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# Internet of Drones: Routing Algorithms, Techniques and Challenges

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**Abstract:** In the past decades, unmanned aerial vehicles (UAVs), also known as drones, have drawn more attention in the academic domain and exploration in the research fields of wireless sensor networks (WSNs). Moreover, applications of drones aid operations related to military support, agriculture industry, and smart Internet-of-Things (IoT). Currently, the use of drone based IoT, also known as Internet-of-Drones (IoD), and their design challenges and techniques are being probed by researchers around the globe. The placement of drones (nodes) is an important consideration in a IoD environment and is closely related to the properties of IoT. Given a base station (BS), sensor nodes (SNs) and IoT devices are designed to capture the signals transmitted by the BS and make use of internet connectivity in a manner to facilitate users. Mutual benefit can be achieved by integrating drones into IoT. The drone based cluster models are not free from challenges. Routing protocols have to be substantiated by key algorithms. Drones are designed to be specific to applications, but the underlying principles are the same. Optimization algorithms are the gateway to better accuracy, performance, and reliability. This article discusses some of these optimization algorithms, include genetic algorithm (GA), bee optimization algorithm, and Chicken Swarm Optimization Clustering Algorithm (CSOCA). Finally, the routing schemes, protocols, and challenges in the context of IoD are discussed.

**Keywords:** unmanned aerial vehicle; Internet of Drones; routing; wireless sensor network; energy efficient

**MSC:** 68-02

## 1. Introduction

With the rise of the Internet of Things (IoTs) and emerging technologies, the need for efficient wireless sensor networks (WSN) has risen. IoT has already been applied in commercial uses. The development accelerated when 4G was transformed to enable device-to-device (D2D) communication [1]. Currently, IoT and WSN terms are used interchangeably because of their similar features. Modern innovation in communication technologies has led to the evolution of a self-organised WSN composed of some sensor nodes and one or more base stations (BS) [2]. A WSN can be realised in a 3D environment with the help of sub-models [3]. According to [4], much contribution has been made to the enhancement of wireless sensor networks. However, some research challenges still must be overcome to manage the large amount of data and handle the communication issues with the deployment of the sensor nodes in the network.

One such WSN challenge is the routing of unmanned aerial vehicles (UAVs), which belong to a category of IoT termed Internet-of-Drones (IoD). The current era of humans-out-of-loop has boosted the popularity of exploiting drones, where the focus is to minimize human interaction. We have seen the usage of drones in daily life during the COVID-19 epidemic worldwide [5]. IoDs have a diverse range of applications in the field of healthcare, agriculture, logistics, data collection, surveillance, and the military domain as shown in Figure 1. In IoDs, drones (UAVs) are used to create a flexible data gathering platform that results in maximizing the lifetime of na IoD because of optimisation of the energy resources [6]. However, routing the collected data efficiently in a network environment with mobile drones is the most challenging task for the research community. Researchers have put forward different techniques to address this challenge [7]. However, there are no standard routing protocols as of now. Moreover, the data collected by IoDs are heterogeneous in nature, including audio, video, haptic, kinesthetic, and scalar data [2]. There is a dire need to review the applications and routing protocols optimized for IoDs. The network routing is a well explored research area. The IoD is an evolutionary research area with vast application areas. Moreover, the network characteristics of IoDs are different than traditional IoT and WSNs. A comprehensive and analytical review on traditional network routing in IoT and IoD can be found in [2,8], respectively. Therefore, this article focuses on the evolutionary and innovative routing protocols optimized for IoDs instead of traditional routing protocols used in IoT and WSN. Moreover, this article includes the challenges in IoD and future research directions to solves these challenges.

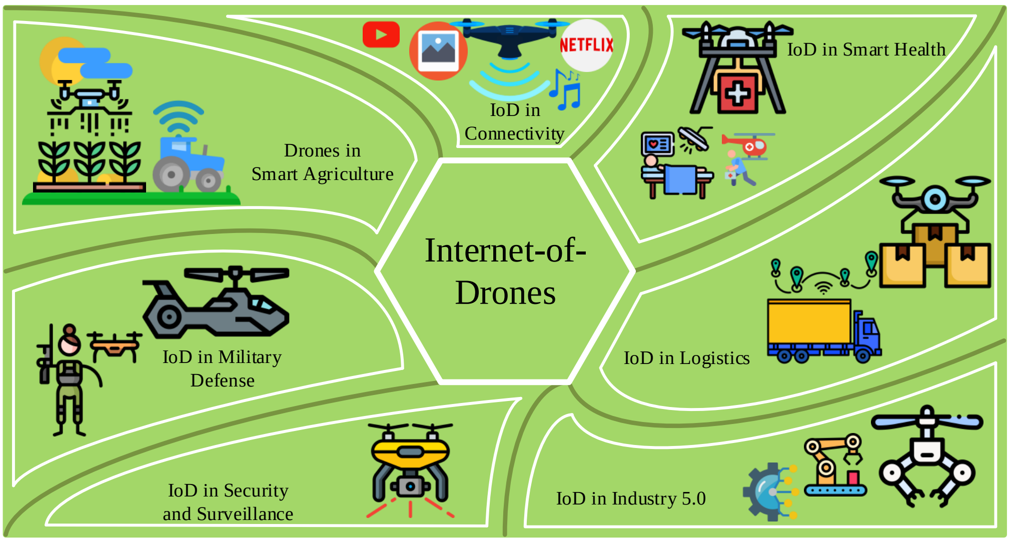


**Figure 1.** Internet-of-Drones and its applications.

### *Article Structure*

Non-terrestrial networks (NTNs) are considered to be prime components of B5G and 6G networks, and drones are major pieces in NTNs. Therefore, this article presents a review of IoD-based routing techniques and challenges and highlights areas for improvement of IoDs in the future. Figure 2 presents visual structure of the article in detail. The rest of the paper is structured as follows: Section 2 details the related work of IoDs. Section 3 describes the classification and architecture of IoDs. Section 4 presents review of the routing algorithms and describes the methods and techniques. Section 5 covers the challenges and future directions. The article is concluded in Section 6.

