



# Wireless Sensor Networks in Healthcare System: A Systematic Review

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Accepted: 10 March 2024 / Published online: 29 March 2024

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## Abstract

In modern era wireless sensor networks used in many areas like military, engineering, surveillance, agriculture, healthcare, home etc. Healthcare is one of the most important areas where wireless sensor networks play an important role. In this paper a detailed review on wireless sensor networks in healthcare system is presented to find out the best communication technology and sensors used in healthcare system. Various sensors (pulse oximetry sensor, sweat rate sensor, glucose sensor, acceleration sensor and ECG electrode) are used in healthcare system are presented in this paper. Several communication techniques (Bluetooth, Zigbee, NFC, UWB and Wi-Fi) are used in healthcare system also discussed. Out of these all-communication technologies UWB is more powerful and widely used in recent time.

**Keywords** Wireless Sensor Networks · Healthcare System · Medical System · Sensor · Wireless Body Area Networks

## Abbreviations

BP	Blood Pressure
ECG	Electrocardiogram
dBm	Decibel-milliwatt
EMG	Electromyogram
Gbps	Giga Bit Per Second
GHz	Gigahertz
HR	Heart Rate
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial Scientific and Medical
Kbps	Kilo Bit Per Second
LED	Light Emitting Diode
Mbps	Mega Bit Per Second
NFC	Near Field Communication
PDA	Personal Digital Assistant

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pH	Pouvoir hydrogene
RF	Radio Frequency
RFID	Radio Frequency Identification
UWB	Ultra Wide Band
WBAN	Wireless Body Area Networks
Wi-Fi	Wireless Fidelity
WMS	Wearable Medical Sensor
WSN	Wireless Sensor Network
3 D	Three Dimensional

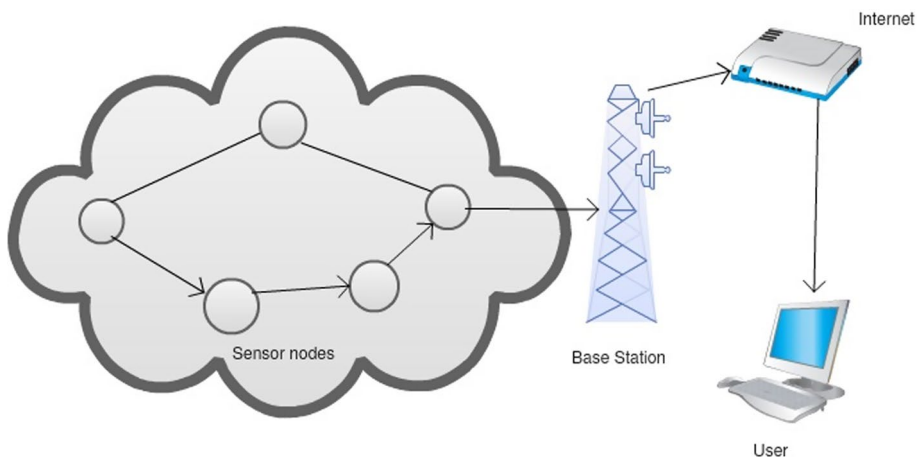
## 1 Introduction

A wireless sensor network (WSNs) is the combination of sensor nodes. Sensor nodes having some capabilities like receiving the data, transmitting the data and process the data. Sensor nodes sensed the data and send to the base station/sink node. Sensor nodes have limitation in terms of power. Wireless sensor networks widely used in many areas like military, traffic surveillance, health care, security monitoring, battlefield, environmental monitoring, machine failure diagnoses, agriculture, transportation and many more [1] (Fig. 1).

Mainly wireless sensor networks are five types [2].

- Terrestrial wireless sensor networks
- Underground wireless sensor networks
- Underwater wireless sensor networks
- Multimedia wireless sensor networks
- Mobile wireless sensor networks

Sensor nodes are deployed on the land surface in terrestrial wireless sensor networks. These types of networks are used in military and to check the condition of land. Sensor nodes are deployed inside the land underground in the underground wireless sensor



**Fig. 1** Wireless sensor networks

networks. These types of networks are used in military boarder monitoring, to check the quality of soil, moisture etc. Sensor nodes are deployed inside the water like in river, ocean in the underwater wireless sensor networks. These types of networks are used to monitor the life of fish or animal those are inside the water. Sensor nodes are capable to store the information like audio, video, picture etc. in the multimedia wireless sensor networks. Sensor nodes are mobile in the Mobile wireless sensor networks. These types of networks are used in military, surveillances and monitor the wild life.

Figure 2 shows the applications of the wireless sensor networks. These are the main applications and further specified into sub applications.

Figure 3 shows the sub applications of wireless sensor networks [3]. Detailed review is presented in the next section. The main motive of this paper is to find out the best communication technology and several sensors used in healthcare system with their different applications.

## 2 Literature Review

The main aim of this paper is to find out the answers of the following research questions.

