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A survey on combined applications of Meta-heuristic Algorithms with Internet of Things

Morteza Salamat Mostaghim, Azam Andalib * and Hossein Azgomi

Department of Computer Engineering, Ra.C., Islamic Azad University, Rasht, Iran

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Abstract

Systems based on Internet of Things are dynamic and complex sets of intelligent objects. Today, the global field of IoT is expanding and is opening up new opportunities for technology. Meta-heuristic algorithms are provided to solve complex problems in an acceptable time. These algorithms select the best solution to the problem in order to maximize profit or minimize cost. So far, meta-heuristic algorithms have been used to solve many problems in the Internet of Things. In this paper, some practical aspects of the Internet of Things are reviewed. In addition, some of the most popular meta-heuristic optimization methods are analyzed. Then, a classification of IoT-based systems that have used meta-heuristic algorithms is presented. This classification includes four levels: discrete or continuous, type of meta-heuristic algorithms, single or multi objectives, and aim or application of the research. This review provides a way for future studies to easily select meta-heuristic algorithms for Internet of Things systems.

Keywords:
Internet of Things
IoT
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Applications of Meta-heuristic Algorithms in IoT.

***Correspondence E-mail**: Azam.Andalib@iau.ac.ir

INTRODUCTION

The Internet of Things (IoT) is designed to promote a pattern in which everything around us can be measured, processed, communicated, or activated into an intelligent thing that is always connected. It is a branch of research wherein both physical and digital entities (i.e. people, machines and objects) are connected via the Internet, thus a new class of services and utilizations is provided (Shah & Yaqoob, 2016). In recent years, the IoT has become a significant research issue because it combines different objects and sensors for direct connection and without human intermediation (Alaba et al., 2017). The IoT has several applications in different domains, including Smart parking (Mukadam & Logeswaran, 2020), Smart homes (Ghayvat et al., 2015), smart governance (Ali & Calis, 2019) and health (Umair et al., 2021).

Meta-heuristic optimization is a field of computer sciences and applied math that converses with the choice of the best solution for a specific problem with the aim of maximizing or minimizing the output solution. Meta-heuristic optimization can be an efficient way to provide possible solutions. In these algorithms, the purpose is to solve a NP-hard problem in an acceptable practical time. The complexity of such problems makes it impossible to get any possible solution or combination. Hence, the goal is to find the feasible solution for desirable timescale. Therefore, optimization can be stated as the process of choosing of the optimal solution from among a set of available options to obtain the best feasible results for a special problem (Meng et al., 2021). Meta-heuristic optimization has various applications in different science, such as computer networks (Donoso & Fabregat, 2016), finance (Soler-Dominguez et al., 2017), data mining (Lessmann et al., 2011), biology (Nakib & Talbi, 2017).

Meta-heuristic optimization methods have been used in many areas to study various real-world problems. With the advancement of these methods, optimizations have become increasingly important in various fields of human life. One of the areas of interest and application of meta-heuristic optimizations is the application of these methods in the IoT. Because of flexibility and robustness of meta-heuristic optimizations, these algorithms have successful design models in relation with systems based on IoT. Several meta-heuristic algorithms have been applied in various fields of IoT, such as routing, management, robotics, business and engineering (Zedadra et al., 2018).

In this paper, we present a classification of applications of meta-heuristic algorithms in IoT systems. This classification is provided at three levels. At the first level, the discrete or continuous nature of the problem and the meta-heuristic algorithms are specified. At the second level, the meta-heuristic algorithms used to solve the problems are stated. At the third level, the single-objective or multi-objective nature of the problems and the meta-heuristic algorithms are determined. At the fourth level, the problems related to the IoT that have been solved with the help of a meta-heuristic algorithms are mentioned. With the help of this classification, an overview of the applications of meta-heuristic algorithms in the IoT can be shown. In this review article, literature are reviewed according to this classification.

The structure of the rest of this discussion is collocated as follows. In Section 2, we describe the topics around IoT. In Section 3, we introduce definitions and applications of existing meta-heuristic algorithms. In Section 4, we present a classification of the application of meta-heuristic algorithms in IoT systems and review related research accordingly. We outline future works for further research in Section 5. Finally, in Section 6, we summary the concluding attentions.

INTERNET oF THINGS

The notion of the IoT was presented in 1999 in connection with the connection of radio frequency identification into the Internet for supply chains (Villa-Henriksen et al., 2020). This concept means connecting a network of "things" to the Internet without straight human interference. "Objects" can be any things with actuators or sensors which can be individually connected, addressed, and accessed through a computer network worldwide, including the Internet.