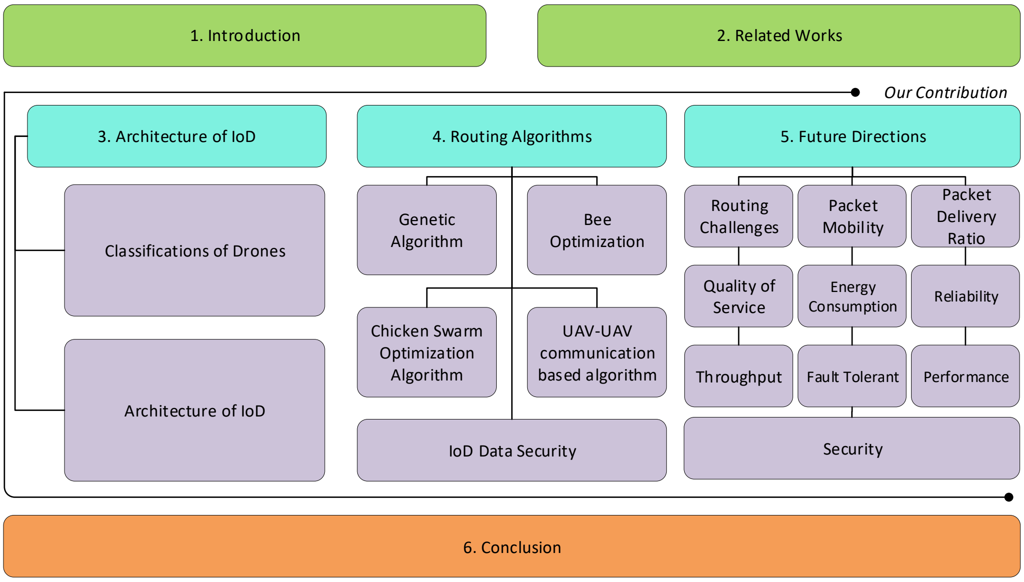


**Figure 2.** Structure of the article.

## 2. Related Work

In order to develop a desired research outcome, the study of previous research done is an integral and important part of the study. This section presents the discussion regarding IoDs. IoD networks have become popular in recent years. Due to the advanced deployment and flexibility of IoD devices, IoD networks are being used as the future wireless communication technology. The reasons for this are low cost and availability of IoD devices. The rapid deployment of technologies such as IoT devices, sensors, embedded microcomputers, low-cost Wi-Fi radio interfaces, global positioning systems (GPS), and batteries has enabled IoDs to be widely used in numerous applications in military as well as civil domains [9,10]. In recent years, routing protocols for IoD networks have been included in the literature. In a previous work [9], it was investigated that a number of cluster-based routing protocols in IoD networks can be used. In [8], the authors provided a comprehensive survey of routing protocols in different categories, including topology-based, position-based, and forwarding-based routing in IoD networks. In traditional and emerging IoD networks, multiple IoDs communicate with each other and with ground stations. IoD-aided WSNs are different from WSNs in terms of communication entities, communication distance, drone mobility, dynamic link quality, and frequent changes in network topology. IoD networks are wireless enabled networks with a drone as a sink, where a drone is used to collect data from ground sensor nodes. A number of routing protocols for IoDs were reported in literature [8].

IoDs have been an integral part of technologies starting from early 2000s. Drone technology has been the favourite of children as well, but it is incorporated in various domestic and commercial applications. Currently, IoD is being used to enhance the operation of WSNs. The various applications include event monitoring [11,12], vehicle monitoring [13], wildfire management [14], remote sensing [15], farming [16], search and rescue [17,18], emergency communications [19], and infrastructure monitoring [20]. IoDs are effectively applied to data collection from sensors [21], data relay [22], and drone-aided wireless communications [23,24].

In wireless communication networks and particularly in WSNs, the nodes sometimes operate in a collaborative manner to perform tasks [25]. The function of nodes is specific to the applications. In many cases, the network is deployed in harsh environments such as battlefields where the nodes are susceptible to damage, resulting in worn out nodes. In addition, nodes may suffer from energy depletion and breakdown in the electronics setting [26]. An important feature in battery operated IoDs is battery failure, which makes a faulty node. In [27], the author have introduced a method that selects new cluster heads to replace the faulty ones. In [28], the authors introduce a packet loss recovery model based on mobile cluster heads. A tendency to move out of coverage of each other affects clusters' ability to communicate with each other. In [29], the authors use "Cluster of CHs" definition to have a master cluster head and detection and replacement of faulty cluster heads. In [30], the authors utilizes time division multiple access (TDMA) in clusters to detect faulty nodes. In [31], the authors use a fault detection method by using acknowledgment from cluster heads in member nodes and neighbour nodes in the same cluster. Similarly in [32], the authors introduce a method that detects types of failure including battery failure, micro controller failure, sensor failure, and transmitter/receiver failure.

Author have proposed an energy efficient cluster head (CH) selection scheme for IoD networks to enhance the lifetime and average residual energy of a single IoD cluster [6]. CH node reuse is made possible by use of energy harvesting techniques, e.g., the capability of extracting energy from the surrounding environment such as solar power, wind, temperature variations, and magnetic fields. Another CH selection method was introduced in [33] where a fuzzy logic-based energy adequate clustering (FLEAC) method is used on the basis of five fuzzy descriptors. An acceptable amount of research work is available in the literature that exploits the LEACH protocol to increase the energy efficiency of CHs in WSN [34]. Moreover, new distance-based algorithms comprising scalable energy efficient clustering hierarchy (SEECH) have been used for the optimal selection of CHs and enhance the lifetime of the network [35]. In the research done by [36] , a security framework has been proposed to handle important issues of security within the IoD coverage area. A need for WSN security also arises because of the worldwide application of WSN. Some challenges faced by ad-hoc networks are also shared with IoDs because WSN is a special type of ad-hoc network. Crossbow tool [37] is a determining agent of different topologies in the network. Similarly, in order to reduce road congestion and urban pollution, ref. [38] developed WSN to gather traffic and environmental data. This helps environmental monitoring and substantial mobility of traffic in urban area. In the context of WSN, ref. [39] have worked to revisit clustering algorithms and parameters. The developed cluster structure facilitates an organised data assembly plus aggregation of network units for the expansion of the IoD. However, some of the issues need to be addressed. One of the crucial issues of IoDs is a decrease in life of nodes, and much work has been done in this field. WSNs comprising UAVs can offer connectivity in disaster-stricken regions in a cost-effective manner [40]. The energy constraint in disaster-stricken areas is also a significant issue [41]. Energy harvesting is deployed in areas where the batteries cannot be easily charged. It is an attractive type of solution as the procured lifetime is ideally infinite [42]. To the best of the authors' knowledge, none of these articles present a detailed survey regarding routing protocols for IoDs. Table 1 presents a comparison of this article with other IoD based routing articles.

**Table 1.** Survey papers discussing the IoD.

| Ref. | Year | Applications | Architecture | Routing | Future Research Directions | Performance Metrics |
|---|---|---|---|---|---|---|
| [9] | 2018 | ✓ | x | x | x | x |
| [8] | 2019 | ✓ | x | x | x | x |
| [43] | 2019 | ✓ | x | x | x | x |
| [5] | 2021 | ✓ | x | x | x | x |
| [44] | 2021 | x | ✓ | x | x | x |
| [45] | 2021 | x | x | x | x | x |
| [46] | 2022 | x | x | x | x | x |
| This Work | 2022 | ✓ | ✓ | ✓ | ✓ | ✓ |

Contributions:

The key contributions of this work are as follows:

1. This article presents the architecture of the IoD.
2. This article investigates the IoD key requirements.
3. This article discusses the routing algorithms for IoDs.
4. This article highlights the future directions and open research challenges related to IoD.