- RQ1: What are the various communication technologies those are used in healthcare system in context to WSNs?
- RQ2: What are the various sensors used in healthcare system and what are the applications of those sensors?
- RQ3: What are the various parts of the body where sensor can be deployed or implemented?
- RQ4: Which communication technology is better in healthcare system?
- RQ5: What is the role of energy in WSNs?
- RQ6: What are protocols used in Wireless body area networks?

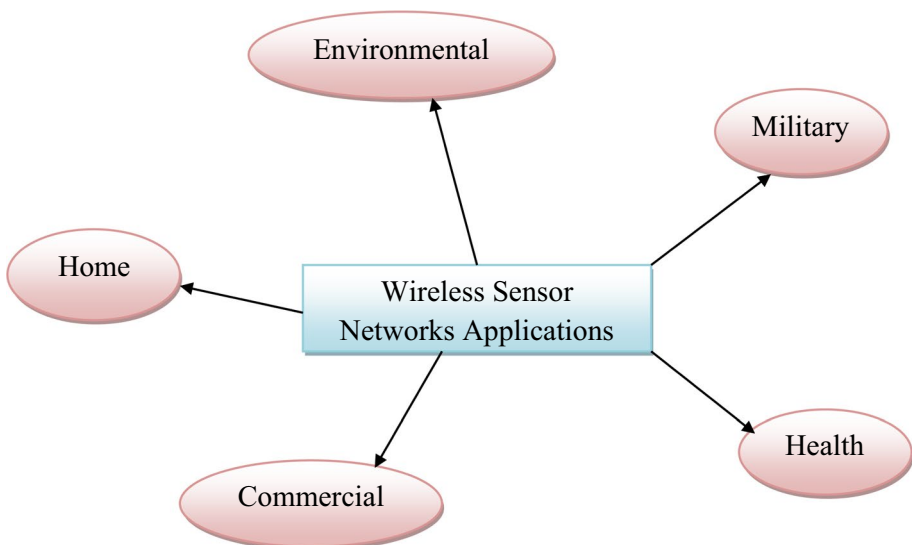
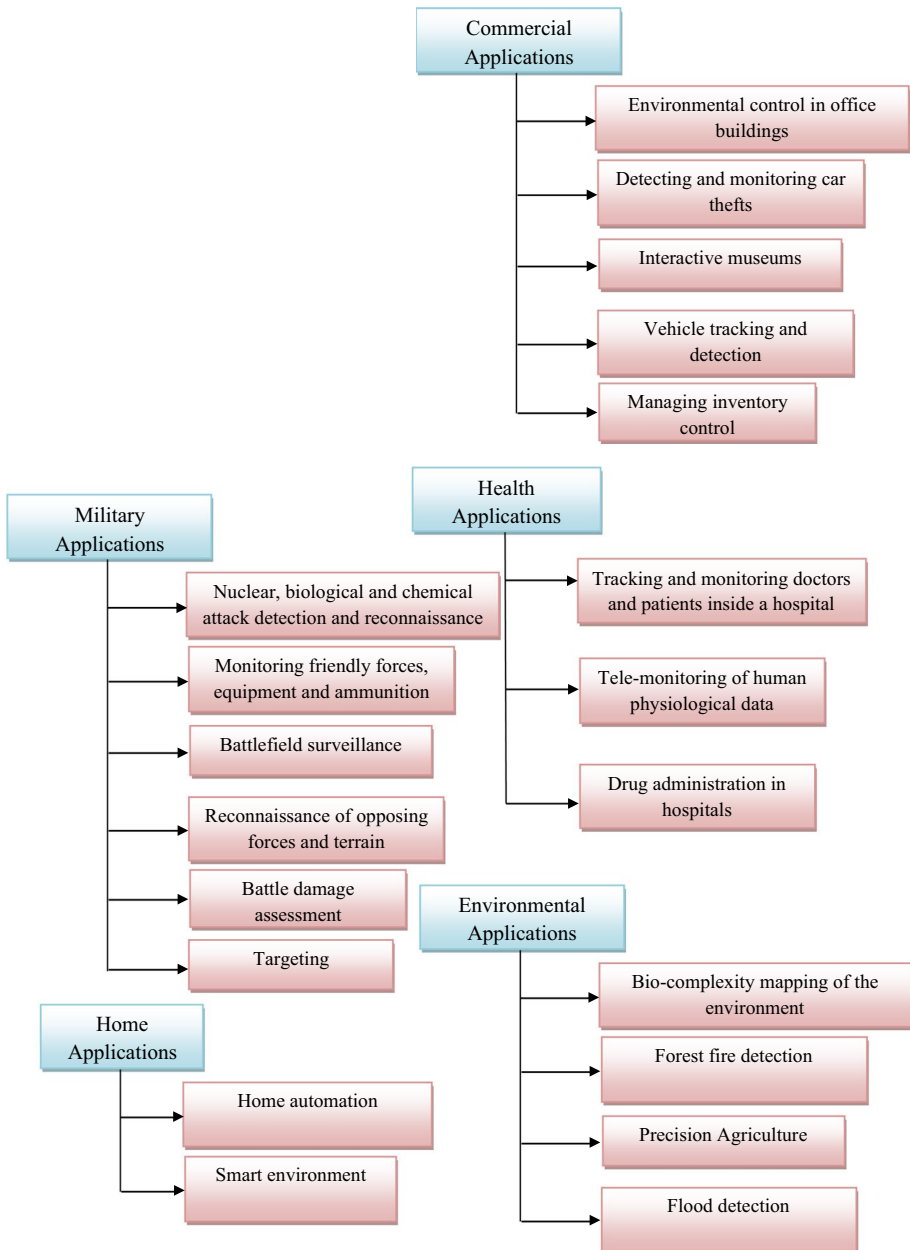


