reference network model, smart healthcare M2M and D2D framework is proposed in IoT World Forum [9]. The devices and processes used in all these layers have different energy requirements, thus having varied impact on the overall energy efficiency of the network. Various energy efficient network models have been proposed in the recent past [10-12]. The flow of data and number of hops in a network can be optimized using node placement technique employing genetic algorithms (GA) keeping a balance between energy and performance [13]. Cross-layer energy consumption parameters have been used for analysis of network lifetime in research works carried out in [14]. Hierarchical wireless network architecture for energy conservation to achieve the green networked IoT for healthcare applications has been proposed in [15].

Adoption of energy conserving routing protocols by monitoring the energy levels of the nodes and balanced energy utilization approaches in low-power healthcare systems have been discussed in [16]. Energy efficient service based on event-driven paradigm in IoT networks is proposed in [17]. In WSN for healthcare, multi-hop routing protocols are employed with minimum energy consumption. A mathematical multi-hop IM-SIMPLE protocol model using short packets for communications is proposed [18]. A new energy consumption balance model based on shuffled frog leaping algorithm (SFLA) is proposed in [19]. Deep Reinforcement Learning (DRL) based intelligent routing scheme for IoT-enabled WSNs for higher efficiency has been discussed in [20].

III. REQUIREMENTS FOR ENERGY-EFFICIENT FRAMEWORK FOR IOT APPLICATIONS

The physical layer of an IoT network includes battery-operated RF devices such as RFID tags, bio-sensors, ambience sensors, smart dust, etc. and network interfaces providing low power radio links. One of the major challenges at device level is energy consumption whereas the challenges at network level include bandwidth, seamless connectivity and communication range with acceptable received signal strength. As such the radio links used in IoT networks (IEEE 802.11, IEEE 802.15.4 standards) are highly unstable and lossy besides having low reliability due to strong interference and weak signal strength. For better energy efficiency, both the devices and radio links are low power and contribute to the energy constraints for device and network designs. The energy constraint becomes more critical for healthcare services where uninterrupted monitoring is required for devices to be in active state with continuous transmission of data across various layers.

One of the major functions of WSNs deployed for preventive healthcare services is to transmit health condition of the patients continuously to the medical experts. Any discontinuity in acquisition and transmission of data may be life threatening especially in case of monitoring patients for chronic diseases. Since these devices are battery driven, the utilization of battery power must be optimized for long battery life. Instead of simply reducing the power consumption, the system should be made efficient in terms of providing reliable and secure communication with minimum energy consumption. This efficiency can be improved by applying energy efficient designs in sensor nodes, communication devices and network architecture, routing protocols and data processing units.

Most of the physiological sensors use smart, adaptive technology to transmit and receive data using wireless communication standards. The factors which affect energy efficiency of such networks include energy hole due to uneven consumption of energy, re-transmission for error-free delivery of data, data collision during multi-hop, idle-listening mode and overhearing due to unwanted reception of data. To increase uninterrupted network life time, the energy consumption needs to be reduced so that the same battery can provide power to the network for longer duration of time. There are several models and techniques which can be considered to balance the effect of these factors. Fig. 1 depicts some of the important energy consumption parameters at various layers of IoT-based WSNs.

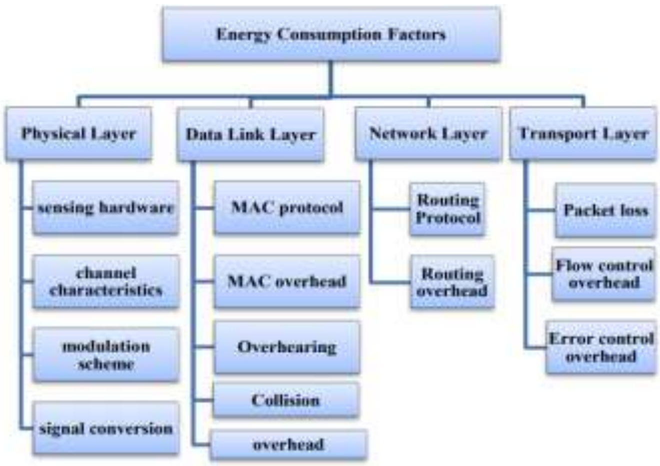

Fig. 1 Energy Consumption Parameters in WSNs

Each layer in the WSN protocol stack has its own contribution in the overall energy consumption and thus network lifetime.

