An Insight on Optimization Techniques for Uncertain and Reliable Routing in Wireless Body Area Networks

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Article Info
Journal of Machine and Computing (http://anapub.co.ke/journals/jmc/jmc.html)
Doi: https://doi.org/10.53759/7669/jmc202303013
Received 22 September 2022; Revised form 15 January 2023; Accepted 12 February 2023.
Available online 05 April 2023.

Abstract – In recent times, Wireless Body Area Networks a subsection of Wireless Sensor Network is a promising technology for future healthcare realm with cutting-edge technologies that can assist healthcare professionals like doctors, nurses and biomedical engineers. Machine Learning and Internet of Things enabled medical big data is the future of healthcare sector and Medical Technology-based industries leading to applications in other sectors such as fitness tracking for commercial purposes, Sportsperson health monitoring to track their day-to-day activities and wearable devices for critical and emergency care. This comprehensive review article addresses Wireless Body Area Network state-of-art and the dependence of Optimization Techniques and Meta-heuristic Algorithms for an efficient routing path between two sensor nodes: source node and destination node and it plays an effective role in optimizing the network parameters such as radio range, energy consumption, throughput, data aggregation, clustering and routing. Designing of energy-efficient routing for wireless body are network is such a challenging task due to uncertainty in dynamic network topology, energy constraints and limited power consumption. Optimization Techniques can help the researchers to achieve the drawbacks mentioned above and energy-efficiency of the network can be improved. In this article, we focus majorly on the efficiency of usage of optimization algorithms for Wireless Body Area Network routing mechanisms and a summary of its earlier studies during 2012-2023 epoch. Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, Artificial Bee Colony and Firefly Optimization algorithms were discussed on achieving local optima for better results through optimization. This article provides an insight into existing gaps and further modifications to the researchers in WBAN that can motivate them to propose new ideas for reliable solutions. Performance comparison and evaluation of different bio-inspired optimization algorithms has been discussed for further improvement in optimized routing algorithms.

Keywords – Wireless Body Area Network, Wireless Sensor Network, Optimization Techniques, Meta-Heuristic Algorithms

I. INTRODUCTION

One of the major concerns and challenges within wireless technologies domain is ubiquitous communication. This concern leads to the extreme need for better functioning of network system architecture and signal sensing and processing techniques. Advancement in wireless networking methodologies has created major impacts in our day-to-day life [1]. Miniaturization of wireless sensor devices offers greater flexibility, interoperability, mobility, powerful and cost-effective. There are few areas where miniaturization of sensor devices needs improvement. Body-based sensor devices induce adoption risks to end-users and very hard for aged people to utilize the technology. Senior citizens and patients with chronic diseases need to be monitored continuously. Patients staying in the hospital are more concerned about financial challenges, and the quality of treatment provided by hospitals is directly proportional [1-2].

WBAN vs WSN

One such technology that offers flexibility, interoperability, easy installations on or off the patient's body and easy access to remote servers by proper forwarding of data through routing protocols is performed by Wireless Body Area Networks (WBAN) .WBAN is an IEEE 802.15.6 wireless standard designed for real-time monitoring and assessing of sick and old aged people to carry out their lifestyle without any contradictions. WBAN supports machine-to-machine (M2M) communication in the healthcare domain with a huge number of sensor nodes communicating to monitor and assess people activities with any intervention to their daily activities [5].WBAN provides an efficient ideology for remote monitoring, telehealth and telemedicine applications that makes a feasible solution and affordable for real-time wireless networking models. Various wearable technologies from different companies such as FitBit, Noise, Apple, Samsung, Vuzix, Huawei, etc. perform real-time monitoring. According to new data from International Data Corporation (IDC) worldwide quarterly wearable tracker about 396 million units were shipped during 2020, which was increased by about 14.5% than the previous year 2019.The compound annual growth rate for the next five years is expected to be 12.4%, increasing the number of units up to 637.1 million.

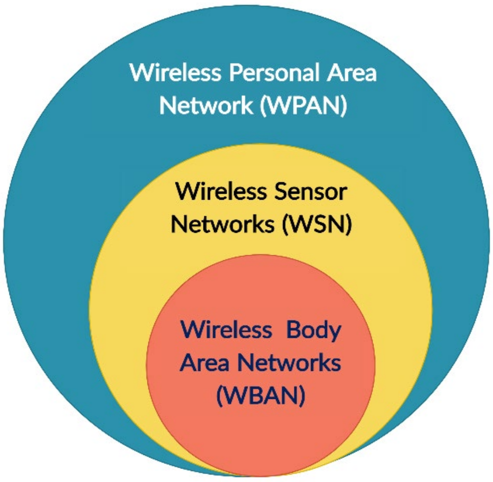

Fig 1. Spatial Scope of Wireless Personal Area Network

Fig 2. Challenges Faced by Patients During Hospital Stay

The application of these wearable devices is not limited to the medical field alone. Wearable technology can be used for various applications such as disaster and rescue purposes, work safety in harsh environments, entertainment, gaming, and critical missions. The spatial scope of Wireless Personal Area Network (WPAN) and the need for WBAN are illustrated in **Fig 1** and **Fig 2**. WPAN is a standard developed by IEEE for short-range communication between two or more closely placed entities. WBAN is a subset of Wireless Sensor Network (WSN), which is a variant of WPAN. WBAN provides an efficient ideology for remote monitoring, telehealth and telemedicine applications that makes a feasible solution and affordable for real-time wireless networking models [7].Differences is mentioned is **Table 1**.

Meta-Heuristic Algorithms

Optimization is a terminology used in various engineering applications and applied mathematics to perform either maximization or minimization of a particular function. Optimization problem involves formulating a problem model with single or multiple objective functions consisting of several variables [10]. These variables are called as decision variables which decide the convergence rate of the problem. Convergence is defined as achieving the required optimization model either attaining global maxima or global minima. Few optimization problems have one global minimum and many local minima. It is the responsibility of the optimization algorithm to make that function fall into global minima from escaping the local minima. Optimization algorithms are classified into four different categories based on the number of objective functions, constraints used, decision variable and nature of equations. **Fig 3** illustrate the various classification of optimization algorithms for engineering and applied mathematics applications. Decision making is the major concept in optimization problems to find the feasible solutions or regions which measure the performance of the optimization algorithm. Meta-heuristic Optimization Algorithms (MOA) are becoming the most widely used algorithms for solving optimization-based engineering problems [13], [14]. MOA is inspired from various methodologies like Simulated Annealing, Nature-inspired algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Fire-Fly Optimization (FOA), Cuckoo Search Optimization (CSO), Grey Wolf Optimization (GWO), Whale Optimization Algorithm (WOA) and Bacteria Foraging Optimization (BFO) [11], [12]. Meta-heuristics algorithms are applied to various engineering applications such as designing, finance, structuring and planning, big data engineering, networking, machine learning, deep learning and artificial intelligence. Despite various algorithms have been proposed, there are few cons in developing and developed algorithms due to the fact of non-linearity, complex problems and stochastic problems introduced in optimization algorithms. Convergence rate may vary based on the specific application in the problems.

II. WBAN STATE OF THE ART

WBAN Introduction

WBAN consists of heterogeneous tiny sensors that are wirelessly connected to sense various human vital physiological parameters such as blood pressure, body temperature, pulse rate, heart rate, movement tracking etc. WBAN supports lifetime monitoring of patients under medical observations without disturbing their daily activities.

Advantages of WBAN include invasive and non-invasive monitoring of patients and forward the sensed data to nearby data aggregator node. Data aggregator collects all sensed data from the body sensors through access points and performs the analysis. Data aggregators pass the data to remote servers located in hospitals through the internet. Researchers and academicians are keen towards this wireless technology which could be the future of healthcare sector as it performs early analysis of problems associated with patients and the compulsion of patients staying in hospitals has been drastically reduced because of the emergence of WBAN [6].

