EMPIRICAL EVALUATION OF DEPLOYMENT MODELS FOR ENHANCING THE PERFORMANCE OF WBSN BASED SYSTEM

THESIS

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

By
Vidhyotma
University Regd. No 1410931005

Supervised by
Dr. Jaiteg Singh
January, 2020

Department of Computer Science and Engineering

CHITKARA UNIVERSITY

CHANDIGARH-PATIALA NATIONAL HIGHWAY

RAJPURA (PATIALA) PUNJAB-140401 (INDIA)

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CHITKARA UNIVERSITY, PUNJAB

DECLARATION BY THE STUDENT

I hereby certify that the work which is being presented in this thesis entitled **“ Empirical Evaluation of Deployment Model for Enhancing the Performance of WSBN Based System”** is for fulfillment of the requirement for the award of Degree of **Doctor of Philosophy** submitted in the **Department of Computer Sciences and Engineering, Chitkara University, Punjab** is an authentic record of my own work carried out under the supervision of Dr. Jaiteg Singh**.**

The work has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgments have been made wherever the findings of others have been cited.

Vidhyotma

CHITKARA UNIVERSITY, PUNJAB

CERTIFICATE BY THE SUPERVISOR

This is to certify that the thesis entitled **“Empirical Evaluation of Deployment Model for Enhancing the Performance of WSBN Based System”** submitted by **Vidhyotma with Regd. No 1410931005** to the Chitkara University, Punjab in fulfilment for the award of the degree of **Doctor of Philosophy** is a *bona fide* record of research work carried out by her under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institution or University for the award of any degree or diploma.

Dr. Jaiteg Singh
Professor and Dean
Department of Computer Applications
Chitkara University, Punjab

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Publications

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1. Gandhi, V., & Singh, J. (2020). An Automated Review of Body Sensor Networks Research Patterns and Trends. *Journal of Industrial Information Integration*, 100132. (SCI)
2. Vidhyotma, J, S., (2020). WBSN Based Safe Life Style: A Case Study of Heart Rate Monitoring System. International Journal of Electrical and Computer Engineering, vol 10 (3). (Scopus)
3. Vidhyotma, J. S. (2019). Optimization of WBSN Deployment Model for Biophysical Data Recording and Communication. *Journal of Advanced Research in Dynamic and Control Systems*, *11*(02-Special Issue), 1523-1532.
4. Vidhyotma, J. S. (2019). Comparative Analysis of Existing Latest Microcontroller Development Boards. In *Emerging Research in Electronics, Computer Science and Technology* (pp. 1011-1025). Springer, Singapore. (Lecture Notes in Electrical Engineering, 2019, Scopus)
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6. Vidhyotma, J. S. & Virk, D. (2018, November). Bluetooth Enabled Anti-Theft System Using Android Based Handheld Device. In *2018 6th Edition of International Conference on Wireless Networks & Embedded Systems (WECON)* (pp. 122-125). (IEEE)

Paper Communicated

1. Gait Adaptive Duty Cycle: Optimize the QoS of WBSN-HAR (Computer Standards and Interfaces)

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ABBREVIATIONS

AF	:	Adult Fast
AMOPA	:	Application for Monitoring Physical Activity
AN	:	Adult Normal
AWS	:	Amazon Web Services
BAN	:	Body Area Network
BaSis	:	Bayesian inference system
BP	:	Blood Pressure
BS	:	Body Sensor
BS	:	Base Station
BSN	:	Body Sensor Network
BT	:	Backoff Time
CBSN	:	Collaborative Body Sensor Network
CCN	:	Content-Centric Network
CFP	:	Contention Free Period
CN	:	Controller Node
CoAP	:	Constrained Application Protocol
CoRE	:	Constrained RESTful Environments
CP	:	Contention Period
CP-ABE	:	Cipher-text Policy Attribute Based Encryption
CSMA/CA	:	Carrier Sense Multiple Access with Collision Avoidance
CTM	:	Correlated Topic Model
CUIDATS	:	meaning “cared-for” in Catalan language
CVL	:	Common Variable Language
CW	:	Contention Window
D2D	:	Device-to-Device
DCF	:	Distributed Coordination Function
DEEP		Density-based proactivE data dissEmination Protocol

DIFS	:	Distributed function Inter Frame Space
DTLS	:	Datagram Transport Layer Security
ECG	:	Electro-Cardio-Graphic
EEG	:	Electro-Encephalo-Graph
EEICCP	:	Energy Efficient Inter Cluster Coordination Protocol
EER	:	Energy Efficient and Reliable
HER	:	Electronic Health Record
EMR	:	Electronic Medical Record
EO	:	Electro-Optical
EPC	:	Electronic Product Code
G-TPC	:	Gait-cycle driven transmission power controlled
GADC-HAR	:	Gait Adaptive Duty Cycle-Human Activity Recognition
GDP	:	Gross Domestic Product
GHO	:	Global Health Observatory
GPU	:	Graphical Processor Unit
GUI	:	Graphical User Interface
HB	:	Human Body
HCR	:	Head Count Ratio
HDL	:	High-Density Lipoprotein
HMM	:	Hidden Markov Model
HR	:	Heart Rate
HTTP	:	Hyper Text Transfer Protocol
IaaS	:	Infrastructure as a Service
ICU	:	Intensive Care Unit
ID	:	Identification
IEEE	:	Institute of Electrical and Electronics Engineers
IETF	:	International Engineering Task Force
IFS	:	Inter Frame Space
IoT	:	Internet of Things

IOS	:	iPhone Operating System
IPV6	:	Internet protocol V6
KNN	:	K-Nearest Neighbor
LDA	:	Latent Dirichlet Allocation
LEACH	:	Low-Energy Adaptive Clustering Hierarchy
LSA	:	Latent Semantic Analysis
LSI	:	Large Scale Integration
LTE	:	Long-Term Evolution
LowPAN	:	Low Private Area Network
M2M	:	Machine-to-Machine
MAC	:	Medium Access Control
MEMS		Micro Electro Mechanical System
MEREA	:	Movement Analysis in Real-world Environment using Accelerometer
ML	:	Machine Learning
MQTT	:	Message Queue Telemetry Transport
MS	:	Main Server
NAV	:	Network Allocation Vector
NLP	:	Natural Language Processing
ONS	:	Object Naming Services
P2P	:	Point to Point
PaaS	:	Platform as a Service
PAN	:	Private Area Network
PCF	:	Point Coordination Function
PD	:	Patient Database
PIFS	:	Point coordination function Inter Frame Space
PLSA	:	Probabilistic Latent Semantic Analysis
PPG	:	PhotoPlethysmoGraphy
QoS	:	Quality of services
RaWMS	:	Random Walks

RFID	:	Radio Frequency Identification
RNN	:	Recurrent Neural Network
SaaS	:	Software as a Service
SIFS	:	Short Inter Frame Space
SLA	:	Service Level Agreement
SMQTT	:	Secure Message Queue Telemetry Transport
SVD	:	Singular Vector Decomposition
SVM	:	Support Vector Machine
TCP/IP	:	Transmission Control Protocol / Internet Protocol
TF-IDF	:	Term Frequency-Inverse Document Frequency
TLS	:	Transport Layer Security
TPC	:	Transmission Power Control
TS	:	Topic Solution
UDP	:	User Datagram Protocol
UPECSI	:	User-driven Privacy Enforcement for Cloud-based Services in the IoT
USEE	:	Uniform Storage and Energy Efficient protocol
WAN	:	Wireless Area Network
WBAN	:	Wireless Body Area Network
WBSN	:	Wireless Body Sensor Network
WBSN-HAR	:	WBSN-Human Activity Recognition
WHO	:	World Health Organization
WLAN	:	Wireless Local Area Network
WN	:	Wireless Network
WSN	:	Wireless Sensor Network
WWBSN	:	Wearable Wireless Body Sensor Network
YF	:	Young Fast
YN	:	Young Normal
YoP	:	Year of Publication

ABSTRACT

Wireless Body Sensor Network (WBSN) originates from the deep research on Wireless Sensor Network (WSN). Although WBSN is similar to WSN, it is different at node size, networking protocols, ubiquity level (scale of range), mobility support, the required accuracy and many more. WBSN is the root of bioengineering and has many application areas like healthcare, defense, sports and so on. This study focuses on the revolutionary contribution of WBSN in the healthcare field. Usually, WBSN consists of tiny biosensor nodes, network routing protocols, communication protocols and the server (private or global). Latent Semantic Algorithm (LSA), a topic modeling algorithm was applied to find out the core research areas and related trends in WBSN systems. The five core research areas defined in WBSN were “Recording of biophysical parameters,” “Cloud and IoT enabled WBSN services,” “WBSN driven smart healthcare solutions,” “Resource management with WBSN,” “Communicating biophysical parameters.” State of the art has identified noticeable contributions of WBSN in healthcare applications but, WBSN systems are facing challenges in terms of energy efficiency, accuracy and reliability. WBSN deployment models were studied to enhance their efficacy in terms of energy consumption and accuracy. WBSN data recording and communication classes have dragged attention during this research. An Energy Efficient and Reliable (EER) algorithm was proposed to increase the energy efficiency and the reliability of WBSN based systems. A WBSN-HAR model with large superframe size and data encapsulation methods was proposed for energy efficiency.

Further, the gait adaptive duty cycle technique was designed for GADC-HAR with improved energy efficiency and reliability. Realtime implementation was done to validate the proposed models. In WBSN-HAR, energy consumption was reduced by 47.01% and in GADC-HAR, energy consumption was reduced by 48.5% in comparison to existing standards.

Chapter 1

Introduction

Wireless Sensor Network (WSN) is a group of spatially distributed tiny sensor nodes for recording and monitoring the corporal condition of the environment. WSN is the blending of sensing, computing and wireless communication technologies [1]. The advanced wireless networking techniques provide connection stability, security and end-to-end less delay, which had boosted the WSN industry [2]. The breakneck growth in Micro Electro Mechanical System (MEMS) had helped to produce tiny sensing nodes with reasonable computation, storage and communication capabilities [3]. These technological evolutions have given an astral scope to WSN in multiple applications like perceiving climate conditions, water quality assessment, earthquake detection, defense, security, healthcare services, vehicle monitoring, animal tracking, ocean event monitoring, home automation, smart cities and so on [4]. WSN is the network of sensing nodes, communication channels and gateway device as shown, in Fig. 1.1 [5].

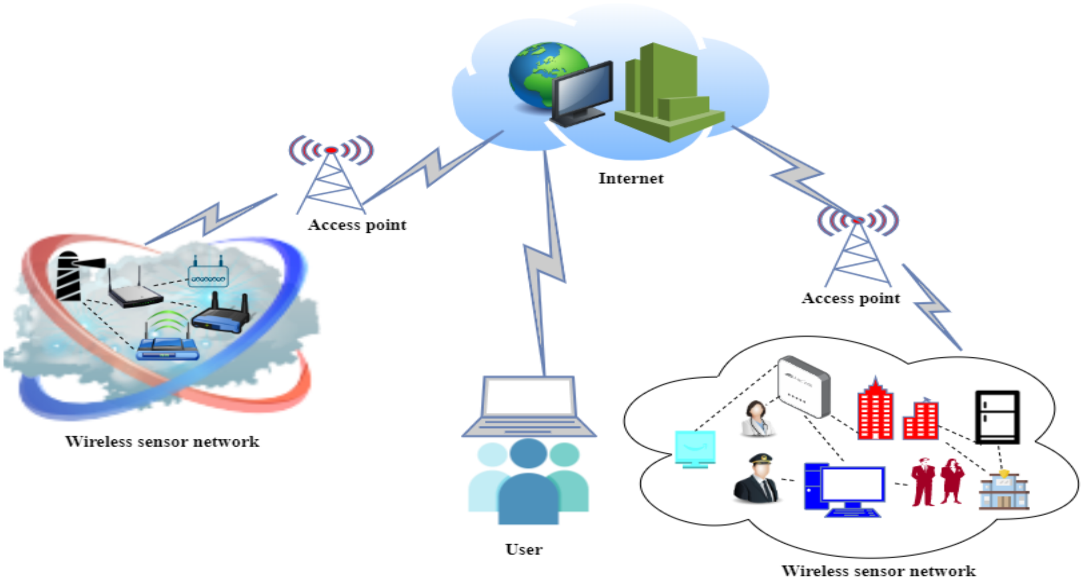


Figure 1.1: WSN architecture

A sensor node fabricated in a manner to efficiently respond to any change in the environment. Different fabrication materials are used to respond according to various parameters. The sensor node consists of a sensing unit, processing unit and storage unit along with one trans-receiver. The sensor unit senses the different parameters of the environment as per its specification and structuring material. The processing unit converts analog data to digital data and further random-access memory (RAM) stores the data until the next data recorded. The trans-receiver responsibility is to set a link between the microcontroller board / data handler device to communicate the recorded data and receive the data recording instructions. The power supply unit fuels energy to the whole network to make it operative [6]. Fig. 1.2 shows the sensor node structure. The innovation in MEMS technology exerts a significant influence on the size, energy consumption and weight. The lightweight, small size and low power sensing nodes intensify the potential of WSN in the field of healthcare by creating the sensor network on the human body. The wireless sensor network used to record the physiological parameters is recognized as Wireless Body Sensor Network (WBSN) [7], [8].

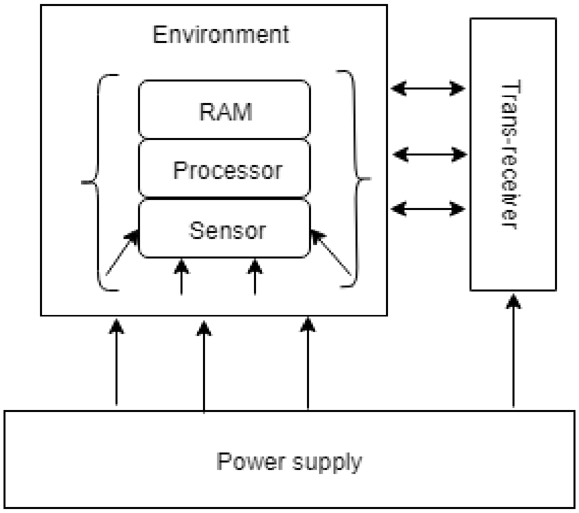


Figure 1.2: Sensing node

WSN research area enriched with previously developed lots of protocols and algorithms. These techniques cannot be deployed effectively in WBSN. Because the human body has unique characteristics and WBSN always created in, on or around the human body. WBSN nodes are heterogeneous, have limited and variable bandwidth. Therefore, the WBSNs are more prone to noise, interference and fading as compared to WSNs implanted in free space. In WBSN, to make safe to the human body tissues, each node must use less energy during communication, whereas in WSN, not such type of constraints are required [9]. A comprehensive comparison of WBSN and WSN has given in Table 1.1.

Table 1.1: Comparison of WSN and WBSN

Key Points	WSN	WBSN
Number of nodes	Can be few or large in numbers	Few in numbers due to limited Human Body (HB) area
Mobility support	Not supportive	Supportive
Environment	Dynamic	Stable
Scope	Universal	On the HB, in the HB, around the HB (depends on the RF frequency)
Scale of range	Meter to kilometres (open environment)	Centimeter to 2 / 3 meters (human body)
Types of sensors	Terrestrial, underwater, underground WSN or multimedia or mobile sensors	Plantable, wearable (invasive or pervasive biosensors0
Scalability	High	Low
Batteries	Easily replaceable	Not easily replaceable
Network lifetime	big batteries (high lifetime)	Small batteries (less lifetime)
Size of node	Can be large or small	Small nodes (MEMS based)
Topology	Support star, P2P, tree, mesh	Support BUS and star

Accuracy	Can be achieved by the redundancy of nodes	Can be achieved by proper placement of sensors and QoS defined for the application
Homogeneous / heterogeneous	Most of the time nodes are homogenous	Most of the time heterogeneous nodes in the network
Latency of data	Application based (>10 milliseconds)	10 milliseconds (can be reduced more)
Source of energy scavenging	Solar or wind energy source	Mechanical, RF, sound or thermoelectric
Security and privacy	Low (general data)	High (personal medical data)
Frequency band	US: 915 MHz, 2.4 GHz Europe: 315, 433, 868 MHz	Unlicensed
Wireless Communication protocols	Bluetooth, Zigbee, WLAN, GPRS	Inter-body: LTE (3G / 4G), WiFi, Zigbee, GPRS Intra-body: Bluetooth, BLE, Zigbee, WiFi, WBAN

1.1 Wireless Body Sensor Network

“Wireless Body Sensor Network” (WBSN) is a branch of WSN. WBSN is the amalgamation of sensing, intelligent information processing, pervasive computing, and communication technologies, as shown in Fig. 1.3. The area covered under the three technologies is the area of concern. It can gather the parametric data from the physiological as well as surrounding environments. It can control / automate the events / medication procedure / system [10].

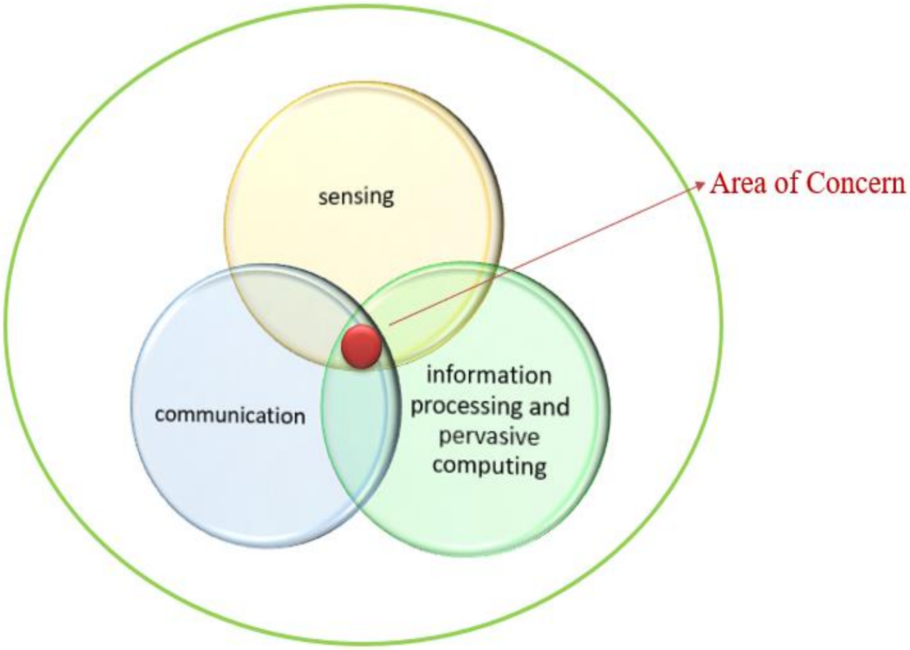


Figure 1.3: Amalgamation of technologies in WBSN

WBSN also recognized as “Wireless Body Area Network” (WBAN) [11], [12]. IEEE 802.15.6, “A communication standard optimized for low power devices for their operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics or personal entertainment and other” for BAN [12]. WBSN is an outgrowth of comprehensive sensor networks technology and is considered the root of biomedical engineering. The key components of WBSN are sensors and communication networks. Sensors can connect the physiological world with an electronic system for pre-processing and further uses. WBSN consists of either homogeneous or heterogeneous or both sensing nodes. The sensing nodes, also known as motes and each node, must be wearable / implantable and biocompatible [11]. The entire use of the sensor node is to record the physiological parameters and transmit the data to the controller unit [13]. WBSN consists of multiple physiological sensors capable of measuring different body parameters. The signals from the body can be sent through wireless for prior recognition of abnormal health conditions in case of emergency [14]. Advancement in wireless communication and microelectronics has changed the scenario of the wireless communication network and it can easily pave the researchers towards WBSN [10]. The healthcare system needs to be made home-center rather than hospital-center because of high medication costs, chronic diseases [15]. The Healthcare system should focus on the well-being of citizens by smart disease management systems [16], [17]. It can change the way of deployment and delivery of healthcare systems by replenishment of the remote access of the patient's physiological parameters to the doctor and online doctor's advice to the patient [17]. It is expected that a smart healthcare system would increase the quality of health, decrease the tension, stress and risk to human life [18]. According to the "world health statistics, 2017" by World Health Organization (WHO), about 460,000 persons depart their life due to fatal heart attacks each year and nearly half of this count patients breath out their life within one hour as brought to hospital [19]. WBSN technology can reduce the death rates due to delay in treatment in case of any sudden diseases, strokes or accidents [18], [20]. According to WHO, ten top reasons for mortality are Ischaemic heart disease, stroke, lower respiratory system, chronic obstructive pulmonary disease, trachea, bronchus and lung cancers, diabetes mellitus, Alzheimer's disease, diarrhoeal diseases, and tuberculosis and road injuries. As per Global Health Observatory (GHO) data, shown in Fig. 1.4, the Ischaemic heart disease and stroke depicted as the world's major slayers. In 2015, 15 million mortality accounted for Ischaemic heart disease and stroke [19]. So, the immediate attention of the research community is required to work towards healthy and greater life of human beings. It is foreseeable that the body sensor network would intensify the quality of human health, along with the diminution of the budget of healthcare services [16]. A refined deployment model of the healthcare system is required to predict and treat the disorders and diseases at the earlier stage before it becomes difficult to handle or maybe a threat to human life [20].

Ever-increasing medication costs and the elderly population demands a pervasive patient monitoring system that can work anywhere and anytime [11]. A set of tiny, intelligent, low-power bio-sensors can be smartly incorporated on / in the human body to form a proficient autonomous WBSN [21]. The WBSN can be more efficient as compared to traditional technologies (manual / apparatus check-up in hospital premises) to examine physiological information of the human body. The stream of recorded physiological parameters is transmitted over long / short distances using the Internet of Things (IoT) to a remote server / cloud for diagnosis / recommendations. The same model can be used to cure many diseases like asthma, cardiac infarction, diabetes, cancer detection, gastrointestinal tract and so on [22]. The combination of WBSN, IoT and cloud can revolutionize the healthcare sector [23]. IoT provides communication connectivity to send patients' physiological parametric recorded data anytime and anywhere [24]. Cloud provides infrastructure for storing and computational analysis of patients' data for future medical investigations [25]. WBSN, with the integration of IoT and cloud, can be implemented in many ways (see section 1.4).

1.2 Applications of WBSN

WBSN can be used in healthcare, sports, military, transport, home security and many more. The prevalent application areas of WBSN are [26]–[30]:

- Healthcare
- Elderly care
- Smart health monitoring
- Physical fitness
- Human activity recognition
- Pre-heart attack detection
- Pediatrics care
- Intensive Care Unit (ICU) etc.

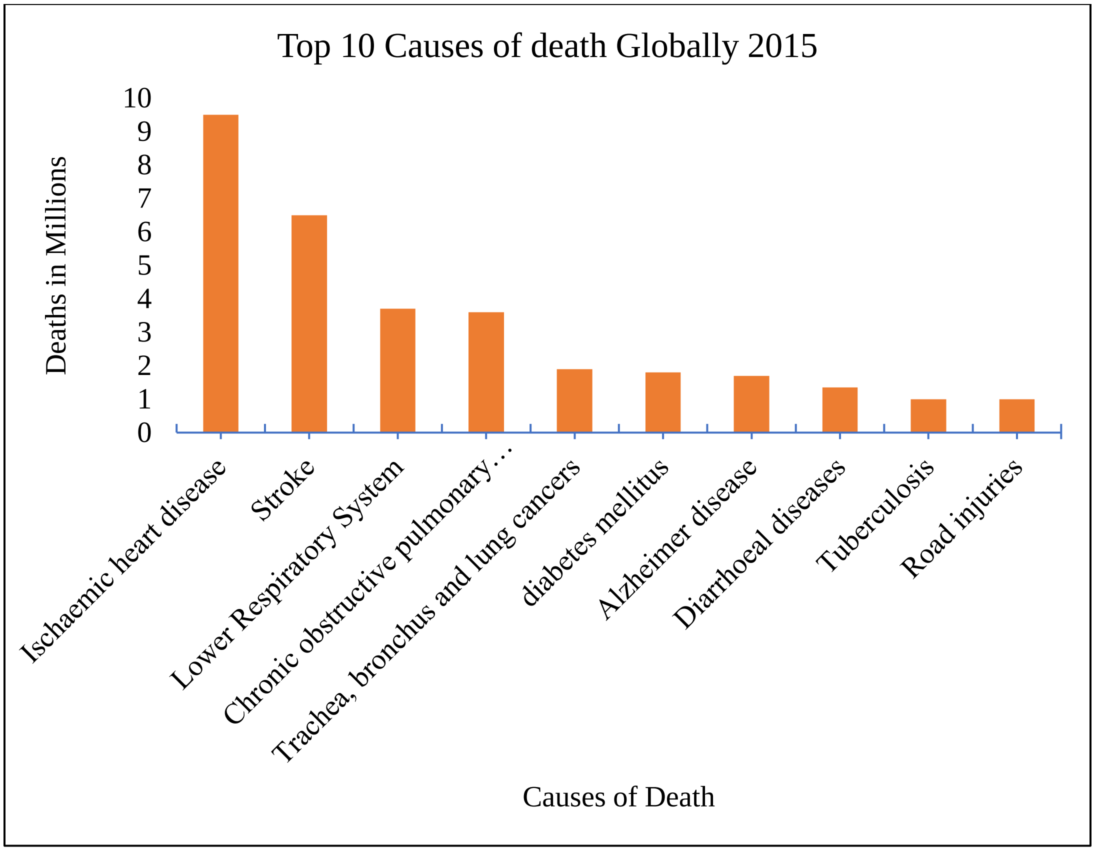


Figure 1.4: GHO data [21]

1.3 Layout of WBSN

The general layered structure of the WBSN model entails five layers: power supply unit, sensors module, a communication module, process module and server [17], [31], [32]. The detailed, layered structure of WBSN is given away in Fig. 1.5.

1.3.1 Sensor module

A sensor module consists of multiple intelligent body sensors that are capable of sensing, sampling, processing and transferring physiological sensed data [10] e.g. ECG sensor, EEG sensor, temperature sensor, accelerometer, inertial sensors, tilt sensors, etc. The significance of the sensor module is to create an association of the physical sphere with the electronic circle. The sensor module constitutes homogeneous / heterogeneous sensing nodes. The sensor nodes must be biocompatible and wearable

/ implantable [33]. The sensor node records the physiological parameters and transmits the recorded data to the controller node [13].

1.3.2 Internal communication module

WBSN internal communication module generates interface in WBSN sensor nodes with one of three types of transmissions: wireless, wired or human body. Wired sensors provide reliable and stable communication modes as compared to wireless sensors but are complicated to be deployed and installed [34]. Wireless sensors follow one of these communication techniques: Bluetooth, ultra-wideband, Zigbee, Wi-Fi or BAN. The comparison of these technologies is given in Table 1.2 [35]. Human Body Communication (HBC) sensors are also in trends and are in the infant stage [36], [37]. HBC sensors are highly reliable and used for short-range and low power networks. It can also be easily integrated into wearable devices and constrained around the human body, which in turn provides high security [38].

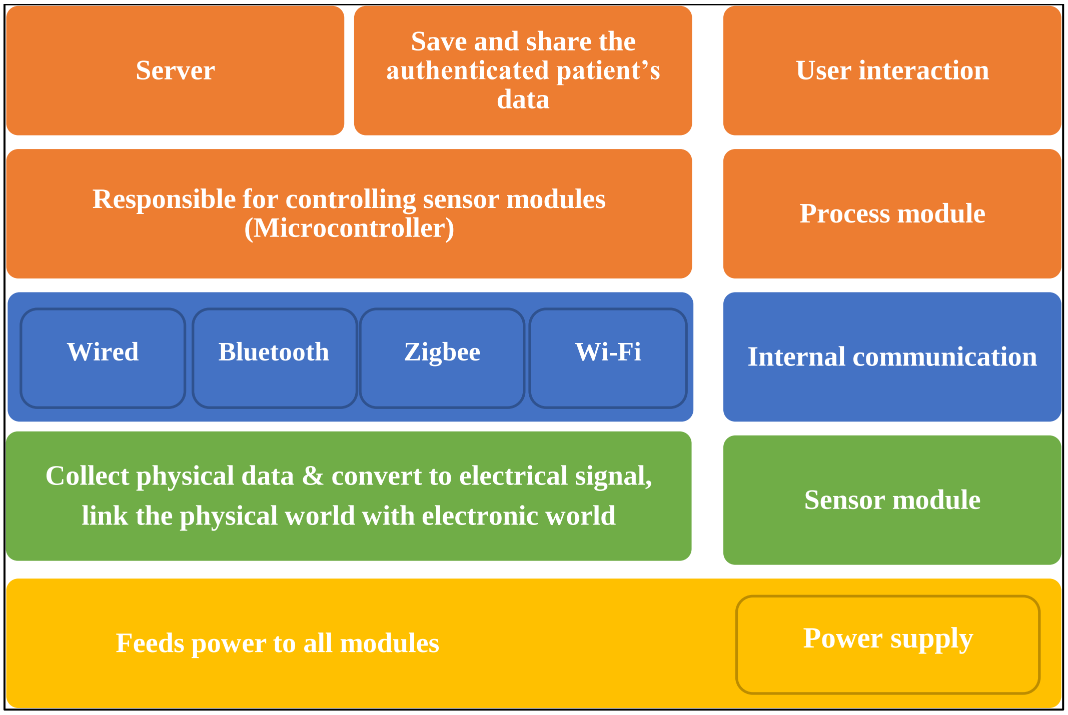


Figure 1.5: Layered structure of WBSN model

1.3.3 Process module

The process module is also known as a personal server or a personal device. It is an integrated module of hardware and software. It consists of a microcontroller unit, register set, and sensor nodes. Processing data, network channel management, time-sharing and sending data to the main / medical server station are the main functions. Sensors are used to collect vital biophysical data. Process module connected to the medical server through mobile telephone networks e.g. GPRS, 2G, 3G, 4G or WLANs or WWANs [39].