Fig. 2 Applications of wireless sensor networks



**Fig. 3** Sub applications of Wireless Sensor Networks

Table 1 shows the different journals and publishers list from which papers are taken to prepare the literature review of this paper. Only SCI indexed papers are included in this review paper. Most of the papers are from IEEE journals.

**Table 1** Article categorization journal wise

S. No	Journal	Publisher	No. of papers
1	Computer Networks	Elsevier	2
2	IEEE Access	IEEE	6
3	Journal of Communications and Networks	IEEE	1
4	IEEE Transactions on Nanobioscience	IEEE	1
5	IEEE Journal of Biomedical and Health Informatics	IEEE	1
6	IEEE Transactions on Instrumentation and Measurement	IEEE	2
7	IEEE Transactions on Industrial Informatics	IEEE	2
8	IEEE Sensors Journal	IEEE	9
9	IEEE Internet of Things Journal	IEEE	1
10	IEEE Transactions on Professional Communication	IEEE	1
11	IEEE Transactions on Multi-Scale Computing Systems	IEEE	2
12	IEEE Transactions on Consumer Electronics	IEEE	2
13	IEEE Systems Journal	IEEE	1
14	IEEE Transactions on Microwave Theory and Techniques	IEEE	2
15	IEEE Transactions on Biomedical Engineering	IEEE	2
16	IEEE Journal of Electromagnetic and Microwave in Medicine and Biology	IEEE	1
17	IEEE Transactions on Emerging Topics in Computational Intelligence	IEEE	1
18	Frontiers of Forestry in China	Springer	1
19	Applied Geography	Elsevier	1
20	IEEE Transactions on Wireless Communications	IEEE	1
21	Biomedical Engineering	De Gruyter	1
22	Artificial intelligence in medicine	Elsevier	1
23	Review of Scientific Instruments	American Institute of Physics	1
24	Medical & Biological Engineering and Computing	Springer	1
25	Diabetes care	American Diabetes Association	1

Table 1 (continued)

S. No	Journal	Publisher	No. of papers
26	Gait & Posture	Elsevier	1
27	Stroke	American Heart Association	1
28	Journal of Alzheimer's Disease	IOS Press	1
29	Neurorehabilitation and Neural Repair	SAGE	1
30	Neuromodulation: Technology at the Neural Interface	International Neuromodulation society	1
31	Epilepsy & Behavior	Elsevier	1
32	The Annals of Thoracic Surgery	Elsevier	1
33	Journal of Rehabilitation and Development	US department of veterans Affairs	1
34	Interacting with Computers	Elsevier	1
35	Applied Clinical Informatics	Wiley	1
36	IEEE Transaction on Biomedical circuits and System	IEEE	1
37	IEEE Transaction on Information Technology in Biomedicine	IEEE	3
38	IEEE Journal of Biomedical and Health Informatics	IEEE	2
39	Fibers	MDPI	1
40	Behavior Modification	SAGE	1
41	Sensors	MDPI	3
42	Chest	Elsevier	1
43	Journal of Chemical Education	ACS Publications	1
44	Journal of Clinical Monitoring and Computing	Springer	1
45	Biomicrofluidics,	AIP	1
46	Biosensors and bioelectronics	Elsevier	1
47	Sensors & transducers	IFSA Publisher	1
48	Pure and Applied Chemistry	De Gruyter	1
49	IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)	IEEE	1
50	Computer Standards & Interfaces	Elsevier	1

**Table 1** (continued)

S. No	Journal	Publisher	No. of papers
51	Computer communications	Elsevier	2
52	IEEE Wireless Communications	IEEE	1
53	Wireless Personal Communications	Springer	2

Lv et al. [4] presented the application of wireless sensor networks in context to position of sensor nodes. Range based positioning technique focused in their paper. Line of sight plays a crucial role in the wireless sensor networks. The area which comes in the non-line of sight refers to the unattended area. Two algorithms 3D and 3DL for unattended area are discussed. Results show the accuracy of the positioning and coverage of the proposed algorithms. Four basic node positioning techniques are in the literature as follow- range based positioning vs range free positioning, distributed positioning vs centralized positioning, incremental positioning vs concurrent positioning and absolute positioning vs relative positioning.