Table 1. WBAN vs WSN

Parameters	WSN	WBAN
Network Scalability	Supports environmental monitoring for several km, large scale network	Supports monitoring of human body, Small scale network
Connected Nodes	Connects upto 1000 nodes / network	Connects upto 256 nodes / network
Node Size	Comparatively larger than body sensor nodes	Miniaturized nodes or tiny sensors
Node Restoration	Easy replacement	Easy replacement of On-body sensors, impossible for Off-body sensors
Energy Harvesting	Renewable energy sources such as wind and solar energy	Thermal effect in body and Body movement
Mobility	Most of the nodes are static	Based on user activities
Compatibility	Compatibility not necessary	Compatible to the human body for implantable sensors
Network Lifetime	More than ten years due to its available energy resources	Maximum of 3 years due to limited energy resources
Link Quality	Good	Not good for implantable
Confidentiality	Recommended	Highly recommended
Network Type	Heterogeneous	Heterogeneous
Network Density	High	Low
Accuracy	Average	High Accuracy is mandatory
Data Transmission rate	Differ	Differ
Latency	Differ from node to node	High
Communication Technology	Bluetooth, ZigBee, RF, WLAN	UWB, BLE, ZigBee
Deployment	Random	Fixed

Sensor Types and its Functions

In WBAN, three distinguished devices are used [1]:

- **Sensor Node (SN):** SN consists of a transducer, processor, transceiver, energy module and memory hardware. Sensors can sense the necessary parameter attached to a body, perform parameter processing and communicates with the aggregator through multiple nodes in the network.
- **Actuator Node (AN):** Actuator is a device that reacts to receive information from the sensors. AN is similar to SN, and one difference is it contains actuator hardware instead of the transducer.
- **Personal Digital Assistants (PDAs):** PDAs are referred to as sink node or data aggregator. Collects data from sensors and actuators and relays it to the remote server located at hospital premises. Wi-MAX, GPRS, 3G or GSM enabled PDAs to utilize services for transmitting data from one location to the other.

The sensors are wirelessly interconnected to the nearby sensors and data aggregator through various wireless communication standards such as Bluetooth, ZigBee, and Bluetooth Low Energy [7]. Based on their role and its placement, the sensor nodes are classified. The sensors that are classified based on their placement are mentioned below:

- **In-Body Sensors:** In-body sensors, also known as implanted nodes, are implanted or placed underneath the skin, or inside the body, is called as In-Body sensors.
- **On-Body Sensors:** On-body sensors are nodes that are placed on the surface of the skin. It is also known as wearable sensor or body surface sensor nodes.
- **Off-Body Sensors:** These sensors are placed close to the body or placed at a distance of 5 meters away from the body. The sensors that are classified based on their role in the network are mentioned below [4].

- **End Nodes:** End nodes are intended to particular sensing applications with limited resources and restricted relaying access in the network.
- **Assistive Nodes:** Assistive nodes act as an intermediate node for end devices since they don't have direct communication with the coordinator or sink node. Relay nodes have better resources than end nodes, and it can forward data to the sink node directly or indirectly with a maximum number of hop counts are 3.
- **Central Coordinator Node:** Coordinators acts as a gateway between sensor nodes and the remote servers. The coordinator is a trust center for WBAN, where most of the sensor nodes rely on it.

WBAN Architectural Framework and Communication Architecture

WBAN includes 3-tier communication architecture for sensing various vital physiological parameters and forwards it to healthcare workers. **Fig 4** depicts the 3-tier architectural framework for WBAN communications. The 3-tier framework is classified as (1) Intra-BAN, (2) Inter-BAN and (3) Extra-BAN or Beyond BAN.

- **Intra-BAN:** Intra-BAN illustrates the Tier-1 communication of WBAN. Sensor nodes form Tier-1 architecture which illustrates the communication between body-sensor nodes and the central coordinator/sink node. Body-sensors attached or implanted to human body perform sensing operations with the help of small-sized energy resources with a coverage area up to 5 m. Since the energy is limited to a small value, the lifetime of each node is comparatively low when compared to WSN nodes. Sink node receives sensed information from the body-sensor nodes located within the same tier. Sink nodes are provided with sufficient resources to perform processing and forwarding operations. Sink receives information and processes it based on end-user applications and then forwards it to the next level.

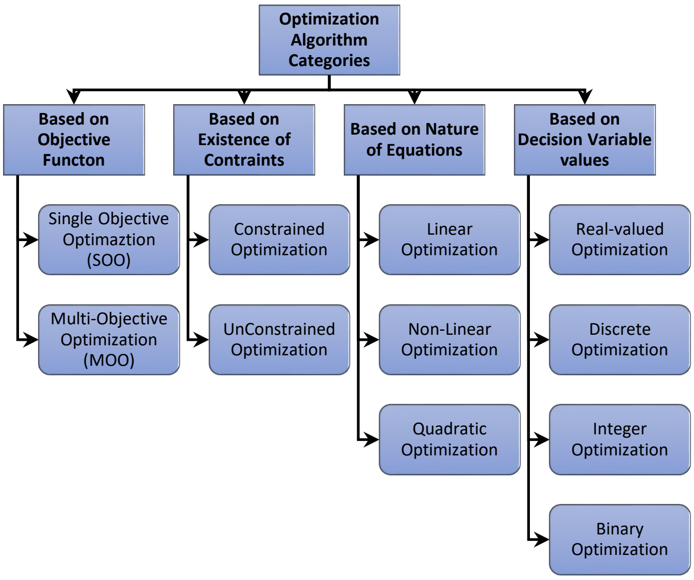

Fig 3. Classification of Optimization Algorithms

- **Inter-BAN:** Inter-BAN illustrates the communication module of WBAN architecture. It forms the Tier-2 framework, which enables the transmission of sensed data from tier-1 to tier-3 using wireless communication standards such as Ultra-Wide Band (UWB), Bluetooth Low Energy (BLE) and ZigBee protocols. The communication link is established between the sink /coordinator node in Tier-1 and the wireless access point. Tier-2 helps the WBAN to connect different WBANs, and transmission of these WBANs is done routinely. Tier-2 communication module operates in two main categories: (1) Infrastructure-based: Applicable for centralized network and administration. Bandwidth is high, highly robust and scalable network. (2) Ad-hoc based: Applicable for distributed or decentralized network with fast deployment possibilities and supports network with high mobility.
- **Beyond-BAN:** PDAs in Tier-2 communicates to healthcare professionals, caretakers through wireless access point and internet. The healthcare professionals monitor the patient data through mobile phone applications or website through secured credentials for specific files in the medical database. The medical database is the central point which stores the patient's record concerning history, present status and patient's personal information. The sensed information can be monitored by his/her family members to monitors continuously 24/7. In case of any emergencies, an alert is sent to both healthcare professionals and caretakers.

The wireless communication architecture of WBAN is classified into three categories

- **In-Body Communication:** In implanted sensor nodes, only limited resources are available, and hence it will not directly communicate with the sink/coordinator node. Implanted nodes forward the sensed data to On-body sensors or wearable sensors fixed on the human body which is called as in-body communication.

- **On-Body Communication:** Wearable sensors with limited resources forward data to nearby sensor nodes and relay nodes forward the data to the sink node, which is called as on-body communication. This network forms a multi-hop WBAN.
- **Off-Body Communication: Transmission of** sensed data from on-body or off-body sensor over a long distance is called off-body communication.