Cross-layer energy consumption parameters have been used for analysis of network lifetime in some research works [21]. Physical, MAC and Network layer energy models are analyzed in unison for more accurate estimation of energy consumption and thus network lifetime for a particular application.

At the physical layer, efficient node placement techniques are considered to implement low-power IoT networks in which multiple sensor nodes send the data to a common data aggregator node or sink in multiple hops. The number of hops and flow of data can be optimized for a balance between energy and performance in terms of reducing congestion in the network. Some of the popular algorithms used for node placement are genetic algorithms [13], bio-inspired algorithms [22], particle swarm optimization (PSO) [23] and optimized artificial fish swarm algorithm (OAFSA) [24], artificial bee colony (ABC) and territorial predator scent marking algorithm (TPSMA) [25]. In healthcare applications, node placement techniques are applied on data aggregator nodes or intermediate relay nodes so as to balance the flow of data to avoid any congestion at aggregator or relay node.

At MAC sub-layer of Data Link Layer of IoT network for healthcare applications, various biosensors are configured to form body area wireless sensor network. Energy-efficient scheduling techniques such as self- scheduled and distributed MAC, self-distributive MAC, distributed hybrid slot scheduling, QoS aware scheduling are applied to optimize the flow of data from sensors to aggregator or sink nodes. Such scheduling techniques improve the energy efficiency of the network by reducing re-transmission of data, over-hearing and idle listening, thus increase the life time of battery operated devices.

Channel allocation techniques are applied for efficient sharing of the radio spectrum which not only improves bandwidth utilization but also reduces the congestion or collision in the channels. Another multi-hop MAC protocol TCH-MAC based on integration of TDMA and CDMA has been proposed recently. This protocol has a TDMA based scheme which is traffic adaptive to handle problems due to heavy burst of traffic and an efficient CDMA based scheme along with adjustable power control for transmitter. This hybrid scheme has been shown to improve energy efficiency of the network while maintaining throughput and losses due to collision to desired levels.

Several transmit power control schemes depending upon the requirement of coverage area and acceptable received signal strength have been used, individually or in integration with other schemes. Such schemes are appropriate for contention-based topologies and implemented using protocols such as power controlled multiple access (PCMA), common power protocol (COMPOW), power controlled dual channel (PCDC), etc.

The idle listening operation of the receiver of a low-power device also needs to be optimized to enhance the efficiency of energy consumption. Several power-off schemes such as power management employing multi-sleep states, power aware multi-access with signaling (PAMAS), pico node multi-channel MAC have been proposed to implement power saving features, leading to improvement in overall energy efficiency at network level. In addition to using these specially designed transmit power control and receiver power-off protocols, fine tuning of transmit and receive power of antenna by using smart directional antenna is also carried out.

The protocols and data flow management techniques applied at transport layer also affect the energy efficiency of the network so as to ensure reliable data transmission. It should comprise of minimum packet routing protocols such as posture/movement aware routing, temperature aware routing, cluster-based routing, QoS aware routing, cross-layer routing and minimum re-transmission due to link failure or network congestion. Different versions of Transmission Control Protocol (TCP) have been developed to provide reliable and energy efficient end-to-end data transmission.

At the application layer, the operating system (OS) or the middleware is responsible for implementation of techniques which increase the performance in terms of energy consumption. In case of healthcare applications, techniques to predict the switching of devices between various modes of operation such as active, standby, or sleep are used to make them more energy efficient. So combinations of techniques are applied at various levels of the overall network framework to improve the energy efficiency. Designing IoT-based framework for healthcare applications should also consider other requirements such as remote operation capability in the form of e-health, m-health, telemedicine, etc.

IV. COMPARATIVE ANALYSIS OF ENERGY-EFFICIENT ROUTING PROTOCOLS

Energy efficiency can be improved by various means such as adjusting physical parameters of communication technology, designing less power consuming devices, and developing energy efficient routing protocols. Routing protocols have been mainly designed for many-to-one transmission as well as data aggregation. The adoption of energy conserving routing protocols by monitoring the energy levels of the nodes and balanced energy utilization approaches are the major challenging issue in low power healthcare systems [16].

In energy-efficient routing protocols, the route request packet having energy data is transmitted in energy efficient reliable path of the network. It is followed by receiving the control data (route reply packet). This whole process is known as flooding. With an increase in flooding, the packet overhead also increases. This may lead to huge consumption of energy. Therefore, there is a need to avoid over flooding situation for efficient design of energy-efficient routing protocols [26].