Amaro et al. [5] proposed a model for animal tracking with the help of wireless sensor networks. Animal live in different environment like forest, polar etc. human can't be monitor the living style manually due to some constraints. Animal those are living some these types of are monitored with the help of wireless sensor networks. Animal monitoring is done by several ways like sensor nodes deployed on the land, movable sensor and sensor put on the animal body also. Every sensor node has a sensing range and a communication range. Sensor nodes able to detect the activity within the sensing range. Sometimes animal may be outside or inside the sensing range. So if the animal outside the sensing range then activity done by animal is not sensed by the sensor node. Markov model is used for the simulation and result analysis.

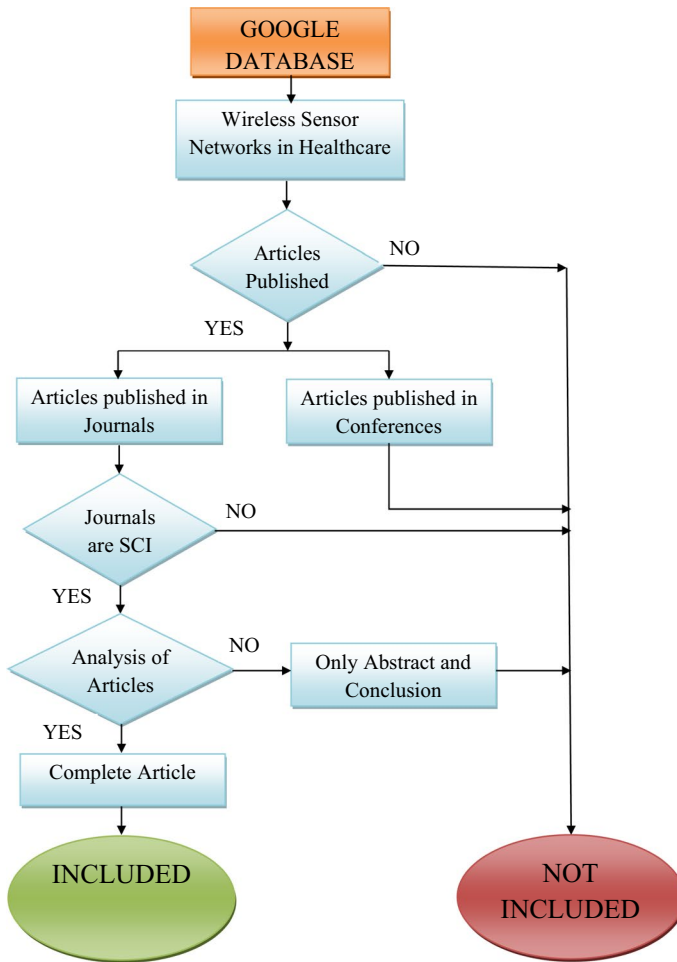
Elhabyan et al. [6] discussed coverage protocol for wireless sensor networks. Coverage protocols classified into three categories sleep scheduling, coverage aware deployment and cluster based. Most of the coverage protocols are affected by the location, sensing and communication range. Network connectivity is one of the most important factors for the coverage protocol design. Guo et al. [7] proposed healthcare technique for the wireless body area networks. Analysis of electromagnetic signals inside the body is performed as results. Path loss inside the body can be calculated by the absorption of the cell and molecules.

Maw et al. [8] explained break the glass access control model for health care in wireless sensor networks. Access control model compared with adaptive access control model. The purpose of BTG-AC model is providing the data in emergency situations. The model has two main modules-Policy decision point and policy enforcement point. Further policy decision point has two sub modules- access control module and prevention detection module. Magalotti et al. [9] presented a characterization of radiation x-ray beam for health care system. Personal sensor nodes are implemented different parts of the body. The Main motos of personal sensor nodes are to improve the lifetime of the network and portability of the networks. There are three prototypes are mentioned for different aspects Prototype 1, prototype 1.5 and prototype 2. Prototype 1 is designed for the power consumption, prototype 1.5 is designed for compact interface and prototype 2 is designed for the portability of the system.

Figure 4 represents the criteria of literature means papers selection for the literature review. Only published papers have considered in this paper out of these published only SCI indexed papers have taken into account.

Habib et al. [10] designed a biosensor-based model for the health care system. Model provides the early warning to the system. Authors have done multiple simulations for their results validation purpose. Decision tree algorithm is used for the data fusion. Fuzzy set theory is used for the decision matrix. This approach reduces the data which would be collected. Wireless sensor networks deployed inside the body. Wireless body sensor network is no limitation in terms of computation and energy because of battery is rechargeable. Liang et al. [11] discussed wearable mobile medical monitoring system. Such type of system consists multiple small modules for different purposes like processing module,





**Fig. 4** Criteria for literature

transmission module etc. Different -different sensors have different working purpose like photoelectric effect, piezoelectric effect, Hall Effect etc. mainly five types of sensors used in wearable monitoring- pulse oximetry sensor, sweat rate sensor, ECG electrode, Glucose sensor and acceleration sensor.