Table 1.2: Basic parameters of the Bluetooth, UWB, Zigbee, and Wi-Fi protocols

Parameters	Bluetooth (802.15.1)	UWB (802.15.3)	ZigBee (802.15.4)	Wi-Fi (802.11a/b/g)
Bandwidth	2.4 GHz	3.1 - 10.6 GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5 GHz
Signal rate (max)	1 Mb/s	110 Mb/s	250 Kb/s	54 Mb/s
Range	10 m	10 m	10 - 100 m	100 m
TX power	0 - 10 dBm	-41.3 dBm/MHz	(-25) - 0 dBm	15 - 20 dBm
Number of RF channels	79	(1-15)	1/10; 16	14 (2.4 GHz)
Channel bandwidth	1 MHz	500 MHz - 7.5 GHz	0.3/0.6 MHz; 2 MHz	22 MHz
Modulation type	GFSK	BPSK, QPSK	BPSK, O-QPSK	BPSK, QPSK COFDM, CCK, M-QAM
Max number of cell nodes	8	8	> 65000	As per bandwidth

Encryption	E0 stream cipher	AES block cipher (CTR, counter mode)	AES block cipher (CTR, counter mode)	RC4 stream cipher (WEP), AES block cipher
Authentication	Shared secret	CBC-MAC (CCM)	CBC-MAC (ext. of CCM)	WPA2 (802.11i)
Data protection	16-bit CRC	32-bit CRC	16-bit CRC	32-bit CRC
Max data rate (Mbit/s)	0.72	110	0.25	0.54
Bit time (µs)	1.39	0.009	4	0.0185
Max data payload (bytes)	339 (DH5)	2044	102	2312
Max overhead (bytes)	158/8	42	31	58
Coding efficiency+ (%)	94.41	97.94	76.52	97.18

1.3.4 Server

As soon as the server received the patients' authenticated physiological data, it saved data in the medical record of that specific patient. The behavior of data is analyzed. In case of any abnormal condition, data will be transmitted to the doctors or caretakers for further medical advice. The doctor's medical opinion is reverted to the patient / caretaker, through the server module for immediate treatment. A cloud-based and IoT based system integrated with WBSN is the promising solution for many applications like medical healthcare, fitness monitoring, gaming, entertainment, sports, military and security. Deployment of WBSN on the athlete presented in Fig. 1.6.

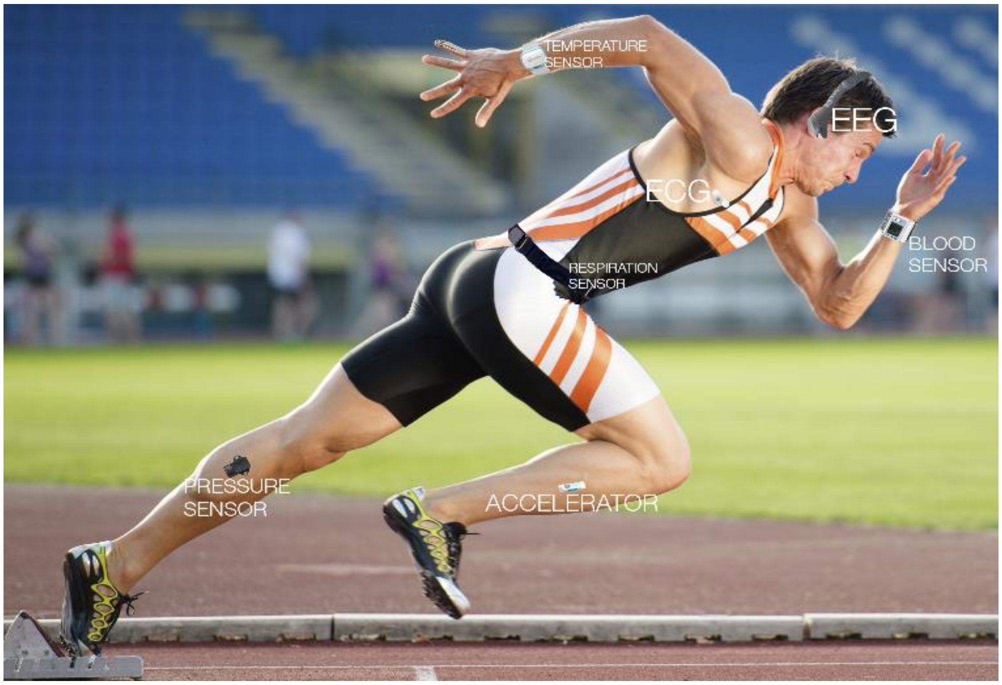


Figure 1.6: Deployment of physiological sensors on athlete

A hybrid network model of WBAN can be used for vital health data sharing and communication in real-time [10]. Although the quality of real-time data dissemination improved by using the content-centric network and adaptive streaming, still it is facing latency issues [20], [36], [40]. IoT-based WBSN healthcare systems can solve this problem of latency but lack in terms of data processing and storage. Healthcare systems broadly divided into five domains: Paediatric (Medicare or illness of children), Remote health monitoring, Private health and fitness management, Elderly care and Chronic disease supervision. Private health and Fitness management are still to be pinned [22]. Although monitoring work done in chronic disease supervision and the elderly care field, still it cannot be controlled remotely [17], [20], [41].

1.4 Body Sensors Network Anatomy

Body sensors network can be separated into four categories on the basis of their characteristics [17]:

1.4.1 On the basis of the measured signal

A body sensor network can measure two types of signals: analog signal and discrete time varying signal. ***Analog signal sensors*** work on phenomena of real-time signal acquisition and collect signals continuously like accelerometer, gyroscope, visual sensor, Electro-Cardio-Graphic (ECG) sensor, ElectroEncephaloGraph (EEG) sensor and auditory sensor. These sensors consume more power and generate a huge chunk of data [20]. On the other hand, ***Discrete time varying signal sensors*** collect the signals slowly like temperature sensors, glucose sensors, humidity sensors, blood pressure and blood oxygen sensors, generate fewer data and consume less power. The sensors can be optimized for sleep mode.

1.4.2 On the basis of deployment position

On the basis of the deployment position, the BSN can be majorly categorized in two forms i.e. wearable (surface mounted) and implantable (invasive). Surface mounted are available in the form of jackets, wristbands or clothes. Invasive sensing nodes injected inside the body like a pacemaker, which is used to check the health of the heart continuously [22], [42].

1.4.3 On the basis of mode of data transmission

A sensor node can be capable of any one of two types of data transmission modes: wireless and wired. In wired mode, all the sensors connected with the microcontroller or main server. Wired body sensors network offers consistent and stable connections concerning to wireless sensors but is complicated during deployment due to the chaotic mesh of wires. In Wireless body sensors network, any wireless communication protocols (IEEE 802.15.1, IEEE 802.15.4, IEEE 802.15.6 or ultra-wideband) can be implemented [43]. Wireless communication protocols are most suitable for short range and low power networks. Wearable devices in healthcare were also integrated with wireless communication protocols and controlled around the human body, which in turn provide high security [38].

1.4.4 On the basis of automatic adjustment ability

BSN can be self-adapting or non-self-adapting. Non-self-adapting is more comfortable to design, but in self-adapting, one has to configure parameters and thresholds according to characteristics of data and human body adaptable parameters. Self-adapting BSNs are now in use to enhance the efficiency of the system.

1.5 Integration of Body Sensors Network, Cloud and IoT

Integration of BSN, cloud and IoT has given a new shape to the traditional healthcare system as a smart healthcare system. BSN integrated with IoT to put health data on the cloud for storage and analytics [44], [45]. Based on these analytics' results, patients can be monitored and controlled remotely by medical experts.

1.5.1 Body sensors

In BSN, body sensors are used to record the biophysical parameters and can be called bio-sensor. Bio-sensors can be wearable or implantable. According to the usage in BSN, bio-sensor can be categorized into two groups: (i) Physiological sensors (ii) Non-physiological sensors.

(i) ***Physiological sensors*** are used to measure physical parameters e.g. ECG, EEG, blood sensor, respiratory sensor and pressure sensor and so on. Physiological sensors are implanted on the human body to generate the network of bio-sensors.

(ii) ***Non-physiological sensors*** during the implementation of BSN, it is necessary to monitor and calibrate the surrounding environment of a person / patient's body. Non-physiological sensors e.g. humidity sensor, temperature sensors and camera pills and so on, are used to monitor the room environment; because it affects a lot to bio-parameters of BSN. As in high temperature, there are more chances of high blood pressure and high body temperature.

Few sensors working and purpose has given below:

- ***Accelerometer*** is physiological, as well as the non-physiological sensor and used to sense human energy disbursement in terms of physical activity frequency and motion. Accelerometer records continuous signal [46].
- ***ECG*** sensors are of three types wet-electrode, dry-electrode, and non-contact electrode. ECG sensor reflects the change of current intensity on the skin caused by heart contractile activity over time [47]. It measures the voltage variance among the two electrodes placed on the body. ECG signal consists of a cyclic waveform of different frequencies: P, QRS, T. The P wave is related to right and left atria depolarization. It is of 120ms with 1.2mv amplitude. A QRS complex follows P wave, the combination of Q, R and S signal. Q is downward, R is upward and S is again downward signal. The duration of QRS is 60-100ms, with amplitude <4.5mv. T wave represents re-polarisation of duration 100ms with 1.25mv amplitude. ECG range is different for different age groups and gender. The T wave is essential before the next depolarization. The absence of the T wave signifies the disruption of the next heartbeat segment [48]. ECG collected at a 0.5-125Hz frequency and 0-50 mV amplitude. It sampled after every 4ms and a total of 65 samples of ECG transmitted in one packet along with other physiological sensors data [17].
- ***Temperature sensors*** fetch the ambient temperature of surroundings / body. Again, it can be used as a non-physiological or as a physiological sensor. It provides discrete values with the output voltage linearly proportional to Celsius temperature. As, the temperature increases the sensors’ resistance decreases and voltage increases and vice-versa. It measures the temperature concerning the variations in materials’ corporeal properties. Data recorded at the 4ms at an interval of 260ms window time. The average value of all taken samples was the final body temperature. Body temperature varies for physical activities. The temperature sensor must be synchronized with a pressure sensor or any other physical activity detector [49].
- ***Motion sensor*** is a non-physiological implantable sensor. These are used to detect any motion in a specific arena. Motion sensors are of many types:

Passive infrared (PIR) sensor sense the radiations of living objects to detect the motion. An ultrasonic sensor is an active sensor. It generates and transmits ultrasonic waves and then computes the back-reflected waves for the motion detection on living or non-living objects. Many other sensors, like the microwave sensor and tomographic sensors are also available in the market.

- ***EEG sensor*** is a wearable physiological sensor to decode the human mindology by tracking the electrical activities around the human beings' scalp.

1.5.2 Cloud computing

Though the term cloud came into existence in 2006, however it was actually in 1996 that this term was first coined when one of the executives of Compaq computer while plotting the future of the Internet business called it cloud computing. The National Institute of Standard and Technologies (NIST) revealed the various features of cloud computing, "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [50]. Knowingly or unknowingly, everyone is using cloud computing. Cloud computing is behind the scenes using all online services like sending emails, editing documents, watching television series or cinemas, playing online games, listening to the melody music, or uploading pictures for storing and other documents (exp. iCloud, google drive). The decade back, apart from the personal computer (local server), the remote server (over the Internet a network of high configuration machines) was started to use for data storage, management, and processing. A variety of industries, non-profitable organizations, government agencies, start-ups, global corporations, are now accepting cloud technology. Cloud computing provides computing services: servers, storage, databases, networking, software, analytics so on over the cloud [51]. The service model of cloud computing given in Fig. 1.7.

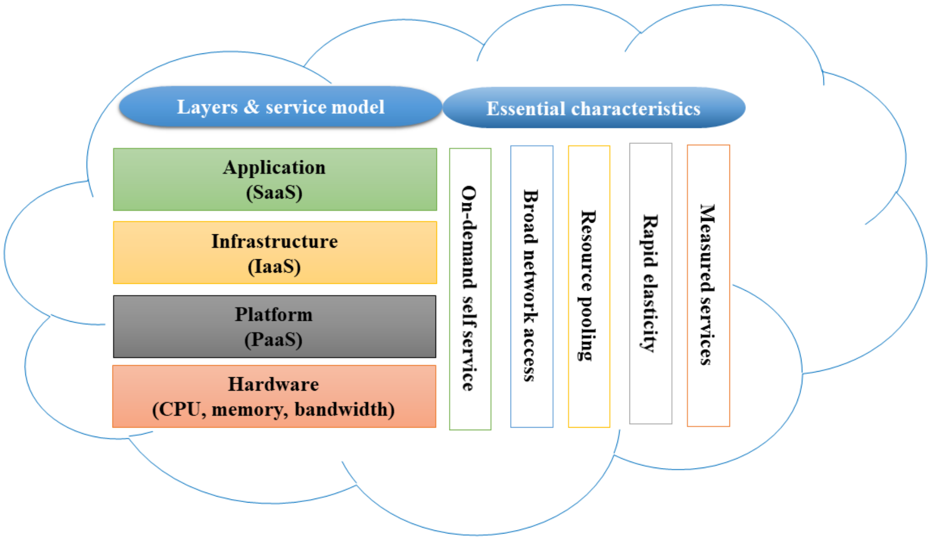


Figure 1.7: Service model of cloud computing

Lots of cloud service providers (Amazon, Google, Microsoft and many more) are available in the market. The cloud providers charge for cloud computing services as "pay-you-go", means charges based on types of services, duration of service and the amount of data to store. One can do with the cloud are creating and hosting new web applications and service models, backup and recovery of data, live streaming of audio and / or video, on-demand software delivery [52].

1.5.3 Internet of Things (IoT)

"Internet of Things" has brightened the future of the Internet. It is an innovative and exciting field. IoT is not a technology; it is a concept. IoT is the integration of various traditional technologies (Internet, WSN, embedded systems and latest communication technologies) to produce new technically advanced applications. 'Kevin Ashton' during his presentation at 'Procter & Gamble' (P&G) in 1999 first time used the phrase "Internet of Things" by trying to relate the idea of RFID with the retail supply chain of the company. At the same time, 'Bill Joy' in Davos in 1999 presented at the 'World

Economic Forum' the D2D (Device to Device) communication as part of his "Six Webs" framework. The real-time implementation of IoT was started in 2008 / 2009, approximately ten years back. IoT can interconnect any number of uniquely addressable embedded computing devices within the prevailing Internet or in the same type of network structure. Smart devices are the building blocks of IoT. Smart devices can communicate with each other. The unique IP address of smart device helps them to transfer / receive the data within the network [53]. The huge availability of IPV6 addresses is the prime factor behind the abrupt growth of IoT. By 2030 it is expected that the number of objects that will be connected to the Internet might exceed the number of persons connected with the internet [54]. Fig. 1.8 demonstrates the reach of IoT in multiple domains.

The pervasive growth of IoT has touched many fields like smart health, smart city, smart grid, smart agriculture, industrial 4.0, smart transportation, cattle tracking system, smart supply chain and so on. [55]. The main objective of IoT is to connect anything, anywhere, anytime which can be achieved by using RFID (Radio-Frequency IDentification) or WSN (Wireless Sensor Networks).

- ***RFID systems*** are the collection of one or more RFID receivers (readers) and 'n' numbers of RFID transmitters (tags). The RFID tag assigns a unique digital identity to the object and RFID reader, recognizes that identity to distinguished that particular object from other objects in a network. RFID tags are passive and do not need an onboard power supply [24].
- ***WSN*** consists of smart objects using sensing and actuation functions, which now have been blended with communicating and actuating capabilities. WSN has fuelled a large number of capabilities in IoT. Potential utilization of sensor systems includes modern computerization, computerized or smart homes, video recording and investigation, movement observing, therapeutic gadget observing, observing of climate conditions, aviation authority, and robot control. Healthcare is a vital area of research. Although many researchers were already working on healthcare, still a significant part is under investigation [56].

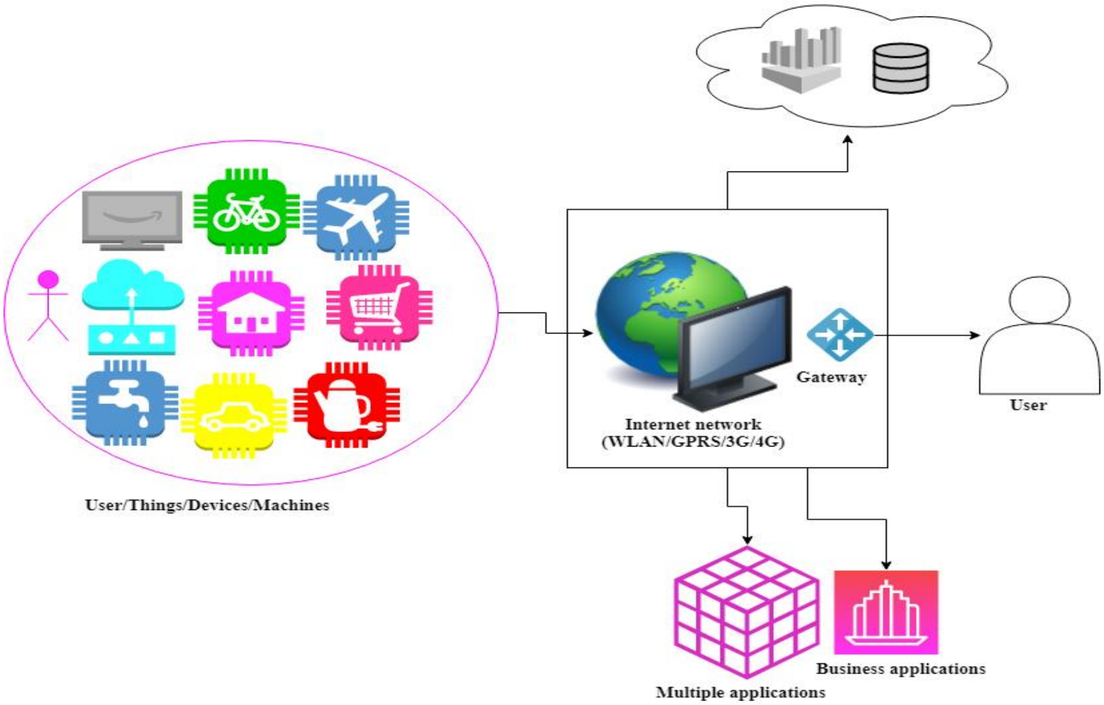


Figure 1.8: Internet of Things

The smart medical sensors, fast and secure communication channels, are the backbone of IoT-based healthcare. This vital transformation demands that the edge convergence of the IoT architectures, cloud computing and WBSN for smart healthcare domains should be deeply taken into consideration [43], [57], [58]. Most of the time, smart devices (building blocks of the systems) have tremendously limited storage and processing resources and normally powered by a battery (a limited energy source). To knockoff the storage and processing boundaries, one of the most promising solutions is the integration of IoT with the cloud. Scalability and ubiquitous availability of cloud computing benefitted smart healthcare solutions [10], [15], [59], [60].

1.6 Motivation for Research

WBSN is the offshoot of WSN. WBSN has become an important part of healthcare solutions and boomed the healthcare industry. The population across the globe is 7.7 billion, of which Asia contributes about 59.76% (4.7 billion) [61], [62]. The population of India is 1,350,531,266 (1.35 billion) as of 02 November 2019 [63]. The number of government hospitals in India is 35416 [64]. In the ratio of the abundant population, the world is lagging in medical resources. Long queues are a daily sight in the government hospitals and doctors are overburdened. The treatment is very costly in private hospitals which a common man cannot afford. The long queues and the high cost of basic treatment are still the major issues. Per capita income in India is Rs.35/-, which is poor enough for Medicaid [65]. 1 / 8 of the global population is above the age of 60 years [66]. This age segment needs more care and medical facilities, which are difficult to handle regularly at affordable prices.

The ample availability of low-cost bandwidth and good functional connectivity made it possible for continuous and unobstructed monitoring of vital health parameters through WBSN. It has minimized the need for caretakers or nursing aid for elderly and chronically ill patients [67]. Most of the diseases are associated with the modern lifestyle. Runtime monitoring of activities helped to predict the diseases caused by unjust routine activities [68]. A WBSN based lightweight device was used for telemedicine and early detection of the emergency conditions [20]. Bio-feedback sensors were used to advise the physical activities based on the calories burned [25]. Physical activity monitoring systems are still the area of thrust [69]. Tiny size WBSN devices can be used for the regular recording of physiological parameters and designed for an emergency alert system. The reactions of the human body depend on the internal environment as well as the surrounding environment. No one can turn thumbs down that the physiological data monitoring needs high accuracy and reliability, as incorrect readings may lead to critical issues related to bodily functioning. Energy efficiency is another major issue faced during the adaptation of WBSN based healthcare system [30], [70]. To improve WBSN system efficiency, a mathematical model based on the coded duty cycle and random linear network coding of biosensor nodes along with relay nodes and sink nodes were adopted [40]. It motivates us to pursue the research on WBSN deployment models and evaluate the same for performance parameters like energy efficiency, reliability and accuracy, also to work on the performance enhancement of the WBSN based systems.

1.7 Organization of Thesis

Chapter 1: Introduction

The chapter provides a brief introduction to WBSN and its application areas. The layered structure of WBSN, along with its anatomy, has been studied to understand the fundamental WBSN operations. The layered architecture of WBSN and its application areas were explored. Afterwards the motivation of the research was given. The major factors of motivation were (i) the intense difference between the ratio of population and the medical resources available across the globe, (ii) the medication cost and per capita income in India and (iii) the ample availability of low-cost bandwidth and good functional connectivity has encouraged the researchers to adopt the WBSN based healthcare systems.

Chapter2: Literature Review

The extensive literature review of WBSN has been done in this chapter. The inference and the research gaps identified from the literature review are summarized. Subsequently, the objectives of the thesis are provided. Further the methodology adopted during this research was illustrated in this chapter.

Chapter 3: Prominent Research Trends and Challenge

This chapter elaborates, how the topic modeling technique can be used to find out research topics in a specific domain. The topic modeling / natural language processing has developed many algorithms (LDA, LSA, PLSA, CTM) to find the hidden terms inside the unstructured text. A semi-automatic technique LSA was used to find out the prominent research trends and challenges pertaining to WBSN.

Chapter 4: WBSN Deployment Framework

The chapter explains the healthcare deployment models designed with wireless body sensor networks. The networking devices, communication and routing protocols are the main entities of the WBSN deployment framework. To propose a refined WBSN framework for better performance, so far, available WBSN healthcare models were studied. The models were compared on the basis of few parameters i.e. application area, sensors used, architecture design, communication technologies and the ubiquity level of the application. Sensor interaction, data abstraction and communication protocols are the prime factors to play a vital role in the performance of WBSN. WBSN-HAR and GADC-HAR were proposed for human activity recognition. To enhance the performance of the model, Energy Efficient and Reliable (EER) algorithm with Gait Adaptive Duty Cycle (GADC) was designed.

Chapter 5: Implementation and Validation of WBSN-HAR and GADC-HAR

The chapter state the real time implementation and performance validation of proposed models. The experiment was performed on forty subjects (male and female) by creating a BSN of six inertial sensors. An activity pattern of 360 seconds was adopted to record the biophysical data at five stages. In GADC-HAR, a strategic process of self-optimization was taken up for gait cycle synchronization. At the end, both models were evaluated and validated for energy efficiency, packet loss ratio and accuracy.

Chapter 6: Conclusion and Future Scope

This chapter concludes the research study carried out during the course of this research. The proposed GADC-HAR model for human activity recognition was found to be more energy efficient, reliable and accurate. For future work energy efficient heart rate monitoring and emergency alarming systems are suggested.

Chapter 2

Literature Review

Wireless body sensor network has originated from the multifaceted research on WSN. IoT is the heart of WBSN. The assimilation of WBSN and IoT with cloud had widened the scope of WBSN in multiple domains.

2.1 Introduction

Research articles published in reputed journals and conferences were studied with the motive to find strengths and research gaps within the WBSN research. WBSN literature published since 2004 was filtered using the keywords viz. “wireless body sensor network”, “body sensor network”, “WBSN”, “BSN”, “wireless body area network”, “WBAN”, and so on. The reviewed literature was divided into five interlinked domains: body sensors network, healthcare, security, IoT and cloud. Fig. 2.1 shows these interlinked research areas of WBSN.

Milenkovic A. et al. (2006) discussed the issues related to implementation of WBSN based system. The authors designed a sensor network for health monitoring in the clinic and ambulance and presented the system architecture along with the hardware and software organization. The prototype was designed with the concepts of power management, time synchronization and on-chip signal processing [14].

Akl Robert et al. (2007) explored grid-based coordinated routing in WSN. After specified time intervals, the available energy was compared in different grid size networks. It was observed that the network lifetime increased by decreasing the input power transmission. The authors concluded that the network of 150-meter grid sizes shows consistent better performance as compared to other grid size networks [56].

Valenzuela S. G. et al. (2010) designed A two-tier wireless system to monitor the health of non-critical convalescing patients. The placement of the WBSN coordinator node directly affects the systems' performance. Irrespective of the patients' speed. The wrist position was observed as the best position for implanting the temporary relay [58].

Ramli S. N. and Ahmad R. (2011) reviewed the present development of wireless body area networks and related security issues related. As part of the communication medium, WBAN faced various security issues such as data loss, access control and authentication. The authors also discussed the differences between WBAN and WSN [43].

Jovanov E. and Milenkovic A. (2011) discussed the potential of m-Health technologies created with WBAN. It has high potential in ubiquitous health monitoring, such as daily living activities. In this paper, the author presented new trends, challenges and opportunities of BAN for ubiquitous healthcare applications. Highlighted challenges were the ad-hoc interaction of sensors and the continuous incorporation of data [71].

Hu S. et al. (2012) designed an energy efficient, intelligent Body sensor network (iBoSen). It was a real-time wearable and lightweight ECG monitoring and logging system. The smartphone was used as a gateway for visualizing and transmitting the ECG signals and other physiological signals like skin temperature, EEG and respiration rate [41].

Custodio V. et al. (2012) wearable health monitoring systems were year-wise reviewed and compared for the medical area, ubiquity level, and network segments. The authors summarized all projects with details of funding, target applications area, decoded parameters, system architecture, communication protocols and system application. The author also implemented LOBIN: E-Textile and suggested to use WBSN based systems for health monitoring in the upcoming hospital environment [17].

Yeongjoon Gil et al. (2012) developed a lightweight, ultra-compact and low power system for recording four signals: ECG, EEG, PPG (PhotoPlethysmography) and respiration. All sensors' data was verified in aspects of frequency responses and quantities. The system was tested for 31 years normal right-handed person sitting on a chair in a relaxed mood. Bluetooth was communication media. The authors suggested that the Zigbee communication platform would help to increase power efficiency [20].

Trobec R. et al. (2012) designed a multi-channel ECG sensor based on a respiration rate body sensor. The amplitude difference between two neighboring electrodes was compared with the reference respiration signal obtained from the air and temperature difference between the nose and mouth. The developed respiration sensor used to examine seven persons (age 45-50) with no medical record. The authors identified the best position of electrodes for the respiration rate sensor by their experiments and confirmed a viable option. This sensor is not accurate for cardiovascular patients and also not energy efficient [47].

Tsouri Gill R. et al. (2012) proposed a global routing protocol based on Dijkstra's algorithm augmented with a novel link cost function for energy consumption balancing and increasing novel link in WBAN. The link cost function was calculated to ensure that all nodes deplete their batteries at the same time. The designed algorithm evaluated by a real-time implementation. During the experiment, multiple antennas were deployed as on-body and off-body access points on a 70K.g. person [60].

Yong Song et al. (2012) proposed an innovative signal transmission technique based on the human body medium. The author used a Mach Zehnder Electro-Optical (EO) sensor for high speed and reliable transmission. The system consists of sensors, a transmitter, and a receiving circuit and provides a steady frequency response in the 2MHz - 30MHz range. The system was tested and authenticated for carrier frequency > 1MHz and most suitable for 8MHz. The baseband frequency range of 100KHz - 8MHz can be achieved with 8KHz carrier frequency [38].

Lai Xiaochen et al. (2013) presented an extensive survey of BSN in three aspects sensors, data fusion, and network communication. The author classified the sensors according to the measured signal, type of data transmission, deployment position and network adjustment ability. The authors surveyed data fusion in aspects of pre-processing of data, feature extraction, computing and compression. BSN communication design factors, network topologies, physical, MAC, routing and cross layers were discussed with their trends and challenges [10].

Fortino G. et al. (2014) proposed a novel framework for collaborative BSN for distinct applications e-entertainment, e-emergency, e-health, e-sport, e-factory. The authors extended the well-known SPINE framework to C-SPINE (collaborative SPINE) framework. It supports all four logical implementations of BSN. The C-Spine framework was successfully tested for emotion reaction detection [72].

Lee B. and Ouyang J. (2014) proposed an intelligent service model for patients to autonomously manage metabolic syndrome such as blood pressure, obesity, diabetes, triglycerides and (High-Density Lipoprotein) HDL cholesterol. These are the leading causes of cardiovascular disease and brain stroke. Authors proposed an intellectualized service application algorithm that used two types of messages one is ‘join’ that is data request and the other is ‘leave’ that is data acknowledgment. The format used for the message was: i) Type of message ii) medical data iii) source address iv) destination address v) sequence number vi) length of payload vii) payload. A comprehensive assessment information protocol generated the relationship between mutual diseases and risk factors [35].

Romo P. et al. (2014) designed a smart mobile phone app "Application for Monitoring Physical Activity" (AMOPA). It would provide help to adults or sedentary people in the urban area to monitor their daily physical exercises. A log would be maintained to check revolutionary records concerning routine activities. Pedometer and an indicator of the intensity of the users' movements are used to record the data. Through AMOPA a doctor, caretaker or a person itself remotely monitors the user. The user interfaces were separately designed for doctors, caretakers and users. AMOPA consisted of energy efficient devices [33].

Adame T. et al. (2016) proposed an integrated RFID and WSN enabled health monitoring system CUIDATS. It provides the location status and tracking of patients and assets. It was an end-to-end patient / asset monitoring system in hospital environments. It was an electronic wristband that reports data for pulse, temperature and movement of the patient and activates alarms with respect to their threshold values. It was tested in reality in the "Asepeyo" hospital in Spain [13].

Bhatia M. and Sood S. K. (2016) marked to IoT based patient monitoring in ICU to enhance the deliverance of curative services. IoT technology is capable of sensing of acute details of sensitive events and provides services in time as well as efficient manner. The author worked on a mobile healthcare system based on cloud and IoT [73].

Yu Daeun et al. (2016) introduced the two power-saving techniques for the WBSN system, low-power MAC protocol and Transmission power control (TPC). TPC technique used for saving the energy consumed in communicating the sensed data from the sensor node to the sink node. The multiple sensing devices can be implanted on the human body for collecting the diverse human body parameters [74].

Gravina R. et al. (2017) surveyed on multi-sensor fusion in the body-sensor network and concluded although BSN is transitioning multi-device synchronous measurement environment. But still, it is a non-trivial task that directly impacts practical application functioning. This survey focused on low-power MAC protocol and physical activity recognition. Authors compared the reviewed work in traditional classification of fusion technique, data level, feature level and decision level [34].

Miramonte R. et al. (2017) presented a technological platform called "PlaIMoS". It consisted of a fixed measurement station, wearable sensors, a network with IEEE 802.11 and IEEE 802.15.4 communication protocols, the security mechanisms and a server to investigate the recorded data. Mobile apps for android, ios, and windows10 were designed to provide real-time user interface. The authors primarily designed the architecture to decode the body temperature, ECG, heart rate, galvanic resistance, fall detection, respiration rate, and patients' blood oxygen saturation [48].