## 3. Architecture of IoD

### 3.1. Classification of Drones

An unmanned aerial vehicle is defined and constructed to be an aircraft piloted by remote control or on-board computers, also known as drone without pilot, crew, or passengers, and is maneuvered by a ground-based controller and a communication system [47]. The words drone and UAV have the same meaning and can be used interchangeably. Currently, there are many types of drones commercially in use. Technically, there are various models of drone based on the requirement and application. Common categories are Pioneer, Skyeye, Hunter, Watchkeeper, Fire scout, and Eagle eye, as shown in Figure 3 [48].

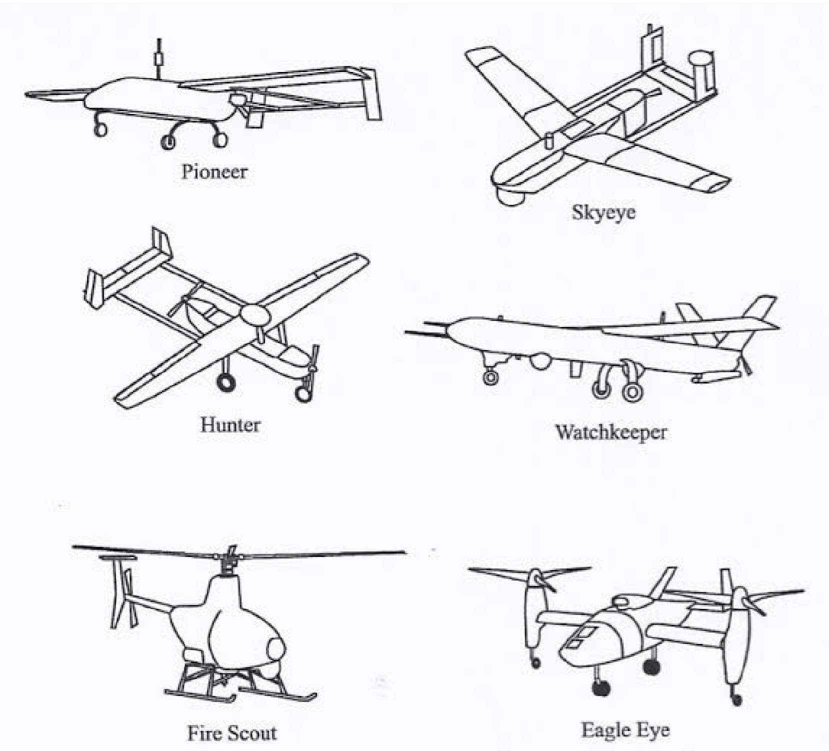


**Figure 3.** Application-specific drone models.

### 3.2. Architecture of IoD

A WSN is a sensor network is considered as a collection of sensors that is wirelessly controlled by the main network and/or it provides wireless transmission and reception of data from the network nodes called sensor nodes [49]. A WSN can be of any type, ranging from Wi-Fi and WiMAX to optical networks. The main purpose of a WSN is wireless data dissemination. A UAV-based WSN, i.e., IoD, operates on the same principal with the addition of a drone [50].

Cluster-Based IoD Network

In literature, drones are used as data or ferry nodes whose main job is to collect data across domains through a TCP based network channel [2]. Drones are deployed in payload delivery, traffic monitoring, mobility in dangerous environments, and surveillance. Three-dimensional algorithms are used for path planning of drones. Computational intelligence is used to form paths for drones. Accordingly, people have incorporated the use of drones in their daily lives. In the past few years, the use of drones in wireless sensor networks has begun and is under vast study. New products are formed as the technology improves. The integration of new products with the old system becomes an unavoidable deployment issue. This issue is addressed with a thorough survey of the development and integration of new or familiar solutions by technologies under study. In order to address the UAV routing problems, we must first define the problems and then provide the challenges faced by UAV and WSN environments. Clustering conserves the energy of WSN as a solution to achieve stability, scalability, and effective resource utilisation and allocation. Clustering can make groups of nodes to improve the efficiency of the WSN. The main objectives of a CH are processing and transferring of the member's data. One or more base stations (BS) are deployed as gateways or data processing nodes. The solution to drone data dissemination problems is mainly clustering. Dividing a WSN into 'clusters' is one of the techniques that improve the topology management. Clustering ensures good quality of service (QoS), efficient resource consumption, load balancing, and optimisation. The cluster heads (CHs) belong to each cluster and gather data from other "members". The combined data are then sent to the base station directly or indirectly with the help of middlemen nodes. Grouping of the nodes makes clustering an efficient aspect of WSN. This helps to manage resources and configure responsibilities in a fair network.

Drones receive a plethora of data from the sensor nodes. How that data are recorded and processed is the backbone work of the BS. The drone identifies the data collection nodes, the paths, and the data to the sink, whereas the BS strives for network connectivity, in addition to every WSN requiring a routing protocol.

Drones reach CH and transfer information as required by the sensor nodes. The authors in [51] state that clustering helps to lessen the problems faced by IoDs due to formation of sensor nodes and cluster heads. The CHs communicate with other CHs and also with the sensor nodes. The drones interact with CHs and the BS. The energy of the drones is conserved in this manner and the life span of a drone is increased. Efficient resource allocation is also possible because of clustering. Recent years have seen advancement in smart cities, industries, and IoT applications. Another key challenge faced by IoDs is topology management, important for ad-hoc networks as well. Greater number of nodes poses a problem that can be mitigated by hop-by-hop transmission of data and recognition of best 'neighbours' for transmission.

The main role of clustering in an IoD environment is the grouping of nodes done by Voronoi diagrams. Each network is divided into 2D or 3D sections, each having a number of sensor nodes. Figure 4 demonstrates a generic UAV based WSN cluster and the path of a UAV. The UAV path is determined by routing algorithms. Hence computational intelligence is the crux of the UAV path formation. Throughout the application, the UAV is programmed to follow the specified routes in the inter-cluster or intra-cluster coverage area.

Consider Figure 5, which shows a drone-aided data gathering system. There are two clusters, each with a cluster head and number of sensor nodes. Data from a cluster is routed to a UAV and a UAV beacon is established.