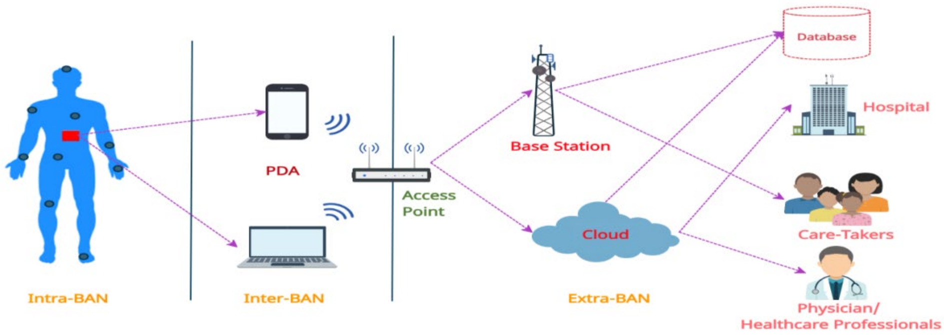

Fig 4.WBAN Architectural Framework

Network Structure and Topology of WBAN

WBAN can interconnect all other networks with a maximum of 256 nodes in a network. WBAN deploys short-range communication with a coverage area of 2-5 m. Sensors in WBAN should have the following features:

- Sensors are connected to a central coordinator node either by star topology or hierarchical tree structure
- End sensor nodes are supported with limited processing capabilities and limited energy resources
- End nodes should be highly energy efficient
- Relay nodes and central coordinator nodes are supported with all processing capabilities and an enormous amount of energy resources than end nodes
- Communication between end nodes and the coordinator node is the simplex mode.

The network topology is defined as the arrangement and interconnection of devices or nodes in a network which may be a physical or logical connection is illustrated in **Fig 5.** WBAN is a heterogeneous network with different specifications and processing capabilities. Based on the node specifications, energy allocated, and processing capabilities, the network hierarchy is implemented [8]. Nodes with limited processing and energy resources are placed at the low-level of hierarchy. Nodes having processing capabilities and adequate energy resources are placed at mid-level of hierarchy.

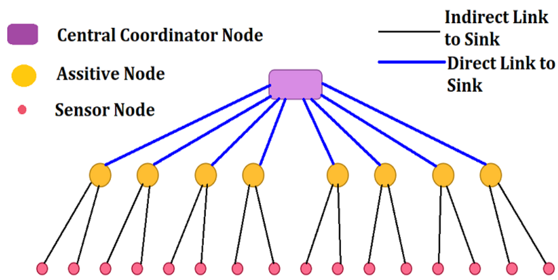

Fig 5. Topology of WBAN

All the nodes converge at one single point called the coordinator node. Coordinator node performs most of the processing and analyzing of sensed data. It is supplied with an enormous amount of energy and processing capabilities. Hence, the coordinator node is placed at the top-level hierarchy. For a single-hop WBAN, star topology is deployed with the coordinator node as the central node [6]. For multi-hop WBAN either meshes, tree or hierarchical tree topology is deployed with coordinator node at top-level of hierarchy.

WBAN Network Layers

A framework defines WBAN communication model to implement networking protocols in all layers which divides the communication architecture of WBAN into five layers namely Physical (PHY) Layer, Media Access Control (MAC) Layer, Network Layer, Transport Layer and Application Layer. PHY and MAC layers play a major role in improving WBAN. These two layers are responsible for managing all parameters required to build a proper network [9]. As the paper is focused on reliable and energy efficient routing in WBAN, the impact of clustering in network layer influences the performance metrics in other layers especially physical layer and application layer. So, it is necessary to understand the challenges in other layers of wireless body area networks.

Network Layer Challenges

The main function of the network layer in WBAN is to route the packets to the destination and also to other external networks, servers, remote systems and data centers. For efficient packet routing, suitable routing protocols should be chosen. It should not compromise on other parameters such as energy consumption, delay, and throughput and network lifetime. **Table 2** illustrates the challenges faced in the network layer of WBAN [9].

Table 2. Challenges in Network Layer

Challenges in Network Layer	Reason
Optimal Routing	WBAN has to choose the best optimal routing path to route the packets. Due to minimal bandwidth constraints communication is badly affected.
Multi-hop routing	Single-hop routing consumes more energy, whereas multi-hop consumes less energy. Multi-path WBAN protocol establishes robust and reliable communication
Network Status	Stable network link should be established. The network becomes unstable due to channel conditions, buffer, packet priority etc.
Real-time data streaming	WBAN monitors crucial data, and without any delay, it should reach its destination. If there is any delay in transmission the probability of delay is estimated
Mobility	WBAN has dynamic topology due to its mobility. Wearables and fitness devices placed on the body imposes mobility in WBAN
Localization	Due to mobility, localization of nodes for seamless data transmission has to be addressed
Security	Network Security threats such as Sybil, sinkhole, blackhole, forwarding attacks should be mitigated
Fault-Tolerant Network	Faults arise during routing and topology formation which should not affect the performance of the network
QoS	Improved data routing, Low latency, Congestion control, error detection and correction improves network QoS

Routing Evaluation Metric

During the WBAN design process, the evaluation metrics for routing protocols must be identified to know the challenges and issues in designing the best routing protocol. As discussed earlier, the challenges and issues in network layer vastly affect the performance and QoS of WBAN design. The challenges include topology of WBAN, node mobility; available network resources, heterogeneous network, network lifetime and hindrance due to node mobility or user mobility for evaluating WBAN design are specified in the following **Table 3.**

Table 3. Performance Metrics in Routing Evaluation

Metrics	Definition
Network Stability	The first node to be dead in the network
Network Lifetime	Time taken for the last node to be dead in the network
Delay	The average time taken by WBAN packet to reach sink/coordinator
Path Loss	Difference between source transmitted power and sink's received power
Residual Energy	Amount of energy left over after completion of transmission
Packet Delivery Ratio	The ratio of packets received at the sink to packets sent by the source
Throughput	Number of packets received at the sink node

Classification Routing Protocols in WBAN

In this comprehensive review article, a brief knowledge transfer on the complete state-of-the-art of WBAN and its challenges in designing routing protocols. The authors discussed the challenges related to WBAN layer design. The different classification of WBAN routing protocols and the network performance parameters were analyzed. The authors in optimizing the routing path and enhancing the network parameters by including routing protocols objectives, advantages, disadvantages of performance parameters of WBAN routing protocols. Based on the medical and non-medical applications, the design and implantation of WBAN routing protocol are categorized into five types. The categories of WBAN routing protocols are

Cluster-based Routing Protocols

Due to limited energy constraints in WSN and WBAN, researchers developed efficient clustering protocols to minimize the usage of power consumption and to increase the stability and network lifetime. Clustering in routing protocols supports both direct and indirect transmission of sensed data to the sink node [3]. Clustering concept reduces the energy consumed by the node during transmission. The intermediate nodes or relay nodes will forward the data to sink node from the source node to reduce power consumption and load in the network. Researchers introduced various clustering protocols to reduce power consumption. Low-Energy Adaptive Clustering Hierarchy (LEACH) is applicable for small networks with 10 to 20 nodes for the efficient clustering routing protocol. AnyBody protocol works well with an increased number of nodes with the number of clusters in the network is same as LEACH. Cluster-Based Body Area Protocol (CBBAP) enhances the overall efficiency of the network than the LEACH protocol. Hybrid Indirect Transmission (HIT) protocol enhances network stability and network lifetime, far better than LEACH, AnyBody and CBBAP. The performance metrics used for evaluating clustering-based routing protocols are throughput, residual energy, network lifetime, cluster size, number of alive nodes, packet delivery ratio and average delay. Cluster Tree Based Routing Protocol (CT-RPL) selects the best cluster head based on the Euclidean distance and the efficient route is selected using a game theory approach [29].