Cai W. et al. (2017) designed and implemented an RF switch for BSN shunt-series topology. At 5 GHz insertion loss and isolation were obtained 0.906dB and 30.95dB, respectively as per the desired requirements. The third-order distortion of 53.05 dBm and 1 dB compression point at 50.06dBm was decoded. The performance of the RF switch met the anticipated specification requests [75].

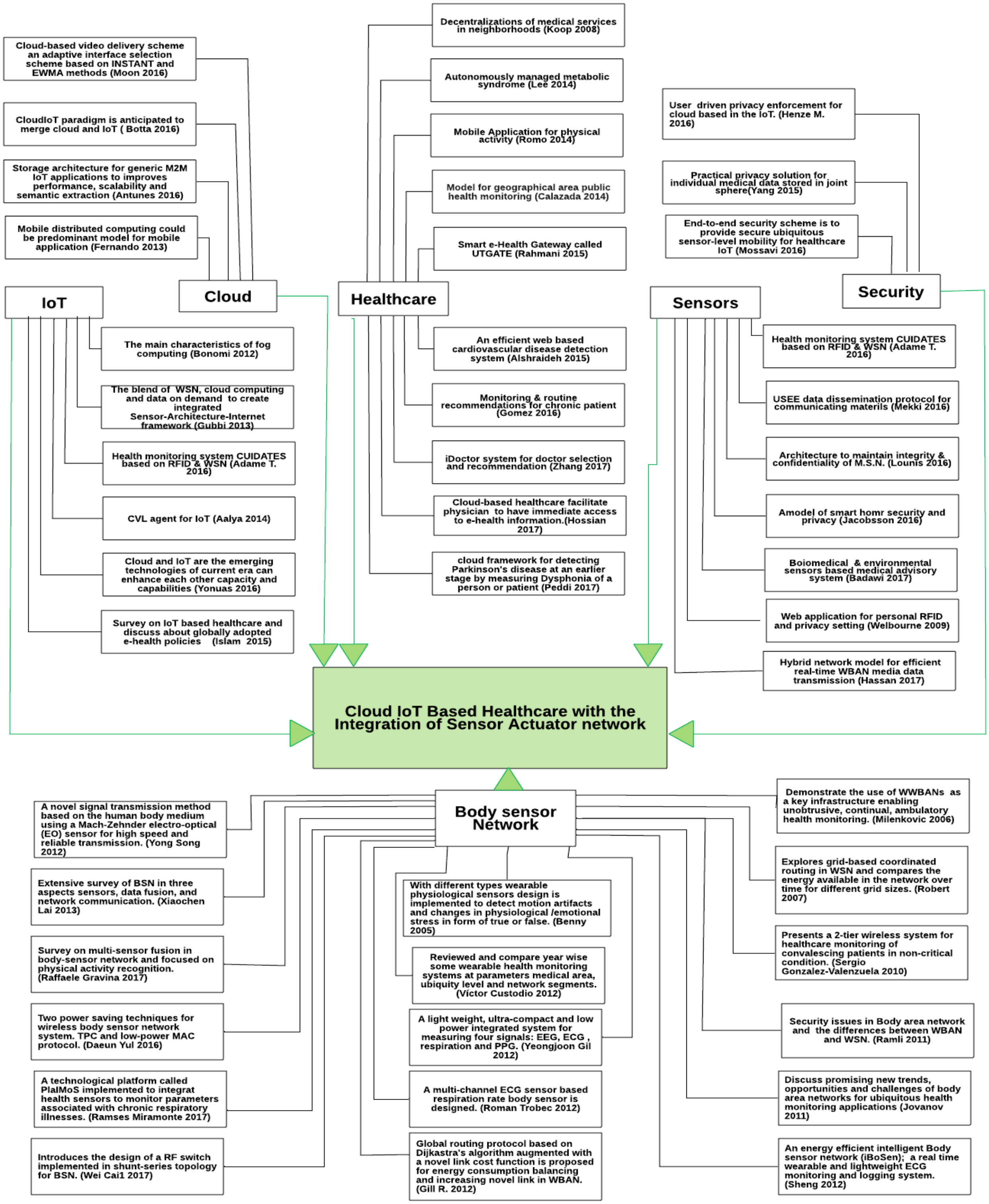


Figure 2.1: Interlinked research areas of WBSN

Lounis A. et al. (2016) proposed an architecture to easily share medical sensors network data among healthcare professionals during the emergency and routine conditions. A security mechanism based on Cipher-text Policy Attribute Based Encryption (CP-ABE) was developed to provide fine-grained access control to outsourced medical data by maintaining its confidentiality and integrity. The simulation results proved that the proposed scheme was efficient and scalable in emergency and normal conditions. For an emergency time, authors worked on batch files for load balancing [76].

Mekki K. et al. (2016) proposed a data distribution protocol for communication, named as Uniform Storage and Energy Efficient protocol (USEE). In USEE the data distribution was smartly managed by replicating the data in nearby WSN nodes. Every node in the network ensured information retrieval. USEE was based on a combination of neighbor storage information, probabilistic storage, and counter-based flooding. USEE guarantees uniform distribution as well as low communication overhead as put side by side to other protocols like DEEP, supply, and RaWMS [77].

Jacobsson A. et al. (2016) designed a model of smart home privacy and security. Work had divided into three domains: analyzing the risk exposures, security design principles to control the risk of exposure, and privacy-aware information management. To integrate security and privacy, all heterogeneous data was analyzed and classified. Autonomous decision-making processes of the connected entities that form the smart home system were applied [78].

Badawi H. F. et al. (2017) designed a cloud-based activity advisory system with the help of biofeedback sensors and environmental context to offer customized advice with suitable time and location. The authors conducted a three-month trial of six users to evaluate the proposed system. Each user was tracked for two-weeks. Based on the physical activities, the number of burnt calories was computed and suggested the amount of physical activities performed in the future. The results showed a positive effect of the proposed system by increasing the awareness of the calories to be burned [25].

Hassan M. M. et al. (2018) introduced a hybrid network model for real-time efficient data transmission in WBAN. In the proposed model, the cloud was integrated with WBAN to share and communicate the vital data. The Content Centric Network (CCN) and adaptive streaming used to improve the quality of real-time data dissemination. The architecture entails four layers: application, network, cloud and perception layer. The robust combination and interaction of TCP / IP and Zigbee were deployed in the coordinator devices to work as bridges among WBAN and multiple local networks. It improved the communication quality and guaranteed the patient physiological data transmission [79].

Boudargham N. et al. (2018) exhaustively study the Collaborative Body Sensor Network (CBSN). Authors compared the WSN, WBSN and CBSN to figure out the similarities and dissimilarities. Based on the comparison, challenges and research directions were outlined. Communication protocols and algorithms for CBSN were suggested to design in the future [80].

Many researchers worked to improve the healthcare systems for social welfare and tried to minimize human life risk. The technical details of adopted technologies for smart healthcare systems can be figured out from their publications given below:

Koop C. E. et al. (2008) proposed the design of the medical care system to deliver medical services in neighborhoods and personal homes. Telemedicine, computer technology was used to link patients with primary care providers and tertiary medical facilitators. This decentralization process would reduce the cost of medical insurance coverage provided to all citizens. To save the countrys' resources and protect the citizens during natural disasters and biological terror were the significant benefits of the proposed medical care system [16].

Calzada A. et al. (2014) proposed a decision model for the geographical area of public health monitoring. The model helped in making timely decisions for sanctioning budget, controlling crimes of that area. The authors experimented in the year 2011 questionnaire. The data collected in Northern Ireland and the result was the same as earlier evaluated. But it was more efficient than previous systems [81].

Rahmani A. M. et al. (2015) proposed a Smart e-Health Gateway called UTGATE. The author exploits the typically adopted position of traditional gateways that offers some higher-level services like local storage, embedded data mining, real-time onboard data processing and many more. UTGATE can handle many challenges of ubiquitous healthcare systems such as reliability, scalability and energy efficiency. An IoT-based health monitoring system resulted in improved energy efficiency, reliability, performance, security and interoperability [11].

Alshraideh H. et al. (2015) identified an efficient web-based cardiovascular disease detection system that can be used by patients anytime, anywhere, through an android application. The data collected in January 1998 by the University of California at Irvina was used for experiments. The dataset of 279 attributes for 452 instances distributed among 16 types of arrhythmia classes. All WEKA (a data mining tool) algorithms were applied on this ECG data to check the best efficiency. The J48 algorithm provided the maximum accuracy of 98.29% and Navi Bayes resulted in the least accuracy of 75.06% [33].

Gomez j. et al. (2016) aimed to develop an architecture for health monitoring and workout, routine recommendations for chronically diseases patients. This paper explained the proliferative capabilities of IoT that allow us to integrate the Internet connectable devices and provide the health status of patients' in real time to doctors. The authors worked on chronic diseases such as diabetes, heart rate, and blood pressure. A questionnaire was used to prove the efficiency of the system [82].

Zhang Y. et al. (2017) proposed an iDoctor system to overcome the challenges in traditional onsite doctor selection. A complete analysis performed on healthcare crowd-sourced reviews. The topic model and other methods were used to analyze text sentiments and generate the matrix factorization. Two significant differences between iDoctor and traditional onsite doctor selection were (a) a topic-model based approach,

b) An emotion-aware approach. Both approaches were combined into the matrix factorization method to offer the additional objective recommendation [83].

Peddi S. V. B. et al. (2017) The cloud-based framework was designed for earlier stage Parkinsons' disease detection by regular measuring dysphonia of patients. Healthcare professionals and patients used a cloud-based automated system to store the voice of a patient in the cloud database and identify the Patient Database (PD) for dysphonia symptoms in his voice. An artificial neural network based; a feed forward backpropagation was designed to classify the extracted features of the recorded voice with high accuracy. It could provide alert to remote specialists to identify and advise the medication therapy plan to the patient through this framework [84].

Smart healthcare systems need high speed and broad bandwidth connectivity for real-time data transmission. Some researchers use the Internet of Things (IoT) to provide connectivity for physiological data transmission. The following literature tells the need for IoT in WBSN recorded data transmission.

Bonomi F. et al. (2012) discussed how fog computing brought the revolution in IoT services and applications like smart cities, smart grids, networks of WSNs and actuators. The authors examined the characteristics of fog computing and IoT. The characteristics of fog computing, defined by authors, were location awareness, low latency, mobility, ubiquitous geographical distribution, 'n' number of nodes, wireless access, the strong presence of streaming and real-time applications. All were helpful in IoT to become an edge of the network [85].

Gubbi J. et al. (2013) suggested the blend of three technologies: wireless sensor network, cloud computing, and data on demand by ubiquitous web (web3 technology). This blend will help to create a novel integrated sensor-architecture-internet framework. The framework was implemented with the integration of private cloud Aneka and public cloud Microsoft Azure. Azure allowed Aneka to launch any number of instances and each instance can have advanced PaaS multiple programming models, runtime execution services, workload management, dynamic provisioning, QoS based scheduling and flexible billing. Aneka was the middleware between Azure and the users' applications [42].

Ayala I. et al. (2014) worked to enhance the capabilities of IoT. A Common Variability Language (CVL) process was used to create Self-star MAS agents with basic properties like distributed nature, context-awareness, and self-adaptation. The main goal of this paper was to increase the scope of IoT applications using agents and advanced software techniques like variability modeling. CVL was a domain-independent language belongs to the object management group and useful for specifying and resolving variability. The authors reconfigure the heterogeneous and interconnected devices for the evolution of IoT applications. Self-star MAS agents and advanced software engineering techniques were used to achieve variability modeling [53].

Islam S. R. et al. (2015) briefed the surveys of different domains of advancement in IoT-based healthcare. The network architecture, industrial trends, applications, data security and privacy features were overviewed. The author also talked about various IoT and eHealth policies and regulations that are globally adopted by different countries. The end of the paper points out some open issues and challenges related to the growth of the IoT healthcare field [22].

Younas M. et al. (2016) point out the emerging technologies of the current era. Authors stated that IoT and cloud are complementary technologies, so both can enhance the capabilities and capacity of each other. IoT enabled devices were having less storage and computational power, but the cloud is a stack of storage, computational power and analyzing data. The combination of IoT and cloud could bring a revolutionary change in technological applications [86].

Alsheen H. et al. (2018) proposed a WBSN based system with improved energy efficiency. To improve efficiency, two techniques were adopted: 1) mathematical model based on the random linear network coding and coded duty cycle. 2) network coding in terms of biosensor nodes, relay nodes and sink nodes [37].

The Research community tried to use cloud infrastructure for the storage and cloud analytical platform for physiological data analysis. Few articles have included in this literature survey.

Fernando N. et al. (2013) displayed diverse meanings of portable distributed computing in writing. The authors exhibited a scientific categorization of issues founded and respective handling approaches. Authors concentrated on the operational level, administration and application level, end-client level [23].

Antunes M. et al. (2016) evaluated multiple models with a stress simulation designed by three M2M projects. The d-dimension model inspired the anticipated context storage solution design. It improved the scalability, performance, and semantic extraction of context storage to provide useful information about the entities available in IoT. The authors proposed a new context storage architecture for generic M2M (as part of IoT) applications [51].

Moon S. et al. (2016) proposed the “CloudIoT” environment to merge IoT and cloud. It enabled several novel applications and scenarios such as ubiquitous healthcare applications, smart cities and homes and so on. To realize the benefits and promises of the CloudIoT environment, the authors recognized several open issues like the heterogeneity of involved devices and technologies; reliability, performance, scalability, security and privacy preservation, legal and social aspects, power and energy efficiency [52].

While sending data on the cloud, many security and privacy issues can arise. To overcome the physiological data forging some researchers devised security and privacy algorithms as given below:

Yang J. J. et al. (2015) proposed a practical privacy solution for the individual privacy protection of the stored medical data in the combined database. Authors classified the existing privacy protection into three types: privacy by statistics, privacy by cryptography and privacy by policy. The author innovatively combined statistical analysis and cryptography to provide multiple paradigms of balance between medical data utilization and privacy protection. The effectiveness of a privacy solution was proved with the help of a case study in which each algorithm is running exclusively on the server / client architecture [87].

Gope P. and Hwang T. (2015) proposed a secure IoT-based modern health care system using BSN. Primely authors address some security factors that are mainly required in BSN healthcare systems. A lightweight authentication protocol was created and compared with two previously designed security mechanisms 'Alarmset' and 'Median', at many security levels [88].

Moosavi S. R. et al. (2016) The certificate-based Datagram Transport Layer Security (DTLS), an end-to-end security scheme was designed to provide secure, ubiquitous sensor-level mobility for healthcare IoT. In this paper, handshake and the session resumption technique between smart gateways and end-users were implemented on hardware as well as software. The author claimed that the proposed security scheme reduced 26% communication overhead and 16% communication latency among end-user and smart gateways. The proposed system was around 97% faster than the certificate based and 10% faster than the symmetric key based DTLS [39].

Henze M. et al. (2016) proposed comprehensive privacy policy, User-driven Privacy Enforcement for Cloud-based Services in the IoT (UPECSI), to eliminate the hindrance in the adaptation of cloud-based IoT. The policy consisted of several organizational processes and many technical components. Each component equally focused on developers of cloud services and individual end-users. UPECSI shifted the choice and control over the usage and handling of data from service providers and developers to the individual end-user [89].

The literature survey concluded that the multiple body sensors were used for numerous health applications by different authors and analyses performed on different datasets. The summary of bio-sensors and healthcare applications, along with the used dataset illustrated in Table 2.1.

Table 2.1: Literature summary sheet

Ref. no.	Bio Sensors										WBSN Applications						Data
	ECG	EEG	EMG	Pressure	Respiration	B. P. Sensor	Temperature	Mach-Zehnder EO	Accelerometer	Motion	Paediatric Management	Remote Health monitoring	Private Health & Fitness Management	Chronic Diseases Supervision	Elderly Care	Normal Person	Experimental Data
[18]	✓					✓	✓		✓					✓			Virtual
[14]	✓									✓			✓				Synthetic
[58]	✓								✓							✓	1 person
[71]									✓	✓							Virtual
[15]	✓	✓			✓		✓					✓		✓		✓	Synthetic data
[17]	✓						✓		✓							✓	Survey
[20]	✓	✓		✓												✓	1person(31years)
[47]	✓				✓											✓	5F+2M
[60]	✓															✓	1 person
[38]								✓									Synthetic
[34]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							Survey
[13]				✓			✓		✓				✓				Real time Asepeyo hospital

[25]				✓						✓		✓			✓		Virtual
[35]						✓											Virtual 1000 patients' sample
[33]	✓																ECG data set of University of California at Irvina
[82]	✓			✓		✓								✓			16 people (1month)
[73]	✓			✓		✓	✓					✓	✓				81 patients >17 years, 31 ICUs, 1 month
[22]	✓	✓	✓			✓	✓										Survey
[39]	✓						✓										One patient

M: Male, F: Female

Energy efficiency plays a significant role in WBSN systems. The energy efficiency in WBSN majorly depends on the four techniques: Node activity management, data aggregation and transmission, MAC protocols, Topology management, Routing of the network. The comparison for hardware and software platform for the above said techniques is given below:

Techniques	Hardware	Software (MatLAb)
Node activity management	Active time set as per gait cycle	Active time is coded once
data aggregation and transmission	To save bandwidth, n packets were logged and encapsulated in one packet before transmission (EER algorithm used for network coding)	Once coded cannot be changed (can be coded in simulator)
MAC protocols	Used as per platform (Raspberry pi) (WiFI works on 2.4 GHz.)	Alshaheen H. used IEEE 802.15.4 (Works on 2.4 GHz.)
Topology management	Star topology	Tree topology
Routing of the network	all sensors were connected in cooperative sensor interaction and collaborative data abstraction mode	Network was programmed to check the nodes for active or inactive mode and the priority.

Energy consumption directly affects the networks' lifetime. The energy in WBSN is conserved in two ways, energy consumption and the way the power supplied to the network. Lots of research work has been done in this direction, but still, it is a challenge.

Rani S. et al. (2013) proposed an Energy Efficient Inter Cluster Coordination Protocol (EEICCP) for WSN. The EEICCP evenly distributes the energy load in network nodes. The algorithm was applied to multi-channel WSN and proved much efficient than LEACH and HCR protocols [90].

Elghers S. et al. (2014) worked on the energy efficiency of WBSN by detecting the emergency condition at the node level. The authors designed two algorithms, one for biosensor data recording time variations and second, to detect the emergency at the node level. The algorithm reduced energy consumption by sending the data only in emergency conditions [91].

Sadiq B.O. et al. (2017) stated that the effect of placement of biosensors nodes in WBSN mobility models. Three routine postures (sitting, standing and walking) usually affect the efficiency of BSN due to interrupted communication of nodes. That, in turn, affects energy consumption [92].

Alshaheen H. et al. (2018) worked on energy optimization of WBSN network. The authors designed a mathematical model. Random linear network coding and the coordinated duty cycle algorithms were designed to handle the traffic in the bottle neck zone. Beacon transmission was controlled on the bases of priority and the traffic behavior in the network. The result of the simulation was matched with the mathematical results [37]

Rahmani A. M. et al. (2018) presented the practical implementation of the IoT-health system by exploiting the features of fog computing. As a proof of concept, authors implemented a smart e-health gateway. Fog computing supports seamless mobile sensors connectivity. Early warning scores did the system demonstration with hierarchical fog-assisted computing [93].

Zang W. et al. (2018) proposed the Gait-cycle driven Transmission Power Controlled (G-TPC) for human activity recognition. The gait cycle beacon function periodically used to link WBSN only at low power consumption points for transmission, which in turn saves the energy of the network [94]. To validate the effects of locomotive tasks, the authors created gait data of forty healthy subjects. The multiple-task gait analysis protocols: self-selected, higher or lower gait speed especially for heels / toe walking or ascending / descending walking. All data were compared for gait speed and spatiotemporal parameters: stance time, cadence and double support time [95].

Bovi G. et al. (2011) created a gait database, MEREA (Movement Analysis in Real-world Environment using Accelerometer) of twenty healthy subjects for walking and running. The database was generated in controlled and outdoor environments by implanting three accelerometers on the subjects' body. Six GED algorithms, available in the state-of-art, validated the MEREA database and resulted well in an indoor environment with high accuracy of heel stroke recognition [96].

Martinez-Hernandez U. (2018) designed an adaptive Bayesian inference system (BaSis) to predict the walking gait events. The authors combined the probabilistic formulation with sequential analysis for activity recognition. An adaptive perception method worked on a weighted combination of prior knowledge and time stamped predictions based upon the observed decisions to improve the efficiency of the system [97].

The outcome of the literature study elaborates that there is ample scope for WBSN based healthcare solution and there is a need to pursue research on it [92]. The bio-sensors, healthcare and performance of WBSN are arisen as main areas to be pinned more.

Bio-sensors: In the context of the sensor, its storage capabilities, power consumption must be brought to the edge. Complex embedded systems require flexibility [23], added-value and close interaction to reach the potential user and also need integration with IoT [98]. Low-power operation requires not only low-power hardware but also careful software design and protocol selection [99]. The design of sensor nodes, especially the node size, energy consumption requires research attention, which will help in reducing the risk of human skin or underneath tissues damaged by the increase in temperature of body sensor while in the active state [10]. Multi-sensor fusion and data heterogeneity is another challenge for future researchers [34]. To develop new and innovative semantic applications, the multidimensional cloud storage models have more scope in the future; they attain advanced performance and offer a platform for exploring real-time applications [51]. BSN generates data in large quantities, so data storage, management, privacy, losses are still the areas to be underpinned [42].

Healthcare: Mobile-healthcare applications and services provide health facilities at all times and everywhere with low and affordable costs as compared to the old healthcare services and systems. Mobile-health applications have significant improvement scope in future and high impact on user lives e.g.: elderly, chronic patients and specially-abled persons [48]. A software and in-depth diagnostic tool are required for the cross-reference of WBSN recorded physiological parameters for medical practitioners [84]. The dynamic cloud allocation algorithms need attention in the future to improve the overall accuracy of the system [100]. The architecture of WBSN that can cover many rooms buildings and big places is still in its infancy stage. GUI based software applications are required to handle multiple sensors data from multiple sites / nodes / locations [101]. Mobile phone platform variability (android, ios, windows), reliability, efficiency, cost, energy consumption, a user interface for health apps, health data quality, privacy and security are the main challenges for future researchers [86]. In future logical networking can be designed for WBSN. The reliability and integrity of WBSN data are significant factors for healthcare applications. Robust machine learning / deep learning algorithms and GPU based machines will be required for real time health data simulation [57], [86]. For real time applications, an integrated design and development process is required for user and developer to analyze the risk for original, qualitative and quantitative physiological data [78]. To maintain the quality of services of sensor network a novel security mechanism is required to adapt the capabilities and constraints of heterogenous WBSNs data [18], [86].

Performance of WBSN: [102] researchers suggested developing the energy efficient and reliable communication mediums for real time applications with heterogeneous types of bio-medical sensor nodes. S. Majumder, recommended to develop an algorithm to guaranteed highly secured communication channels in present short-range, low power wireless platforms to maintain the privacy and security of sensitive medical data [103]. Future researchers must develop mobile health apps to gratify the current legislation of security and privacy [104]. To increase the privacy of health data, the pioneers of WBSN evoked to work on the fog layer in the future [39]. Issues arose in physical and MAC layers were throughput, delay in delivery of packets of the whole system.

2.2 Inference Portrayed by Literature

The inference and challenges portrayed by WBSN literature are tabulated in Table 2.2.

Table 2.2: Inference and challenges

1 Recording of biophysical parameters is essential and mandatory for any WBSN based healthcare application [30], [70].

2 Effectively managing the resources (viz. power, networking and communication protocols) of WBSN and communicating the recorded WBSN data is a big challenge [105], [106].

3 Collaborative WBSN models and cloud-enabled services are the groundwork for allowing unobtrusive, frequent, ambulatory or remote health monitoring systems [72], [107].

4 The choice of right routing protocol for WBSN plays a significant role in the effectiveness of the system [108].

5 The real time usage of WBSN can revolutionize the healthcare sector [29], [97].

6 The performance of the WBSN model in terms of energy, accuracy and reliability is still to be pinned more [37], [40], [94].

7 The evolution of WBSN and its applications in multiple domains is helpful to control the things remotely [101], [109]

2.3 Assessments and Research Gaps

The far-reaching study of WBSN literature published since 2004 abrogated the core research gaps in WBSN and healthcare applications. The future research work can be pursued on these gaps: The less energy consumption of WBSN systems requires low-power operations. Further low power operations require low-power sensors, controller nodes, intelligent software design and smart protocol selection [110]. Incessant availability of communication networks for regular BSN data transmission and efficient use of network resources will increase the load efficiency and reliability of the system [73]. Cloud assistive body area networks for the collection of Body Sensor (BS) data stream and effective body sensor data management, scalable processing framework, BS data storage and analysis along with timely effective decision making were also in demand [34]. A framework was required for a multisensory fusion method based on self-configuration, self-optimization, self-protection and self-calibration [39]. The framework must be embedded with innovative synthesis methodology to manage multi sensors' (sensors can be millions in numbers) big data for real time healthcare applications [36], [108].

WBSN two open issues: first was the real-work implementations and second was the overheads and computational time of clustering the network; figured out from previous research. A lot of problems and challenges were faced to replicate these real-time datasets in simulation [70].

The use of WBSN in healthcare was the transformation of current healthcare systems. But heterogeneity, reliability, integrity and data management of WBSN were critical factors for healthcare applications and needed the attention of researchers [86]. Contemporary WBSNs were not context aware and collaborative [57]. Wearable systems based on the multimodal interface and shared control architecture to monitor and control different kinds of physiological parameters were not reliable and efficient [11]. A generic IoT or / and cloud based WBSN healthcare deployment model was required, to enhance the performance parameters like energy, latency, lifetime, reliability and, the security of the WBSN healthcare system [111].

Energy efficient realtime mobile-healthcare applications and services systems had a significant improvement scope in the future for elderly, chronically ills, specially-abled persons and Insomnia patients [33], [51], [99].

Presently computer-aided ambulance and intensive care of physiological parameters while traveling provide high latency and errors in data [57], [112]. Remote monitoring and controlling of BSN were not time efficient. Software and in-depth diagnostic tools are required for the cross-reference of these parameters to facilitate medical practitioners [48].

The existing architecture of WBSN for big and high buildings lags in many accepts. A GUI based software application was required to handle multiple sensors data from multiple sites / nodes / locations [100]. Logical networking can be designed for WBSN [102]. Mobile phone platform variability (android, ios, windows), reliability, efficiency, cost, energy consumption, the user interface for health Applications (Apps), health data quality, privacy and security were the main challenges for future researchers [101].

2.4 Problem Definition

WSN offers an ample environment for the amalgamation of BSN, IoT, cloud, security and healthcare. The WBSN based smart healthcare solutions are proliferating the field of biomedical engineering. Among healthcare, WBSN is stimulating research areas like human activity recognition, elderly care, chronic diseases, cardiovascular disease alert system and so on. The primary challenge for smart healthcare solutions is the performance of the WBSN deployment framework in terms of energy efficiency and reliability. It has the potential to carry forward the research.

2.5 Thesis Objectives

1 To study and analyze the prominent research trends and challenges pertaining to WBSN.
2 To propose a deployment framework for better performance of WBSN based system.
3 To implement the proposed deployment framework as proof of concept.
4 To validate the performance of the proposed framework through case analysis or scenario

2.6 Methodology

Fig. 2.2 shows the methodology adopted during the research.

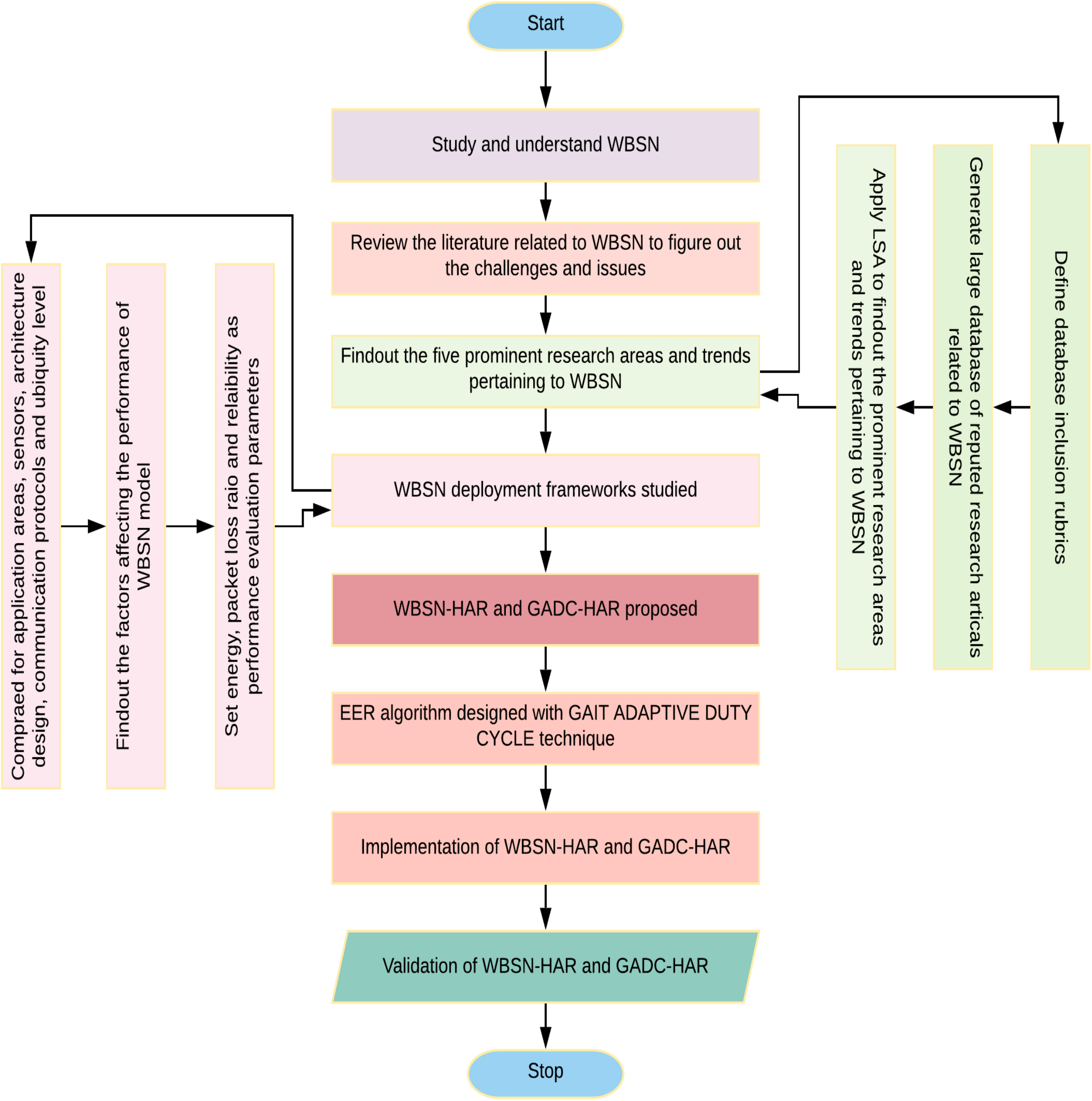


Figure 2.2: Methodology

At the initial stage of the research, we study and understand the WBSN technology. For around one-and-a-half-decade literature was reviewed to know the state-of-the-art and figure out the challenges and issues to be resolved. The Latent Semantic Algorithm (LSA), a topic modelling algorithm, was applied to find out the prominent research areas and trends in WBSN. The steps followed at this stage were:

(i) Define database inclusion rubrics
(ii) Based on the inclusion rubrics, an extensive database of 927 documents related to WBSN was generated.
(iii) Apply the LSA algorithm and find out the prominent core research areas and trends pertaining to the WBSN.
(iv) Manually set the correlation in the core research area and trends.