In the network structure, the angles formed by nodes to the BS are equally important in addition to the distance to the BS. Therefore, the clusters are organised based on different angles and distances between BS and sensor nodes. In these structures, a process called layering can be performed. The idea is to make use of multi-hop transmission of data, which makes the network more efficient in terms of consumption of resources. Intra-cluster routing can be achieved by breaking a long cluster-head to node journey into shorter paths, reducing the energy consumption. However this can cause delay, a QoS issue, but connectivity is achieved through every member of the cluster. The authors in [52] have made a framework for industrial environments where IoT based system is necessary. Development and testing time is minimised, abiding by the needs and standards. Efficient adoption of IoT in industry must be treated as a interdisciplinary issue. Steps must be taken to minimise disruption and risks. We should approach this problem holistically with end-to-end verification from sensor nodes for the interfacing with end user. Considering the hardware and software requirements, a method should be devised for the overall optimisation of the WSN. This study searches for UAV-compatible routing protocols and defines them in the context of IoDs. In the same manner, the challenges faced by IoDs are explained in detail.

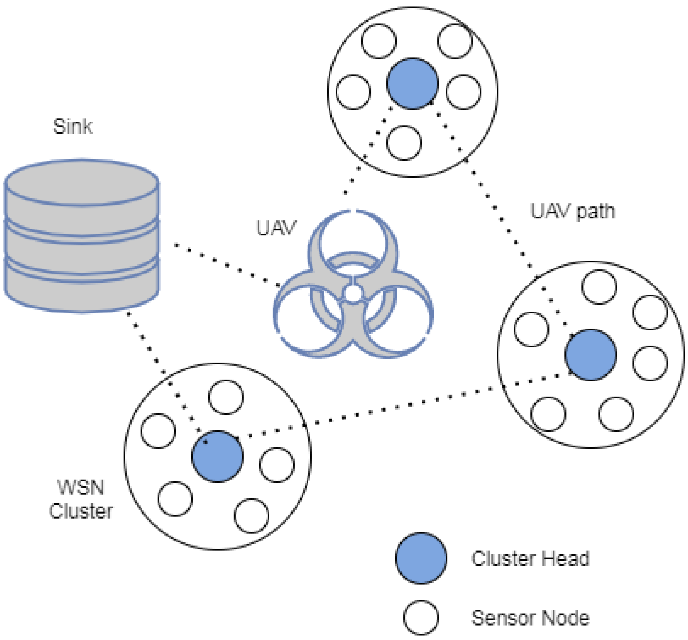


**Figure 4.** Drone path in a WSN cluster.

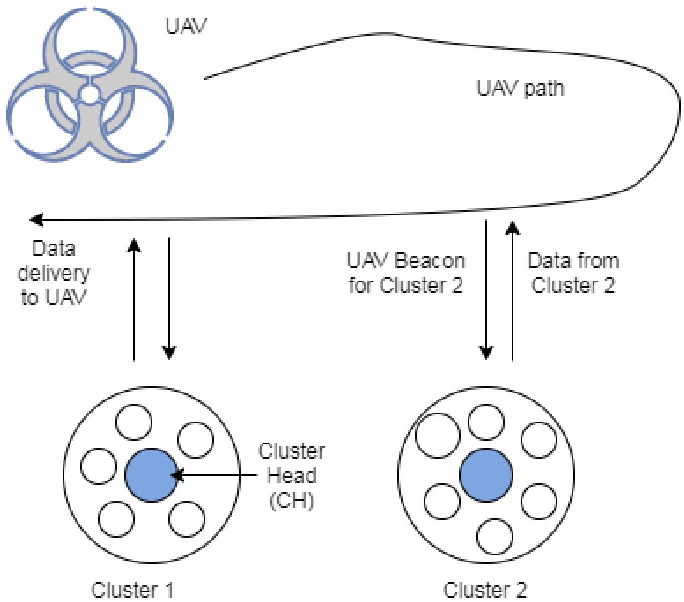


**Figure 5.** Drone data gathering system.

## 4. Routing Algorithms

Routing is the process of data transfer between entities in the form of packets. The entities can be base stations, link layers, end devices, or all of these. There are various routing protocols being used in industry, some are complicated, whereas others are relatively simpler. The following discussion addresses some of the complicated routing algorithms in a simple manner.

In inter-UAV communications, the link quality differs because of the mobility of UAVs, dynamic change in topology, and communication distance changes between UAV nodes [53]. Different types of routing protocols for IoD are explained in the following sections.

### *4.1. Genetic Algorithm*

The genetic algorithm is named so because of the generation of new datasets (offspring) obtained from existing ones (parents). It mimics biological evolution by solving optimisation problems based on a natural selection process as it provides new solutions and discards the old ones. This helps to curb the mundane elements of the routing process. GA has four main steps: [54]

- Elitism
- Crossover
- Mutation
- Elimination

In the first step "Elitism", the best possible paths are set aside as pure solutions. The data routes must be maximally utilised for this step, as the most probable solutions are kept in record. In the next step, a crossover of best data locations is carried out. This is basically a shuffling of routing data possibilities in order to find new ones. The new possibilities or routes are then altered through mutation of 1 bit to help keep up the change in process. Finally, the possibilities least feasible are eliminated from the routing list.

Drones are programmed to gain assistance from genetic algorithms through a programmable code that is accepted by their GUI. Each BS keeps track of the drone path possibilities with the help of GA. However, GA also has some disadvantages. The choice of all the parameters (fitness function, population size, and mutation and crossover rate) must be carried out very carefully. However, GA still remains one of the most important optimisation techniques. Figure 6 is a flow diagram that shows how routing is done with the help of GA. After creation of the initial population, a fitness assessment is made. If the end condition is reached, this is the choice of the best chromosome. If the end condition is not reached, the chromosome is subjected to crossover with a crossover probability and mutation with a respective mutation probability after which the chromosome reaches the fitness function. If it does not, it is eliminated. These best chromosomes give the paths of drones in a WSN cluster.

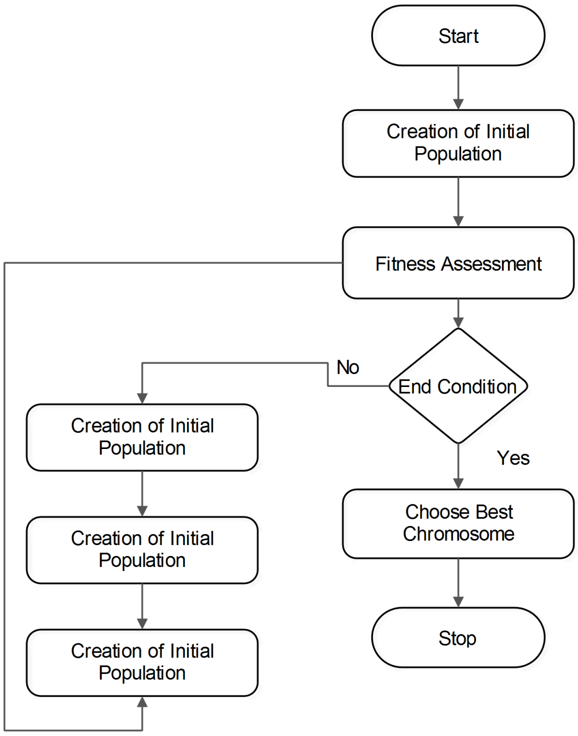


**Figure 6.** The genetic optimisation algorithm.

### *4.2. Bee Optimisation Algorithm*

Another algorithm used for IoD routing is the bee optimisation algorithm. The bee algorithm is based on how bees employ foraging in their search for food. The algorithm uses the best solution to an optimisation problem. The best solution is the path the UAV has to take. Bee optimisation algorithm has three contributors:

- Worker
- Supervisor
- Scout

The possible routes for data transfer are considered as "food" (analogous to "chromosomes" in GA). The workers are equal in number to the supervisors, and the number of food sources is set equal to the number of workers. A new candidate that is a possible route solution serves as food. Selection is based on the previously occurring neighbours of food sources. The best solutions are compared with the previous sources and a quality check (analogous to fitness function in GA) is made. The worker bees return to the hive to share the food source information with the supervisor bees, and the supervisor bees select food sources according to their fitness. Food is termed as possible routing solutions. Figure 7 illustrates the step-by-step organisation of the bee optimisation algorithm.

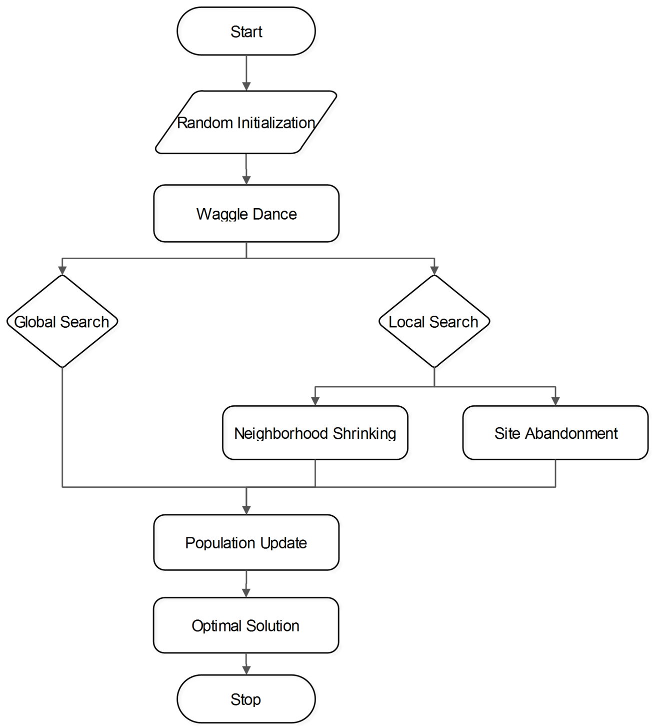


**Figure 7.** The bee optimisation algorithm.

After a random initialisation, the bees are subjected to a "waggle dance", and the "food" search is divided into global search and local search. When the neighbourhood shrinks, the bees return or some of them abandon the site. All the information is treated as a population update that is a reduced number of paths. Finally, the quality check determines which paths the bees should take. The UAV would take the path in a similar manner using the bee optimisation algorithm.

### *4.3. Chicken Swarm Optimisation Algorithm*

Chicken swarm optimization based clustering algorithm (CSOCA) addresses the the energy efficiency problem in WSNs. CSOCA with genetic algorithm (CSOCA-GA) is an improvement to CSOCA by employing the genetic algorithm's processes in CSOCA. CSOCA-GA utilises crossover and mutation processes for individuals with low fitness value to extend the population diversity as shown in the Figure 8. CSOCA and CSOCA-GA have been tested and compared with other similar algorithms to gather their efficiency in terms of extending WSN lifetime and reducing energy consumption.

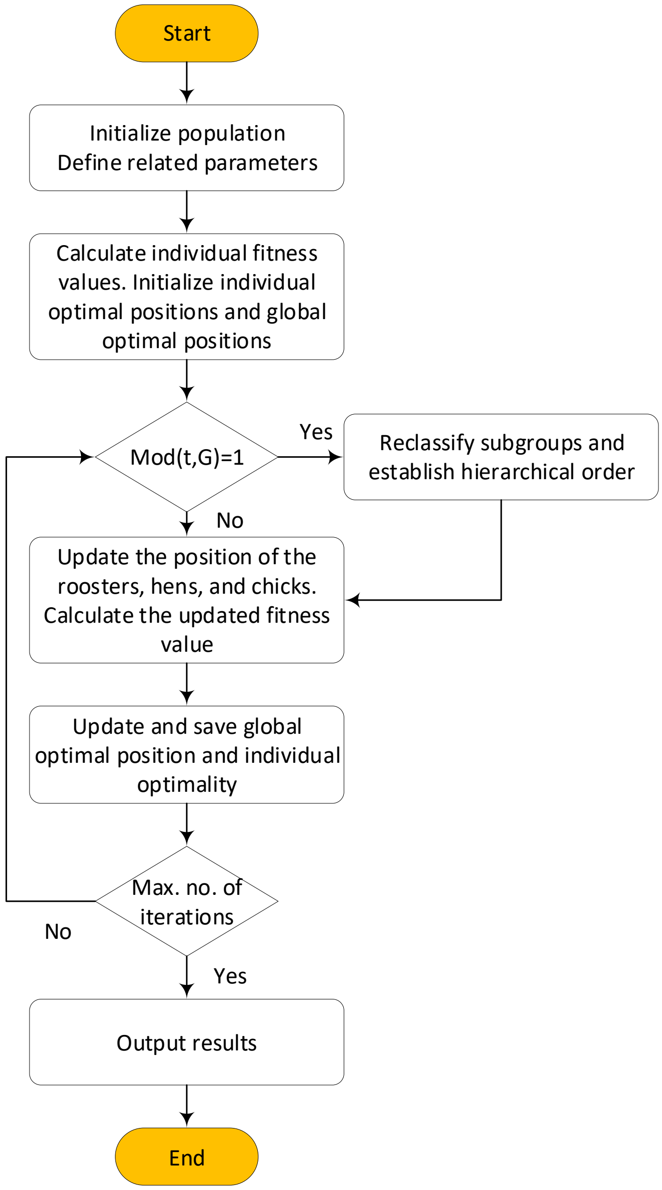


**Figure 8.** The chicken swarm optimisation algorithm.

### *4.4. UAV-UAV (U2U) Communication*

As a part of routing, UAVs must also be able to communicate with each other in order to establish effective communication. These arrangements are called U2U (UAV to UAV communication) and U2I (UAV to infrastructure communication). For this purpose, UAVs come in different shapes and sizes in order to meet their demand. The new framework is UAVs collecting data from WSNs. The structure and services of a UAV-WSN need to be specified.