The IoT is basically like a system for connecting computer devices, mechanical and digital machines, objects, or individuals provided with the unique system and without transfer to transmit data over an ability human-to-human or computer-to-human relation. Another thing on the IoT is that the items in the IoT are like a connected manner with humans and computers to which internet protocol addresses can be assigned and which can transfer data over the network or another man-made object (Laghari et al., 2021).

The IoT has various uses. These applications are developing every day in different areas. Our needs are changing every day due to industrial and individual variations. Therefore, we use the IoT for these needs. In the following, we refer to some of the concepts and applications of the IoT.

Routing

There are networks of objects on the IoT. In these networks, the devices are equipped with low memory and cost, high processing and message transmission capability. These devices connect to the Internet through gateways. IoT devices are arranged in a mesh network and are connected to the Internet through a gateway router. In order to achieve the vision of connecting devices, we require the routing protocols. These protocols provide communication between objects in a dynamic and distributed infrastructure. The IoT network properties are changed according to network size, mobility and traffic pattern flow. The routing protocols are analyzed in different scenarios based on energy efficiency, traffic patterns, mobility, scalability, transmitter amplitude and reciprocity. New routing protocols are based on the nature of IoT devices in a network. More details about routing protocols can be found in (Marietta & Chandra Mohan, 2020).

Quality of service

Using all smart devices such as telephones, televisions, medical devices and home appliances to generate data is one of the new topics in the Internet of Things. Because of the variety of services, IoT service integration issues mainly deal with quality of service (QoS) parameters. Depending on the demand of users, different types of services can be imported into the Internet of Things. The QoS is one of the criteria for choosing the suitable service. The QoS is related to issues such as availability, cost, reliability, response time, and energy consumption. More details on service quality can be studied in (Singh & Baranwal, 2018).

Smart home

In recent decades, human life has been surrounded by many electronic devices, including refrigerators, televisions, air conditioners, fans etc. Installing sensors in smart homes helps to use enough energy and increase human comfort. For example, these sensors can control and manage the cooling, heating and lighting of the house. This work reduces cost and increases energy efficiency (Alaa et al., 2017).

Internet of vehicles

Today, due to the increasing use of vehicles, the amount of traffic and road accidents have increased. For this purpose, the internet of vehicles (IoV) has been considered. The IoV as a branch of the IoT is about vehicles communicating with together and with road over the Internet. The IoV helps to reduce traffic and accidents. It is also used to provide travel plan, Drivers access to the network, and manage traffic. As a result, it is used to find the shortest route, improve the traffic monitoring system and protect people from accidents (Priyan & Devi, 2019).

Smart health system

The smart health system means using various biometric sensors. The information from these sensors is used to ensure human health. In this regard, the IoT leads to improve health and quality of health care. Doctors can use this system to access patient's medical information. Also, they can aware of the patient's physical fitness. More information on the smart health system is provided in (Kalarthi, 2016).

Other applications and issues

Other applications and issues in the Internet of Things include cluster sensors (Thangaramya et al., 2019), Trustable object selection (Sakthivel &Vidhya, 2021), Network manager (Sahlmann et al., 2017), Intrusion detection (Zarpelão et al., 2017), Identify Sybil's in communities (Zhang et al., 2014), Cluster head selection (Reddy et al., 2019), Data manager (Torre et al., 2016), Clustering of big data (Bangui et al., 2018) and Features selection (Sun et al., 2018).

META-HEURISTIC ALGORITHMS

Meta-heuristic is a problem-independent high-level algorithmic framework that provides a set of strategies for developing optimization algorithms. Meta-heuristic algorithms do not seek completely optimal solutions and try to solve complex problems in an acceptable time by searching for solutions close to optimal randomly (Glover, 1986; Bozorg-Haddad, 2018; Yang, 2020; Fausto et al., 2020). Prominent examples of meta-heuristic algorithms include genetic algorithm, ant colony, particle swarm optimization, artificial bee colony, gray wolf optimization, bat algorithm, and cuckoo search (Kaveh & Bakhshpoori, 2019; Vasuki, 2020; Rani et al., 2024). Some of the popular meta-heuristic algorithms are reviewed below.