Further, the research work was carried forward to deeply understand the so far implemented the WBSN deployment frameworks in the following manner:

(i) Compare the deployment frameworks based on the application areas, sensor deployed, architecture design, communication protocols used and the ubiquity level.
(ii) Identification of the factors that affects the performance of the frameworks.
(iii) Energy, packet loss ratio and efficiency were fixed as the performance evaluation parameters.

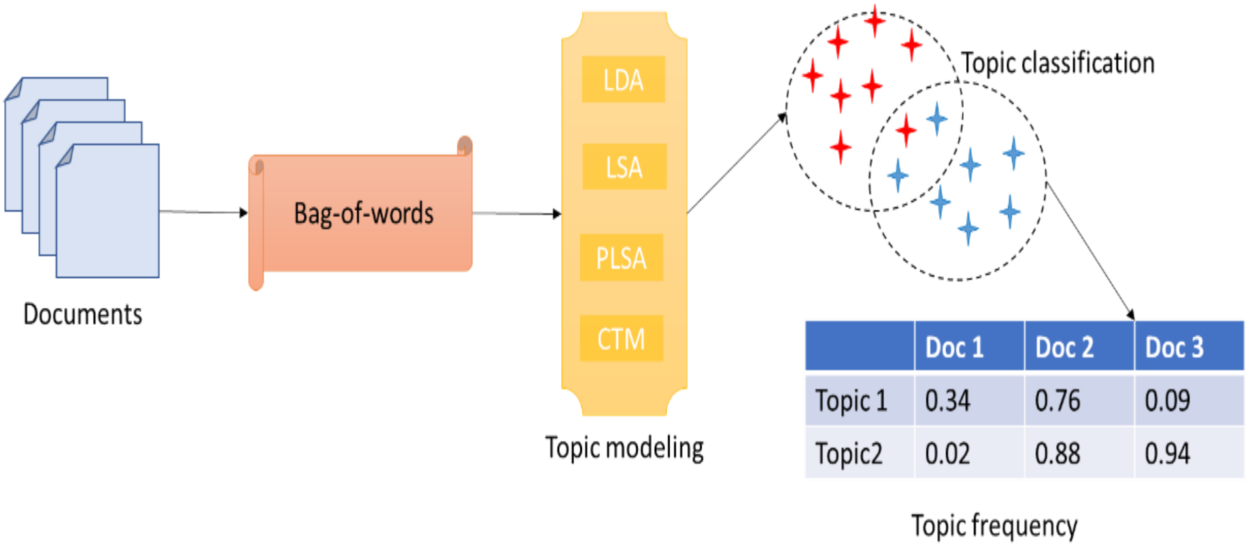
By taking care of the factors that affect the performance of WBSN frameworks, the WBSN-HAR and GADC-HAR frameworks were proposed. An Energy Efficient and Reliable (EER) algorithm was designed to work at the backend of the proposed frameworks. At the last stage of the research, the proposed frameworks were successfully implemented and validated.

Chapter 3

Prominent Research Trends and Challenges

To start research in any domain it is mandatory to be aware of existing research trends and challenges. Most of the time, it is done manually, which is a very exhaustive and time-consuming process. The topic selection sometimes may get affected by individual bias or expertise. The outgrowth of machine learning (ML) and natural language processing (NLP) has facilitated the researchers with automated / semi-automated methods to browse, search, organize and index the electronic documents precise to the topic or domain. It is the best way to understand the text corpus by knowing the hidden terms available of the text. Most of the time, text classification or topic modeling used to find out the hidden terms in the given text corpus. Text classification is used where the classes are already given. In topic modeling, the classes are defined based on repetitive terms find in the text corpus [113].

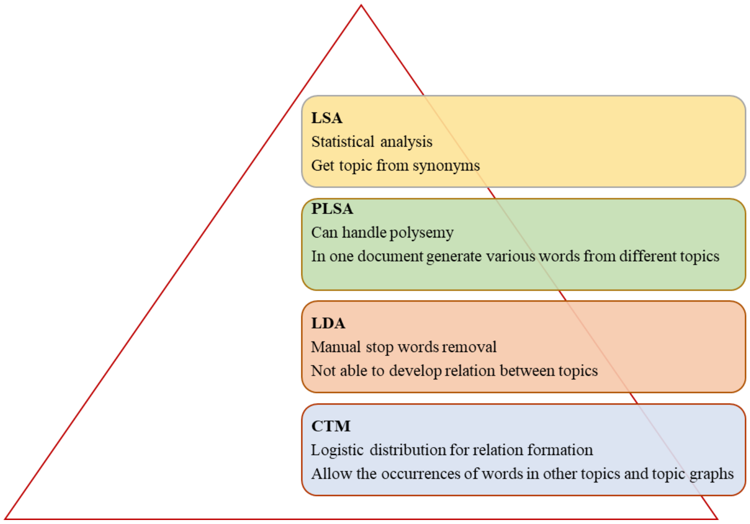
Topic modeling (probabilistic modeling) is a statistical model of NLP, frequently being used for text mining. It helps to make visible the unseen semantic structure of the prearranged text content. The hierarchical probabilistic modeling made it easy to find the patterns of words in the document. It helps to find documents with similar patterns. Topic modeling is used in many scenarios like recommender system (suggest articles as per similarity index), text classification (clustering of contextual words) and detects trends in publications (uncover the themes available in the text) [114]. Fig. 3.1 shows the basic flow of topic modeling.



	Doc 1	Doc 2	Doc 3
Topic 1	0.34	0.76	0.09
Topic2	0.02	0.88	0.94

Figure 3.1: Topic modeling

Various topic modeling algorithms are available for text mining (to uncover the hidden patterns) such that LDA (Latent Dirichlet Allocation), LSA (Latent Semantic Analysis), PLSA (Probabilistic Latent Semantic Analysis), CTM (Correlated Topic Model) and so on [114]. Fig. 3.2 demonstrates an overview of these algorithms.



LSA
Statistical analysis
Get topic from synonyms

PLSA
Can handle polysemy
In one document generate various words from different topics

LDA
Manual stop words removal
Not able to develop relation between topics

CTM
Logistic distribution for relation formation
Allow the occurrences of words in other topics and topic graphs

Figure 3.2: Topic modeling algorithms

The characteristics and limitations of LDA, LSA, PLSA and CTM are given in Table 3.1.

Table 3.1: Topic modeling algorithms characteristics and limitations

Algorithm	Characteristics	Limitations
LDA	• In the given text, all stop words are removed manually. • After the LDA implementation, the topic relations can't be represented.	• It is challenging to model relations between topics that can be resolved by the CTM method.
LSA	• LSA is the syntactic algorithm and gets a topic from the synonyms of clustered words. • Statistically, LSA is not a robust algorithm.	• In LSA, it is tough to get the topic and to finalize the count of topics. • It is challenging to execute on a large dataset and to interpret the loading values through probability.
PLSA	• PLSA works on the polysemy phenomena. • Topic-wise 'n' numbers of words are generated in a document. So, from one document topic-based, multiple words can be generated.	• PLSA is not as good as a probabilistic model at the document level.
CTM	• In CTM, the logistic normal distribution is used to form the relation amongst topics. • Existences of the same words in different topics and different topic graphs are acceptable.	• More calculations are required in CTM • Various general words are available on selected topics.

3.1 LSA

LSA is an unsupervised learning technique in NLP. In 1990, Scott Deerwester et al. had patented an LSA based informational retrieval technique named as Latent Semantic Indexing (LSI) [115]. The process of LSA is explained below [116].

Generating document-term matrix: Basically, the LSA used the bag-of-word model. In LSA, a document is represented as a word vector. Each document vector is compared with another document vector. The vector contains all the related terms that occurred in the document. The matrix of terms and the document is generated ($A = m * n$), where 'm' is the number of terms and 'n' is the number of documents. Terms are rows and documents are columns in the matrix. 'n' spars vectors were generated for 'm' documents. A bag-of-word was created for every document, which represents the number of occurrences of a word in a document.

TF-IDF (Term Frequency-Inverse Document frequency): TF-IDF represents the relation of two statistics (i) term frequency (ii) document frequency. It represents the rank of a term in the document / corpus. TF-IDF is the utmost accepted term-weighting scheme for text mining. In TF-IDF weight $W_{i,j}$ is assigned to each i_{th} term as it appears in the j_{th} document with respect to the total number of terms in the j_{th} document. The weight of i_{th} term is counterbalanced (offset) with the number of documents having i_{th} term. The equation 3.1 represents the TF-IDF weight assignment matrix.

$$W_{ij} = tf_{ij} * \log\left({N}/{df_j}\right)$$

Equation 3.1

Dimensionality Reduction: After generating the document-term matrix A, many redundant and noisy terms were observed. These terms may mislead to select latent topics to create the relationship between the terms and documents. To avoid the mislead dimensionality reduction is performed of matrix A by using singular vector decomposition.

Singular Vector Decomposition (SVD): SVD is a linear algebra technique, used for dimensionality reduction. Matrix M is factorized in three different matrices $M = U\sum V'$. Where $U = m \times n$ and $V = m \times n$ are left and right singular matrices respectively. $\sum = n \times n$ is a diagonal matrix of real numbers (non-negative). To reduce the dimension / noise, the largest singular values (let it be 't') are selected and keep only that number of columns in matrices U and V. These columns were used to select the number of topics. Dimensionality reduction is shown in Fig. 3.3.

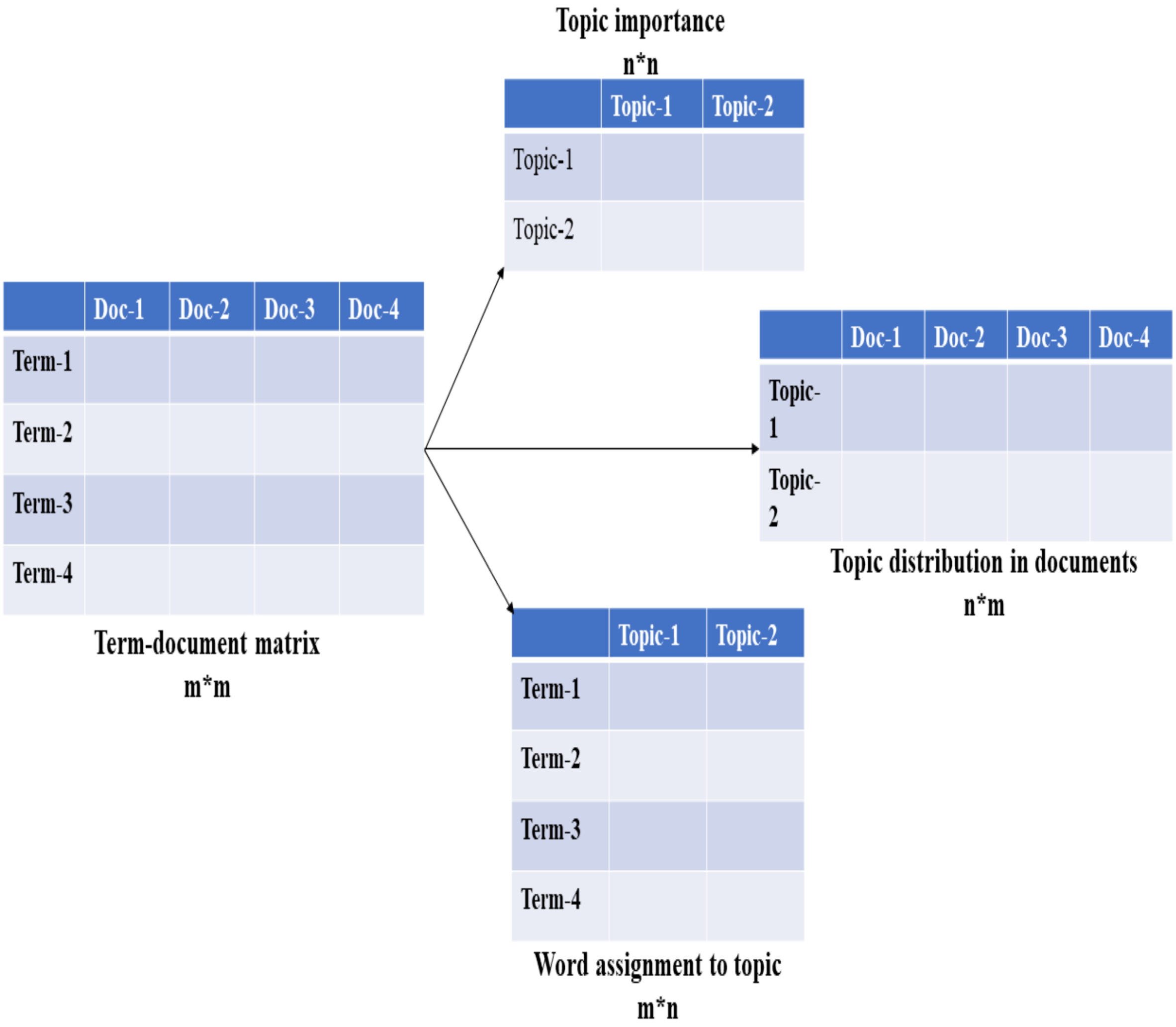


Figure 3.3: Dimensionality reduction

To promulgate the prominent research trends and challenges in WBSN, a semi-automatic research algorithm was applied. LSA is a previously well-grounded and unquestionable machine learning algorithm to infer the contextual relation of words within a domain database. LSA was used to eradicate human bias because it is a mathematical technique to figure out the topic solution with the help of textual meaning. For LSA application, an extensive database of WBSN related articles' text files were prepared.

3.2 Database Preparation

A manual intensive online search was made to create a database of WBSN for LSA. The ***inclusion rubrics*** defined for database creation are:

- The research article published since 2004 was included in the database.
- The article must be published with reputed publication houses like mdpi, Elsevier, IOP Science, PubMed Central, Springer, ACM DL, IEEE and so on.
- The research articles must be centrally focused on WBSN or its applications.

First of all, 1513 research articles were found by using keywords wireless body sensor network, WBSN, body sensor network, BSN, Wireless body area network, WBAN, BAN healthcare and so on. After applying the filter duplicate and non-focused articles, 273 and 313 respectively were abolished from the initially searched WBSN database. Finally, 927 research articles were included in the WBSN database. Finally, LSA was applied to the database of WBSN articles that lies in the bracket of inclusion rubrics. Export filter was used to convert the database in Comma Separated Values (CSV). The export files contain the articles' title, authors, year and the abstract. LSA was applied to the WBSN corpus to find the latest trends and the challenges still faced by the research community in this domain.

3.3 LSA implementation

LSA consists of multiple phases such that Pre-processing, term filtering, Term Frequency-Inverse Document Frequency (TF-IDF), Singular Vector Decomposition (SVD). Dimensionality reduction for optimal topic label selection, selecting threshold values for topic label solutions, topic labeling [117]–[120]. The steps followed in LSA algorithm implementation are given below:

Step 1: Pre-processing and term filtering

	[from corpus a dictionary (bag-of-words) was created] [121]
11	Tokenize the title and abstract of each article in the corpus
12	Convert in lowercase to each token.
13	Eliminate punctuations (comma, dot, quotes, colon, a hyphen, question marks and so on)
14	Eliminate English stop words (Python NLTK library)
15	Eliminate common keywords (WBSN, BSN, WBAN, BAN, IoT, cloud)
16	Filter out the words < 3 characters
17	Words appearing once was removed
Step 2:	***TF-IDF (identify the significant of an entity (term / document)***
21	$tf = \frac{frequency\ of\ a\ term\ in\ a\ document}{sum\ of\ total\ terms\ in\ document}$ (term frequency) [113], [122]
22	$W_{i,j} = tf_{ij} * \log_2 \left({n_d}/{df_i} \right)$ (weighted matrix from n_d document corpus) [123], [124]
Step 3:	***Singular vector decomposition (SVD)*** [125], [126]
31	$XX^T = (U\Sigma V^T)(U\Sigma V^T)^T = (U\Sigma V^T)(V^{T^T}\Sigma^T U^T) = U\Sigma V^T V\Sigma^T U^T = U\Sigma\Sigma^T U^T$ (term loading values for the topic)
32	$X^T X = (U\Sigma V^T)^T(U\Sigma V^T) = \left(V^{T^T}\Sigma^T U^T\right)(U\Sigma V^T) = V\Sigma^T U^T U\Sigma V^T = V\Sigma^T\Sigma V^T$ (document loading values for the topic)
Step 4:	***Dimensionality reduction for optimal topic label selection*** ***(Find prominent trending areas)***
41	Select the top one hundred topics (optimal value for 1000 documents)
42	Set threshold 0.227
Step 5:	***Find core research areas***
51	Select three, five and ten topic solutions
52	For three topic solution set thresholds 0.263
53	For five topic solution set thresholds 0.248
54	For ten topic solution set thresholds 0.229

Step 6:	***Topic labeling***
61	Sort the term loading and document loading values in descending order
62	The group with the highly loading values based on occurrences and weightage
63	Label each topic manually

After the implementation of LSA three, five and ten topic solutions were extracted as the prominent research trends of WBSN. The topic solutions represented as $Ts_{i.j}$, where i represent topic and the j represents the factor of respective topic solution. For instance, $Ts_{5.3}$ means the third factor of five topic solution. All the topic solutions were manually labeled by considering the highly loaded bag-of-words. Table 3.2 states the topic solutions.

Table 3.2: Three, five and ten topics solutions

Ts	**Topic solution label**
$Ts_{3.1}$	Recording of biophysical parameters
$Ts_{3.2}$	WBSN driven smart healthcare solutions
$Ts_{3.3}$	Collaborative WBSN models
$Ts_{5.1}$	Recording of biophysical parameters
$Ts_{5.2}$	Cloud and IoT enabled WBSN services
$Ts_{5.3}$	WBSN driven smart healthcare solutions
$Ts_{5.4}$	Resource management with WBSN
$Ts_{5.5}$	Communicating biophysical parameters
$Ts_{10.1}$	Recording of biophysical parameters
$Ts_{10.2}$	WBSN driven smart healthcare solution
$Ts_{10.3}$	Cloud and IoT enabled WBSN services
$Ts_{10.4}$	Resource management with WBSN
$Ts_{10.5}$	WBSN networking and routing protocols
$Ts_{10.6}$	Communicating biophysical parameters
$Ts_{10.7}$	Big data storage and analysis using machine learning
$Ts_{10.8}$	WBSN data and feature extraction

$Ts_{10.9}$	Fog layer implantation in WBSN
$Ts_{10.10}$	Collaborative WBSN models

T_S: Topic solution

3.4 Core Research Areas of WBSN

Ten, five and three topic solutions exhibit by LSA had given the core research areas for WBSN. “Recording of biophysical parameters,” “WBSN driven smart healthcare solutions” and “Collaborative WBSN models” were spin-off as $Ts_{3.1}$, $Ts_{3.2}$ and $Ts_{3.3}$, respectively. “Recording of biophysical parameters” topic solution also appeared as a prime factor in five and ten topic solutions. “WBSN driven smart healthcare solutions” arisen as a third and second factor in three and five topic solutions, respectively. All three topics emphasize the expansion of body sensor networks in healthcare. WBSN data recording and collaborative designing are the essential and challenging part of the wireless body network designing. “Cloud and IoT enable WBSN services,” ($Ts_{5.2}$) “Resource management with WBSN” ($Ts_{5.4}$) and “Communicating biophysical parameters” ($Ts_{5.5}$) were three new core research areas unveiled in five topic solutions. Both domains are interlinked. Effectively managing the resources of WBSN and communicating the recorded data in WBSN are significant challenges. The choice of communication protocols for WBSN plays a substantial role in the effectiveness of the system [128], [129]. “WBSN networking and routing protocols” and “WBSN data and feature extraction” were labeled as a fifth and eighth factor in ten topic solution. Researchers have tried to implement various established network topologies and communication protocols [130], [131] for the WBSN applications development. The evolution of WBSN and its applications in multiple domains were found valuable to control the things / objects remotely [29]. Researchers frequently explored the WBSN communication protocols, data security and privacy credentials [132]–[134]. “Fog layer implementation in WBSN” and “Big data storage and analysis using machine learning” were also seen as the latest areas of research in ten topic solutions. The detail discussion on core research areas, along with associated prominent research trends is given in the forthcoming sections.

3.5 Prominent Research Trends

The hundred topic solutions provide prominent research trends in the field of WBSN. Threshold 0.227 was applied to find the research trends along with the highly loading articles. Hundred topic solutions and the number of highly loading articles associated with these topics are given in Table 3.3. “Collaborative model of cloud, IoT and BSN” was the most rifled trend in the 100-topic solutions and remained constant with 10, 5 and 3 topic solutions. “WBSN healthcare applications” was appeared as the second highly loading article. The articles loaded under this trend revel the researchers interest in different fields [48], [131] like Parkinson's disease detection [135], elderly care [136], specially-abled persons, human activity recognition [25], [137], ECG data monitoring [20], [138] and many more. WBSN based healthcare systems were divided into two categories, preventive and responsive systems [139]. WBSN well supports preventive healthcare systems for the early detection of the causes of diseases or preventable deaths, for instance, pre heart attack detection [140], physical activity recognition and recommendations [68]. An example of responsive healthcare systems are ICU patient monitoring system [73]. The research trend “WBSN mobility support” was stated in thirty-one articles that focused on wearable multi-body sensor network for modern ubiquitous healthcare systems like physical activity monitoring and advisory systems [26], [58], [93], [141]. The latest trend of “Mobile health app” was open up as an exciting area. An android application was designed for the graphical representation of the human movement by collecting accelerometer and gyroscope data [142]. “Cloud-based healthcare framework” focused on the secured transmission of medical data and the cloud architecture of medical sensor networks [76]. An ultra-low-power substitution-box architecture with the amalgamation of programmable cellular automata and advanced encryption standard was designed for WBSN application data security [143]. An ontology-based architecture for health monitoring was designed for chronic patients and recommended routine workout exercises [82]. WBSN based detection of heart attack system previously was designed by recording the blood pressure, temperature, ECG signal and humidity of the human body [140]. The “IoT enabled wireless body sensor network” trend uncovered that the blending of the IoT with BSN can generate efficient WBSN [93]. Wearable Wireless Body Sensor Network (WWBSN) was used as a backbone to provide regular or ambulatory health monitoring [14]. Clustering-based WBSN system was designed to tell the highly probable diseases in the future by using the recorded physiological parameters [133]. [39], [87], [144] deal with the “Security issues in WBSN”, another trend in the context of the sensitivity of the medical data. [145] focused on private health data, end-to-end security, authentication and authorization. Mobile based security algorithm for m-health was designed. The “Cloud assisted BSN” research trends revealed the use of outhouse secure data storage [23]. The d-dimension model based M2M context storage solution was proposed to enhance the utility of things and entities in IoT to increase scalability, performance and efficiency of the system [51]. The “Cloud computing,” “BSN recorded big data storage,” “Big data analytics” and “Fog computing” came into sight as new trends in WBSN [23], [67]. WBSN creates a considerable amount of health data to evaluate the health status of the patient [26]. To handle such enormous data, one must take care of significant data management policies [146]. Few researchers used the Hadoop platform for big data analytics [84], [87]. IEEE 802.15.4 and IEEE 802.15.6 lightweight networking protocols are used in WBSN [147]. Some researchers had worked on the quality of services based routing protocols and data security [134], [148]. Another emerging research area revealed in WBSN was “Smart health monitoring.” It was expected that smart health services would upgrade the quality of health and decrease the risk of human life loss [18]. The extravagant medication, nuclear families and the extensiveness of chronic ailments everywhere in the world immediately demand the revolutionary changes of current healthcare systems from a centralized hospital system to a personal care system, by focusing on city residents’ disease management in addition to their welfare [13], [71].

Table 3.3: Hundred topic solutions

Ts	**Topic solution label**	**Highly loading articles (since 2004)**
$Ts_{100.1}$	Collaborative model of cloud, IoT and BSN	213
$Ts_{100.2}$	WBSN healthcare applications	103
$Ts_{100.3}$	WBSN mobility support	31
$Ts_{100.4}$	WBSN data security	22
$Ts_{100.5}$	Cloud assisted BSN	29
$Ts_{100.6}$	Platform independent WBSN data	15
$Ts_{100.7}$	Heterogeneous WBSN data	4
$Ts_{100.8}$	Multi-sensor data fusion	6
$Ts_{100.9}$	IoT based BSN	10
$Ts_{100.10}$	WBSN deployment models	8
$Ts_{100.11}$	IoT enabled wireless body sensor network	13
$Ts_{100.12}$	ECG data from sensor network	4
$Ts_{100.13}$	Pick and shovel of respiratory data	1
$Ts_{100.14}$	Human activity strenuous	6
$Ts_{100.15}$	MEMS based BSN	2
$Ts_{100.16}$	Data analytics for BSN data	7
$Ts_{100.17}$	Security issues in WBSN	13
$Ts_{100.18}$	Authentication of WBSN data	11
$Ts_{100.19}$	Authenticated WBSN data	3
$Ts_{100.20}$	IoT enabled BSN data	15
$Ts_{100.21}$	Standardization of BSN data	23
$Ts_{100.22}$	IoT and cloud in sports	4
$Ts_{100.23}$	Authentication of data access	7
$Ts_{100.24}$	Data losses issues	5
$Ts_{100.25}$	Latency issues during data transmission	4
$Ts_{100.26}$	Cloud configuration	6

$Ts_{100.27}$	Cloud computing	8
$Ts_{100.28}$	Parameter setting of BSN data	2
$Ts_{100.29}$	BSN recorded big data storage	9
$Ts_{100.30}$	Fog computing	7
$Ts_{100.31}$	Big data analytics	5
$Ts_{100.32}$	Telemonitoring healthcare system	8
$Ts_{100.33}$	Cloud-based healthcare framework	13
$Ts_{100.34}$	Patient’s BSN data privacy	4
$Ts_{100.35}$	Mobility aware healthcare system	3
$Ts_{100.36}$	Communication protocols for WBSN data	8
$Ts_{100.37}$	Security attacks in wireless medical sensor network	7
$Ts_{100.38}$	Automatic healthcare system	8
$Ts_{100.39}$	Elderly e-health diagnosis	4
$Ts_{100.40}$	Challenges in existing healthcare systems	7
$Ts_{100.41}$	Sharing of medical sensor data	3
$Ts_{100.42}$	Privacy of personal health data	3
$Ts_{100.43}$	Energy efficient WBSN	1
$Ts_{100.44}$	Configuring WBSN according to IEEE 802.15.6	2
$Ts_{100.45}$	6LowPAN	3
$Ts_{100.46}$	Networking and routing protocols of BSN	7
$Ts_{100.47}$	Power management of WBSN	3
$Ts_{100.48}$	M-health monitoring system	1
$Ts_{100.49}$	Collaborative techniques for BSN / health data	3
$Ts_{100.50}$	Configuring of WBSN	2
$Ts_{100.51}$	E-supervising of human lifestyle	3
$Ts_{100.52}$	Low power communication media for WBSN	2
$Ts_{100.53}$	Light weight communication protocols for WBSN	3
$Ts_{100.54}$	Collaborative computing	1
$Ts_{100.55}$	Multi sensor data fusion	4

$Ts_{100.56}$	Big data storage	5
$Ts_{100.57}$	Machine learning in BSN	3
$Ts_{100.58}$	Continuously updating real-time data flows	2
$Ts_{100.59}$	Biophysical monitoring	3
$Ts_{100.60}$	WBSN pathloss	7
$Ts_{100.61}$	Power consumption and analysis of bio sensors	1
$Ts_{100.62}$	Evolution in smart healthcare system	3
$Ts_{100.63}$	Accuracy during biophysical data recoding	4
$Ts_{100.64}$	Categorization of BSN	5
$Ts_{100.65}$	Wearable WBSN based health monitoring system	7
$Ts_{100.66}$	Multibody sensor framework	2
$Ts_{100.67}$	Synchronous and asynchronous WBSN	2
$Ts_{100.68}$	WBSN stability period	5
$Ts_{100.69}$	Cloud-based data processing brokers	2
$Ts_{100.70}$	Ubiquitous healthcare applications	3
$Ts_{100.71}$	WBSN based pervasive healthcare monitoring	6
$Ts_{100.72}$	Wearable and multimodal interface for health monitoring	7
$Ts_{100.73}$	Traffic management in WBSN	2
$Ts_{100.74}$	WBSN lifetime	3
$Ts_{100.75}$	Transmission media of WBSN	2
$Ts_{100.76}$	Scalable storage space	3
$Ts_{100.77}$	Unobstructed BSN	1
$Ts_{100.78}$	Invasive biosensors	4
$Ts_{100.79}$	Pervasive biosensors	4
$Ts_{100.80}$	Routing and energy balancing of WBSN	2
$Ts_{100.81}$	Scheduling algorithms	8
$Ts_{100.82}$	Channel routing and characterization of WBSN communications	1
$Ts_{100.83}$	Intelligent hospitals	1

$Ts_{100.84}$	Cloud platforms	18
$Ts_{100.85}$	Classification of BSN data	6
$Ts_{100.86}$	Smart health monitoring	21
$Ts_{100.87}$	End-to-end security systems	7
$Ts_{100.88}$	Collaborative IoT personal health devices	7
$Ts_{100.89}$	Data sharing and accessing policies	11
$Ts_{100.90}$	Patient medication tracking system	9
$Ts_{100.91}$	WBSN QoS-based routing protocols	8
$Ts_{100.92}$	Bio chip platforms	3
$Ts_{100.93}$	Remote health monitoring	12
$Ts_{100.94}$	Sensor node calibrations and placement	2
$Ts_{100.95}$	Antenna design	2
$Ts_{100.96}$	Energy harvesting	3
$Ts_{100.97}$	Human body vital sign detection	2
$Ts_{100.98}$	Hadoop implementation	4
$Ts_{100.99}$	Mobile health apps	12
$Ts_{100.100}$	Bio-informatics	3

T_S: Topic solution

3.6 Correlation of Core Research Areas and Research Trends

After analyzing the documents loading frequency, a manual correlation was established in research trends and core research areas [117], [149], [150]. The detailed mapping process of research trends and core research areas presented in the following sections.