Zheng et al. [12] discussed implantable medical devices those are used for treating and monitoring the health condition of human body. Mostly implantable medical device is used for patient monitoring those are suffering from parkinson's disease, diabetes, cardiac arrhythmia etc. Implantable cardiac defibrillators, artificial heart pacemakers and cardiac implant are the best examples of implantable medical devices. Mahmud et al. [13] explained the prototype of wireless sensor networks for health monitoring system. Authors focused on measuring of heart rate and electrocardiogram for real time. Generally, most of time heart rate is measured by the optical sensor but in their approach, they used dry electrode. EPIC is a type of sensor which is able to measure the electric field of the body without touch the body.

Alaiad et al. [14] explained adoption of wireless sensor networks for the health monitoring regarding barriers and facilitators. Authors conducted interviews for fifteen patients and 140 patients' data from online to validate their results. Designed model prepared for the prediction of the diseases. They analyzed effort expectancy, performance expectancy and social influence, privacy concern, life quality expectancy, human detachment concerns, cost concern and emotional support. Mosenia et al. [15] presented a survey on wearable medical sensors for health care monitoring. Initially wearable medical sensor used for only health care but now a day's used in many other fields like education, security and forensic, human computer interaction etc. The architecture of wearable medical sensor system includes three layers. Layer 1 is for wearable medical sensors, layer 2 is for base stations and layer 3 is for cloud servers.

Chen et al. [16] proposed an implementation of micro controller unit for wireless body sensor networks. The design of micro controller includes asynchronous interface, register bank, shared filter, multi-sensor controller, error correcting coding circuit, universal transmitter/receiver and power management. A shared filter is used for low pass high pass filter according to the body signals. A lossless compressor is used for compress the different body signals and characteristics of the body. Huang et al. [17] discussed the data transmission in health care system private as well as secure data. Health care systems architecture includes digital pulse sensor HK-2000H, oxygen finger clip DS-100A, temperature sensor DS-18B20, communication module CC2420. An app also designed based on above architecture and installed patients phone doctor phones and nurse phones. Authors have taken three real time data set and four data set from simulation, for their results verifications.

Samarah et al. [18] proposed a framework for human activity monitoring based on wireless sensor networks. Spatiotemporal technique is used to design the framework for efficient monitoring of human activity. Micro aggregation is applied on the coordinator nodes to remove the redundancy of data collected from the networks.  $S_1, s_2 s_3 \dots s_n$  are the sequence generated by the smart phone. There are assumptions that sensor nodes are in two states either open-close or on-off. Yin et al. [19] discussed a system for the decision of diseases diagnosis with the help of wearable medical sensor. Wearable medical sensors are designed for the protocol and hardware only. Such systems are not efficient to collect the data from the disease diagnosis. They proposed multitier architecture for hierarchical medical data diagnosis with the help of clinical decision support system. Dey et al. [20] developed the residential WSNs for ECG healthcare monitoring. Recently wireless technology rapidly grows because of its cost effective and convince as compare to the wired technology. Home based application ECG monitoring is used Zigbee wireless technology. Doctor can monitor the patient health from hospital where patient lives at home with ECG monitoring. ECG monitoring is generally used for heart rate monitoring.

Zhang et al. [21] proposed a scheme for fault detection based on Bayesian Network. Sometimes sensors send the false information. False information in medical system may cause the serious problem so this type of sensors detection is necessary. The network for body area is trained with the help of historical data set with conditional probability distribution. Bayesian network is designed for capture the temporal and spatial correlation of the body sensors. Lin et al. [22] implemented antenna interface for the biomedical monitoring system. System used a RF-DC convertor to convert RF energy into required power of DC. A rectifier is used to cross coupling. A ring-oscillator scheme designed for IC interface for medical using different rectifiers. Saleh et al. [23] designed architecture for healthcare application using wireless sensor networks. Deployment of the sensor nodes in wireless sensor networks an important because the energy consumption is one of the critical issues.

To solve this problem authors used quaternary transceiver in place of binary. So ultimately number of bits transmitted per symbol is increased.

Milici et al. [24] designed a monitoring system for wireless sensor networks based on magnetometer. Sleep parameters can calculate with the help of earth magnetic field. Those parameters may help for the measuring the changes in the body at breathing time. An algorithm which can use for low power consumption is designed. Pirbhulal et al. [25] discussed the generation of binary sequence number for heartbeat using wireless sensor networks. Binary sequence number for heartbeat plays an important role in security point of view. Generation of binary sequence number for heartbeat takes a lot of time for processing. Yang et al. [26] explained the battery free body area network to mobile healthcare. Authors discussed the model of wireless body area network which is operated with direct current in place of battery. Conversion of direct current from radio frequency is done by triple band rectifier. Wu et al. [27] discussed the blood leakage detection using cloud computing with the help of flexible sensors. Blood leakage and infiltration are the crucial issues in dialysis therapy. Authors proposed a model for detection of blood leakage and infiltration. Sensors are arranged into array structure and fabricated with the soft substrate. Bidirectional hetero-associative memory network consists a virtual alarm for warning purpose.

### 3 Healthcare System

Current healthcare system is well structured and optimized with different solution of existing problems. A wireless sensor network has several advantages over healthcare like remote monitoring, real time monitoring, and context identification. Day to day patient monitoring, patient location tracking such type of challenges are in healthcare monitoring.