Cross-Layered Routing Protocols

Cross Layered Routing Protocols are applicable for both WSN and WBAN. Protocol stack of each layer shares their information to both adjacent and non-adjacent layers [6]. In WSN architectural designs, cross layered protocols are used for different requirements in WSN applications [28].In WBAN, cross-layer routing is applied to the MAC and Network layer to enhance the network routing performance. Various cross-layer routing protocols were developed to enhance network performance [30]. Biocomm and Biocomm-D is a cross-layered architecture that enhances performance by optimizing the network parameters in both MAC and network layers. Biocomm and Biocomm-D analyze the temperature rise, mean energy consumption, packet delivery ratio, packets dropped and throughput of the network. Cascading Information Retrieval by Controlling Access with Distributed Slot Assignment (CICADA) reduces end to end delay by introducing scheduled slots for data with most priority to least priority. CICADA reduces delay and power consumption in the network. Wireless Autonomous Spanning Tree Protocol (WASP) analyzes end-to-end delay to reduce power consumption, network delay and packet loss [31]. WASP is compared with legacy CSMA in the MAC layer, and fixed routing in the network layer ensures better packet delivery ratio. Cross-layered routing protocols are applicable for both in-body and on-body sensor network routing.

Postural based Routing Protocols

Postural based routing protocols were designed to overcome the problems created by node mobility or user mobility leading to link disconnection [3]. The cost function is introduced by researchers for periodic analysis of network performance by helping the nodes to choose the best routing path for better transmission of packets. Energy-efficient Thermal and Power-Aware (ETPA) routing protocol analyze the node's temperature placed under human skin or in-body sensors. Due to which the nodes temperature and forms a hotspot surrounding that node. ETPA controls the number of hops taken by the packet to reach its destination. Various metrics analyzed by ETPA is throughput, temperature rise, stability and scalability. ETPA prevents the rise in node temperature and formation of a hotspot. Prediction based Secure and Reliable (PSR) routing protocol supports reliable routing and secured transmission of data. PSR concentrates on the number of dropped packets and user authentication for data security. Distance Vector Routing with Postural Link Costs (DVRPLC) deploys distance vector routing based on the body movement link costs to enhance packet delivery ratio. It reduces end-to-end delay and reduced hop count. On-Body Store and Flood Routing (OBSFR) is used for routing packet between on-body nodes and sink node, which provides better routing and reduced hop count. OBFSR uses average delay, several packet transmission and packet delivery ratio. Probabilistic Routing with Postural Link Costs (PRPLC) reduces end-to-end delay. OBFSR is better when compared to other postural based routing protocols which provide better network performance and less delay in the network.

QoS Aware Routing Protocols

Various QoS based routing protocols were deployed in WSN, which cannot be implemented in WBAN due to its various network parameters and size of the nodes. Since WBAN is a heterogeneous network, it requires different QoS protocols, unlike WSN. Based on the application of node or data-centric applications routing protocols were assigned with different QoS metrics [3]. Efficient Next-hop Selection Algorithm (ENSA) identifies the best next-hop selection based on distance and energy available in the nodes. The metric used for evaluating ENSA is energy consumption, number of packets sent delay and packet delivery ratio through link cost function, which improves overall network performance. Multi-hop Protocol using Cost Function (MPCF) utilizes multi-hop routing of data packets from the source node to the sink node. MPCF improves network performance based on nodes distance and residual energy. Critical Data Routing (CDR) used for forwarding critical data packets by assigning a high priority to those packets. CDR is applicable for implanted sensors which reduces temperature rise and hotspot formation. CDR concentrates on on-time successful packet delivery ratio due to forwarding of critical data. Threshold-sensitive Energy Efficient sensor Network (TEEN) protocol assigns threshold value for all critical data. TEEN continuously monitors the node's temperature and the human body and tries to minimize the temperature by forwarding data to the nodes with less temperature. Adaptive Routing and Bandwidth Allocation (ARBA) protocol monitor the bandwidth usage in the network. ARBA assigns different bandwidth for different nodes for efficient utilization and enhances the network routing in WBAN. Network Lifetime is improved when ARBA is used. Reliability Aware Routing (RAR) is used for packets which require reliability performance metrics. RAR analyzes energy consumption, delay and packet delivery ratio in the network. Cooperative Link Aware and Energy Efficient protocol for Body Area (C-LAEEBA) network protocol selects the best forwarding node for cooperative transmission of data packets. C-LAEEBA minimizes the path-loss in the network through cooperative network transmissions. Energy-aware Peer Routing (EPR) protocol are reliable data-sensitive protocol. QoS-aware routing protocols provide reliable communication, data-centric routing, delay-sensitive for reliable data transmission.

Temperature Aware Routing Protocols

Implanted body-sensor nodes undergo various radiation issues from antenna, interference and absorption in designing a reliable WBAN. These radiations induce a temperature rise in node, and it forms a hotspot region around the muscles and skin which will damage the tissue [3]. The temperature rise not only affects network performance, but it also affects human body tissues. Reliability Enhanced Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Routing protocol (RE-ATTEMPT) is a protocol used for implanted nodes to maximize the network lifetime by reducing average dead nodes count, throughput, packet delivery ratio and the number of packets dropped. Mobility-supported ATTEMPT (M-ATTEMPT) sense the node temperature and formation of hotspot region around the node. M-ATTEMPT efficient routing enhances the network lifetime by reducing the rise in node temperature. Hotspot Preventing Routing (HPR) algorithm decreases delay in packet transmission by reducing the occurrence of hotspot formation. Least Total-Route Temperature (LTRT) protocol reduces the temperature rise in implanted sensors. Thermal Aware Routing Algorithm (TARA) analyzes the temperature value of neighboring nodes and route the packets through the nodes with low-temperature value. TARA is suitable for implanted nodes. Thermal-aware Shortest Hop Routing (TSHR) algorithm reduces the rise in node temperature and hotspot formation in the network.

III. CLASSIFICATION OF META-HEURISTIC ALGORITHMS

Genetic Algorithm

Genetic Algorithm (GA) is a branch of meta-heuristic search-based optimization algorithm which mimics the process of natural evolution. Theory of Evolution is based on the natural selection which selects the best in population and discards the inefficient population. Genetic Algorithm simulates the evolution species through natural selection. GA procedure involves the following steps: Initialization, Selection, Crossover, Mutation and Fitness Evaluation is given in **Fig 6**. Convergence rate of GA is based on the number of iterations or generations. **Fig 7** illustrates the process flow of GA [26]. An optimal solution is estimated by generating individual solutions through a genetic algorithm. GA terminologies used for the optimization process is illustrated in **Table 4**.