Genetic Algorithm

One of the first proposed meta-heuristic algorithms is the genetic algorithm (GA), which was presented by John Henry in 1960s. This algorithm is derived from the concepts of natural evolution and selection. Its goal was to realize the events of natural adaptation. The GA algorithm starts with a random population of solutions called chromosomes. It then attempts to improve the chromosomes in the population through two steps, using mutation and crossover operators (Yang, 2020). The details of the genetic algorithm are shown in pseudocode in Fig. 1.

```
Initialization
    Select size N as initial population
    Define f(X) as objective function
    Population encoding as chromosomes
        along L_C
    Calculatefitness values of the all
        population
    Describe termination criteria, if there is
    Select MaxIteras maximum number of
        iterations
    iter = 1
while (iter ≤ MaxIter)
    Selection: Parents are selected for
        reproduction
    Crossover: Crossover is used on parents to
        generate offsprings
    Mutation: Mutation is applied on chosen
        chromosomes
    Calculate the fitness values of the population
    Select members for the next descendant
    If termination condition seen then
      exit
    else
      continue
    iter= iter+ 1
end while
```

Fig. 1. Genetic Algorithm pseudocode

As shown in Fig. 1, an initial population of chromosomes is created. Then, in a loop, chromosomes are selected from the population at each stage and new chromosomes are created through crossover and mutation. Then, in a loop of repetition and at each stage, chromosomes are selected from the population and new chromosomes are created through crossover and mutation.

Ant Colony Algorithm

The Ant Colony Algorithm (AC) was introduced by Dorigo (1992). This algorithm is derived from the natural behavior of ants in search of food. This behavior enables the ants to find the shortest paths between their food source and their nest. As the ants move from their nest to the food source, they deposit a substance called a pheromone on the ground. They move in a direction marked by higher pheromone concentrations. This behavior paves the way for mutual interaction and the emergence of the shortest paths. If the ants get a good (short) path from the colony to the food source, the other members will probably follow the path marked by the ant with the pheromone. Eventually, all members are directed to the optimal path of the unit. The pseudocode of the ant colony algorithm is presented below.

```
begin
    Initialization
        Take S_C and N_A
        Define f(X_i) as Fitness function
        Pheromone update model
        Describe termination criteria
    while (termination condition not
        seen) do
        Create Ant Solutions
            Construct solution vector X_i until
            the vector length is equal d
        Pheromone Update
    end while
end
```

Fig. 2. Ant Colony Algorithm pseudocode

In Figure 2, S_C and N_A are considered as the solution components and number of ants, respectively. In this algorithm, a model for updating and pheromone evaporation as well as a stopping condition for the iteration loop must be considered. In the AC algorithm, each ant creates a solution vector X_i based on S_C. Ants always try to optimize the solutions in the iteration loop using the available pheromone. In the end, the ant with the best answer has the global optimal answer.

Particle swarm optimization

In 1995, particle swarm optimization (PSO) was introduced in (Kennedy & Eberhart, 1995). This optimization follows the behavior of a flock of birds in search of a suitable food source. In this algorithm, each solution is considered as a particle. The particles move and search in an iterative loop, generating new solutions. The factors that affect the particle search are the particle velocity, the best particle position, and the best position of the total particles. The goal is to find the best global position during the search process. The steps of particle swarm optimization are presented in pseudocode in Fig. 3.

```
Initialization
    Select size N as initial population
    Define f(X) as objective function
Determine initial positions and particles velocity
Calculate fitness values of the particles
Initial local best and global best
Parameters: inertia weight w_i, coefficients b_1 and b_2
Random parameters: μ_1 and μ_2
    Select MaxIter as maximum number of iterations
    Describe termination criteria, if there is
iter= 1
for iter= 1 to MaxIter do
Update particles position and velocity
    Computefitness values of the all particles
Update local best and global best
if termination condition seen then
  exit
else
  continue
 end for
```

Fig. 3. Particle swarm optimization pseudocode

According to Fig. 3, first an initial population of particle swarm is considered and fitness is calculated for them. Initially their initial fitness is the best position of the particles. Then, in the iteration loop, new solutions are created by the movement of the particles. After that, the best position of the particles and the best overall position are updated and again in the next iteration of the loop, new solutions are generated. After the loop stopping condition is established, the best overall solution is the optimal solution.

Artificial bee Colony algorithm

The Artificial Bee Colony (ABC) algorithm was presented by Karaboga & Basturk (2008), where an artificial bee colony is considered as the search agent. In this algorithm, bees search for a food source, and each food source location represents a possible solution to an optimization problem. The members of the bee colony are divided into three groups: worker bees, spectator bees, and scout bees. The performance of bees varies depending on the mechanics used to search for food. For example, the task of worker bees is to find places with more nectar and share these places with other bees. The pseudocode of ABC algorithm is given in Fig. 4.

```
Initialization
    Select size N as initial population
    Define f(X) as objective function
    Select size d as Number of stages
    Current best solution C_Best is initialized to
        any feasible solution
    SelectMaxIteras maximum number of
        iterations
    n_p= 1
    iter= 1
while (iter≤ MaxIter)
    for n_p= 1 to M
        The bees fly out of the hive and make
            partial solutions as they move
            forward
        When returning, the bees return to the hive
and information is interchanged
    end for
    if (S_iter better than C_Best) then C_Best = S_iter
    iter= iter+ 1
end while
```