3.6.1 Recording of biophysical parameters

The recording of the biophysical parameters of a human / animal is a vigorous task. It is a mandatory and prime task for every WBSN application. The accuracy of the system depends on the accuracy of the recorded parameters. In turn, the accuracy of recorded parameters depends on three factors: i) type of sensors used ii) the placement (position) of the sensor on the body iii) skills. According to the result's data, out of hundred topic solutions, thirty-three research trends were associated with this core research area. The research topics “configuring of WBSN” [43], [77], “multi-sensor data fusion” [34], [111], “sensor node calibration and placement” [92], “energy efficient WBSN” [60], “energy harvesting” [151], [152] revealed the methods to be adopted while data recording and also shown the necessity of the accuracy of parameters. All the related trends with “Recording of biophysical parameters” are shown in Fig. 3.4.

3.6.2 Cloud and IoT enabled WBSN services

The results of hundred topic solutions indicate that twenty-one research trends from WBSN majorly give the impression of the core research area, “cloud and IoT enabled WBSN services”. Fig. 3.5 shows all trending areas associated with the cloud and IoT enabled WBSN services. The research trends “collaborative model of cloud, IoT and WBSN” [7], [54], [86],”cloud assisted BSN” [44], [67], “IoT based WBSN” [88],[35], “IoT enabled wireless body sensor network” [153],[154], “IoT enabled BSN data” [67], [82], [98],[151], “BSN recorded big data storage” [156], “Fog computing” [85], “big data analytics” [146], “cloud-based healthcare framework” [76] show how the complement features of cloud and IoT enhance the capabilities of each other and used to implement body sensor networks for health monitoring systems and other applications. Huge data generated by body sensor networks communicated through IoT and stored on the cloud for later use or analytics [146].

3.6.3 BSN driven smart healthcare solutions

Fig. 3.6 shows the relation between “WBSN driven smart healthcare solutions” and the trending areas aroused in a hundred topic solutions. “WBSN healthcare applications” [157] focus on pervasive healthcare systems. Research community broadly divided BSN based healthcare in 5 domains: pediatric (Medicare or illness of children) management, Remote health monitoring, Private health and fitness management, Chronic disease supervision and elderly care. “Telemonitoring healthcare system” and “elderly e-health diagnosis” was implemented to monitor the biophysical parameters of elderly or chronical patients without the help of any caretaker or clinical staff [67], [136]. “Intelligent hospitals” [17], “smart health monitoring” [13], [93] and real-time fall detection system were mainly focused areas in healthcare applications [99], [158]. “Remote health monitoring” [48], [103], [159] “WBSN mobility support” [18], [160] has attracted the researchers [48], [84]. The amalgamation of the features of IoT and cloud with light-weight BSN networking protocols has paved a traditional medication system to a new era, which provides mobility to the patient [88], [161]. Personal health data were observed and controlled remotely to provide safety and comfort to society [162]. The pioneers suggested putting more efforts to secure the vital health data [45], [145].

3.6.4 Resource management with BSN

Resource management with BSN is as essential as the recording of biophysical parameters. The research trends associated with the “Research management with BSN” are shown in Fig. 3.7. The efficiency of the WBSN system is directly related to the efficient use of all the resource e.g. battery, networking scheme and protocols, communication methodology (security algorithms, data losses) and so on. The research trends “data sharing and accessing policies” [87], [159], “BSN data security” [39], [88], [163] are linked with this class. [161] implemented “Datagram Transport Layer Security” (DTLS) based on certificate authentication. Handshaking or acknowledgment approval from smart gateways to end-users or vice-versa were applied for session continuation or resumption technology on hardware and software. “Security issues in BSN” [163], “data losses issues” and “latency issues during data transmission” were tried to resolve by OMNET++5 [46]. Mobile healthcare data transfer security algorithm and data log security app was also designed.

3.6.5 Communicating biophysical parameters

In the performance of BSN applications, a significant role has been played by the communication of biophysical parameters. Fig. 3.8 shows the research trends associated with "communicating biophysical parameters". IEEE networking protocols 802.15.4, 802.15.6, WiFi and Bluetooth majorly use for communicating BSN data [128], [134]. "Networking routing protocols of BSN" [31], [56], "low power communication media for WBSN" [17], [43], [164], "light weight communication protocols for WBSN" [165] the research trends in this core research area provide awareness and importance about the communication technologies. As we know, health data privacy is the fundamental right of a person. Data privacy, while communicating biophysical parameters, is essential. [87] classify the existing privacy protection into three groups: privacy by statistics, privacy by cryptography or privacy by policy. Different cryptography approaches were applied by the number of researchers for WBSN data privacy. This technique smartly integrated with statistical analysis by the authors to offer multiple standards balancing within privacy protection and medical data utilization. "Authentication of WBSN data" [166] and "Authentication of data access" [167] are still in its infancy stage. To prevent the privacy of patient's health data, a four-party security model has been generated with the integration of encryption and digital signature technique [168].

The results of the study demonstrate that "cloud and IoT enabled BSN services" and "BSN driven healthcare solutions" have been the utmost explored topic solution label within BSN research. BSN data integrity and quality are the areas of consideration due to the heterogenous BSN sensors. Every BSN application is mandatory to bind with the topic solution label "Recording of biophysical parameters". Few researchers [169] worked on BSN data recording and collection algorithms to maintain the quality of the collected data and reduce the power consumption of the network. Some researchers also compressed the sensed signal to save energy [170]. Trust management [171] and data integrity [88] are two main unveiled topic solution labels in BSN. Collaborative model of cloud, IoT and BSN [17], [100], [111], [172]–[175], WBSN healthcare applications are widely investigated by researchers [76], [144], [176]–[178]. Some researchers developed domain-specific health and sports activity monitoring kits with WBSN [179]–[183] and contributed to the BSN research pool. Other research areas explored by researchers are mobile-healthcare [104], [158], [184]–[187], e-healthcare [84], [93] BSN data security [188]–[192] and privacy [44], [104], [167], [192]–[195].

3.7 Recommended research areas

LSA results divulged that WBSN has undeniably increased thrust in the last decade. As the new era technologies "Cloud computing" launched in 2006 [23] and "IoT" launched in 2009 [50]. After the evolution of these two technologies, researchers started working on the integration of WBSN with cloud and IoT [54] to create wireless body sensor network applications [57]. "Cloud and IoT based body sensor network" persisted as a trending area throughout the total time and is closely-fitted with WBSN [20], [29], [43], [196]. Different types of body sensors are available in the market for diverse application areas. All these sensors provide heterogeneous [34] data that is still a challenge to handle for the research community. Communication protocols [47],[171] and power management [129], [169] are the areas of consideration for future. After the rigorous study; It was figured out that BSN or WBSN are growing in demand.

Few recommended research areas for future researchers are:

- Collection of BSN data, data consistency, communication and storage need more attention.
- To design robust models to confirm the reliability and quality of collected BSN data.
- Identify empirical fundamental quality measures for the valuation of BSN data and develop a framework for data quality validation for different applications of BSN.
- Trust management of BSN data.
- The integrity of BSN data.

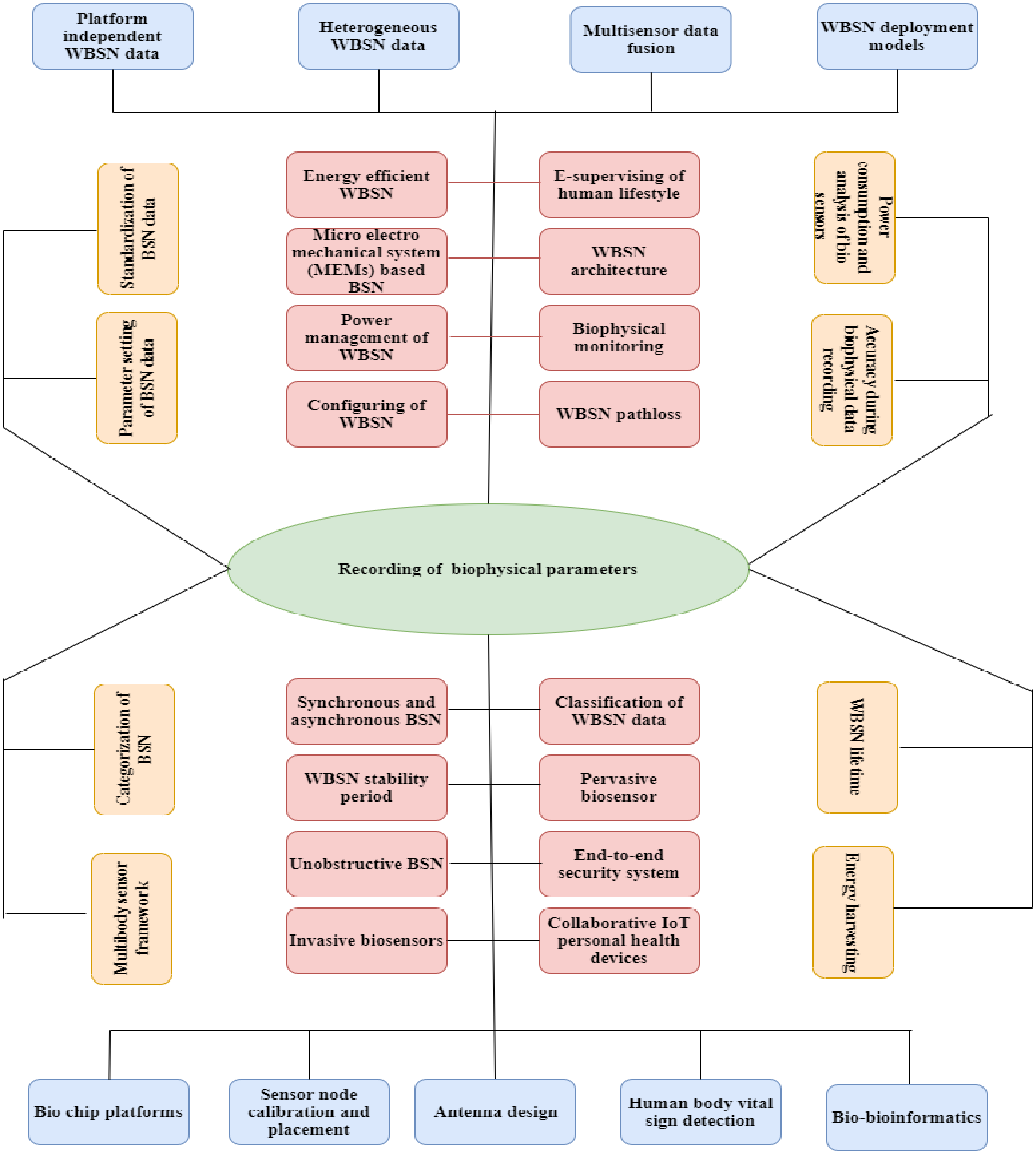


Figure 3.4: Research trends associated with the recording of biophysical parameters

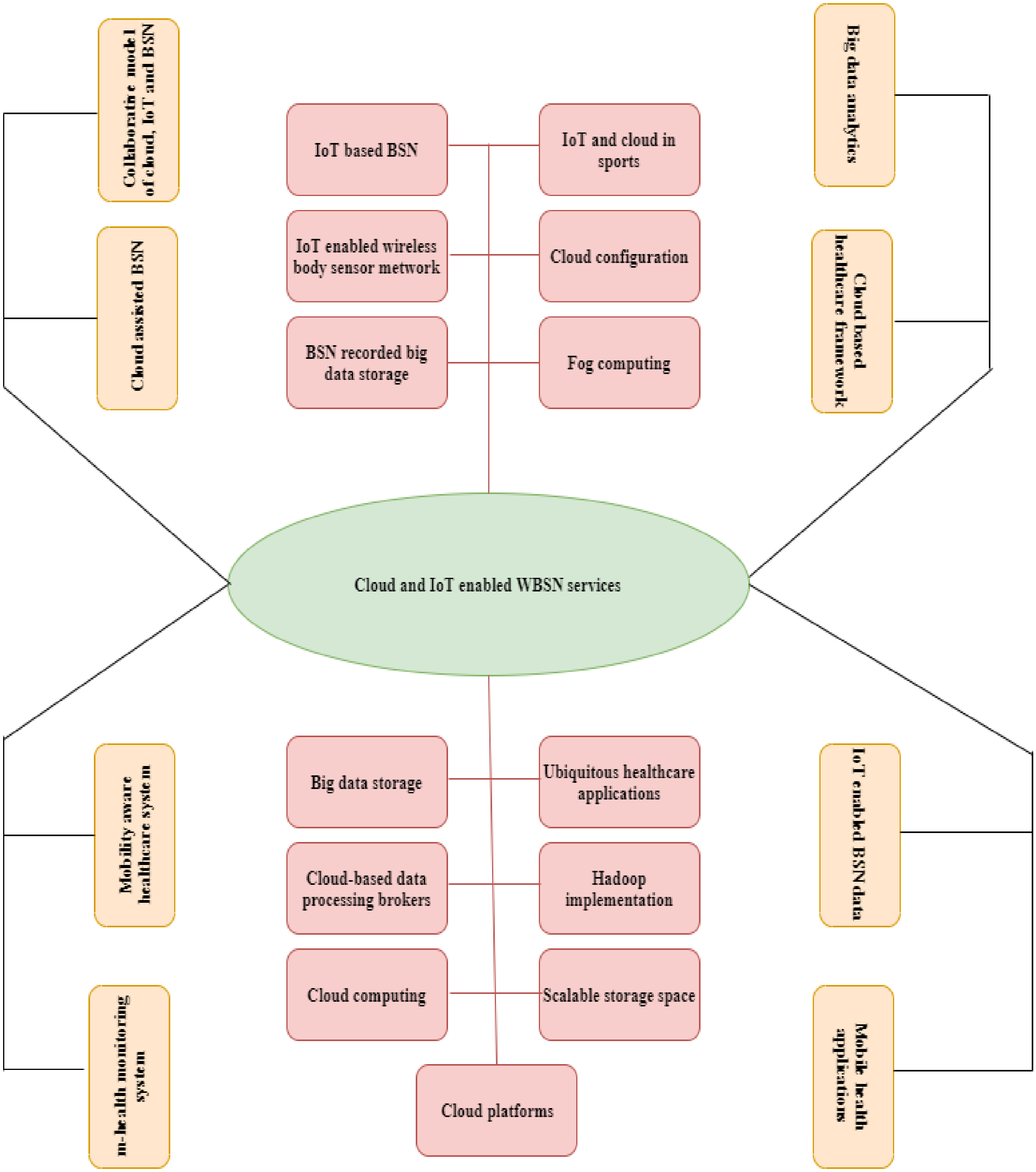


Figure 3.5: Research trends associated with cloud and IoT enabled WBSN services

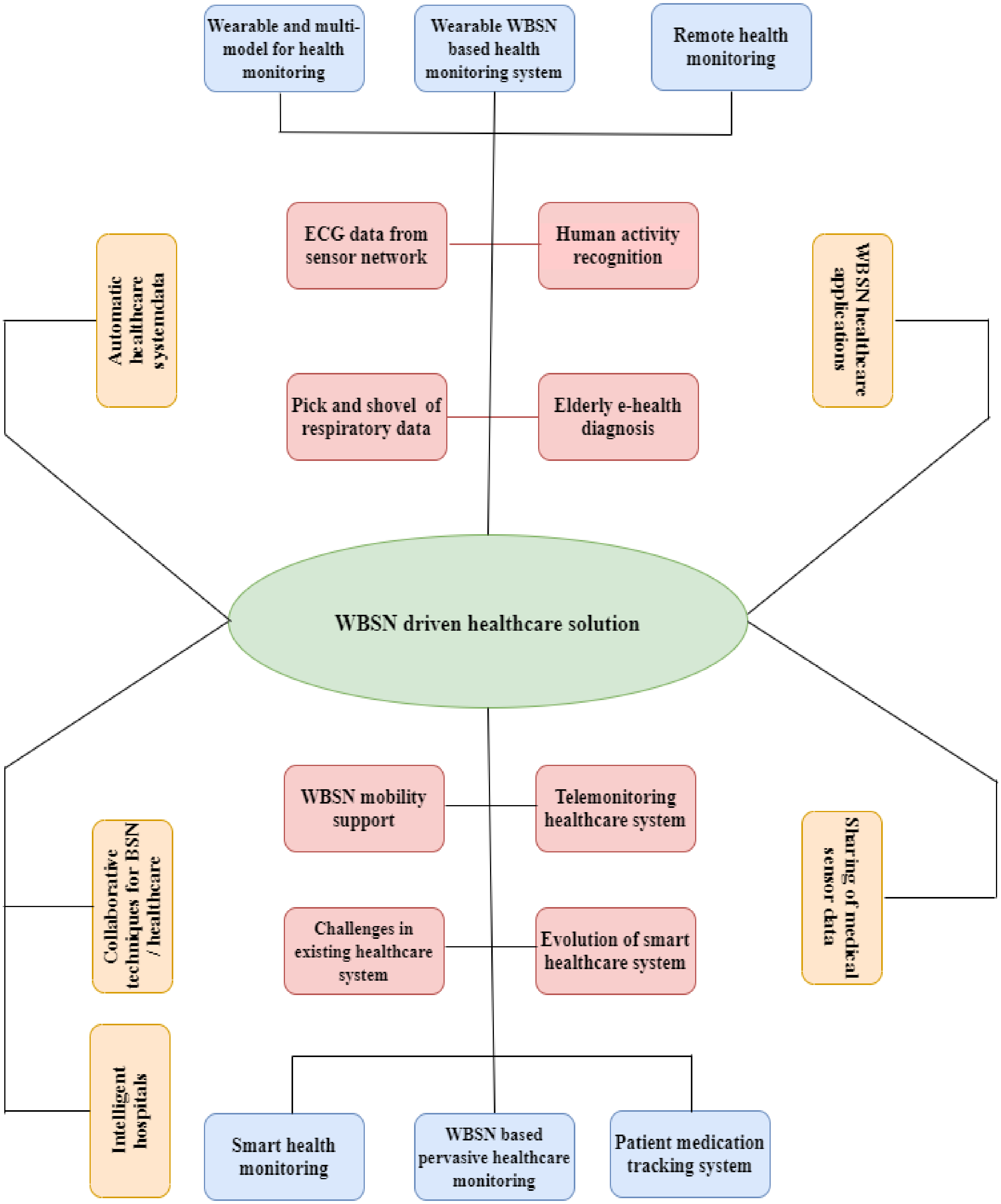


Figure 3.6: Research trends associated with WBSN driven smart healthcare solutions

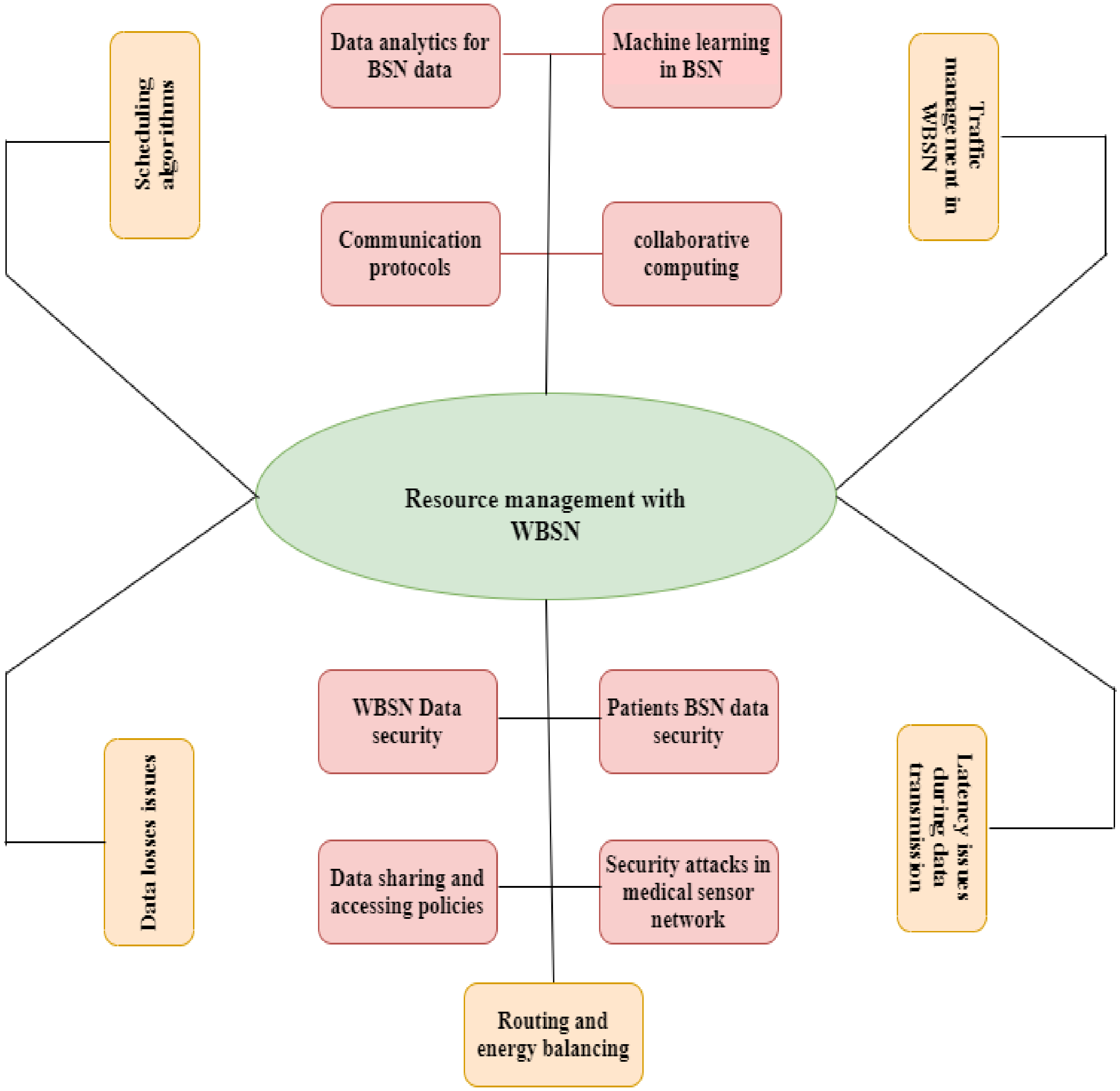


Figure 3.7: Research trends associated with resource management with WBSN

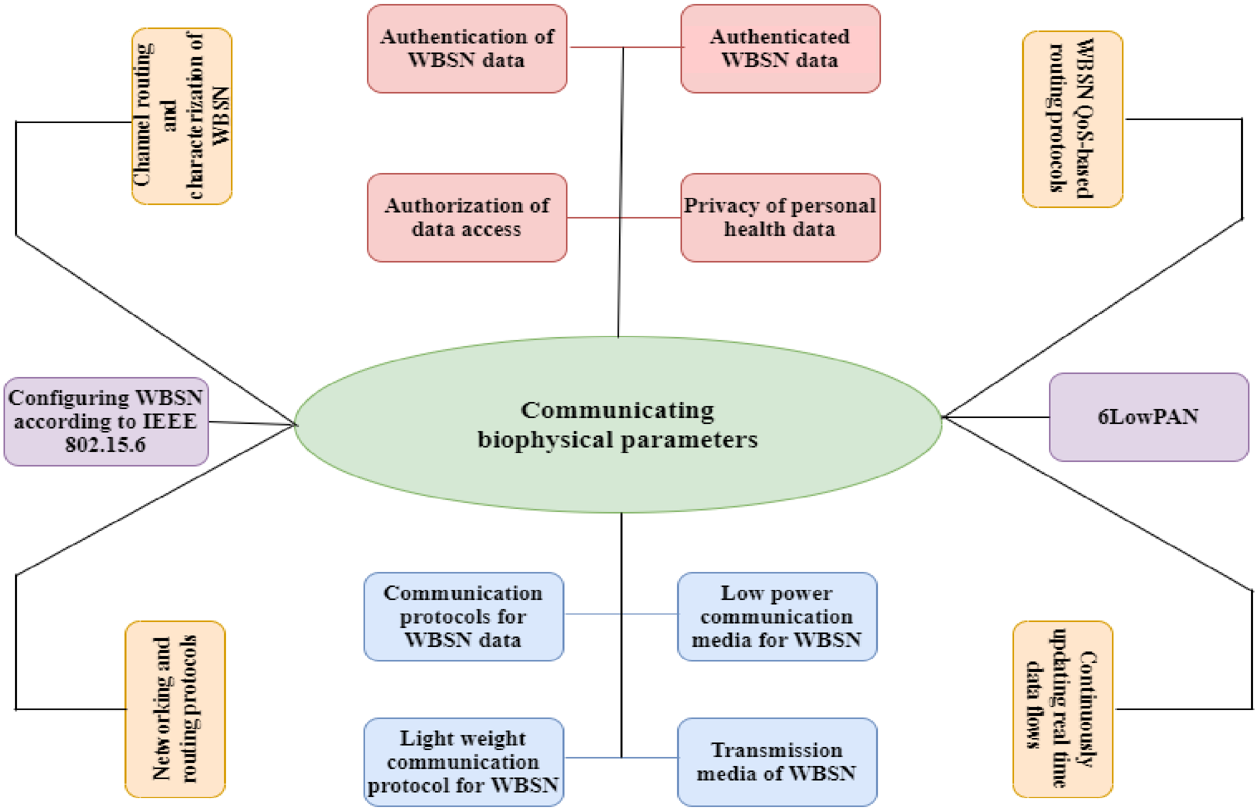


Figure 3.8: Research trends associated with communicating biophysical parameters

3.8 Challenges

After the LSA execution on the WBSN data corpus, the study has divided the WBSN system into four phases “Recording of biophysical parameters,” “Communicating biophysical parameters,” “Resource management with WBSN,” “WBSN driven smart healthcare solutions”. Fig. 3.9 presents the challenges associated with each phase.

Figure 3.9: Challenges in WBSN

Apart from the above mentioned, few more challenges about WBSN were discussed and hashed out in available literature. The results suggest future research should be continued on real-time applications, radio technologies, sensor nodes, physical and MAC layers. The research problems and challenges pertaining to the above set themes are discussed here.

Routing protocols: Routing protocols play a significant role in the energy efficiency and accuracy of the system. It must follow QoS standards like dynamic network adaptability, noise and data packet collision handling and load balancing of the network. Most of the time, the WBSN network time and space change frequently. Even in that case, routing protocols must support guaranteed and timely data delivery. The heat and temperature of the network should remain controlled [9], [105].

MAC layer protocols: Mac layer protocols should be less complicated in hardware as well as processing design. It must support the scalability of the network so that more nodes can be easily added to the system. Mac protocols design must follow the less energy consumption methodologies along with low time synchronization models and reduce the overhearing or idle listening overheads [17].

Physical layer: Radio technologies and the sensor nodes are the main areas of concern in the physical layer of WBSN. The critical parameters associated with the sensor node are energy efficiency, sensitivity and efficient data acquisition. In literature frequently seen, challenges related to radio technologies are the bandwidth and interoperability problem [197].

Sensor nodes: The challenges sticked with sensor nodes are their low power design to increase its lifetime. It would be achieved with a low power processor, fabrication material, transceiver and architecture design of the sensor node. The optimized placement of sensor node and wear-ability are other challenges related to the sensor nodes. These would help to reduce the number of nodes in the network, which in turn avoids redundant data recording and save energy of the system [6].

Radio technology: The term radio technology is interrelated to wireless communication technologies. Channel bandwidth and the data interoperability between WBSN layers are still a challenging task for researchers. WBSN is a collection of heterogeneous sensors and all sensors operate on different frequencies, which may instigate interoperability or channel interference challenges [198].

Chapter 4

WBSN Deployment Framework

WBSN has a wide range of diversified healthcare applications. Prominent application areas include the identification of chronic diseases, elderly care, especially abled persons, wellness and fitness of person or sportsman, cardiovascular diseases, respiratory functioning [175]. WBSN consists of small physiological sensors known as sensing nodes or computing devices, microcontroller (coordinator node), communication protocols (IEEE MAC protocols), Base Station (BS) and Main Server (MS). The sensing nodes are wearable, very lightweight, power-efficient but have limited memory. The sensing nodes continuously record the vital physiological parameters and send them to the Coordinator Node (CN). CN sends the data to BS or MS for storage and analytics. CN uses very lightweight, energy-efficient MAC protocols for communication [105]. IEEE has designed a lightweight protocol for the MAC layer and physical layer communication. IEEE 802.15.1 (Bluetooth communication standards), IEEE 802.15.4 (ZigBee communication standards), IEEE 802.15.6 (BAN) and IEEE 802.11 (WiFi) are the most commonly used communication protocols in WBSN. Table 4.1 exhibits the detailed characteristics of IEEE wireless communication protocols. MAC protocols are typically used for WBSN internal / external communication to transmit the recorded data from CN to BS or CN to MS or BS to MS.

Table 4.1: Characteristics of wireless communication protocols

Wireless Protocols	IEEE 802.11	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.15.6
Conventions	WiFi	Bluetooth / (BLE 4.0)	ZigBee	BAN
Data Rates	54Mbps	3Mbps	250Kbps	40 – 400Kbps

Superframe Time	138µs/1s	1s	2s	----
Range	120m	77m	291m	1.2 m
Bandwidth	2.4GHz	2.4GHz	868/915 MHz/ 2.4 GHz	-----
Tx energy	-------	~10µW	30mW	0.1µW
Deployed	MAC layer and network layer	Physical and MAC layer	Physical and MAC layer	Physical and MAC layer

The ubiquitous and pervasive healthcare solutions allow monitoring patients' health status anywhere and anytime in an invasive or non-invasive way. Due to the diversity of healthcare applications, WBSN based healthcare systems framework / architecture must be in harmony with the target application. The variations in the framework design of WBSN depend upon the ubiquity level, communication technologies used and the aimed healthcare scenario. In a survey paper [30] author presented a three-tier communication network, as shown in Fig. 4.1.

Tier 1 (intra-BSN):

In tier one, the communication happened between biosensors and the sink node [199]. The mode of communication can be wireless or wired. Tier 1 peripheral was approximately two meters and the communication technologies used in it were Bluetooth or Zigbee [153]. The sensors sense the physiological data and sent it to the sink node to log, process and transmit the data to tier 2.

Tier 2 (inter-BSN):

In this tier, the communication network was set up between the sink node and the access point (one or multiple). The access points were adaptive to the dynamic environment to handle emergency conditions. Tier two provides interconnectivity among the different accessible networks like sink node to laptop or mobile phone.

Broadband cellular networks (3G or 4G), WLAN, Bluetooth or Zigbee were used in this tier [70].