Table 4. GA Terminologies

GA Terminologies	Description
Population	The possible solution set in an optimization problem
Chromosome	Set of solutions to frame a population
Gene	A single unit of chromosome
Individual Solution	Every candidate which provides a solution
Fitness Function	A function used to calculate the fitness of each individual selection

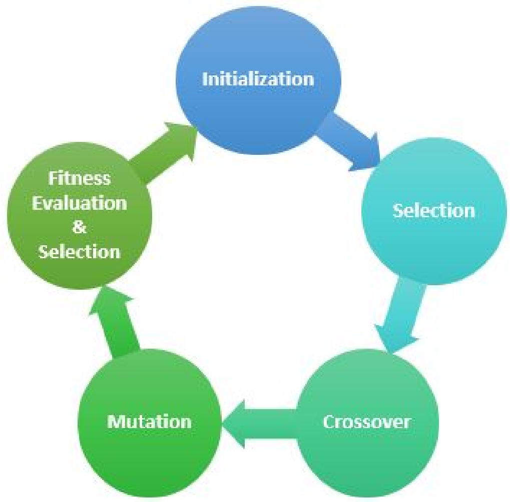

Fig 6. Genetic Algorithm Procedure

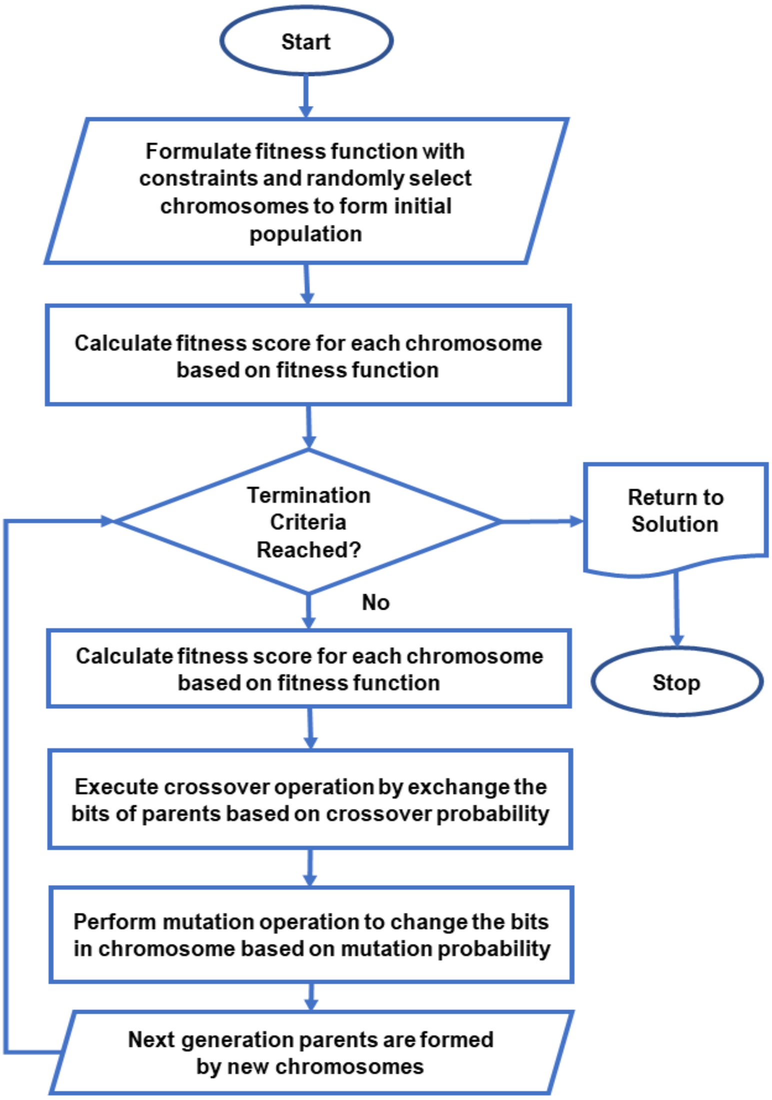

Fig 7. Genetic Algorithm Process Flow

Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a bio-inspired search based meta-heuristic optimization algorithm. In PSO, each bird will search for its particle or food to a particular breed of birds. PSO is based on a flock of birds searching for its prey which depends on position and velocity of the bird. The bird with more fitness finds its prey sooner than other birds. In PSO, it is necessary to update the position and velocity to achieve convergence [24], [25]. The optimal solution is obtained when the algorithm has obtained it convergence factor in **Fig 8** and **Fig 9**.The searching process can be stimulated artificially by formulation a non-linear optimization problem. PSO is a population-based meta-heuristic random search method.

Table 5. Terminologies used in PSO

PSO Terminologies	Description
Swarm	Set of feasible solutions based on population
Particles	Number of populations
Velocity	Determines the speed of swarm towards the solution
Personal Best	Determines the fitness value of each bird
Global Best	Determines the overall best solution from all particles
Fitness Function	The function used to calculate the fitness of each individual selection

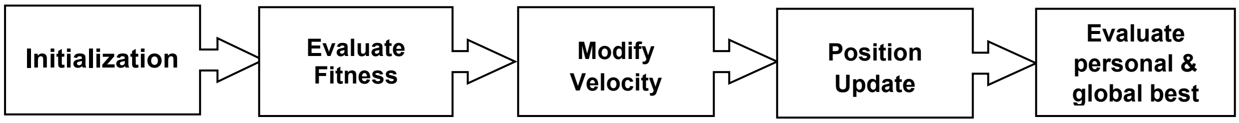

Fig 8. PSO Procedure

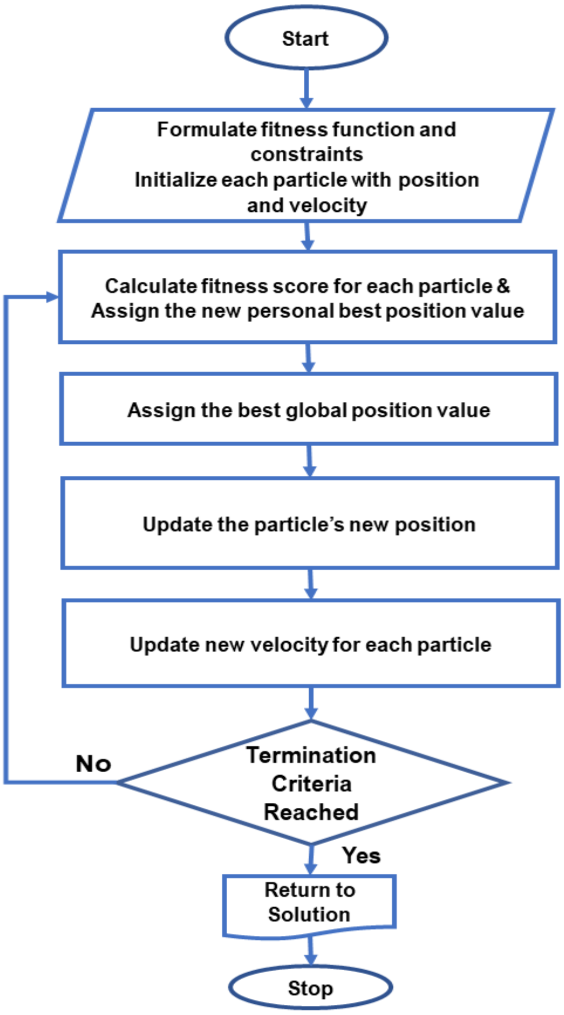

Fig 9. PSO Process Flow

Each bird is considered as a solution called particle formulated by a fitness function to calculate its fitness score. Each particle has its fitness score based on the flocks' position and the particle's velocity in a random direction. Birds having less fitness value follow the bird with more fitness value to catch its prey. Birds with the highest fitness value will have a high probability of sustainability compared to birds with less fitness value since the chances of catching the prey by less fit bird are too low. The best fitness value is calculated based on its rate of velocity and direction to its prey. Velocity is updated by the effect of inertia with a random learning factor. Terminologies are specified in **Table 5** [16].

Firefly Optimization Algorithm

Firefly Optimization Algorithm (FOA) is a classification of swarm intelligent based meta-heuristic optimization algorithm which is a nature-inspired algorithm involving mating of firefly insects. Fireflies have a special characteristic which illuminates flashing light on their body to attract their partners for performing mating between their species, communication between other fireflies and alerts regarding incoming predators in **Fig 10**. Fireflies are unisexual, and hence it attracts other fireflies is directly proportional to intensity brightness of each individual [19]. Fireflies with a brighter intensity level attract fireflies with fewer intensity levels. If the fireflies have the same brightness level, they move in a random direction in **Fig 11**. The formulation of the fitness function is dependent on distance and intensity of flashing lights exhibited form fireflies.