Fig. 4. Artificial Bee Colony algorithm pseudocode

Based on Figure 4, an initial population of artificial bees is initially considered as the solutions. The initialized solution elements are $X = \{x_1, x_2, \dots, x_d\}$. The current best solution, C_{Best}, is initialized for each solution. Also, n_p indicates the step index variable, which in the first step is $n_p = 1$. On the outward path, the bees fly from the hive to stage n_p and a partial solution $S(n_p)$ is generated. On the return path, the bees fly to the hive, exchange information, and make a decision. In the iteration loop, partial solutions are selected from the set in stage $S(n_p)$. Each worker bee generates a candidate solution S_{iter} in the neighborhood of the given position. This solution is compared with C_{Best}. If S_{iter} is better than C_{Best}, S_{iter} is replaced; otherwise, C_{Best} remains unchanged. After establishing the loop stop condition, the best solution in the population is the optimal solution for solving the problem.

Cuckoo Search Algorithm

The Cuckoo Search Algorithm (CS) was introduced by Yang & Deb (2009). This algorithm is based on the behavior of some cuckoo species. Cuckoos secretly lay their eggs in other birds' nests. If the host bird does not recognize these eggs, it is almost certain that new cuckoo chicks will emerge; otherwise, the host bird may remove the eggs from the nest or may even leave the nest. In the following, the steps of the cuckoo search algorithm are summarized as pseudocode in Fig. 5.

```
Initialization
    Create initial population of N host nests
        (each with K eggs)
    Define f(X_k) as objective function
    Describe termination criteria, if there is
    Select MaxIteras maximum number of
        iterations
    iter= 1
while (iter≤ MaxIter) do
    Select randomly X_c and evaluate F_c
    Select randomly k and evaluate F_k for
        k=1,…,K
    if (F_c>F_k)
        Change the host egg with the cuckoo
            egg
    end if
    Discard Fraction p_h of host nests with
        least fitness values
    Retain nests with higher fitness and built
        new nests
    All the nests are ranked based on their
        fitness values
    Current best optimal solution is selected
        based on nest with highest fitness
        where lie on the Pareto Optimal
        Front
    if termination condition seen then
        exit
    else
        continue
    iter= iter+ 1
end while
```

Fig. 5. Cuckoo Search algorithm pseudocode

In Figure 5, the steps of the CS algorithm are given. The multiple objective functions $f(X_k)$, k=1,…,K, are defined for initial values of the solution elements as $X = \{x_1, x_2, \ldots, x_d\}$. k shows the number of host nests. Then, the maximum number of iterations, MaxIter, is defined for the problem. The initial value of the iteration variable is equal to iter=1. The X_c is randomly selected and its fitness value is calculated. Also, a host nest k is randomly chosen and its fitness value is evaluated for k=1,…,K. The iteration loop of checking $F_c > F_k$ is repeated for all eggs in each nest. If this condition is met, the nest egg is exchanged for a cuckoo egg. The number of available host nests is fixed and the cuckoo egg is discovered by the host bird with probability $p_h \in (0,1)$. If a cuckoo egg is discovered, the host bird can either discard the egg or abandon the nest and build a completely new nest. All solutions (nests) are ranked according to their fitness values. Nests are selected whose fitness function values lie on the Pareto optimal frontier.

Bat algorithm

The Bat algorithm (BA) was introduced by Yang (2010). This algorithm is inspired by the behavior of a specific species of bats. Most bats are equipped with the biological sonar called Oculation. The location of the oculus involves the emission of high-frequency tuned sound pulses and the reception of reflective sounds from surrounding objects. Bats use the sonar system to detect prey, escape obstacles, and locate. The steps of the BA are expressed in Fig. 6 as pseudocode.