Networking, data traffic requirements, protocols, and network topologies make up IoDs. Linear sensor networks (LSN) is a network topology being considered for these jobs, in addition to geometric and clustered WSNs, and is a very efficient one. The advantages include a decrease in energy consumption, low interference, and greater flexibility for the sensor nodes. As a result, UAVs can provide connectivity to the WSN.

In areas where accessibility is difficult, for example, disaster-stricken locations and remote areas, UAVs can play their part in gathering data. Cellular (3G, 4G, 5G), Internet (WiFi 802.11 n/g), and even satellite localisation is possible through UAVs in these areas. UAVs can be efficiently deployed to perform and monitor tasks in a dynamic, cost-effective manner using sensors like cameras, heat sensors, radiation readers, and gas monitors. Efficient and reliable data transfer is possible through UAVs. Storage of collected data and performing tasks on the stored data is considered as a pioneer task of UAVs.

For a given application, UAVs can be homogenous or inhomogenous depending upon their capability and storage capacity. If the UAVs collect unequal amounts of data, they are equipped with heterogenous capabilities. In this case, a collaborative storage of data is desired among UAVs to conveniently store collected data.

### *4.5. IoD Data Security*

A number of methods and techniques have been employed for drone-based WSN clusters. According to a study by [55], it was found that some data collection and information monitoring schemes are not suitable in terms of security. Therefore, there is a need to select a CH keeping in mind the security requirements in the environment covered by the drone. In research done by [56], data are allowed to buffer at the source nodes until the collection of mobile data over a single-hop wireless communication. This reduces latency in the system. The underlying ideas in this state can be classified according to the mobility patterns of the mobile data collector, namely, random mobility data collection, predictable or deterministic mobility data collection, and mobile data collectors with controlled mobility [57,58].

#### 4.5.1. Random Mobility Data Collection

In this type of drone data collection, the mobile data collectors move randomly using a Markov model and collect data at the opportunity directly from sensor nodes. Then they transfer data to access points (APs). In [59], an improvement for routing protocol is proposed for mobility of the sink node because the sink's geological location update is restricted to a confined zone in order to reduce energy consumption. This reduces the generation of extensive data traffic due to the sink's movement. On one hand, the on-demand sink discovery exists for nodes, and on the other hand, the nodes are confined into zones. When the sink is not discovered, the zone is incrementally increased and updated until a network broadcast is initiated for the discovery of a possible route [56].

#### 4.5.2. Deterministic Mobility Data Collection

For a deterministic mobility of UAV, the system allows the static and mobile nodes to have a specific time for initiation of data transfer. Because of a strict schedule, the nodes know where mobile nodes will be in a given amount of time. For example, in [60], the mobile nodes are studied as part of transportation shuttles visiting sensor notes as per schedule. Sensor nodes calculate the "wake up" time by this method and start communicating to transfer information. The authors in [61] have evolved a scheme called multiple enhanced specified-deployed sub-sinks (MESS) for WSNs. This method consists of multiple sub-sinks for data collection. The sub-sinks are created in the coverage area, which provides data collection in a more effective way as compared to a single sink. Wireless high speed routing (Whisper) [62] was also proposed for forwarding of data to a high speed sink. The scheme is based on the assumption that all node locations of sinks and sensor nodes are known by each other along with the displacement from the sink. In addition to this, the nodes have their own, their neighbours', and the sink's location information. If the sensor nodes cannot directly send a message to the sink, they transfer it to a "meeting point", which is calculated based on experienced delays in transmission of the message along with the locations of node, its neighbours, and the estimate of sink's location [56].

## 5. Future Research Directions

Any communication system or telecommunication system is not free of challenges. The technical aspects of any communication system face major drawbacks and challenges that need to be overcome in the process of development. WSN and IoDs are equally prone to errors—there cannot be a fully fledged solution to the communication problems. However, scientists work tirelessly to improve the infrastructures. Currently deployed 5G networks include channel characterisation and path planning for drones. Integration of drones and IoT devices is also a solution to the transmission problems in IoDs. Another challenge is to determine the number of sensor nodes, CHs, and drones for effective communication in the network. For the deployment of drones in city areas, path loss and attenuation models need to be considered. The battery power of drones present a problem in the networks. The drones must have an optimum battery time so that the stationary and mobile components of the network can all sustain corresponding data transmission and reception from the drones. Table 2 gives a summary of characteristic improvement areas that one comes across in an IoD.

**Table 2.** Improvement areas for IoDs.

| | **Characteristics** | **Improvement Area** |
|---|---|---|
| 1 | Routing | New Path Formation |
| 2 | Packet Mobility | Seamless Data Transfer |
| 3 | Packet Delivery Ratio | Time Constraint |
| 4 | Quality of Service | Latest Equipment |
| 5 | Energy Consumption | Li-ion, H-fuel batteries |
| 6 | Reliability | Lossless Transfer, Improved PDR |
| 7 | Throughput and Delay | Efficiency |
| 8 | Failure detection | Fault replacement |
| 9 | Performance Evaluation | On-time Delivery |
| 10 | Security | Encryption |

The following outlined challenges occur when designing and operating a UAV-based WSN. All the areas are given equal importance as the UAV problem is approached and outsourced.

### *5.1. Routing Challenges*

Routing in a IoD is prone to challenges like any other communication/localisation system. It is evident that IoD routing protocols are still in their developmental stage [9]. Changes in the network environment demonstrate a great need to provide new equipment that can overcome network challenges. New paths in IoDs bring dynamic changes to the network. Therefore, enabling effective routing to these paths is the job of the network administrator. Table 3 lists the routing techniques of IoD and their challenges.

In general, IoD routing is broadly classified into structure-based routing and protocol-based routing, as shown in Figure 9. Structure based routing consists of changes in the network structure while deploying an efficient routing mechanism. Protocol-based routing, in contrast, encompasses changes in the protocols being used in the routing mechanism. Structure-based routing is further classified into flat routing, linear sensor routing, cluster-based routing, location-based routing, and tree-based routing. Protocol-based routing is further classified into swarm intelligence routing, multi-path routing, and shortest path routing.