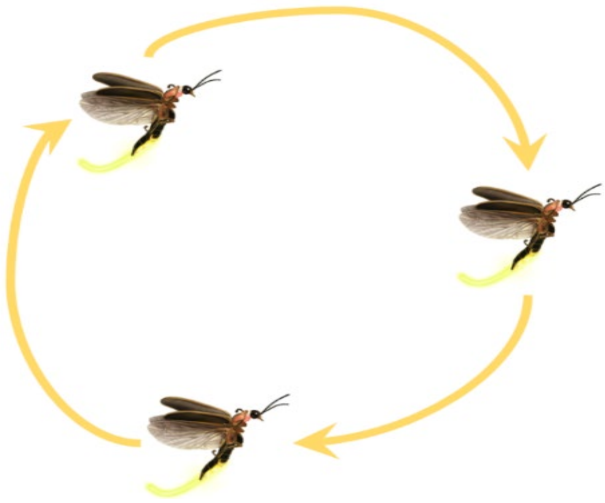

Fig 10. Firefly Optimization Process

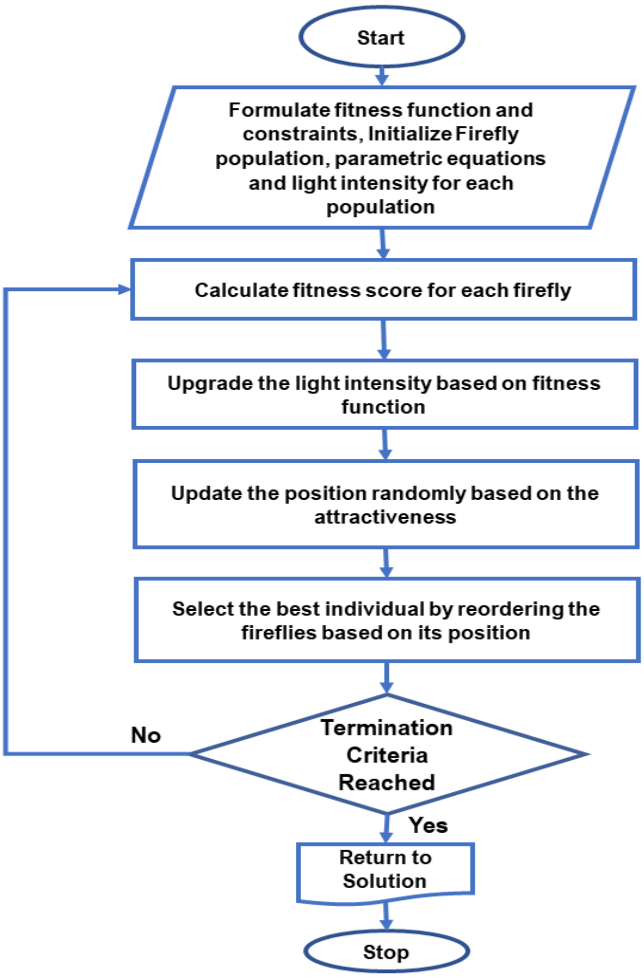

Fig 11. Firefly Optimization Process Flow

Based on light intensity principle, the light intensity is inversely proportional to quadratic proportional to the square of the area, which determines the distance between two fireflies. For continuing the algorithm process, a random principle and absorption which is interlinked to the attractiveness of fireflies when its value changes from 0 to ∞. FOA deals with solving multi-objective optimization problems which have more success ratio than PSO and GA. Table6 specifies the terminologies in FOA [19].

Table 6. Terminologies used in FOA

FOA Terminologies	Description
Population	The possible feasible solution set in an optimization problem
Fitness Function	The function used to calculate the fitness of each individual selection
Light Intensity	The brightness level of each firefly
Attractiveness	Induces the mating process between two fireflies
Randomization	Movement of fireflies towards the best possible solution
Absorption	Controls the decrease in the range of light intensity

Artificial Bee Colony Algorithm

Artificial Bee Colony (ABC) is a nature-inspired meta-heuristic algorithm derived from the intelligent behavior of honey bees in search of food. In ABC honey bees are classified into three categories based on their role in bee-hive [17].

- **Scout Bees:** Scout Bees are responsible for identifying the source of food. Scout bees are responsible for finding the food source location and mark the location, but it does not differentiate the richness of nectar in the food source.
- **Employee Bees:** Collects the information about the sources having rich nectar content. It communicates to other bees by varying its dancing style. Specific dancing style is followed by employee bees to indicate the presence of abundant nectar in the source and attracts the attention of onlooker bees by adjusting its speed.
- **Onlooker Bees:** The abundant availability of nectar is indicated by employee bees to onlooker bees. The onlooker bees tend to move towards the food location based on signaling from employee bees.

Food Source is considered an individual solution for problem formulation. Converging the bees to optimal solution relies on the richness of objective function or richness of nectar in the food source. ABC supports a multi-objective optimization problem with a faster convergence rate since there are no control parameters utilized in this optimization algorithm. **Fig 12** specifies the process flow of ABC optimization.

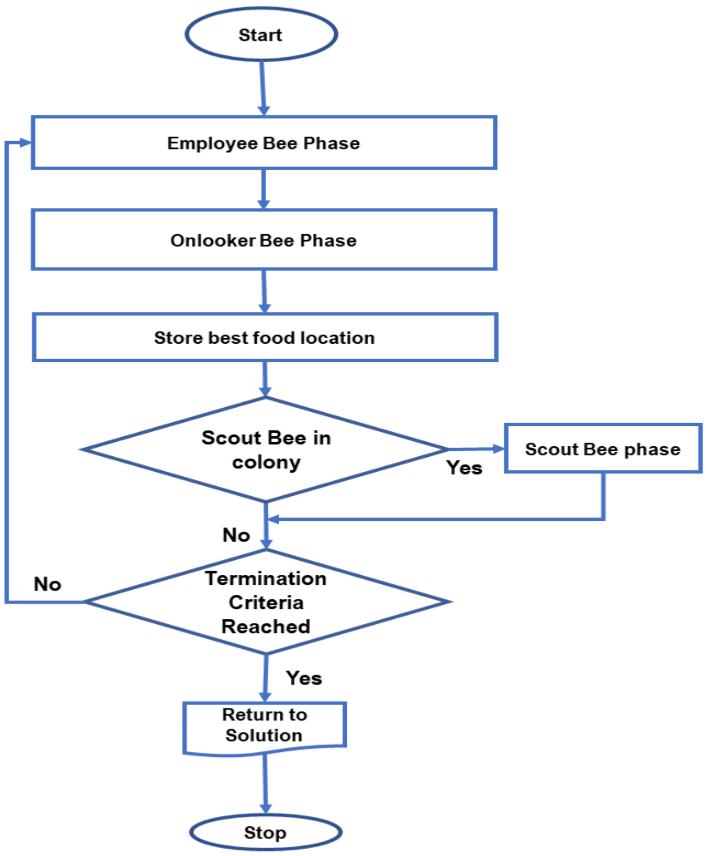

Fig 12. ABC Optimization Process Flow

Ant Colony Optimization

Ant Colony Optimization (ACO) is similar to PSO, a population-based meta-heuristic and nature-inspired optimization algorithm. This algorithm mimics the behavior of ant colonies for approaching their food. Every member of the colony identifies the path towards the food source. Ants finding the path towards food source signal other colonies' members by secreting pheromone to mark their path to the source. Ant with stronger pheromone density creates a path for follower ants to approach the food source. ACO is developed by analyzing the ant's behavior towards food searching. The objective function of ACO is based on the search area and follower ants' movement towards its food. A graph with randomly selected paths of ants is analyzed. The path is defined as the route between source and destination, categorized as the best path or worst path based on the pheromone density in that path [18].The best shortest path from the source is classified based on the pheromone density, which creates a higher probability of path selection by follower ants. This process repeats until the ants in the colonies complete its target for food. During this process, the pheromone level is updated when the follower ants travel through a path. The optimal solution is selected based on higher pheromone level and all the ants reaching its target [20]. The convergence rate is higher when the density of the pheromone level is high. **Fig 13** specifies the process flow of ACO.