Figure 5 shows the healthcare system. Mainly there are 4 layers in the system. Layer 1 shows the wireless body area networks. Layer 1 includes different sensors like blood sensors, EEG sensor, pulse oximetry sensor etc. these sensors are placed inside the body or outside the human body. Layers 2 include the number of devices like Bluetooth enabled device, personal device assistant and access point access. Layer 3 is used for decision

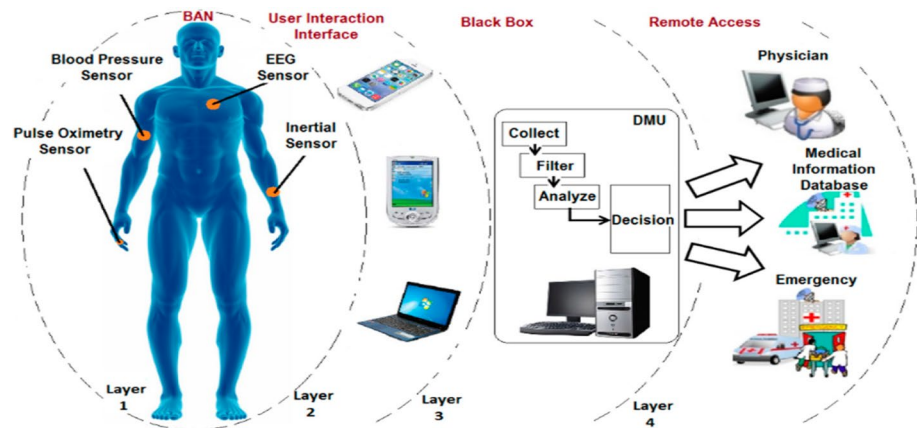


Fig. 5 Healthcare system [77]

making. A decision-making unit is placed at layer 3. Layer 4 is used for the accesses the services for the patient. This layer provides the emergency and healthcare services.

Figure 6 shows the architecture of the healthcare system. There are some crucial challenges in healthcare system like privacy of patient personal information, protection of the data, receiver point should be correct. Power management of patient devices, security and privacy are the also challenges in healthcare system. Healthcare of the patient is monitored by the doctor even patient stay at home. Patient data forward to the hospital with the help of wireless sensor networks and data from hospital to doctor is also forwarded with the help of WSNs. If sometimes emergency occur with the patient, then patient directly goes to the emergency center. Ambulance works as the network from patient home to emergency response center.

#### 4 Sensors in Healthcare

Five sensing technologies are discussed in this section. There are different sensors used for sense the different effects. Photoelectric effect, piezoelectric effect, Hall Effect are the mainly effect which are sensed by the sensors. Mainly two types of sensors electrical signal based and non-electrical signal-based sensors [60]. Bioelectricity electrode comes under electrical based sensor those are derived from human body like neuronal discharge, ECG,

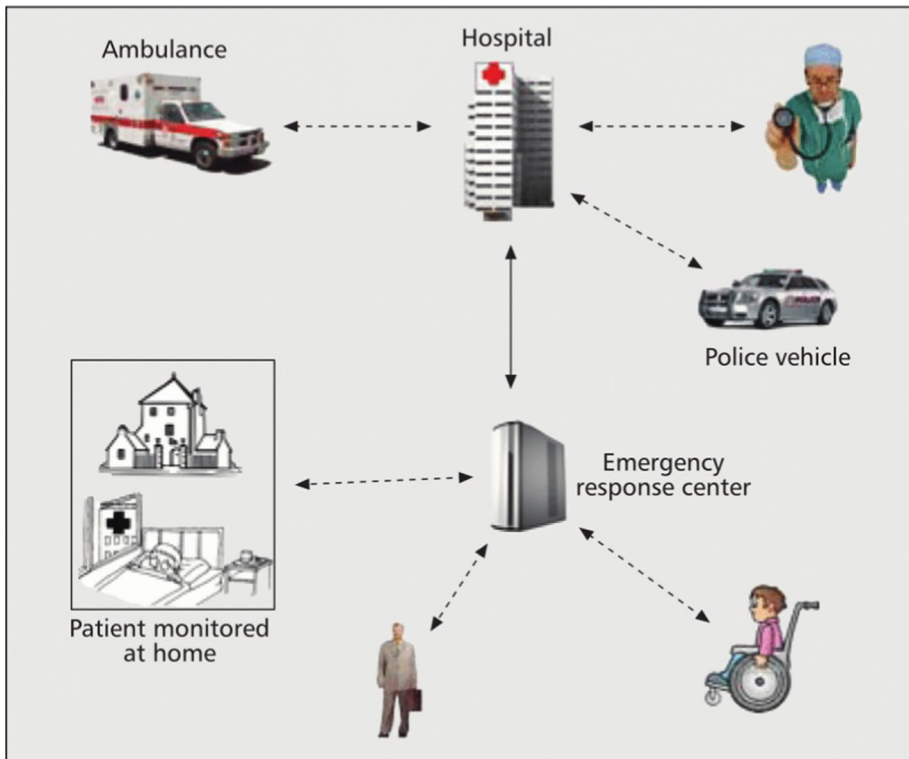


Fig. 6 Architecture of healthcare system [78]

electromyogram etc. physical sensor, biosensor and chemical sensors come under non electrical based sensors [61].