Tier 3 (beyond-BSN):

Tier three connects the biosensors to the external world through internet services or any other communication network. It made health data accessible to doctors for medical investigation, caretaker or patients for timely awareness [200]. The patients / user data was stored in a database that was available for a long time on the cloud or the personal server. WBSN deployment framework consists of network devices, communication protocols and the routing protocols used during its design. The next section elaborates on the general architecture of WBSN.

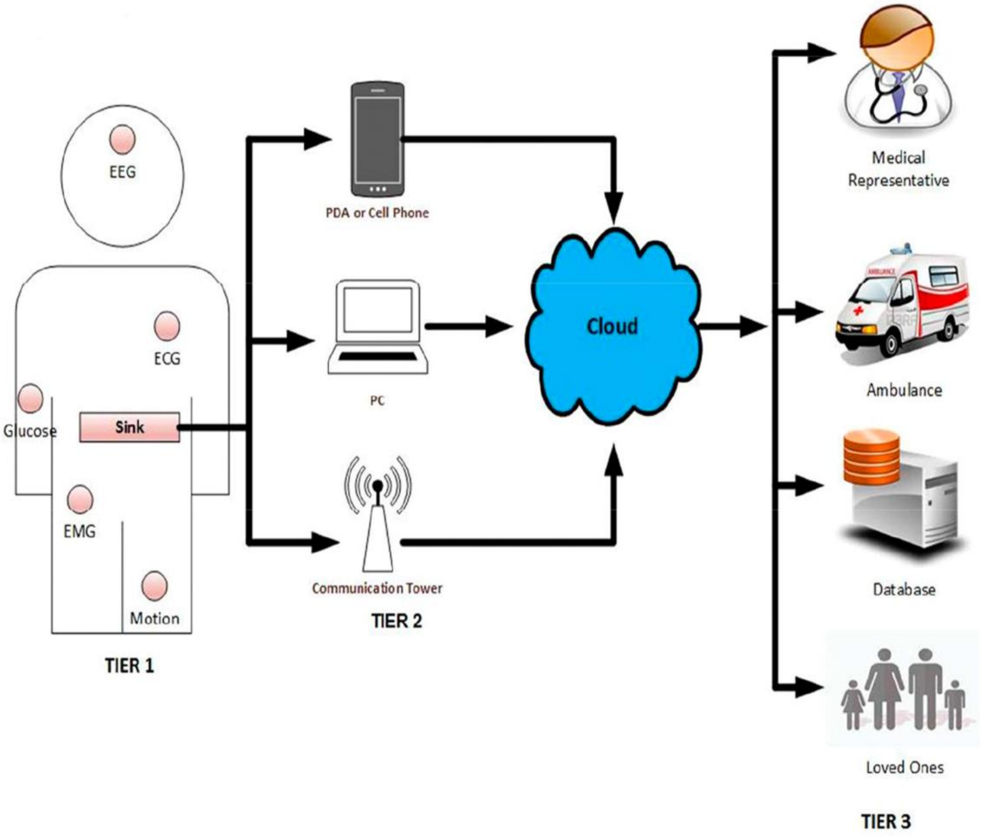


Figure 4.1: Three-tier communication network [32]

4.1 General Architecture of WBSN

The architecture of WBSN broadly divided into two parts, hardware stack and software stack. Each stack consists of two layers [24], [201], [202]. The hardware stack consists of two layers: physical / device layer and network & data acquisition layer. The software stack contains the edge / transport layer and application layer, as shown in Fig. 4.2. Working on the physical and network layer, along with protocols used in both layers, was given in the forthcoming section.

4.1.1 Hardware stack

Physical / Device Layer

Small size, lightweight, low power constrain devices (sensors) forms the physical layer. These devices sense the surrounding environment and record the relevant data. According to the Internet Engineering Task Force (IETF) publication RFC7228, constrained devices can be classified into three classes that shown in Table 4.2 [203], [204]. IEEE 802.15.1 and IEEE 802.15.4 are the protocols used in the physical layer. It is a trade-off low power consumption and long battery life.

Table 4.2: Constrained devices according to IETF (RFC7228)

	Class 0	Class 1	Class 2
RAM (KB)	10(less than)	~10	~50
Flash(KB)	100	~100	~240
Protocols	MQTT, CoAP, EXI	UDP, CoAP, TLS, DTLS, HTTP	All protocol stacks
Cost	Low	Low	High

Sensors can be wearable or implantable and can record continuous or discrete signals. RFID tags and readers, sensor networks, embedded systems or other sensors form the device layer [205]. The physical layer is responsible for primary biophysical data generated by biosensors. RFID tags, Mac or IP address of sensor networks provide identification. Embedded systems collect and store information. Further, the processing, communication of information and actuation control are the responsibilities of embedded systems [42].

Network and data acquisition layer

In the physical layer, all constrained devices are connected over the network with their unique addresses. The communication network ZigBee, BLE, BAN, IPv6, WiFi, 6LoWPAN used in WBSN have their address range [206]. After the data acquisition, the network layer is responsible for analog to digital conversion, measuring of data and data aggregation. The network layer controls the flow of data and valuable data is searched and presented in a required way to the edge / transport layer. The network layer is responsible for publishing, message routing and subscribing, based on the requirement. It can perform cross-platform communication. Data handling and conversion happen in the first stage of this layer [202]. The second stage of the network layer executes processes like data measurement, aggregation and control.

4.1.2 Software stack

Edge / transport layer

The edge / transport layer is the interface between the bottom hardware surface and the top application surface [202]. Many software agents and APIs are used for data processing and analytics. Edge layer is responsible for critical functions, device management, as well as information management. The edge layer has responsibilities of all the issues like filtering and pre-processing of data, access control, analyzing of semantic, the finding of information i.e., Electronic Product Code (EPC), information facility data analytics and Object Naming Service (ONS). Middleware surface works in bidirectional mode [207]. IPv4, IPv6, 6LoWPAN and IETF’s RPL protocols can be used to send data to the application layer [206]

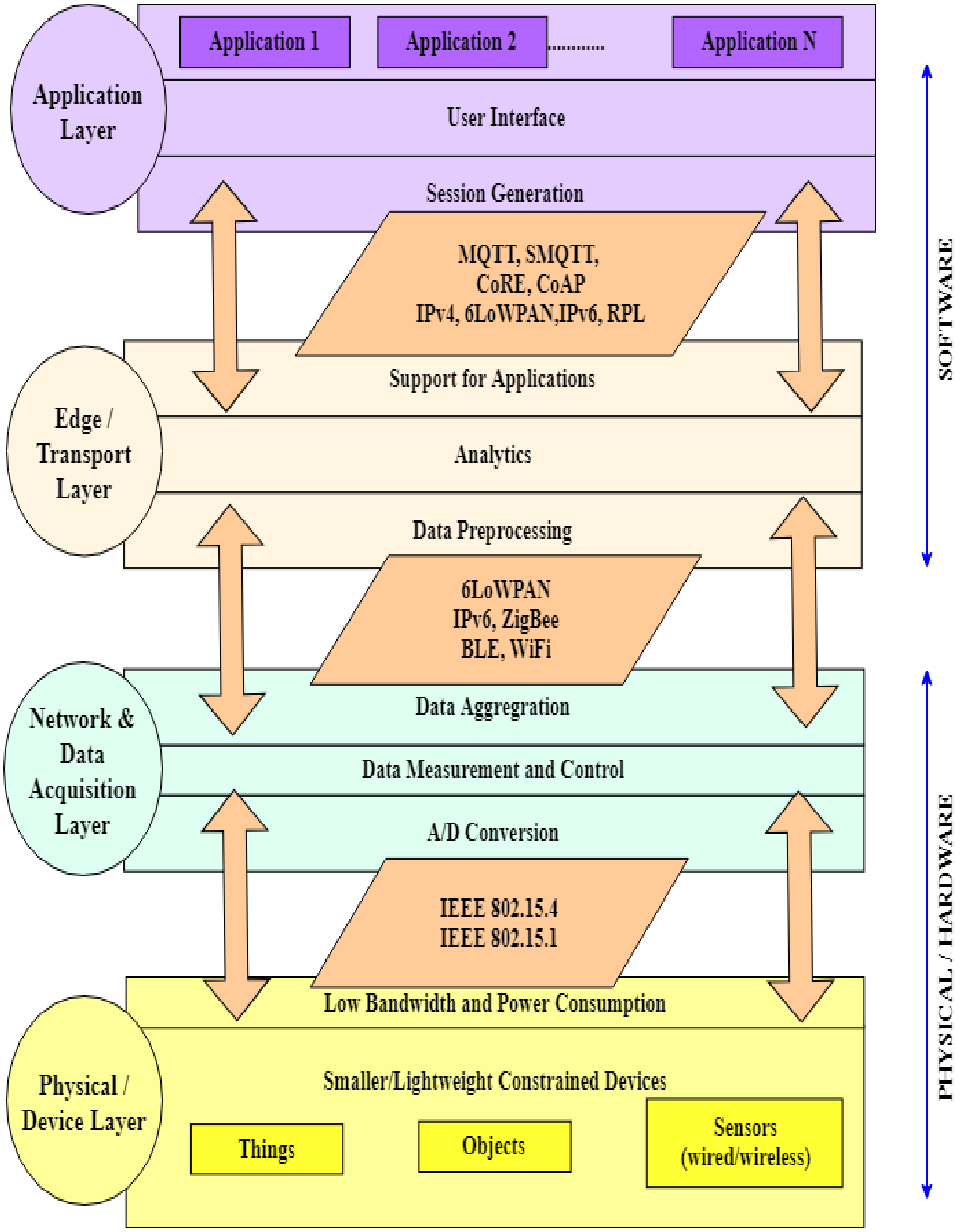


Figure 4.2: WBSN general architecture

Application layer

The application layer is the user interface on the top of the architecture, which is responsible for generating the session for several applications to the different users or industries in WBSN [6]. MQTT, SMQTT, CoRE and CoAP protocols can be used to design the application layer [208]. The intended application can belong to the different healthcare industry verticals such that: elderly care, pediatric care, heart rate monitoring system, human activity recognition [6]. Session generation for every user and designing of the user interface for each application is also part of the application layer.

In the WBSN framework, the selection of the communications network scheme is a decisive point. The communications network architecture can be divided into different network segments, Body Area Network (BAN), Private Area Network (PAN) or Wide Area Network (WAN) / (Backhaul). BAN is the mandatory part of every WBSN and the supplementary communication network segments are added conferring to the ubiquity level of the application. In self-monitoring WBSN, in LifeGuard, C. Otto, added PAN to connect BAN with the data processing unit [31], whereas in HealthGear, N. Oliver, did not add PAN [209]. In controlled-area WBSN, in MASN, Fie Hu. has integrated BAN and PAN communication networks to increase the coverage area [210]. The remote monitoring WBSN systems are considered as wide-area ubiquity level systems. For implementing these types of systems, most of the time, WAN is added with BAN. The LOBIN is bestowing example of such kinds of systems [211]. The WBSN density of traffic and the frequency of packet delivery are the key factors to adopt some specific technologies in architecture designing. [212], [213] used PAN (MICS, Zigbee) with BAN to design the architecture of WBSN to handle the little traffic with less energy consumption and packet loss. Even PAN can be generated using Bluetooth or WiFi, the high power consuming technologies. The projects like LOBIN [211], LifeGuard [214] need high bandwidth technologies (WiFi, Bluetooth or wired) to handle a higher amount of traffic with a high delivery ratio. The comparison of the few previously implemented projects is given in Table 4.3.

Table 4.3: Comparison of WBSN projects

Project	Application	Sensors	Architecture	Communication technologies	Ubiquity level
WEALTHY [215]	Rehabilitation for elderly people by monitoring	Accelerometer, temperature, ECG, EMG and respiratory	e-textile with BSN + WAN	Bluetooth, GPRS	Wide area
CodeBlue [216]	Activity Monitoring	Motion sensor, ECG, EMG and SaO2	Wrist strap + finger sensor + EM```G & ECG + PAN	Zigbee	Controlled area
Human++ [217]	Wearable sensor system for ambulatory health monitoring	ECG, BP and motion sensor	BAN + BS + PDA or PC (PAN)	Zigbee	Controlled area
MobiHealth [218]	Tele-monitoring and tele-treatment	ECG, BP, GPS	BAN + PAN +WAN	Bluetooth, wired and GPRS	Controlled area
CareNet [219]	Motion sensing and fall detection	Gyroscope, accelerometer	BAN + WAN	Zigbee, WiFi	Controlled area
CUIDATS [13]	Location tracking and health status of patient	Pulse, temperature, motion sensor	Wrist band + PAN	RFID, WSN	Controlled area
PlalMos [48]	Remote mobile healthcare for elderly or chronically ill patients	Respiratory, blood oxygen, temperature, motion sensor, ECG, respiration rate	BAN + PAN	Zigbee, WiFi	Controlled area
SPINE-HRV[180]	Heartrate based stress detection	Accelerometer, cardioShield	Chest band + sensor node + BS + PS	Bluetooth	Controlled area
LOBIN [211]	Cardiac system	HR, ECG, temperature	E-textile + location device + WSN + BS + MS	E-textile, Zigbee	Controlled area

KNOWME [220]	Physical activity detection	Accelerometer, ECG, SpO2	BAN + Mobile phone	Bluetooth, GPRS	Wide area

BS: base station, MS: main serve, HR: heart rate, BP: blood pressure

All the projects listed in Table 4.3 were implemented for different healthcare applications. Each project used different communication protocols and sensors, along with their interaction modes. The performance efficiency of the WBSN network depends on many factors. Few of them were well-thought-out during the study.

4.2 Prime Contributing Factor in the Functioning of WBSN Deployment Model

The prime contributing factors i) Sensors interaction mode ii) Data abstraction mode iii) communication protocols made a significant impact on the functioning of the WBSN deployment model [34]. Different modes of sensor interaction, data abstraction and the types of communication protocols are shown in Fig. 4.3.

4.2.1 Sensor interaction [72], [107]

Multiple sensors can be deployed in a WBSN model to fetch the vital, non-vital parameters or surroundings data. The deployment of the sensors in the WBSN model differs in the type of interaction mode. The sensor interaction modes can be divided into categories as given below.

Competitive sensor interaction: It is a very unconventional method of sensor interaction in WBSN models. More than one sensor in the same place is used to record the data. A similar type of sensors records redundant data. By using this data, the network is capable to self-calibrate automatically.

Complementary sensor interaction: Various identical sensors are placed at different body parts to provide complementary data. By using the joint analysis of these complementary signals, accuracy and reliability of the system can be tweaked. For instance, walking or running activities affect the ECG data rate and temperature-humidity level of the body.

Cooperative sensor interaction: In WBSN, Cooperative sensor interaction mode was frequently used for biophysical parameters, which cannot be recorded with the sole entity of a sensor like ECG sensor, 3-axis accelerometer.

Collaborative Sensor Interaction: Multiple sensors in the WBSN collaborate in the direction of a collective parameter decision. The collaborative data analysis of multiple sensors would lead to a robust and accurate decision.

4.2.2 Data abstraction [107]

The data abstraction is a prime factor that contributes to the functioning of the WBSN network. It is the method to abstract the vital or non-vital parameters sensed by sensor nodes. The WBSN data can be abstracted in three modes as given below:

Centralized: In the WBSN model, all the sensing nodes' data was propagated to the sink node. The sink node initiated the uninterrupted controller level data processing and communication for the local or global server.

Distributed: The individual node itself did all the biophysical recorded data processing and communication activities in a distributed way over the network.

Hybrid: For data abstraction, distributed and centralized techniques are collaboratively used in the hybrid technique.

4.2.3 Communication protocols [221]

Another significant factor contributing to the functioning of the WBSN network is the communication link. The communication links are used as the carrier for data within as well as out of the network. WBSN uses lightweight communication protocols. The choice of the type of communication protocol depends upon the ubiquity level of the implemented application. For PAN, protocols Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4) and BAN (IEEE 802.15.6) are frequently used in WBSN. WAN uses WiFi (IEEE 802.11). The characteristics of these protocols are given in Table 1.2.

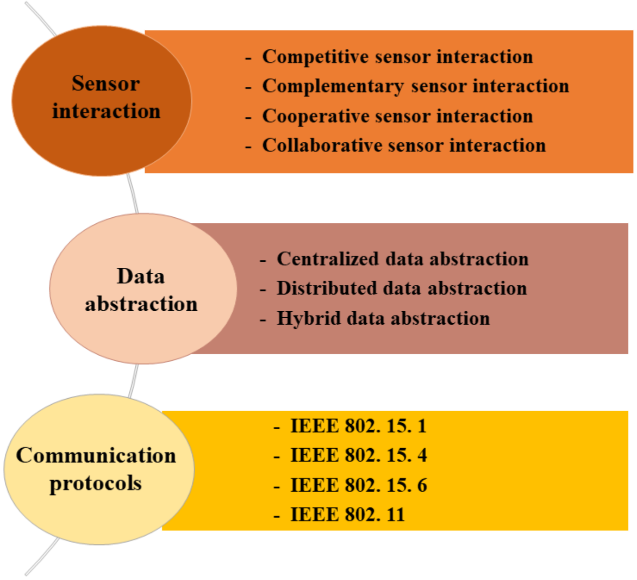


Figure 4.3: Prime contributing factors in WBSN functioning

4.3 Performance Factors in WBSN

The performance of the WBSN model can be evaluated by three parameters: consumed energy, the accuracy of the system and the reliability of the system. The factors that affect these three parameters are communication protocols, sleep / wake time of sink and relay node, superframe time and superframe size [107], [222], [223]. Fig. 4.4 shows the underneath techniques which work for the above said performance factors of WBSN.

4.3.1 Sleep / wake time

Sleep / wake time directly depends upon the duty cycle of the sink node / relay node. The duty cycle is the on / off periods of a clock pulse. The on-time is considered as a wakeup time and off time is regarded as sleep time of the system. The duty cycle is an endeavoring approach to reduce energy consumption in WBSN. The duty cycle can be classified into three categories: Co-ordinated, non-co-ordinated and on-demand [224], [225]. In ***co-ordinated duty cycle*** mode transmitter and receiver nodes, exchange their data packets in a periodical manner. Before the transmission, sender asked for the receiver. They may adopt handshake or acknowledgment policies during communication. In ***non-co-ordinated*** duty cycle mode, transmitter and receiver nodes exchange their data packets in unsynchronized fashion. The duty cycle is used to set the sleep / wake time of the sink node and the relay node. Sleep / wake time can be of fixed, variable, or adaptive type [40].

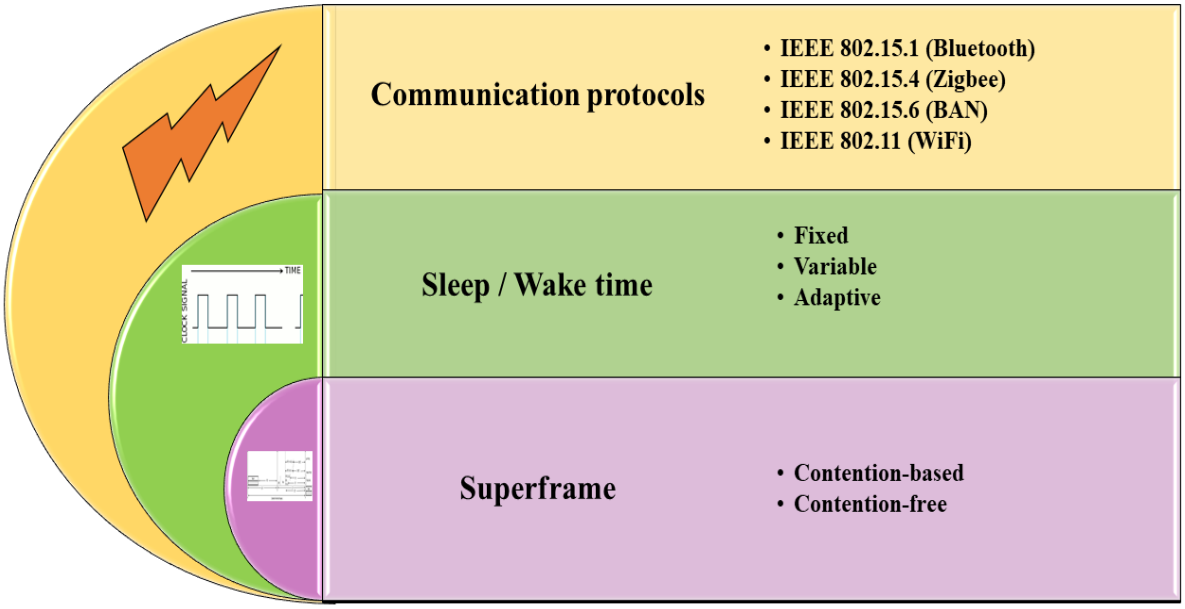


Figure 4.4: Factors affecting the performance of WBSN model

4.3.2 Superframe

In WBSN, a CN in PAN is voluntarily confined to access the channel for data transmission. There are two types of structures to access the channel. ***i) Contention-based:*** A CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance) backoff algorithm-based techniques to access the channel in a distributed mode. ***ii) Contention-free:*** The global telecommunication scheme is used by the CN to access the channel. CN handles the entire process in PAN. The timing of channel access is bounded with the superframe structure. A superframe transmits a beacon frame which consists of active and inactive portions. At the time of idle mode, CN can enter into sleep mode or low power mode, which in turn saves energy of the WBSN network. Here the IEEE 802.11 superframe structure is discussed below.

IEEE 802.11 is a MAC layer wireless Local Area Network (WLAN) protocol. WLAN can be configured either in ad-hoc mode or infrastructure mode. IEEE 802.11 has two different channel accessing modes. Distributed Coordination Function (DCF) based on CSMA/CA and Point Coordination Function (PCF) that works on the polling technique. The superframe of IEEE 802.11 has two consecutive phases, the Contention Period (CP) and Contention Free Period (CFP). Fig. 4.5 depicts the superframe for IEEE 802.11.

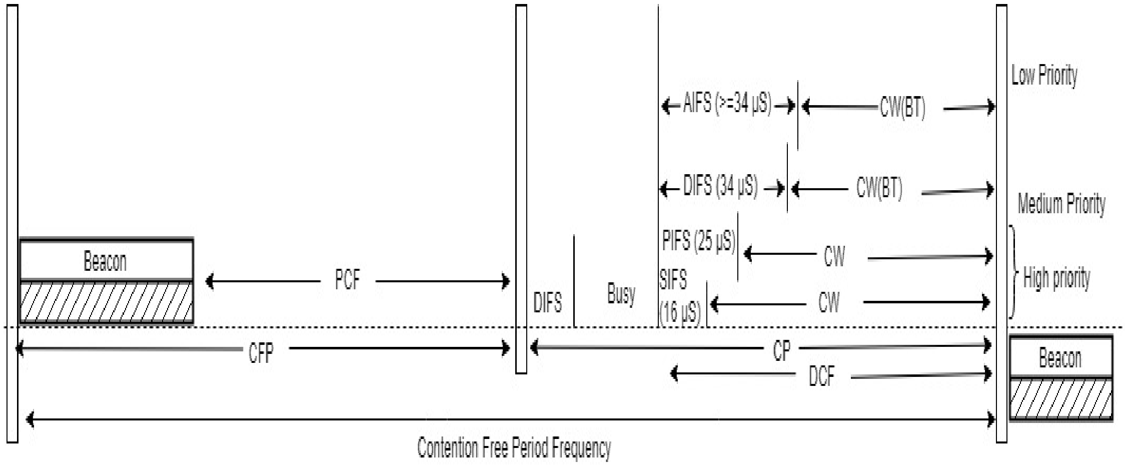


Figure 4.5: IEEE 802.11 superframe

The contention period has three variables Contention Window (CW), Backoff Time (BT), and Network Allocation Vector (NAV). This study elaborates only on DCF mode. The BT is random and depends upon the priority of the beacon. Initial Inter Frame Space (IFS) is the space between two communications. Short IFS (SIFS) has the highest priority, whereas Point Coordination Function IFS (PIFS) has medium priority, respectively. Asynchronous coordination is used by Distributed function IFS (DIFS) and has the least priority. The duration of CFP varies according to the load. IEEE

802.11 slot time is 9µs, SIFS is 16 µs, CWmin is 15 and CWmax is 1023. PIFS and DIFS are of 25µs and 34µs, respectively. The time calculation for the data transmission (T_{tx}) was based on equation 4.1 given in [226]. Here H_{MAC} were 30 bytes.

$$T_{tx} = T_{phy} + T_p + T_{sym} * ceil\frac{\left(22 + 8(H_{MAC} + x)\right)}{N_{dbps}}$$

Equation 4.1

4.4 Proposed Model

WBSN is a battery-limited sensor network. Many researchers worked on energy saving in WBSN. But the more systematic techniques are required to tackle the energy-saving problem [79], [227]. A survey of WBSN elucidated the issues and challenges confronted during healthcare applications' implementation. Energy conservation, low-power consumption, battery lifetime, transmission reliability, data rates, latency, vulnerability, security, privacy, and designing are antagonized issues to win over in WBSN healthcare applications [27], [109]. Usually, in WBSN, sensor nodes are kitted with small batteries. These batteries cannot be frequently replaced or recharged. In the scarcity of battery, the WBSN systems get useless.

WBSN used in a plethora of healthcare applications. Human Activity Recognition (HAR) has been eliciting the attention of the research community. It still requires more effort to put due to the different nature of human activities and the recognition / tracking methods [228]. In this research, initially, a refined deployment framework for "**WBSN-Human Activity Recognition (WBSN-HAR)**" was proposed, as shown in Fig. 4.6. WBSN-HAR reduced energy consumption by 47.01% as compared to Alsheheen H. [40]. During implementation, a well-known fact was experienced that different age groups have different stride time and cadence. There was a scope for more optimization, so WBSN-HAR was further optimized with gait adaptive duty cycle and later on **"Gait Adaptive Duty Cycle-Human Activity Recognition (GADC-HAR)"** model was proposed. The proposed deployment framework reduced the energy consumption, enhance the accuracy and reliability of WBSN model. The next section gives a detailed description of frameworks for WBSN-HAR and GADC-HAR.

4.4.1 Deployment framework for WBSN-HAR

A WBSN based deployment framework for human activity recognition was proposed, as shown in Fig. 4.6. It consisted of raspberry pi B+, Six 3-axis accelerometer, temperature and humidity sensor, communication protocol IEEE 802.11. The global cloud data center was used to store data.

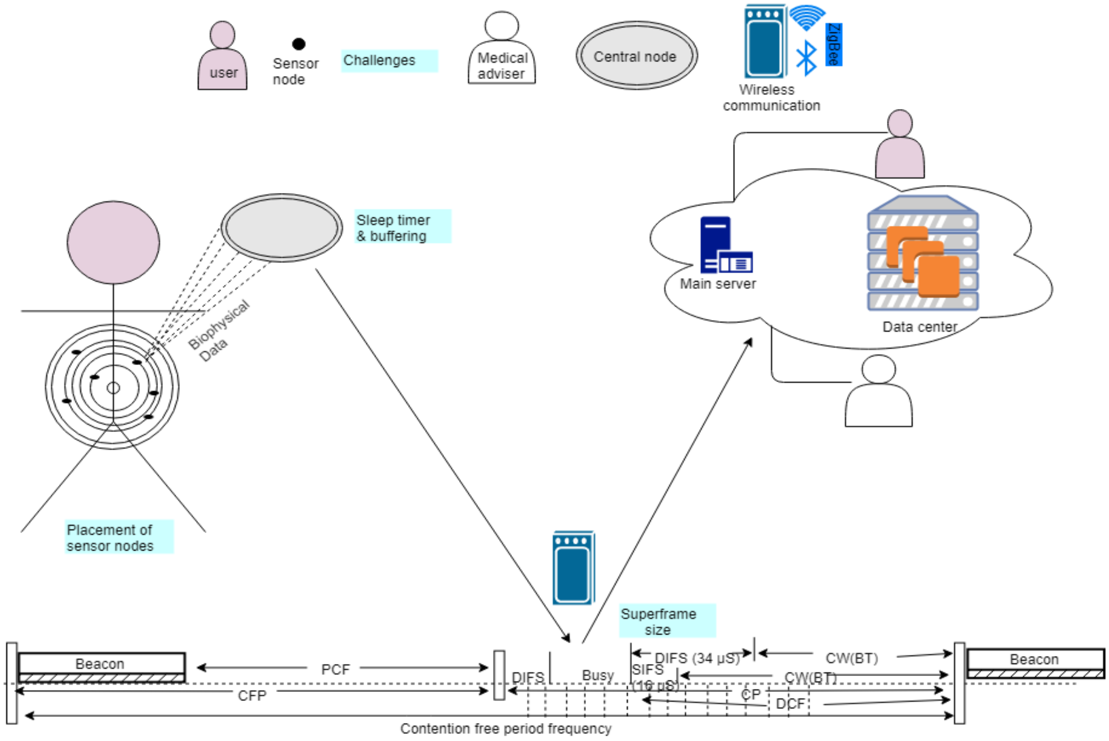


Figure 4.6: WBSN-HAR model

The cooperative sensor interaction and centralized data abstraction mode were adopted to implemented WBSN-HAR. The data sampling frequency was 100Hz. All the recorded data was sent to the relay node or global data center using the IEEE 802.11 communication protocol. Before sending the data to the cloud, data was encapsulated to save bandwidth. Since the data was transmitted over long distances, the path loss was considered as d^4. In WBSN-HAR all sensors were first initialized then calibrated for the respective location. The accelerometer data, the humidity and temperature data were recorded with time stamping. In order to save the energy consumption, the ten rounds, data recording was encapsulated in one packet before communicating to the cloud. IEEE 802.11 communication protocol with a large superframe size of 2KB was used to optimize the bandwidth of the channel, which in turn saves energy of the network. Fig. 4.7 illustrates the working of the WBSN-HAR model. The implementation of WBSN-HAR is given in the next chapter.