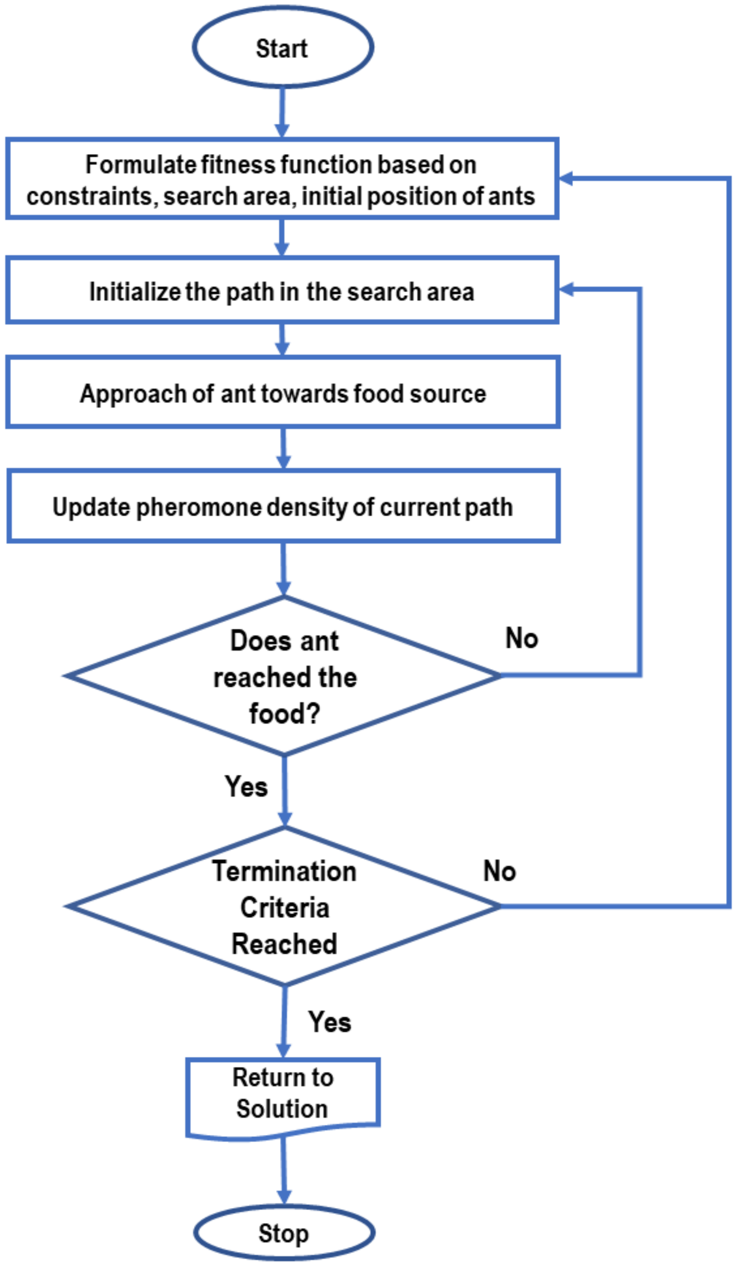

Fig 13. ACO Process Flow

Metaheuristic Algorithms: Advantages and Disadvantages

Table 7 specifies the advantages and disadvantages of the meta-heuristic algorithm, and Table **8** specifies the application of meta-heuristic algorithms.

Table 7. Advantages and Disadvantages of various Optimization Algorithms

Optimization Algorithm	Advantages	Disadvantages
GA	Supports Non-linear, discontinuous, stochastic and multi-objective optimization problems, Most efficient than random search methods, Most suitable for noisy environments, Robust against local minima or local maxima.	Design of fitness function with constraints is difficult since it requires less information, Time-consuming, Computationally expensive.
PSO	Computation is easy, Fast convergence, A robust algorithm for stochastic optimization problems.	Fall easily into local minima or maxima, Does not support high dimensional and complex problems
FOA	Robust for non-linear and multimodal optimization problems, Computation is easy and Good efficiency, Requires a smaller number of iterations, Supports developing hybrid optimization algorithms.	High computational time complexity, Slow convergence, Moderate against local maxima/ minima
ABC	Simple and Flexible, Few control parameters are required, Support complex objective functions	Less accurate, Slow convergence rate, Lack of secondary information
ACO	Best solution for small problems than larger problems, Supports dynamic optimization problems, Derivative free.	Probability distribution changes by iteration, Convergence is guaranteed but time-consuming.

Applications of Meta-heuristic Algorithms

Table 8. Various Applications of Meta-heuristic Algorithms

Meta-Heuristic Algorithms	Applications
GA	Economics, Neural Networks, Image processing, Vehicle routing problems, Scheduling applications, Machine Learning, Robotic Trajectory Generation, DNA analysis, Multimodal Optimization and Travelling Salesman Problem and its applications
PSO	Neural Networks, Telecommunication, Data Mining, Signal Processing, Combinatorial Optimization, Sensors and Sensor Networks, Metallurgy Applications, Security and Military applications, Computer Graphics and Visualization, Detection and diagnosis of fault and recovery, Finance & Economics
FOA	Solving Multi-objective Optimization & Travelling Salesman Problem, Image Processing and Compression, Feature Selection & Fault Detection, Antenna Design, Structural Design, Scheduling and Dynamic & Noisy Problems
ABC	Solves Continuous and Unconstrained Optimization problems, Wind Turbine Generators, Composing medical crews, Data Clustering, Image Processing & Optimization, Multi-objective Optimization Problem and Structural reality Problems
ACO	Vehicle Routing, Scheduling, Telecommunication, Airline Companies, Protein Folding, Graph Coloring, Quadratic Optimization Problem, Digital Image Processing, Dynamic problems and Job-shop Scheduling

IV. META-HEURISTIC OPTIMIZATION ALGORITHM IN WBAN

In **Section 2** describes the WBAN state of the art of architecture dedicated to various medical and non-medical applications. Specific constraints influence sensor nodes because of its heterogeneity network type. One of the major factors in designing WBAN is the type of data transmitted. Different sensors sense different parameter at different frequencies with distinct time intervals. The second factor influencing WBAN design is the architecture and locating nodes concerning central coordinator during mobility, which should not affect sensing and transmission of data. Implanted nodes and individual implementation based on disease influences the WBAN design. Hardware constraints play a vital role in influencing WBAN design. **Fig 14** illustrates the types of constraints that affect WBAN design and maintenance of the network model. The role of optimization in WBAN network is to manage the critical network resources under architectural and communication constraints. Optimization techniques enhance the QoS of the WBAN by maximizing the throughput, network lifetime, stability, residual energy and minimize end-to-end delay and path loss. One such approach is the implementation of a clustering approach in the network. Clustering makes the communication as multi-hop, which tries to minimize the energy consumption of nodes far away from the sink node. Nodes with limited resources which is away from the sink node make use of clustering concept which forwards the data to the cluster head [15]. Cluster head nodes will have high network resources when compared to end nodes. Optimization algorithm improves selecting the best optimal nodes to maximize network lifetime and minimize the amount of energy consumed by the node.