#### 4.1 Pulse Oximetry Sensor

This sensor is used for the analysis the ratio of hemoglobin and oxy-hemoglobin. Pulse oximetry sensor gave the two values saturation of oxygen in hemoglobin and pulse rate in per minute [62]. The theory of spectrophotometry is based on Lambert law, which states that consternation of the material is determined by the observing light by the solution [63]. Recently oximeter used one electronic processor and two LEDs (light emitting diode). This is used for the facing photodiode from the patient body (fingertip, earlobe) [64].

#### 4.2 Sweat Rate Sensor

De Rossi et al. proposed the idea of the sweat rate monitoring. Sweat rate monitoring concept is done with the combination of textile substrate and humidity sensor [65]. Biomarker in sweat is the one of opportunity to make the microfluidic transport and biomarker portioning [66]. Each fluid has a different volume solution. Volume solution of any fluid depends on the concentration level. Ions like  $\text{Na}^+$  and  $\text{Cl}^-$  are measured by the electrical conductivity sweat [67]. Microfluidic model is used for the analysis of flow of sweat inside the skin and sweat mimic.

#### 4.3 ECG Electrode

Basically, ECG is used to check the electrical signal generated by the heart. ECG has main two phases repolarization and depolarization. Depolarization phase consist P-wave and QRS wave. Repolarization phase consist T-wave and U-wave [68]. In modern ear ECG is used as non-contact to the sensors for monitoring system. The main advantage of ECG is that they are washable and very reliable [69].

#### 4.4 Glucose Sensor

Glucose level inside the blood is the indicator of the metabolism. There are some ways to check the glucose concentration inside the blood. Out of these ways biosensor is the highly sensitive and fast detector. Electrochemical sensor is the one of the most important biosensors for the glucose. Electrochemical sensors are three types: conductometric, amperometric and potentiometric [70]. Electrochemical sensors are optimized because they follow the original theory. They further divide two categories enzyme based and non-enzyme based [71].

#### 4.5 Acceleration Sensor

Acceleration sensor is used to sense the motion, tilt, position, shock, vibration etc. most of the case acceleration sensor works on the piezoelectric effect. Nowadays acceleration sensors are also used for the angular velocity. The most common acceleration sensor is triaxial accelerometer [72]. These types of sensors are also able to measure the 3D acceleration. Latest one sensor is the micro electrical system.

## 5 Wireless Communication Technologies

There are number of communication technologies those are used in communication wireless manner. The most popular technologies are Bluetooth, Wi-Fi, NFC (Near Field Communication), RFID (Radio Frequency Identification), ZigBee, UWB (Ultra-wideband) etc. These communication technologies are the responsible for the data transmitting from one node to another node in wireless sensor networks. Out of all these communication technologies UWB is most powerful. Recently UWB is widely used for patient monitoring because of it has higher range of communication.

### 5.1 Bluetooth

The main property of Bluetooth is that it is able to transmit the data and voice at simultaneously. The range of Bluetooth is around 10 m. In recent era Bluetooth is available in laptop, mobile phone, PDA's headset etc. Bluetooth use 2.4 GHz ISM (Industrial Scientific and Medical) band [73]. It supports one to many and one to one connection. Data rate of Bluetooth is approximately 1 Mbps with the help of time division multiple access. Bluetooth also works as client server manner.

### 5.2 ZigBee

ZigBee is based on IEEE 802.15.4 standard. It is suitable for the remote-control devices and sensor-based applications [74]. At the starting time ZigBee is used for home and building for temperature and air conditioning monitoring [75]. ZigBee is an important term in wearable mobile medical monitoring system to transfer the data from patient to healthcare system. In modern ear ZigBee is widely used in many applications [45].

### 5.3 Near Field Communication

Near field communication technology is developed by the Philips, Sony and Nokia. It works on 13.56 MHz frequency. Near field communication's transmission speed is from 100 to 500 kbps. It works in both active and passive mode [46]. NFC is used in many applications like ticketing, social networking, telemedicine etc. [48].

### 5.4 Ultra-wideband

UWB works on 3.1–10.6 GHz. This is the latest wireless communication technology. UWB is more comfortable as compare to the Bluetooth. UWB has high speed, security and

**Table 2** Wireless technologies

S. No	Technology	Data rate	Transmitter power	Upper range	Frequency
1	ZigBee [28]	250 kbps	12 dbm	10–100 m	2.4 GHz
2	Bluetooth [29]	1 Mbps	10 dbm	100 m	2.4 GHz
3	Wi-Fi [30]	1 Gbps	15 dbm	50 m	2.4 GHz and 5 GHz
4	5 G [31]	3.6 Gbps	23 dbm	10 km	Lower bands