Currently, there are several routing protocols which not only address the energy efficiency issue but also the reliability and Quality-of-Service (QoS) issues. For example, Prediction based Secure and Reliable (PSR) routing protocol offers reliable and secure routing as well.

To optimize energy efficiency of healthcare networks, an IoT based routing protocol should be dynamically selected in accordance with on/off power state of the IoT device. It necessitates the monitoring and logging-in of the generation and consumption of energy through communication networks. In IoT-based WSNs, sensor nodes have limited energy associated with its life time. They do not produce much heat as nodes are directly implanted in the human body. All paths are well defined for data routing and must be energy aware. The main issue concerned with energy efficient routing protocols is the implementation of complex algorithms. There are several efficient routing protocols but they do not consider on different aspects such as delay tolerant, postural information, temperature rise, etc. Table II presents a comparative study of various energy-efficient routing protocols that support IoT-based framework for WSNs in healthcare services.

TABLE III
Comparison of Energy-Efficient Routing Protocols

Type of Routing Protocol	**Major Function(s)**	**Remarks**
Attribute-based	It includes energy-aware data-centric in which each node decides either to forward or drop the received content based data packets for improving the energy efficiency at network level.	Possibility of over flooding
Flat-based	A large number of nodes having the same configuration and features collect the data together and transmit it to the destination as per routing tables of different nodes.	Preferred due to improvement in energy efficiency
Geographical	The data is transmitted via the shortest distance path based on the location information.	Improves the overall energy efficiency of the network in addition to reduction in the packet overhead with improved network lifetime
Hierarchical	One of the sensor nodes in a cluster is designated as the cluster head. Different sensor nodes collect the data and transmit it to their cluster head for data aggregation for retransmission to the base station (another sensor node	The most efficient energy balancing low-energy adaptive clustering protocol

	in the network).	
Ad-hoc On-demand Distance Vector (AODV)	The route selection is done by the destination node based on link quality metrics SNR and hop count. A modified data packet Route Request (RREQ) is used for route discovery. On receiving it by the destination node, it sends the Route Reply (RREP) data packet to the source.	The network is energy efficient based on its network lifetime with higher throughput
Meshed Multipath	To avoid increased overhead data due to requirement of retransmission in case of route failure in single path routing protocol.	Improves the energy efficiency and reliability of the network by reducing the system overhead
Dynamic Routing Protocol for Low power (RPL) algorithm for mobility support	They make smart decisions that increase the network lifetime by estimating the energy consumption of the sensor nodes. [17], 27].	Provide energy efficiency while considering the mobility of sensor nodes.
Energy and QoS Aware	Primarily used for communication devices in healthcare network [28].	Reduced traffic load and better energy efficiency

V. ENERGY EFFICIENT FRAMEWORK STRATEGIES FOR IOT-ENABLED HEALTHCARE SYSTEM

Energy efficiency in IoT-based healthcare networks is of utmost importance because of battery-constrained bio-sensor devices used in wireless body area networks. Both wearable as well as implantable sensors must have long battery lifetime for uninterrupted service. But it is more important to have much longer lifetime for the implantable bio-sensors since complex surgery is required to implant them. Moreover, their size is generally very small and this limits the battery power further that can be embedded into them. The framework of healthcare IoT network should, therefore, be designed to have minimum energy consumption at every wireless sensor node.

In IoT-based WSNs for healthcare services, multi-hop routing framework provides required energy efficiency in terms of enhanced network lifetime, reduced overheads and end-to-end delay. As an instance, IM-SIMPLE framework is a mathematical multi-hop model [18] which uses short packets for communication employing TDMA mechanism. A forwarder node is selected based on the distance from the destination node as well as its residual energy. This results in considerable reduction in energy consumption with increased throughput. There are several strategies in different routing protocols which specifically focus on energy efficiency in evolving framework, as depicted in Table III.