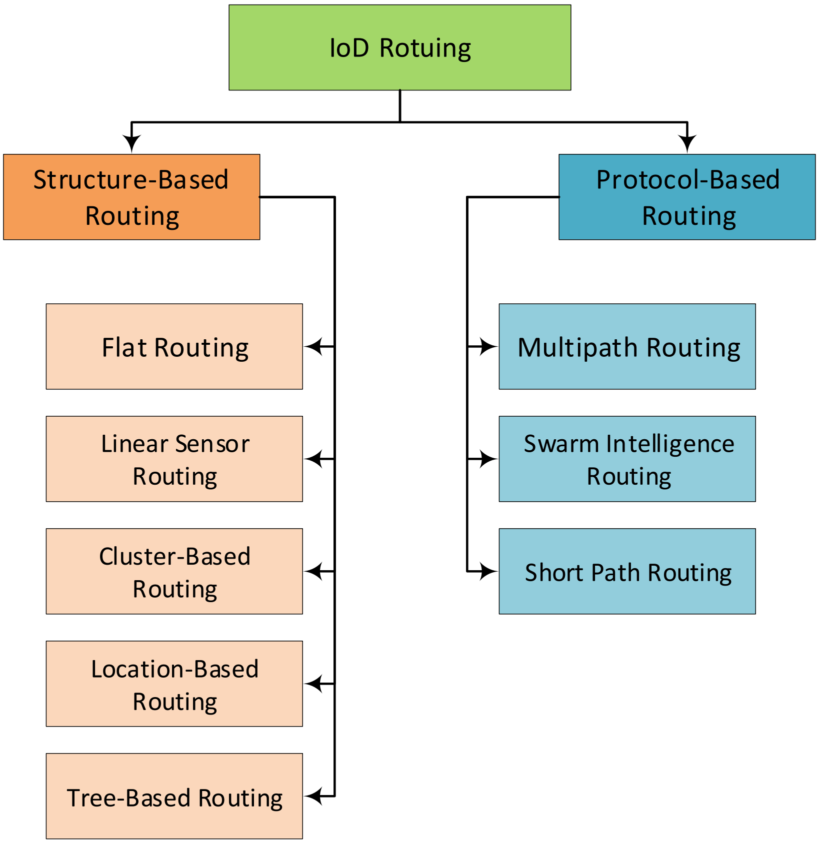


**Figure 9.** Summary of IoD routing protocols.

**Table 3.** Summary of routing techniques and challenges.

| Category | Routing Technique | Facilities | Challenges |
|---|---|---|---|
| Network Structure Based Routing | Flat Routing | Wake-up schedule of sensor nodes and trajectory of UAV | Reliable data collection in the fading channel |
| | Linear Sensor Routing | Nodes remain between two parallel lines that stretch for a long transmission distance | Multi-hop routing can cause high energy dissipation |
| | Cluster-Based Routing | All nodes are allowed to make independent decisions, coordinated clustering | Finding new routes results in significant routing overhead |
| | Tree-Based Routing | Parent node acts as sink node | Overhead in broadcasting and errors in data reconstruction process |
| | Location-Based Routing | UAV broadcast geographical location and clock time | Time required to empower sensor nodes unconsidered |
| Protocol Operation Based Routing | Swarm Intelligence Routing | Determining the network topology and use of UAV for data collection | Wind effect is travel time of UAVs to be taken into account [2] |
| | Multi-Path Routing | Aims to reduce the distance between senders and receivers to obtain better channel quality | Efficient data gathering is a challenging task [2] |
| | Shortest Path Routing | Voronoi diagram provides feasible UAV routing path | Minimizing the UAV overall trajectory distance [2] |

### 5.2. Packet Mobility in IoDs

Seamless mobility of packets is a key concern in IoDs. Telecommunication models identify and create methods for hop-by-hop data communication in the form of bits and frames. The OSI model is widely accepted by TELCOs around the globe. For data packet organisation and delivery, the OSI model is the most viable and widely used. It has seven-layer architecture, but for IoDs, only the lower three layers are considered for our IoD applications. For packet mobility, there are three OSI model layers to be considered. First is the physical layer for a better connectivity; the second layer is the data link layer for network access, and third is the network layer for a lossless data transfer between IoD nodes. Consider Figure 10 in which a flow diagram is given for packet mobility inside a UAWSN.

It is evident from the Figure 11 that each upper layer is dependent upon the bottom layer and vice versa. Considering the conventional fashion of OSI layers, the physical layer allows multiplexing techniques, namely frequency division multiplexing (FDM), time division multiplexing (TDM), or space division multiplexing (SDM), and allows data to be aggregated. The data link layer is responsible for frame interleaving, and the network layer identifies the nodes, the packet path, and its organisation from symbols. In IoD, there can be a large number of nodes present so the data is organised and forwarded accordingly. Figure 11 shows a layer-wise packet transfer in IoT.

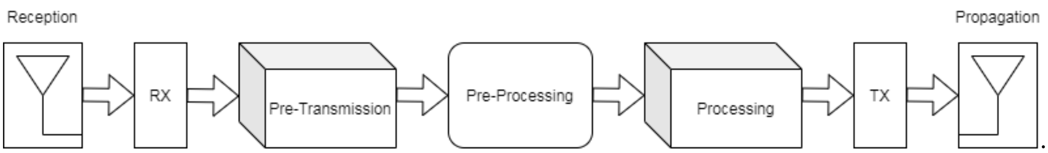


**Figure 10.** Packet mobility in IoT.

| | |
|---|---|
| **PHY** | FREQUENCY, TIME, SPACE |
| **DLL** | FRAME (INTERLEAVING) |
| **NET** | NODE, PATH, PACKET/SYMBOL |

**Figure 11.** Layer-wise packet transfer.

Multiplexing is a requirement for transmission systems in order to utilize the available bandwidth and decrease the delay. For the physical aspect, the frequency, time, or space division multiplexing takes place. At the data link layer, the formation of bits into frames takes place. Data then get transmitted in frames for set periods of time. The network layer defines the nodes, the paths, and the packets in the form of symbols.

### 5.3. Packet Delivery Ratio

After sufficient and best routing is available, the packet delivery ratio (PDR) determines the amount of data that can efficiently be transferred during a given amount of time. When the data loss is less and network structure is reliable, the PDR is ensured [63]. In congested networks, however, packets can drop, leading to decrease in PDR. The authors in [64] have proposed a procedure to improve PDR by selecting those CHs that have energy remaining and can determine the node locations. Data loss can be problematic in WSNs because they are not able to detect and gather important information, for example, fire detection and disaster management. The military usage is also affected by data loss and node failure, which is why the clustering technique is used to mitigate the data loss effects. As opposed to a large data transfer at a given time, clustering can merge smaller data ratios and reduce the PDR, and packets can be sent/received much more efficiently [1].

### 5.4. Quality of Service

PDR reduction ensures better quality of service (QoS). QoS is an important consideration in wireless sensor networks as in all other networks. As UAV based networks have become an important service delivery invention, they can be equipped with cameras and sensors, performing on-demand tasks in military as well as rescue operations. The small-sized UAV devices can replace aircraft in a number of tasks and can perform various tasks and be part of numerous applications. In [65], the proposed system keeps in record the requirements of the drones as a function of QoS. Such systems are able to meet the dynamic needs of the UAV.