**Table 3** Sensors applications

S. No	Sensor	Location	Marker	Application
1	Ultrasound [32]	Wrist	Blood pressure	Cardiopulmonary
2	Radio frequency identification [33]	Finger	Temperature	Vascular monitoring
3	Microwave cardiopulmonary [34]	Thigh	Heart rate	Cardiopulmonary
4	Multivariable [35]	Arm	Blood glucose	Glucose home monitoring
5	Glucose [36]	Subcutaneous	Tissue glucose	Glucose home monitoring
6	Accelerometers [37–40]	Clothes	Walking distance	Neurological function monitoring
7	Inertia [41]	Visual feedback glasses	Walking speed	Neurological function monitoring
8	Motion [42]	Wrist	Seizure activity	Neurological function monitoring
9	Pedometer [43, 44]	Ankle	Step count	Physical Therapy

**Table 4** NFC applications

S. No	References	Application	Platform
1	[45]	ECG	Smart phone
2	[46]	Blood pressure	Smart phone
3	[47]	Remote monitoring	NFC enabled phone
4	[48]	Fetal health monitoring	Android

**Table 5** UWB applications

S. No	References	Application	Advantage
1	[49]	Breathing monitoring	High movement precision
2	[50]	Heartbeat	High Accuracy
3	[51]	Respiratory rate monitoring	Low Cost
4	[52]	Variability monitoring	Low Power

scalability. Recently UWB is widely used in patient monitoring and ubiquitous computing [76].

## 5.5 Wi-Fi

It is the most popular technology for wireless communication. It used for the surfing the internet to users but device should be connected with an access point. Wi-Fi works on IEEE 802.11 a/b/g standards. Any user can connect the device with Wi-Fi enabled device and access the internet. Nowadays Wi-Fi available almost many places like campus, city, railway station, home etc. In medical also Wi-Fi plays an important role like transfer the data from patient to doctor in the form of ECG, heart rate, blood pressure etc. [55] (Tables 2, 3, 4, 5, and 6).

## 6 Conclusions and Future Scope

Wireless sensor networks play an important role in healthcare system. In this paper near about eighty four papers are reviewed and all are science cited indexed. Mainly sensor, communication technologies, and applications of different sensors in different healthcare monitoring are discussed. After rogueries review author found five communication technologies those are used in healthcare system. Communications technologies are Bluetooth, Zigbee, NFC, UWB and Wi-Fi. UWB communication technology used in the existing system. The range of UWB is 200 m but it works smoothly up to 50 m. UWB works over the 3.1 to 10.6 GHz. Mainly five sensors are used in healthcare system those are pulse oximetry sensor, sweet rate sensor, glucose sensor, acceleration sensor and ECG electrode. In future, an energy efficient protocol will be proposed for the wireless body area networks which is helpful in the healthcare system. The Major findings of this paper are as follows:



**Table 6** Different sensors used in healthcare

S. No	References	Sensors	Hardware description	Physiological parameters	Applications	Communication module	Advantage
1	[53]	pH sensor	Multi-parametric patch	Sweat rate	Health monitoring	Bluetooth	Low power
2	[54]	Piezoelectric sensors	Micro-controller	Blood pressure	Harsh environment	ZigBee	Intelligent
3	[55]	3D acceleration	PDA	Posture	Altitude mount	Bluetooth	Low weight
4	[56]	Two axis acceleration	Wrist-worm device	Pulse	Remote monitoring	GSM Link	Light
5	[57]	ECG electrode	Smart micro controller	ECG	Holter monitoring	Wires	High stability
6	[58]	Textile strain sensor	Gesture device	Movement	Angle monitoring	Conductive yarns	More convenient
7	[59]	Wearable sensors	Smart phone	EMG	Long time monitoring	Bluetooth	Friendly user

- (RQ1) There are several communication technologies in the healthcare system but in context to WSNs mainly five communication technologies. Bluetooth, Zigbee, NFC, UWB and Wi-Fi out of these all technologies UWB is more powerful and widely used in currently.
- (RQ2) There are mainly five sensors used in healthcare system (pulse oximetry sensor, sweet rate sensor, glucose sensor, acceleration sensor and ECG electrode). Some other sensors are also used in healthcare system like pH sensor, piezoelectric sensor, 3D acceleration sensor, two axis acceleration sensor, textile strain sensor etc.
- (RQ3) There some specific body parts where sensors are deployed or implemented like wrist, finger, thigh, arm, ankle etc.
- (RQ4) UWB out of all wireless communication technologies is better because of it has higher communication range as per compare to the other existing technologies.
- (RQ5) Energy is one of the most important parameters in WSNs.
- (RQ6) There are number of protocols in Wireless body area networks like temperature sensitive, QoS sensitive, Cluster oriented, Postural-Mobility-Aware etc. out of these protocols cluster-oriented protocols have less energy consumption. Temperature sensitive protocols have high energy consumption.

**Author Contribution** The paper contains the different communication technologies, applications and sensors used in healthcare system. Applications of wireless sensor networks and sub-applications of wireless sensor networks also covered in manuscript.

**Funding** There is no funding for this work.

**Data Availability** Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

## Declarations

**Conflicts of interest** There is no conflict of interest.

**Code availability** There is no code available, this is a review article.

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