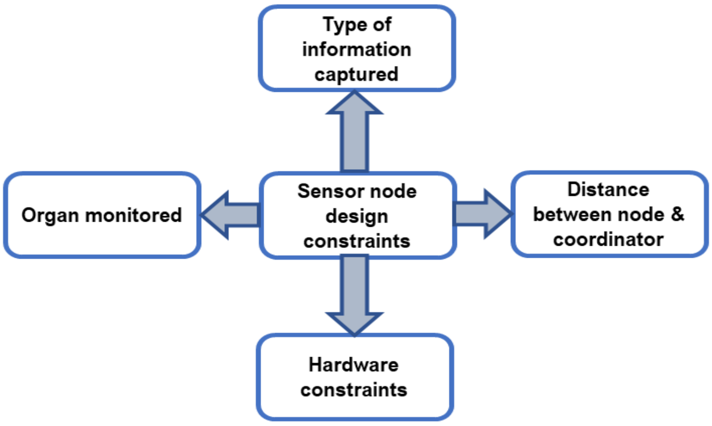

Fig 14. Sensor Node Design Constraints

Hence optimization algorithms speed up finding the best optimal solution with a faster convergence rate as WBAN is a delay-sensitive network. Meta-heuristic algorithms help the researchers to design a specific problem based on constraints to opt for the required solution for application-specific problems. Not all meta-heuristic algorithms are efficient for WBAN for specific application problems. The following **Table 9** helps us to analyze various optimization algorithms deployed in WBAN for different routing and scheduling network problems. Comparison of various optimization algorithms is performed based on the different QoS parameters such as network stability, network lifetime, throughput, packet delivery ratio, end-to-end delay, residual energy, dead nodes, alive nodes, the packet received, packets dropped.

V. FUTURE TRENDS & RESEARCH CHALLENGES

In this comprehensive review article, a brief knowledge transfer on the complete state-of-the-art of WBAN and its challenges in designing routing protocols and the impact of nature-inspired meta-heuristic algorithms were discussed. Firstly, in **Section 1**, a brief introduction to WSN, WBAN and role of meta-heuristic algorithms were discussed. In **Section 2**, a complete description of sensor hardware, WBAN layers, architecture and challenges related to WBAN layer design were discussed. Additionally, the different classification of WBAN routing protocols and the network performance parameters were analyzed.

Table 9. Performance analysis of various Meta-heuristic Algorithms based WBAN

References	Proposed Algorithm	Objective	Research Gaps
[23]	GA	Selection of best optimal routing path using GA between sensor nodes and sink node under a different scenario. Energy-efficient routing by selecting the shortest path	Performance evaluation is based only on packets dropped and dead nodes
[22]	Multi-objective GA	Ensure reliable and energy-efficient routing of data with an optimization algorithm. Multi-hop approach is used for minimum energy consumption in nodes	Energy consumption is high, which affects the network stability and reliability. Residual energy has to be discussed
[21]	GA	GA based initialization with the optimized position of sensor nodes reliable routing is achieved. Fitness function is based on received signal strength indicator	Network stability and reliability are not discussed. Placement of sink node in the ankle is not reliable.

Table 9.			**Continue**
References	**Proposed Algorithm**	**Objective**	**Research Gaps**
[24]	PSO	Relay nodes for assisting transmission over long distance sink node and to minimize energy consumption by minimal randomly selected relay nodes The fitness function of the particle is based on the transmitter's energy consumption model of the network and to update the position and velocity to find the optimal personal and global best	Pathloss is high, The ratio of dropped packets is high, Stability of the network is moderate as the first node dead is at 35% of total simulation
[25]	PSO	Performance evaluation of optimized energy-efficient routing for WBAN by using PSO and Lion mating algorithm PSO returns best results with a 23% decrease in energy consumption. Fitness function is calculated based on distance and residual energy with different costs	Poor network stability and throughput
[19]	FOA	Optimal energy-aware routing based on the relay selection method Fitness function is based on residual energy and Queue size in the network	Energy consumption is high Other network parameters were not discussed
[26]	ABC	ABC for monitoring crowd in Hajj environment Aims at reducing energy consumption and improving network lifetime Nodes with the highest energy are selected as elite bees	Throughput and packet delivery ratio was clearly discussed Energy consumption is too high
[27]	ABC	An optimal routing path selection based on energy consumption assisted by ABC Fitness function is based on path energy difference ratio, cost and transmitter energy consumed	Only energy consumption is discussed, other Network QoS parameters were not estimated.
[29]	FOA	Cluster Tree based routing protocol using firefly optimization for selecting the best parent node to extend the network lifetime	Lifetime enhancement has to be improved as it is analyzed for less simulation time. The proposed model is delay sensitive but the simulated results prove that it has to be reduced.

In **Section 3**, GA, PSO, ACO, ABC and FOA algorithms were discussed. In addition to those pros, cons and applications of these meta-heuristic algorithms were discussed. Various applications of meta-heuristic algorithms and their role in WBAN are discussed in **Section 4**.Very few works have been carried out by researchers in optimizing the routing path and enhancing the network parameters. There are few limitations faced by researchers in designing an optimal routing algorithm for WBAN using meta-heuristic optimization algorithms. **Table 9** illustrates the drawbacks of existing optimization algorithms for designing a reliable and energy-efficient routing protocol. Hence, future research work is based on formulating the best objective problem and on improving the network performance for achieving better QoS. In addition to that, application-specific routing algorithms assisted by meta- heuristic algorithms are another future scope and challenge to be faced by researchers. Each protocol proposed by researchers was found to be better than the previous works, but the results were not found to be satisfactory.

Mostly, the researchers concentrate on formulating the objective function based on multi-constraints. Still, they failed to achieve the ultimate aim of enhancing the network parameters, which is evident from **Table 9**. **Table 9** summarizes the variant of the optimization algorithm used, and the performance evaluation is carried out. Researchers majorly focused GA and PSO with multi control parameters. ABC and ACO do not depend on many control parameters, but the convergence rate concept is where these algorithms lack their intensity. The survey focuses on different bio-inspired optimization techniques with Wireless Body Area Networks (WBAN). It concentrates on the routing in network layer through which an energy efficient routing is achieved. Very few authors have addressed the issues and challenges in incorporating bio-inspired optimization algorithms with wireless body area networks.

VI. CONCLUSION

WBAN a subset of WPAN, where nodes are deployed on the body or within the body for continuous real-time monitoring of vital human biological parameters. In this survey article, various articles such as research, survey and review papers were collected between 2011 – 2020 and briefly analyze the performance of WBAN and meta-heuristic optimization algorithms for WBAN reliable routing. Design of cost-effective, reliable and energy-efficient routing protocols is the major focus of this article. Application-specific WBAN protocol designing is a major challenge. Comparative analysis of existing routing protocols and meta-heuristic optimization algorithm performance was carried out. In this survey, the authors discussed about the basics of WBAN, routing protocols and impact of meta-heuristic bio-inspired optimization techniques. The authors have written in such way to incorporate bio-inspired optimization with WBAN and analyzed the network performance metrics. The authors have discussed about the drawbacks of existing optimization algorithms for designing a reliable and energy-efficient routing protocol. Hence, future research work is based on formulating the best objective problem and on improving the network performance for achieving better QoS. The authors focused on formulating the objective function based on multi-constraints as they face various issues in formulating a single objective function with multiple constraints as they have failed to enhance the network performance. Future research work of the authors is based on multi-objective and hybrid optimization techniques.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

Funding

No funding was received to assist with the preparation of this manuscript.

Ethics Approval and Consent to Participate

The research has consent for Ethical Approval and Consent to participate.

Competing Interests

There are no competing interests.

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