One of the open challenges of UAWSNs is meeting the QoS requirements in UAV routing. Some applications require fault tolerance, which can be performed by the CHs in order to support a better QoS. It is possible to enable a highly accurate GPS location system for UAV routing being an essential parameter. Another important and challenging task in UAV routing protocol is localisation. For WSNs it is important to localise the CHs and rescale the "power" to a single CH.

### 5.5. Energy Consumption

In wireless sensor networks, energy efficiency has become an important issue and must be addressed with care [66]. Most of the network components like sensor nodes, cluster heads, and UAVs are operated on batteries and hence, battery life is a major energy conservation issue. This can be addressed with energy efficient batteries. In WSNs, clustering resolves the energy conservation issue as the transmission delay is minimized with the help of clustering because each cluster is responsible for the battery life of its members. The four major areas to be resolved are delay, security, energy, and distance; therefore, energy limitation is a real bottleneck in UAWSNs. Recent developments in battery improvement and the use of lithium-ion and hydrogen fuel batteries are best for long UAV paths [67]. Another technique is energy harvesting, used to extend the duration of UAV flight. The use of solar powered cells is also mitigating the limited battery effects. Another solution is wireless transfer of power, which is a smart solution to make the system energy efficient. In general, UAVs need more mobility, easy deployment, more programming, and scalability, so they can be applied to IoT systems with minimum battery requirements.

### 5.6. Reliability

Reliability in WSNs means the accurate transfer of data between entities. It also means less delay. A WSN is reliable if all the sensor nodes are able to process data correctly and the duties by CH and UAV are performed well. Data dissemination should never be a problem when it comes to WSNs. Reliability is also ensured when the packet delivery ratio (PDR) is improved [68]. The work by [69] develops a procedure that is cost friendly and reliable. Their tree-based method is used to establish connections between any two nodes as a result of a weighting method. The authors in [70] have proposed a packet reporting and packet forwarding mechanism for UAV path planning. According to [71], clustering leads to a more scalable network and increases network reliability by reducing end-to-end delay of packet delivery.

### 5.7. Throughput and Delay

One paradigm that affects a WSN is throughput, which means the amount of data successfully transferred through the network. The efficiency of the whole network is depicted by throughput in accordance with a reduction in latency. Different clustering techniques are used to improve the efficiency in terms of throughput of WSNs. Generally, there is a trade-off between energy consumption and delay [72]. This means that the greater the delay, the greater the energy consumption. The features of 5G, such as high speed and low latency, have increased the demand for wireless technology. These features require continuous connectivity and sustainability in low power networks with efficient routing. The authors in [73] have proposed a comprehensive survey on UAV communication in 5G wireless networks.

It is time-consuming for engineers to configure the WSNs manually. Some of the main difficulties include a large number of nodes, distance from the remote management, replacing and updating of failure nodes, and the relocation of existing nodes inside the coverage area. These problems make up the backbone of the UAV based WSN. The time that UAV takes to reach each node accounts in turn for its delay.

### 5.8. Failure Detection

Detection of failure is an important parameter in WSNs. Different procedures have been devised to capture defective nodes in a WSN. By detecting failures, they can be fixed or tolerated. The nodes and CHs are checked regularly to detect failures. It is then possible for spare nodes to take over the responsibility of faulty nodes. In addition to this, the failure in a hotspot network creates a negative impact on network efficiency because of data loss and delay. In these situations, it is good to have spare CHs that can replace faulty CHs as hotspots and solve the problem effectively.

### 5.9. Performance Evaluation

After the detection of failure, the performance of the network can be determined. In UAV networks, it is difficult to exchange data efficiently. The simulation results of UAVs at high-speed motion have shown added delay, which is a prominent drawback. Threshold of delay is considered to be a challenging issue in UAWSNs.

The onus is on the ability to make the routing protocols effective when the UAV is mobile and to reduce the overhead the UAV mobility creates. Moreover, it is important to estimate the link prediction, link establishment, and cluster formation in a routing protocol. To date, most of the routing protocols are inclined towards delays and issues reducing overhead. Generally, there are many possible metrics to consider in UAV-WSN routing. An efficient routing protocol design and other additional metrics, such as route mobility, QoS metrics, stability, link quality, and security measures, can be considered for further research. These performance evaluation metrics must be carried out on an on-time basis so that any faults will not occur.

### 5.10. Security

The last but major concern and challenge for WSNs and UAV-based WSNs is network security. Failures of data transfers or data breaches occur as a result of compromised security. Malicious activities, extraction of information, device duplication, and phishing can prove to be major threats to network security. It has been observed that the attacks on IoT devices can be mitigated at the cost of performance. The heterogeneity of devices poses as a problem to IoT. It was noted that some networks based on IoT require constrained security measures. Security is therefore a main parameter to be ensured for any device, whether WSN, UAWSN, or IoT.

Cluster based WSN are also not free from security attacks. The network structure and routing protocols should account for the security concerns. The techniques for network security management are hashing and key-based encryption. For added security, WSNs can be integrated with wireless or wire-line security systems. In smart cities, the security is seldom compromised. This is due to their robust infrastructure. Mobile systems, however, must have an integrated security system within the WSN environment.

## 6. Conclusions

To conclude, it is necessary that, while in the process of devising a network route, the protocol architecture needs to be understood first. Next, it should be considered that all possible security breaches are considered. A strongly connected network needs no bit errors, therefore proper equipment testing and verification should be done before purchasing the equipment. Similar concerns are of timing, throughput, and delay. The battery life can be increased by techniques like green solutions. The greater the mobility of a UAV, the more data it can store, process, and transfer. The processing task is mostly left to the base station, and the UAV acts as the aggregate data transfer machine. The major concerns of UAWSN are lossless data delivery and seamless mobility. Therefore, these become the main concerns in the formation of UAV-based wireless sensor networks.

In this paper we have discussed the various routing protocols for WSN, the methods and and techniques for efficient routing, routing protocols, and the challenges faced by the UAWSN industry. Some of the main challenges related to WSNs are propagation delay, packet delivery loss, timing and jitter, and security breaches. All of these problems have been addressed in a heuristic approach. The routing algorithms also need to be defined for a WSN, some of which were explained in this survey. It has been seen that the routing protocols for mobile UAV-WSNs should be made robust and able to work in 3D scenarios. An analysis of various routing challenges and techniques was also given in this paper.

Challenges are faced by every mechanism in wireless data transmission, and UAWSNs are not entirely safe. Techniques and methods have been developed as a result of detailed surveys, because of which UAWSNs have a promising future in academia as well as industry. It has been observed that the UAWSN networks can conform to routing protocols as they perform the different tasks as required by the applications. However, WSNs are also prone to security attacks like any other system, and proper authentication must be used in them.

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