TABLE IIIII
Energy-Efficient Framework Strategies

Framework Strategies	**Attributes**	**Remarks**
Relay Nodes	A relay node is selected in the network which enables balancing the load as well as reducing the energy consumption. Data from multiple nodes is combined by the relay node to form a unified data packet prior to forwarding it with maximum energy efficiency.	A two-hop extension routing protocol can also be deployed in order to send data packets directly for further reduction in the energy consumption.
Leader Selection	A relay node with capability of amplifying the data prior to forwarding it to the neighbouring relay nodes acts as leader.	This results in overall improvement in network performance in addition to conservation of energy.
Packet size optimization	To overcome possible data bit errors in large size packets, optimized data packet size are considered to achieve higher energy efficiency and lower packet error rate.	Higher energy efficiency
Cloud computing	This method is approximately 20 times faster in storing, analyzing, processing, delivering, distributing, and securing critical healthcare data. Integrating cloud computing with WSNs offers convenient remote health monitoring techniques. [29]. [30].	However, it poses major challenges in providing security and authentication.
Restricted Tree Topology	A star topology using opportunistic and dynamic relays is deployed. The link performance metric used is the received signal strength indicator (RSSI). [27].	Results in higher reliability with minimum energy consumption under high signal loss conditions
Critical data routing	Only the critical data is sent by source nodes to two intermediate nodes which have minimum transmission path loss. [17].	Offers energy-efficiency along with reduced propagation loss, improved network lifetime, enhanced stability period and higher throughput
Co-LAEEBA protocol	Different nodes in the network use collaborative learning by sharing each other's resources. The destination node combines the received data packets using Fixed Ratio Combining method. This protocol uses shortest path routing algorithm based on minimum hop count. [28].	Yields better residual energy, higher throughput, and greater stability period
Adaptive Multi-hop Routing (AMR)	It is basically an adaptive tree-based with multiple hops in which fuzzy logic evaluates routing metrics such as residual energy, hop count, and RSSI [28].	Results in better load balance, higher network lifetime and

protocol		energy efficiency
Energy-aware Peer Routing	The peer node is discovered and the data packets are exchanged between them. Without employing a fully centralized system, the display unit is discovered dynamically in real time, thereby improving patient mobility and privacy. [18].	Results into enhanced performance with respect to reducing traffic load and overall energy consumption. Offers a real-time indoor healthcare monitoring services
Cross-layer Opportunistic MAC Routing	Any node may serve as either a sensor node or a relay node. It is based on use of appropriate handshake mechanism such as RTS/CTS along with ACK. Relay node is selected having highest residual energy and located nearer to the destination node.	Offers higher energy per bit, more network lifetime, reduced end-to-end delay along with higher energy efficiency

The sensor nodes in IoT-based WSNs for healthcare services continuously acquire and transmit data to provide monitoring of clinical state of the patient. To increase the network lifetime, different techniques within the preview of energy harvesting can be considered, thereby reducing the need to change the battery. For example, energy from human body due to its actions and movements acts as a source of energy in different forms which can be converted to electric energy and thus provide power to the bio-sensors. Similarly, energy from surrounding environment including natural renewable energy such as solar, wind, heat, light etc. can be harnessed and converted by the sensors as power source. Likewise, energy from surrounding environment from man-made sources such as electromagnetic waves (RF signals) present almost everywhere in wireless communication systems can be harvested by the sensors as a source of power.

For sensors used in healthcare applications, the natural sources of energy present in environment may not always be present since the person wearing the sensors could be present indoor where sufficient wind or solar energy is not available to generate enough electrical energy. Harvesting energy from human body is also not reliable since the movement of the patient is generally restricted and cannot act as source of energy. Any extra device or component to store and amplify these weak or sparsely available energy sources will add to the discomfort in wearing the device, thus making it less user friendly.

Since most of the sensors rely on wireless communication for connectivity, RF energy is expected to be present and can be used as a source of energy for the sensors. The channel connecting the sensor and its network access device i.e. data aggregator or sink node, carries both the RF energy and data between the two. This RF channel is one prime source of energy since there is continuous supply of energy from the network access device. Moreover, the device is designed and configured to operate in the same frequency band as that of RF channel, thus simplifying the design of energy harvesting module for the sensor.

VI. CONCLUSIONS

The IoT-based Wireless Sensor Networks for healthcare services use energy-efficient bio-sensors and other network devices. All these are continuously engaged in computation, processing and transmission of data by using energy-efficient routing protocols. Various energy efficient models and algorithms are available at each layer of WSN protocol stack. Energy efficient designs are required in sensor nodes, communication devices and network architecture, routing protocols and data processing units. Overall energy efficiency can be improved by adjusting physical parameters of communication technology, designing less power consuming devices, and developing energy efficient routing protocols. The evolving frameworks for IoT-enabled healthcare applications must be inclusive of the following three strategies to be broadly acceptable, efficient and secure operation:

(i) The topology used for sensor deployment can be stationary; although the whole body area network may be mobile as a complete unit.
(ii) Use of energy harvesting from RF signals should be incorporated to provide for consistent and QoS based requirements of health related data collection.
(iii) Energy-aware routing protocols should be used to utilize the available energy resources efficiently leading to better network lifetime.

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