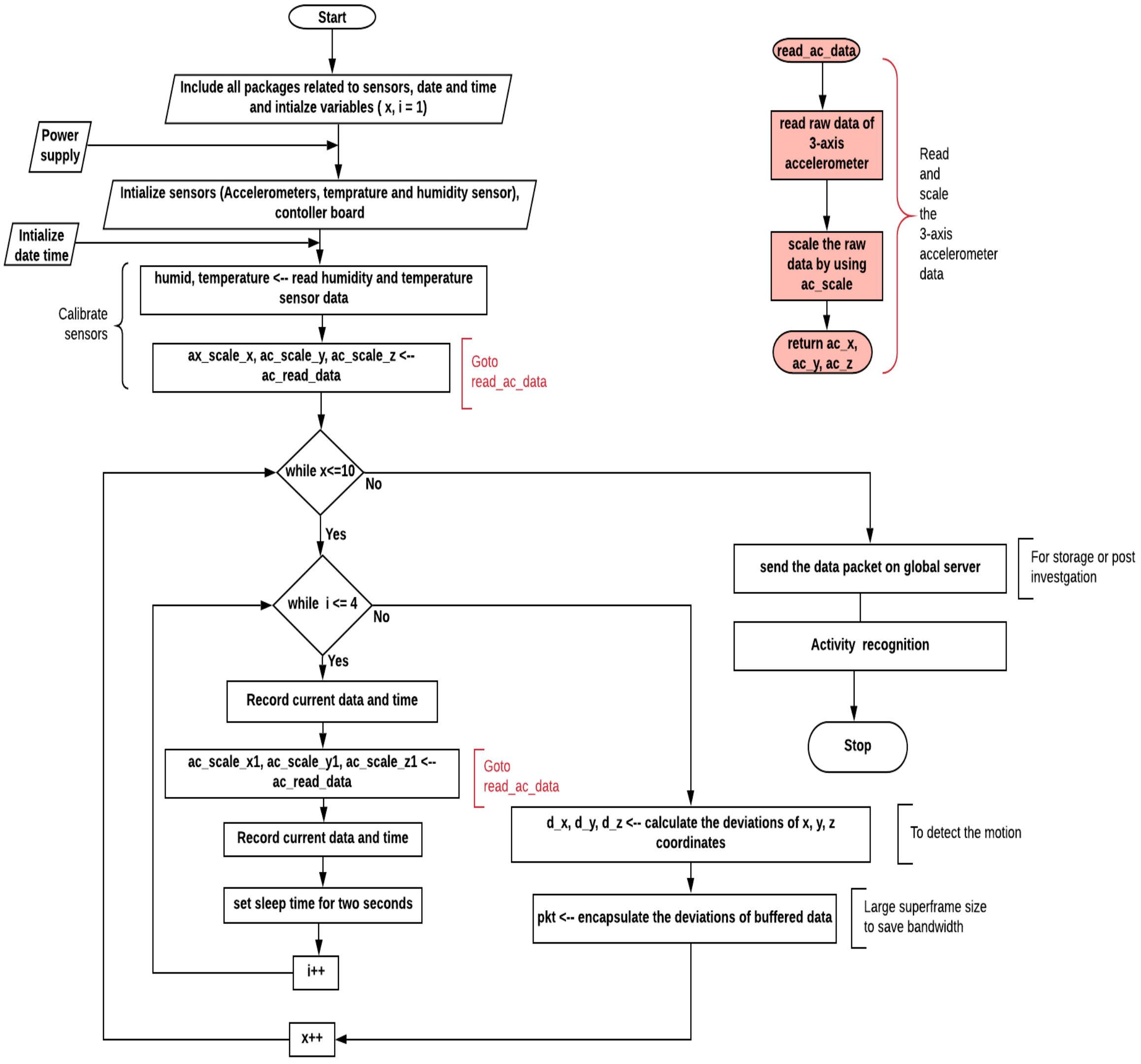


Figure 4.7: Working of WBSN-HAR

4.4.2 Gait cycle

Gait cycle analysis is used in human activity recognition, robotics, human health fitness, security etc. The four controls which affect the walking of a human being are equilibrium, locomotion, musculoskeletal integrity, neurological control [141]. Walking disability may be caused due to many health problems i. e. arthritis, co-morbidities, cerebellar disorders, neurological diseases and so on. Any injury, pain, paralysis attack, tissue damage or ligament tearing can alter the normal gait cycle [97]. The deviation of the gait cycle must be accurately interpreted to compute of detecting the human body activation.

Gait cycle is the sequence of prosaic alternating movements of the trunk and limbs that results in the forward progression of the body. Gait has two phases: a) stance phase (feet touch to the ground), 60% of the gait cycle and b) swing phase (feet do not touch the ground), 40% of the gait cycle. Fig. 4.8 shows the eight events of the gait cycle i) initial contact, ii) loading response, iii) mid stance, iv) terminal stance (heel off), v) pre-swing (toe-off), vi) initial swing (acceleration), vii) mid-swing (toe-off), viii) terminal swing (deacceleration).

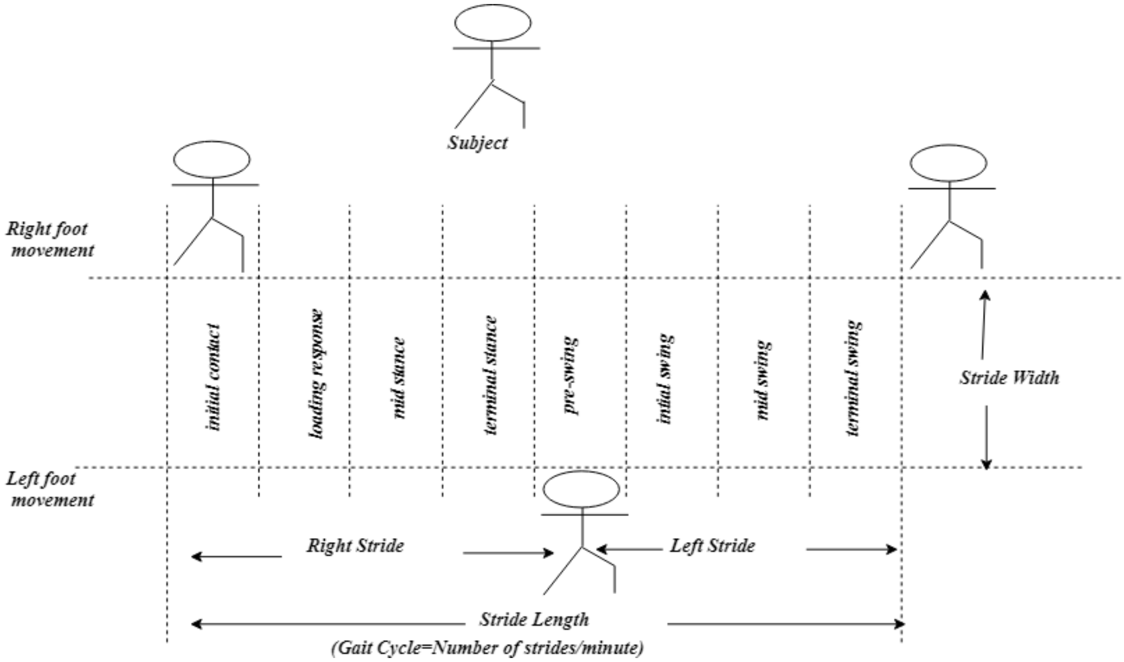


Figure 4.8: Gait cycle events

4.4.3 Gait Adaptive Duty Cycle - Human Activity Recognition (GADC-HAR)

Gait Adaptive Duty Cycle-Human Activity Recognition (GADC-HAR) model was proposed as the improvised version of WBSN-HAR. Fig.4.9 shows the detailed framework of GADC-HAR. A network of six 3-axis accelerometer was created to record the walking movements of a person. All sensors' data was fused to the sink node (raspberry pi B+) for the collaborative decision about the activity. Communication protocol IEEE 802.11 was used to send data to the relay node or on a global cloud for data storage. In the proposed GADC-HAR model, the collaborative and cooperative sensor interaction modes were coupled with centralized data abstraction mode. The Energy Efficient and Reliable (EER) algorithm was designed as a routing protocol for the GADC-HAR model. Next section indicates the steps followed in EER algorithm.

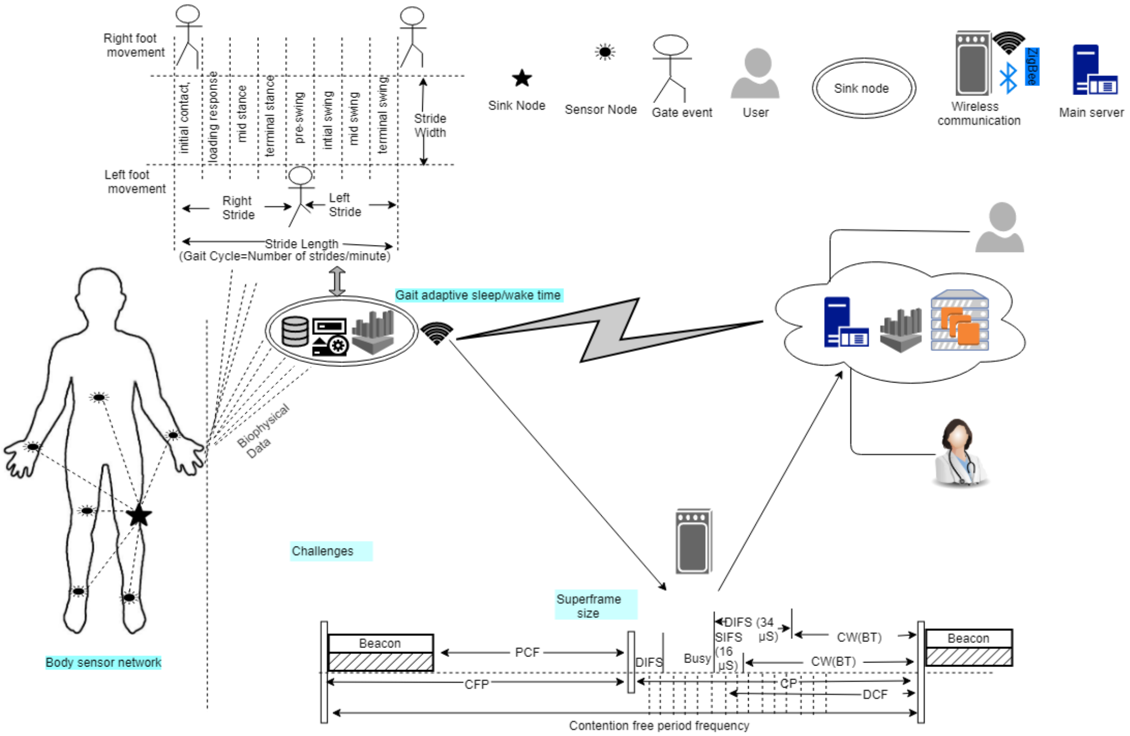


Figure 4.9: Framework for GADC-HAR

4.4.4 EER algorithm

An Energy Efficient and Reliable (EER) algorithm work as a routing protocol in WBSN-HAR as well as in GADC-HAR model. In EER step 1, To recognize the gait event or activity, the accelerometer raw data was recorded for x, y and z coordinates. According to the accelerometers' datasheet [229] the raw accelerometer and magnetometer data were scaled for 16384 and 131, respectively.

Energy Efficient and Reliable (EER) Algorithm:

Input Variables: ac_scale_x, ac_scale_y, ac_scale_z, Humid, temp, Wake_time, dt

```
Step 1:     Read accelerometer data
            rd_ac_data():
              a.  read raw data of 3 (x,y,z) coordinates
              b.  scale the raw data by using ac_scale
              c.  return ac_x, ac_y, ac_z

Step 2:     Gait Cycle Detection
            encode_gait_cycle():
        a.  set timer for 360 seconds
        b.  (ac_ak_xr, ac_ak_vr, ac_ak_zr) ← read_ac_data(ax_r)
        c.  set timer for one second
        d.  (ac_ak_xr1, ac_ak_vr1, ac_ak_zr1) ← read_ac_data(ax_r)
        e.  if the delta of acceleration range(3 : 3.75) then
        f.  increment the step by one
        g.  calculate gait_cycle time with the ratio of step in one minute
```

```
h.  return gait_cycle
```

Step 3: ***Gait-Adaptive Duty Cycle (GADC)***

```
wake_time(gait_cycle):
a.  if 0.5 < gait_cycle < 1 then
        wake_time ← 1ms
b.  elif 1 <= gait_cycle <= 1.2 then
        wake_time ← 2ms
c.  elif  1.2 < gait_cycle <= 1.5 then
        wake_time is ←3 ms
d.  else default
        wake_time ← 5 ms
e.  return wake_time
```

Step 4: ***Record accelerometer data for HAR***

```
a.  initialize accelerometer
b.  initialize time
c.  (ac_scale_x, ac_scale_y, ac_scale_z) = read_ac_data() //calibrate
    the sensor with initial readings
d.  for x =1 to 10:
e.  record the current date and time
f.  for i =1 to 4
g.  (ac_scale_x1, ac_scale_y1, ac_scale_z1) = read_ac_data()
i.  humid, temp=recorded data of sensor1
h.  sleep time ← dt - wake_time
k.  calculate the deviations of the x, y, z coordinates as d_x, d_y, d_z
l.  pkt← encapsulate the data in one packet {date, time,
    accelerometer_data [d_x, d_y, d_z, tem, Humidity]}
m.  end for loop
```

```
n.  end for loop
o.  send the data on the global server as per wake_time
```

The gait cycle of the subject was decoded in EERs’ step two. The accelerometers data was recorded for three minutes by the interval of one second. The cadence and gait cycle was calculated after every minute for further use [95]. Every human being has a unique walking habit or speed by nature or affected by age or gender or any physical disability or accident. EERs' step three, sync the sleep timer of the GADC-HAR with the gait cycle of the subject, to optimize the energy consumption and reduce the data packet losses. In step four, data encapsulation and large superframe size (2KB) of IEEE 802.11 were used for the optimum use of the network bandwidth to save energy.

Chapter 5

Implementation and Validation of WBSN-HAR and GADC-HAR

Wireless body sensor network is the amalgamation of biophysical parameters sensing, pervasive computations and communication. WBSN helped to make healthcare smart, remote-controlled and mobile. State-of-art is the evidence of innovations of WBSN based healthcare applications. Stackable design of multiple wearable physiological sensors and IEEE 802.15.4 was implemented to perceive motion artifacts and variations in physiological / emotional stress in the form of true or false [18]. Human Activity Recognition (HAR) has been starring the attention of the research community. It still requires more effort to put, due to the divergent nature of human activities and the recognition / tracking methods [228]. A novel WBSN based gait-cycle driven transmission power controlled (G-TPC) was proposed. The periodic function of WBSN link quality was exploited with the help of gait cycle beacon and control the transmission power at specific points [94]. A gait data of forty healthy subjects were created to validate the effects of locomotive tasks. The multiple-task gait analysis protocols: self-selected, higher or lower gait speed, especially for heels / toe walking or ascending / descending walking, were designed. All data were compared for gait speed and spatiotemporal parameters: stance time, cadence and double support time [95]. Twenty healthy persons had participated in creating MEREA (Movement Analysis in Real-world Environment using Accelerometer), a gait database. The database was generated with three accelerometers implanted on the human body. The implementation involves walking and running in controlled as well as outdoor environments. Six previously designed GED algorithms were applied to validate the data. All algorithms resulted well in an indoor environment with high accuracy of heel stroke recognition [96]. A probabilistic formulation was combined with a sequential analysis method to recognize the walking activities. An adaptive perception method was used to predict gait events during walking. The BaSis (adaptive Bayesian inference system) automatically adapts the system performance by using an action-perception method. Adaptive BaSis layered architecture shows that the weighted combination of prior knowledge and time-stamped predictions based upon the observed decisions improve the efficiency of the system [97]. There are few techniques mentioned in state-of-art are energy saving algorithms, network coding, duty cycle, data processing in network, placement of sensor and choice of network communication techniques [40], [222], [225], [230].

This research focuses on the design and implementation of energy efficient WBSN deployment model. The integration of two techniques was adopted to save WBSN energy i.e. i) network coding ii) sleep / wake timer.

The previous chapter proposed a refined WBSN deployment framework with the coordination of the interconnections and relationship between biosensor nodes as a vital data collector and sink node as a vital data logger or receiver and relay node as a vital data transmitter.

WBSN sink node was coded for sleep time according to the decoded gait cycle of the subject (user). The CN / relay node was coded to log 'n' packets of vital data before transmitting it to the medical server / cloud. Logging of 'n' packets saves the 'n-1 / n' bandwidth, which in turn saves energy.

The implementation of WBSN-HAR and GADC-HAR was done to validate their performance. The experiment involves the forty subjects of different gender and age group.

5.1 Experiment Setup

The realtime implementation of WBSN-HAR and GADC-HAR was conducted. The easily implantable body sensor network of the accelerometer (MPU 6050) was created. The framework uses Raspberry pi as central / relay / sink node with the functionalities of the data logger as well as a data transmitter. IEEE 802.11 used as an onboard communication protocol for the WBSN data transmission. The rest of the chapter elaborates on the detailed procedure followed for the implementation and validation of WBSN-HAR and GADC-HAR.

5.2 Body Sensor Network

A bio-sensor network was created on the human body, to recognize human activities. Six inertial sensors (3-axis accelerometer) were used to record and report the human body's acceleration (the rate of change of velocity), orientation, angular velocity and magnetic field around the body. Four sensors were placed on both (left and right) wrists and ankles. Two sensors were placed on the right thigh and center of the chest. The sink node was placed in the left pocket, as shown in Fig. 5.1. All the sensor nodes were connected in co-operative and collaborative mode. The data propagated by sensor nodes were infused to the sink node. The decision of gait event / activity was made on the collaborative data outcome.

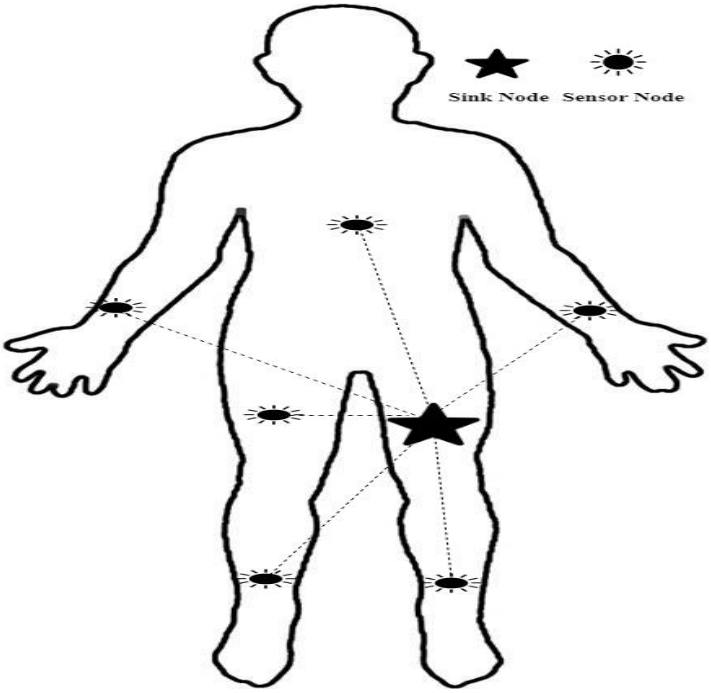


Figure 5.1: Bio-Sensor network on body

5.3 Population Size and Activity Pattern

The population size of forty subjects was taken for WBSN-HAR and GADC-HAR implementation. The population includes the same ratio of males and females. Further, both categories were divided into two groups, with an equal ratio of young and adult.

The subjects in the age group of six to twenty-five were considered as young and in the age group of thirty-five to seventy years were put in the adult group [95]. All subjects involved in this study were having no walking disability. Population details are given in Table 5.1.

Table 5.1: Population detail

Gender	**Age group**	**Medical record**	**subjects**	**Trials / duration**
M	A	NWD	10	4 / 6m
	Y	NWD	10	6 / 6m
F	A	NWD	10	4 / 6m
	Y	NWD	10	6 / 6m

NWD: No walking disability, A: Adult (35-70), Y: Young (6-25), M: male, F: Female, m: Minutes

Six minutes task was performed four times by adults and six times by young subjects. Each task was divided into five parts. Initially, thirty seconds stand, hundred seconds normal walk, hundred seconds fast walk, then a hundred seconds normal walk, which was followed by thirty seconds stand. The initial and last stage of standing was planned to avoid malfunctioning of gait event recording. The activity pattern followed for the implementation is given in Fig. 5.2. The following section states the process followed in GADC-HAR.

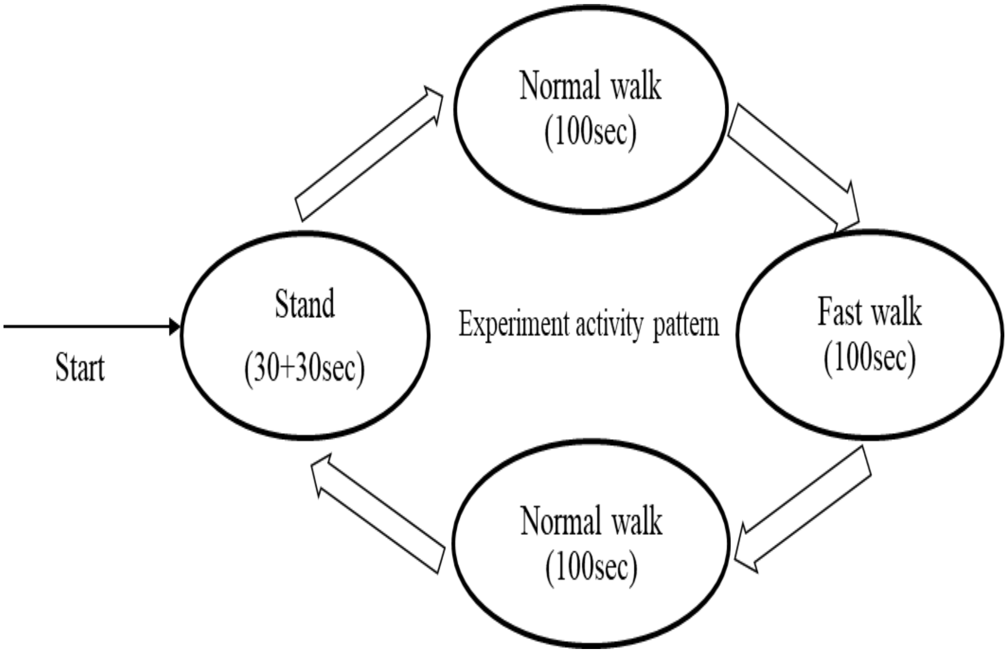


Figure 5.2: Implementation of activity pattern

5.4 Process Diagram

Fig. 5.3 demonstrates the strategic process followed for gait cycle synchronization in GADC-HAR. Movement or stationary conditions were noticed at the start state. In the case of the stationary condition, the default state of GADC-HAR was adopted. In the case of movement detection, GADC-HAR entered the self-optimization mode. In self-optimization mode, typically, the gait events of the subject were encoded for 360 seconds. If any movement was not detected till 240 seconds, then it would be diverted to the default state. If the movement was detected, then the gait cycle was decoded as per EER algorithm step two (proposed in the previous chapter).

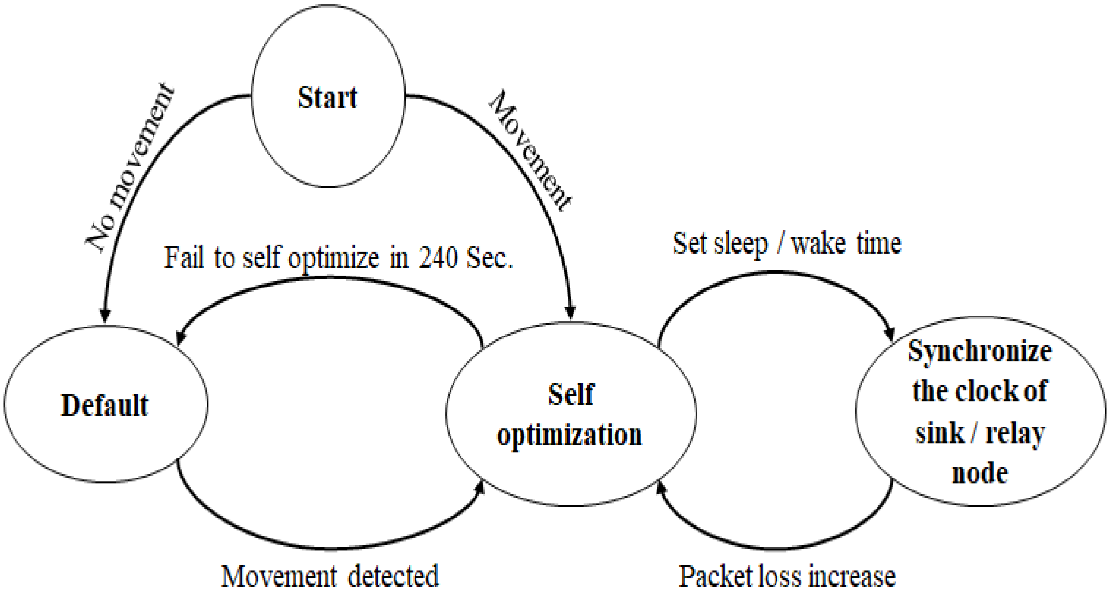


Figure 5.3: Process diagram

5.5 Gait Cycle Detection

The data of six inertial sensors were recorded for 360 seconds to detect the gait cycle event. The acceleration signal vector magnitude was calculated to reduce the sink node orientation effects. The equation 5.1 gives the calculation details.

$$ax =< ac_x, ac_y, ac_z >$$

$$|ax| = \sqrt{{ac_x}^2 + {ac_y}^2 + {ac_z}^2}$$

$$ac = |ax|$$

Equation 5.1

Here, ac_x, ac_y, ac_z are the acceleration on the x-axis, y-axis and z-axis respectively, caused due to the movement of the subject. The fluctuations in acceleration signal were corresponding to the heel stroke followed by the stance and swing phase of the gait cycle. The data was recorded at 100hz frequency and the mean value of data deviation of each second from its consecutive values was considered for the gate cycle [94]. After all the trials of each subject, the mean cadence value and the mean stride time was calculated. The results are shown in Table 5.2. The results of this study were the same as the results of G. Bovi [95]. Young and adult subjects were classified in normal and fast categories according to their cadence and stride (gait) time. The plotting of cadence and gait is given in Fig. 5.4.

Table 5.2: Cadence and stride time

	YN	YF	AN	AF
Cadence (steps / min)	115	124	90	110
sec / cadence	0.52	0.48	0.66	0.54
sec / stride (gait)	1.04	0.96	1.3	1.09

YN: young normal, YF: young fast, AN: adult normal, AF: adult fast, min: minute, sec: second

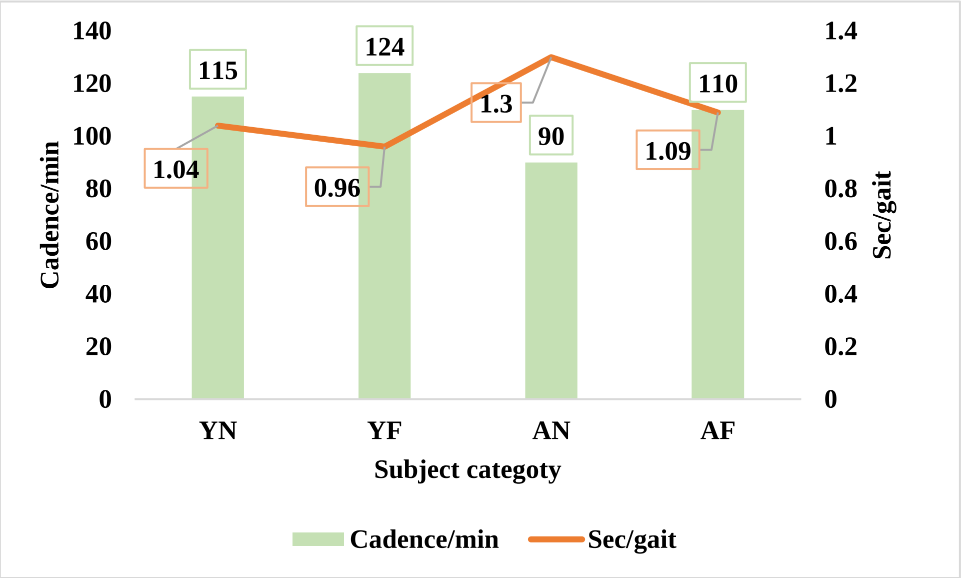


Figure 5.4: Cadence and gait

Gait of a person can alter due to injury or any other reason. In our study we decode the gait cycle of the subject for 360 seconds regularly. in case of injury altered gait would be efficiently decoded and accordingly the network duty cycle wake time would be selected. Even clothing (Indian saree, formal skirts) may affect the gait cycle of the subject. In future implementation, such cases would be taken.

5.6 Gait Adaptive Duty Cycle

In the GADC-HAR process, after the 360 seconds of self-optimization mode, it gets the gait cycle time of the subject. Based on the gait cycle time, the sleep time of the system was set according to the EER algorithm, step three (proposed in the previous chapter). So that the energy consumption of the GADC-HAR could be optimized. The default sleep time was set as 0.5 seconds with a 50% duty cycle. In this study, gait cycle time was distributed in three categories, 0.5 seconds to 1 second, >1 second to 1.2 seconds and >1.2 to 1.5 seconds and the respective sleep time were 1, 2 and 3 milliseconds.

5.7 Data Processing

The sensor produces raw, noisy data. Some data processing techniques were applied to data to remove noise and harmonics. The order of data processing stages was followed, as illustrated in Fig. 5.5.

5.7.1 Buffering and sampling

Gait event data was buffered for 360 seconds on the sink node. On the sink node, data were preprocessed before analytics or sending to the cloud. Bio-sensor data can be sampled at a fixed data sampling rate, variable data sampling or adaptive data sampling. The fixed data sampling rate was employed in this study. The 3-axis accelerometer data were sampled at 100 Hz frequency. Duty cycle (dt) time was calculated as per the equation 5.2.

$$\mathrm{dt} = {}^{1}\!/_{f}$$

Equation 5.2

(here f = 100Hz & dt was 10ms)

5.7.2 Filtering

The filtering of data is the removal of noise and harmonics from the recorded vital data. Filtering algorithm complexity depends upon the recorded data quality and application of interest. A maximally flat magnitude filter was used to get the frequency response as flat as possible in the passband. A higher-order butter worth filter with the roll-off rate of continuous data of 40 dB / decade was used to get the gait cycle frequency response as smoothen as possible in the passband. The initial and the end peaks were found within the approximate gait (stride) time [95], [231].

5.7.3 Feature extraction

For feature extraction, segmentation and classification methods were applied.

Segmentation: Sensors data was recorded in continuous data streams. The windowing function was applied to convert the continuous data streams to the discrete signals. A sliding window of three hundred milliseconds with the overlap time of hundred milliseconds was used. Segmentation was done in such a manner that each discrete time interval must contain a multidimensional feature vector [96], [97]. Within each window, the threshold value was computed with the help of local signal statistics to isolate the valley and peak candidates of each gait cycle [96].

Classification: *E*vents can be detected based on the feature vector. SVM, KNN, HMM, RNN and naïve byes are classification algorithms [97]. All the algorithms were deployed to test the accuracy of the system. But SVM with the combination of RNN had proved the highest accuracy. The detailed description is given in section 5.8.2.

5.8 Performance Evaluation and Validation

The proposed model was evaluated for energy consumption, the reliability in the form of data packet delivery ratio and accuracy in terms of recognition of walking / gait event detection.

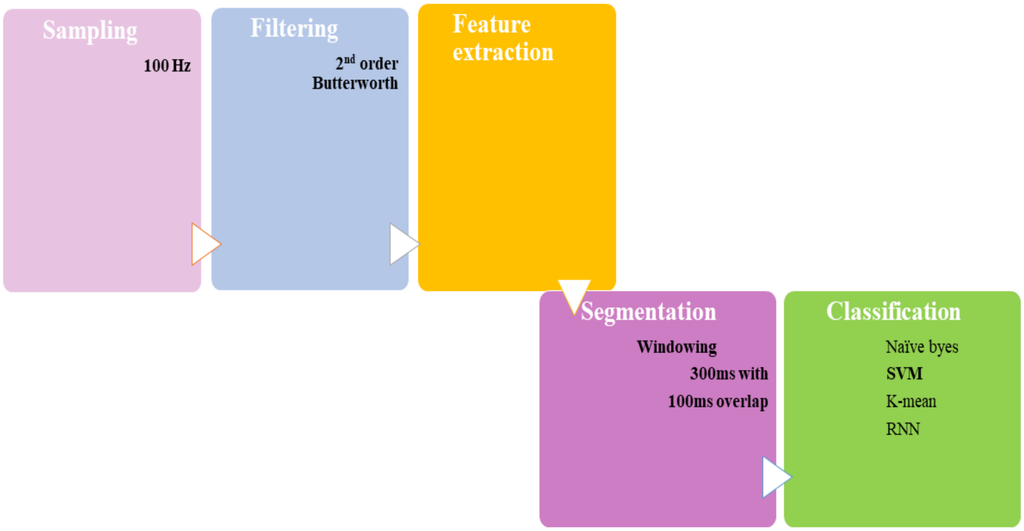


Figure 5.5: Data preprocessing stages

5.8.1 Accuracy

GADC-HAR and WBSN-HAR, accuracy was validated with the recognition of walking activity. The implementation data (angular velocity) recorded by six inertial sensors were divided into training and testing datasets. Machine learning algorithms SVM, KNN, HMM, RNN and naïve byes were tried to check the accuracy of the system. The combination of SVM and RNN has provided the highest accuracy in all cases and results are shown in Fig 5.10. From the figure, it was observed that GADC-HAR was more accurate than WBSN-HAR. GADC-HAR young normal was 10.45%, young fast is 11.28%, adult normal was 25% and adult fast was 25.13% precise than WBSN-HAR young normal, young fast, adult normal and adult fast respectively.

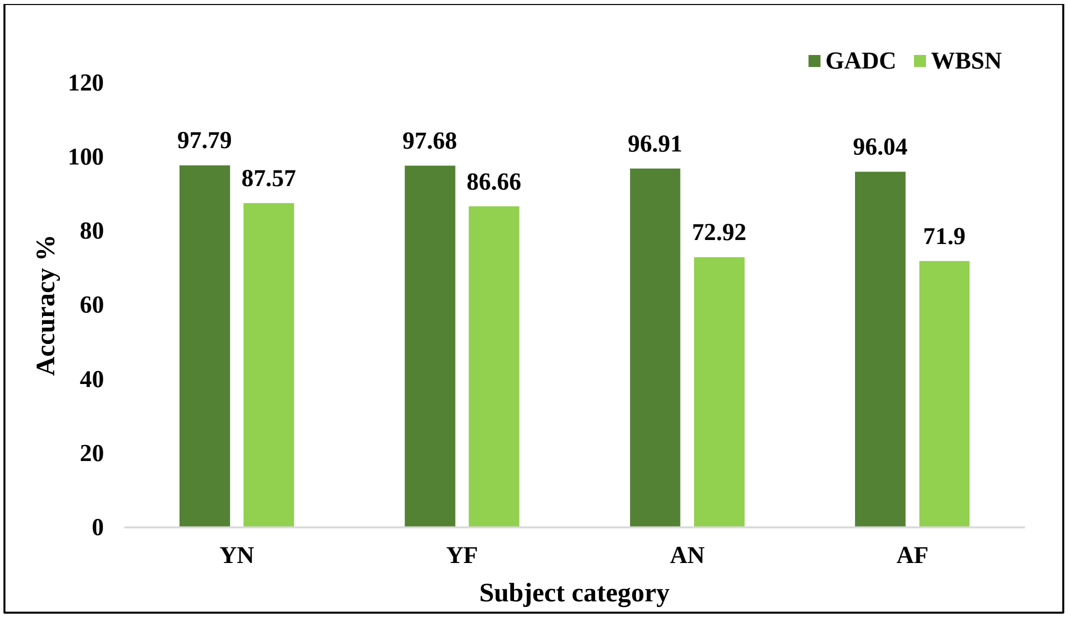


Figure 5.6: Accuracy of GADC-HAR and WBSN-HAR

5.8.2 Packet loss ratio

Two techniques were adopted to make the GADC-HAR and WBSN-HAR reliable. First, data packet loss was controlled by the ***store and forward*** technique. Inertial sensors' data was buffered for 360 sec at central / relay node and encapsulated in a packet before transmission.

Second, the data packets transmission in GADC-HAR has synced with ***gait adopted duty cycle function*** to reduce the data packet loss ratio. GADC-HAR and WBSN-HAR were compared for packet loss ratio and results are shown in Fig. 5.11.

For the reliability validation, the average of all classes of both frameworks were compared with Zang W. [94] and results are shown in Fig. 5.12. GADC-HAR model was 7.92 % and 53.6 % packet loss ratio was less as compared to Zang W. [94] and WBSN-HAR, respectively.

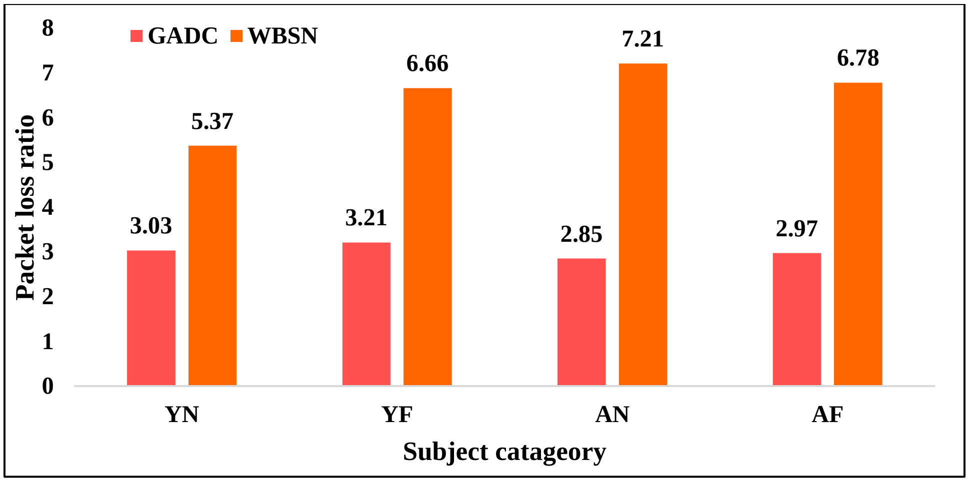


Figure 5.7: Packet loss ratio

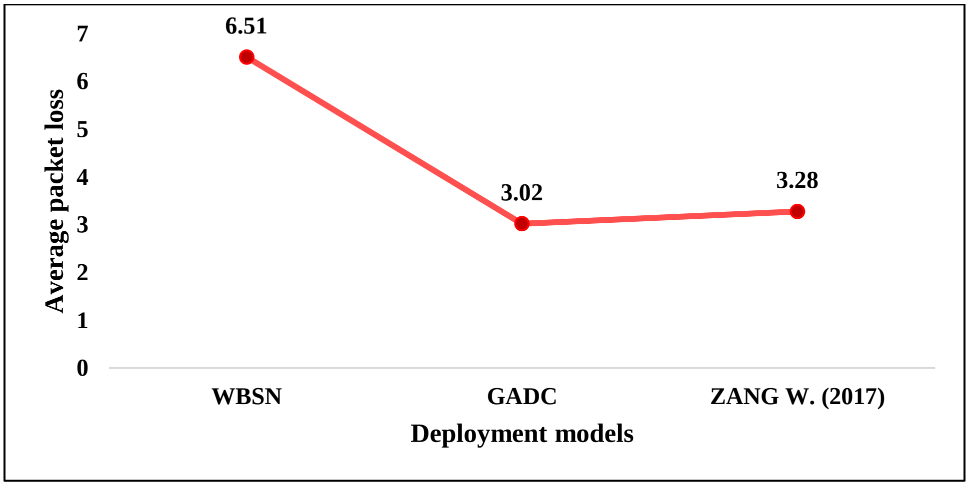


Figure 5.8: Average packet loss of different deployment models

- The proposed model WBSN-HAR is 47.01% energy efficient than Alshaheen H. [37].
- The refined model GADC-HAR is 48.5% energy efficient than Alshaheen H. [37] and packet loss ratio was reduced by 7.92% as compared to Zang W. [94].

5.8.3 Energy consumption in GADC-HAR

The model was evaluated to find out the better option. The boot energy (E_B) required for the CN was 3.24mw. It was calculated by equation 5.3, the E_{ig} was the ignition energy and t_{ig} was the ignition time needed to boot the CN.

$$E_B = E_{ig} * t_{ig}$$

Equation 5.3

The communication protocol IEEE 802.11 with 2.4 GHz frequency was used. The total number of bits (b_r) sent in one time was 1940. The communication energy (E_c) consumed to communicate the data bits were calculated using equation 5.4, Here E_{sc} was the standard communication energy required for standard bits (E_{st}).

$$E_c = \left(\frac{E_{sc}}{E_{st}}\right) * b_r$$

Equation 5.4

E_c was calculated 0.00012. E_{ctr}, is the energy required by CN to record the data was given in equation 5.5. Here E_{st} was the standard energy needed by the central node during load time and T_D was the time entailed to communicate the recorded data. This time was considered as the latency or delay of the network.

$$E_{ctr} = E_{st} * T_D$$

Equation 5.5

The total energy ($\boldsymbol{E_T}$) consumed to record and communicate the data of one packet. $\boldsymbol{E_T}$ was calculated with the computations illustrated in equation 5.6. The central node boot energy $\boldsymbol{E_B}$ was added to the summation of all activities, data recording and communication energy. Here 'n' is the number of rounds performed during one task. $\boldsymbol{E_{ctr}}$ was the energy required by the controller node during recording, $\boldsymbol{E_c}$ is the communication energy and $\boldsymbol{d^4}$ is the path loss during the data communication [232].

$$E_T = E_B + \sum_1^n (E_{ctr} + E_c) * d^4$$

Equation 5.6

For calculations, the standard parameters of CN are stated in Table 5.3.

Table 5.3: CN standard parameters

Parameter	Central Node (CN)
Boot energy	0.72A
Boot time	4.5 sec.
Load	1.13mA
IEEE 802.11	0.31mA / 500kbits

The recorded data were classified into four classes; two main classes, young and adult further, both classes have two subclasses normal and adult. The energy consumed in data recording and communication was calculated for both models, WBSN-HAR and GADC-HAR. For WBSN-HAR default, sleep time was used, whereas, for GADC-HAR, the sleep timer of each class was set according to EER algorithm step three concerning to their gait cycle time. The energy consumption, along with the gait time for the respective class and subclass of GADC-HAR, was given in Table 5.4. Fig. 5.6 shows the relationship between energy consumption and gait time. The gait time and the energy consumption have a positive relation, lesser the gait time lesser the energy consumption and vice-versa. The energy consumed in one packet in GADC-HAR and WBSN-HAR was stated in Fig. 5.7. Per bit energy consumption of GADC-HAR, WBSN-HAR and Alshaheen H. [37] are compared in Fig. 5.8.

Table 5.4: Consumed energy and gait time in GADC-HAR

	Young		Adult	
	Normal	Fast	Normal	Fast
Gait (Sec)	1.04	0.96	1.3	1.09
Energy (μJ)	559	540	668	651

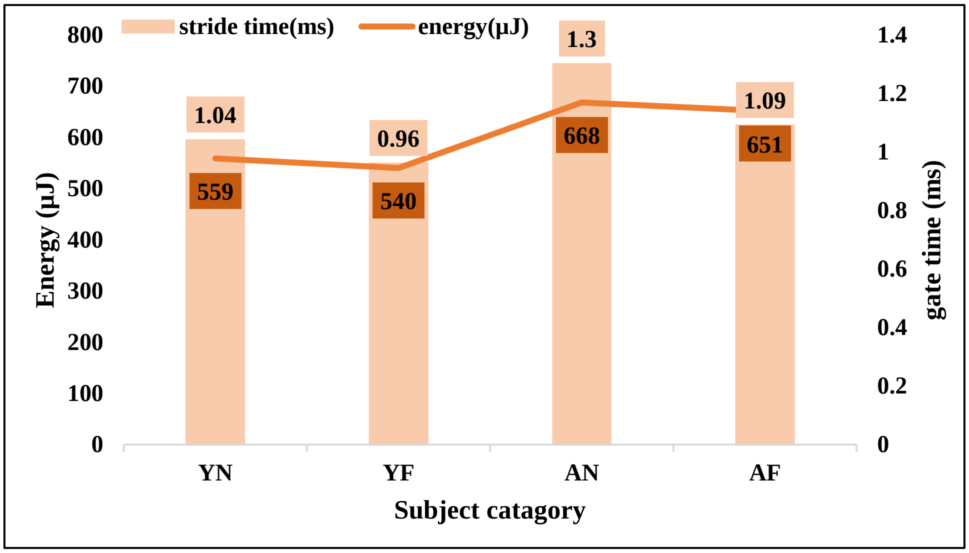


Figure 5.9: Relation between gait time and energy consumption in GADC-HAR

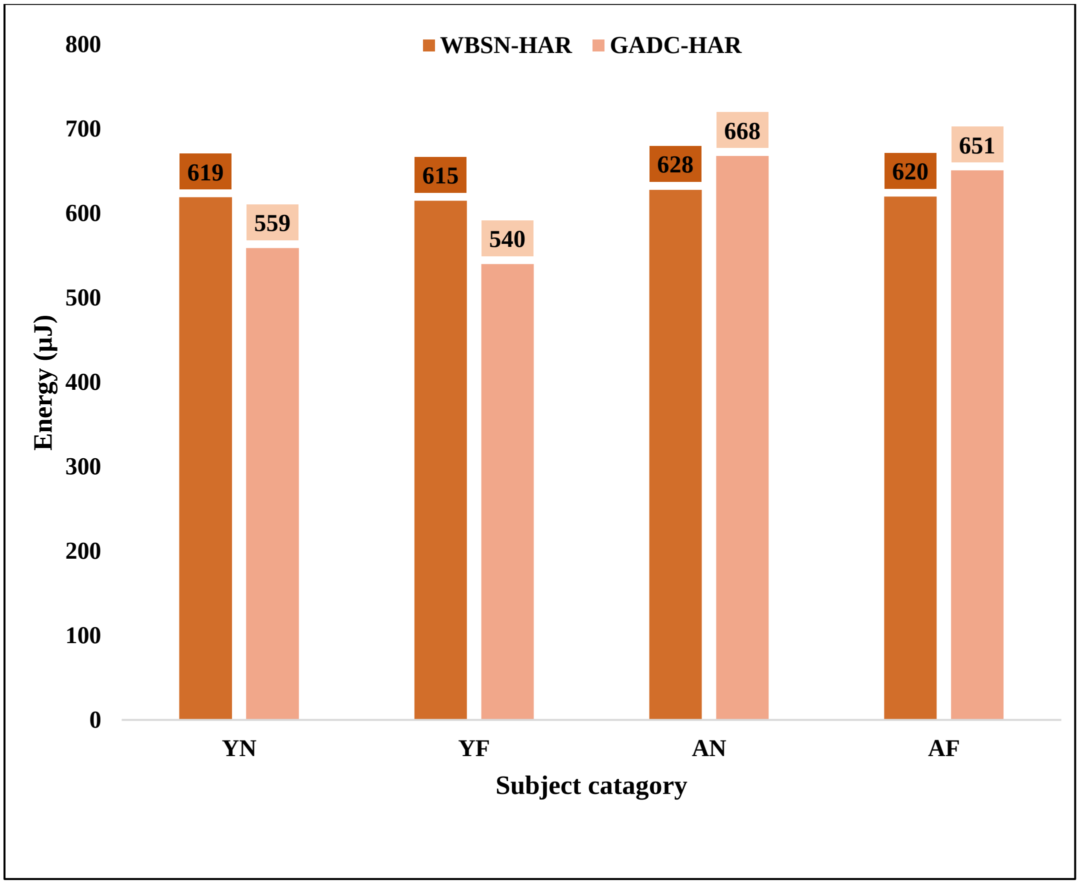


Figure 5.10: Energy consumed in one packet in WBSN-HAR and GADC-HAR

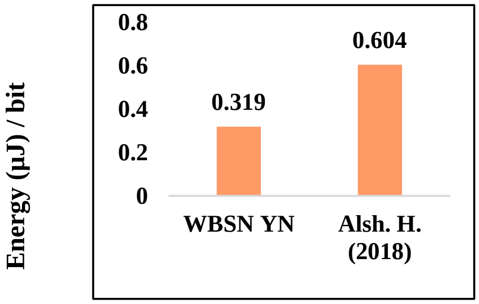
For the performance validation of proposed models, the average per-bit energy consumption of WBSN-HAR and GADC-HAR was compared with Alshaheen H. [37] and shown in Fig. 5.9. Alshaheen H. et al. had designed a mathematical model for coordinated duty cycle algorithm (based on traffic behavior and priority of the node data) to save energy of the biosensor nodes in bottleneck zone. The same model was implemented in Matlab and the simulation results were compared for energy consumption with XOR NC (a previous technique).

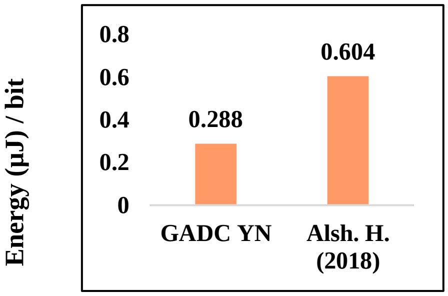
In our study, A case study of human activity recognition was implemented. In the proposed model energy was saved by large superframe size and the gait adaptive duty cycle. The comparison techniques considered are given below:

Techniques/metods	Alshaheen H. et al.	GADC-HAR/WBSN-HAR
Platform	Simulator (MatLab)	A case analysis
Superframe size	250 Kb	2KB
Duty cycle coding	Priority based	Gait adaptive/default (50%)
Data transmission	Regular / traffic behavior	Network wakeup time (gait adaptive duty cycle)
Energy calculation	$E_{whole\_network}^{total} = t\left[\left(E_{TXbr}^{t} + E_{RXbr}^{t} + E_{TXrl}^{t} + E_{TXrs}^{t} + E_{TXbnc}^{t} + E_{RXbnc}^{t} + E_{TXrnc+E_{TXncs}^{t}}^{t}\right)\right]$ Where: E_{TXbr}^{t} $: biosensor\ nodes\ to\ relay\ no$ E_{TXrl}^{t} $: relay\ nodes\ to\ another\ nod$	$E_T = E_B + \sum_{1}^{n}(E_{ctr} + E_c) * d^4$ Where: $E_B = E_{ig} * t_{ig}$ E_B : Boot energy E_{ig} : ignition energy t_{ig} : Ignition time $E_{ctr} = E_{st} * T_D$ E_c : Communication energy

	E_{TXrs}^{t} $: relay\ nodes\ to\ sink\ node$ E_{TXbnc}^{t} $: biosensor\ node\ to\ NC\ node$ E_{TXrnc}^{t} $: relay\ nodes\ to\ NC\ node$ E_{TXncs}^{t} $: NC\ node\ to\ sink\ node$ E_{RXbr}^{t} : Total energy of data reception on relay nodes	E_{ctr} = CN energy required to record data E_{st} : CN load time energy T_D : Time required to communicate data $E_c = \left(\frac{E_{sc}}{E_{st}}\right) * b_r$ $\frac{E_{sc}}{E_{st}}$: the standard communication energy required for standard bits (E_{st}) b_r : Number of bits d^4 : path loss during the data communication

It was observed that GADC-HAR was 2.89% energy efficient than WBSN-HAR and 48.5% energy saving than Alshaheen H. [37], whereas WBSN-HAR was 47.01% efficient than Alshaheen H. [37].





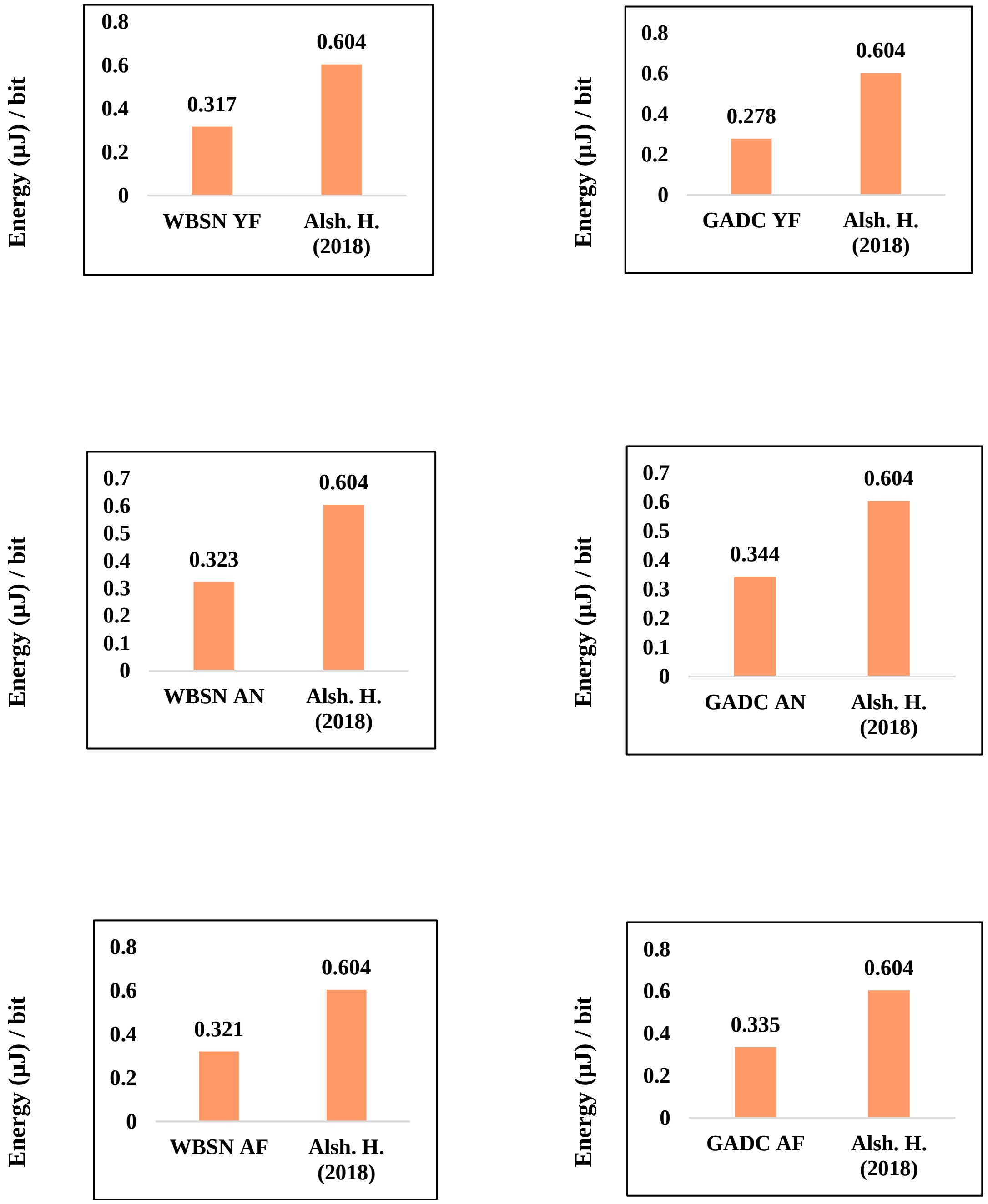


Figure 5.11: Per bit energy consumption

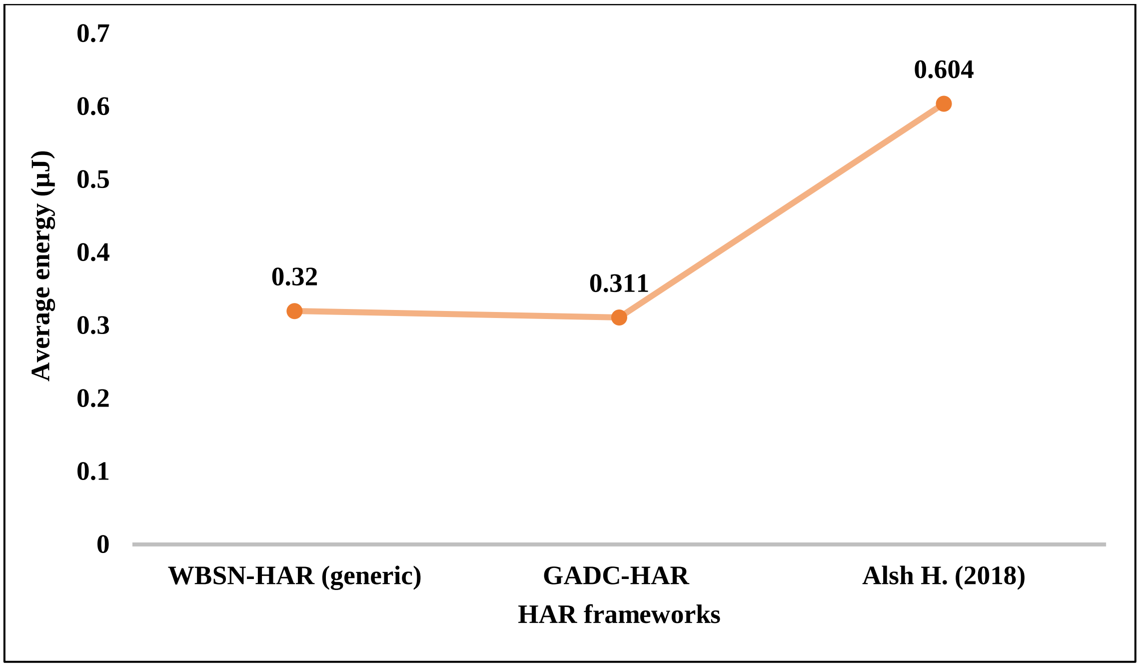


Figure 5.12: Average per bit energy consumption and comparison of WBSN-HAR, GADC-HAR and Alshaheen H. (2018)

Chapter 6

Conclusion and Future Scope

WBSN is the byproduct of WSN insight research and has many vertical application areas like healthcare, sports, defense, surveillance and many more. WBSN can be contemplated as the origin of biomedical engineering. This research focused on healthcare applications, precisely human activity recognition. In the last two decades, advance research in the domain of communication technologies and MEMS gives wings to WBSN researchers. The key components of WBSN are sensors, communication protocols, computing devices and routing protocols. A refined WBSN model is required to diminish the death rates due to delays in treatment or unawareness of disease.

The prominent hundred research trends associated with the top five core research areas of WBSN were inferred with the help of LSA, a topic modeling algorithm. Recording of biophysical parameters, cloud and IoT enabled WBSN services, WBSN driven smart healthcare solutions, resource management with WBSN and communicating biophysical parameters were analyzed as five core research areas ($Ts_{5.1}$ to $Ts_{5.5}$). The challenges associated with these topics are choice of sensors, placement of sensor, data packet size for communication to optimally use the bandwidth available in the network, energy efficiency, reliability, accuracy and the real-time application in healthcare. In this research, recording of biophysical parameters ($Ts_{5.1}$) and communicating biophysical parameters ($Ts_{5.5}$) were carried forward to study the previously implemented WBSN models.

To propose a refined WBSN framework for better performance, so far, proposed WBSN healthcare models like WEALTHY, CodeBlue, Human++, MobiHealth, CareNet, CUIDATS, PlalMos, Spine-HRV, LOBIN and so on were studied. The earlier models were compared based on the application area, sensors used, architecture design, communication technologies and the ubiquity level of the application. Sensor interaction, data abstraction and communication protocols are the prime factors to contribute a significant role in the performance of WBSN. Energy efficiency, accuracy and reliability parameters were taken to evaluate the performance of the WBSN deployment model. These parameters can be optimized by altering the sleep / wake time, superframe size and right choice of communication protocols.

At the initial stage of the study, a refined **WBSN-HAR** deployment framework was proposed. For the optimum use of the channel bandwidth, a large size (2KB) of superframe was used by the data buffering and encapsulating the data in a packet.

Further, to enhance the performance of the system, a gait adaptive duty cycle technique was introduced in WBSN-HAR. **GADC-HAR** deployment framework was proposed by optimizing the wake time of the system. An **EER** algorithm was designed for gait adopted duty cycle.

The real time implementation of proposed models, WBSN-HAR and GADC-HAR, were carried out to validate the performance. A BSN of six 3-axis accelerometers was created to decode the subjects' gait cycle and walking activity. The experiment was performed on forty subjects, including both genders. Five stages activity pattern, comprising of 360 seconds, was performed by every subject to decode the gait events. In GADC-HAR, a strategic process of self-optimization was adopted for gait cycle synchronization. The magnitude of accelerometer data was computed to decode the gait cycle. Accelerometer data were recorded at 100Hz, mean cadence value 115, 124, 90 and 110 were calculated for YN, YF, AN and AF subject categories, respectively. The mean stride time (gait cycle) 1.04, 0.96, 1.3 and 1.09 were respectively calculated for categories mentioned above. Wake time of 1, 2, 3 or 5 ms for the central node was automatically adopted for the particular gait cycle time as elaborated in the EER algorithm.

WBSN-HAR and GADC-HAR were evaluated for consumed energy, accuracy and packet loss ratio. The WBSN-HAR proved 47.01% and GADC-HAR 48.5% energy efficient with respect to Alshaheen H. [37]. The combination of SVM and RNN was applied for walking activity recognition. GADC-HAR resulted in 10.45%, 11.28%, 25% and 25.13% more accurate than WBSN-HAR YN, YF, AN and AF, respectively. The GADC-HAR was ascertained as more reliable because the average packet loss ratio of GADC-HAR was reduced by 53.6% and 7.92 % in reference to WBSN-HAR and Zang W. [94].

In the future, the same model with different clothing which affect gait (Indian saree, formal skirts and different types of footwears) would be implemented and validated. In future implementation, the energy efficient and accurate model can be implemented for multiple healthcare applications like cardiovascular diseases, Parkinson patients, pediatric patients and so on. For elderly care and chronically ills, the reliable, accurate and energy efficient WBSN systems can be designed to record numerous types of data related to their medical record or advised by the physician. For WBSN based heart rate monitoring system, sleep / wake time can be optimized by computing the mean of the decoded pulse rate of the respective person.

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