Initialization
size N as initial population
  Initialize randomly the bats position X_i^{iter}=[x_{i1}^{iter}, x_{i2}^{iter},…, x_{id}^{iter}], where i = 1, 2,…, N
e $f(X)$ as objective function
  Define f_i, E_i and L_i
  Select *MaxIter*as maximum number of iterations
  iter= 1
while (*iter*≤*MaxIter*) **do**
  Update the positions, velocities, and frequencies of the bats in the search space
  if ($r(i) > E_i$) **then**
    Select the current best solution according to the fitness values
    Produce a local solution in the vicinity of the chosen solution
  end if
  structure a new solution by random motion of a bat
  if [($r(i) < L_i$) **and** ($f(X_i) < f(X_{gb})$)] **then**
    Adopt the new solution
    Increase the emission rate
    Reduce emission loudness
  end if
  The bats are ranked based on their fitness values and discover the current global best
    iter= *iter*+ 1
end while

Fig. 6. Bat algorithm pseudocode

According to Fig. 6, an initial population of bats is considered as the solutions. The position of the i-th bat in the d-dimensional search space for the iteration *iter* is denoted by X_i^{iter}. The pulse frequency, pulse emissions rate, and loudness of the emissions are shown by F_i, E_i, and L_i, respectively. The bat moves through the search space. As it searches and finds its prey, it changes the frequency, loudness, and loudness of the pulses. By assumption r(i) is a random number with a uniform distribution in the interval [0, 1], if $r(i) > E_i$, then the best solution is selected from the solutions obtained from the fit values, and a local solution is created in the neighborhood of the selected solution. Each bat position is updated for the local search at each iteration. The search is intensified by a local random walk. All solutions are ranked based on the their fitness values and are considered the global best solutions. The selection of the best solution continues until certain stopping criteria are met. After the loop stopping condition is met, the bat with the highest fitness value is the global optimal solution.

Gray wolf optimization

Gray wolf optimization (GWO) was presented by Mirjalili et al. (2014). This optimization is derived from the behavior of a specific species of wolves. The gray wolf community consists of four groups: alpha, beta, delta, and omega. Alpha wolves, as group leaders, decide to hunt, rest, and move. Each group of beta, delta, and omega wolves is obedient to higher-order wolves and commands subordinate wolves. These wolves first chase the identified prey, then surround and kill it. These distinctive features are used to solve optimization problems. In the following, the GWO pseudo-code is summarized in Fig. 7.

```
Initialization
   Select size N as initial population
Define f(X) as objective function
   Initialize parameters a, c_a, and c_p
   Compute the the population fitness value
   Three highest fitness values are allocated to
      Xα, Xβ,Xδ
   SelectMaxIteras maximum number of
      iterations
   iter= 1
while (iter≤MaxIter) do
   for i = 1 to Nω
         Update position of Xi by Xω^(iter+1)=(
            Xω1^iter+ Xω2^iter+ Xω3^iter)/3
   end for
   Update the parameters a, c_a, and c_p
   Compute the fitness values of the all wolf
      population
   Update Xα, Xβ,Xδ
   iter = iter+ 1
end while
```

Fig. 7. Gray wolf optimization pseudocode

The steps of the GWO are presented in Fig. 7. The algorithm starts with a problem statement and constraints, if any. A population of gray wolves is randomly initialized in the search space. The objective function of d-dimension and the maximum number of iterations, MaxIter, are defined for the problem. The initial value of the iteration variable is equal to iter =1. The parameters c_a, c_p, and a^{iter} are initialized with a random component provided by the variables r_1 and r_2. The objective function or fitness is evaluated at the location of the gray wolves and the best three solutions are determined as α, β, and δ. The remaining candidate solutions are ω. N_ω represents the size of the population of omega wolves. The value of the parameter c_a ensures that half of the number of iterations is for exploration and the rest is for exploitation. Finally, the maximum number of iterations, the alpha gray wolf with the maximum fitness value X_a, is the global optimal solution to the problem.

Other Meta-heuristic Algorithms

As mentioned, many meta-heuristic algorithms have been proposed so far, each inspired by a process found in nature. Other meta-heuristic algorithms include the flower pollination algorithm (Bozorg-Haddad, 2018), the Ant Lion optimization algorithm (Bozorg-Haddad, 2018), the Dragonfly algorithm (Bozorg-Haddad, 2018), the Moth-Flame optimization algorithm (Kaveh & Bakhshpoori, 2019), the Whale optimization algorithm (Kaveh & Bakhshpoori, 2019), the Fireworks algorithm (Kaveh & Bakhshpoori, 2019), the Crow search algorithm (Kaveh & Bakhshpoori, 2019), the Firefly algorithm (Vasuki, 2020), the Elephant herd optimization (Vasuki, 2020), and so on.

COMBINATION of META-HEURISTIC ALGORITHMS with IOT

In this section, researches on the utilizations of meta-heuristic algorithms in the IoT are reviewed. Four indicators are considered to classify the application of meta-heuristic algorithms in the IoT. These indicators include the discrete or continuous of the problem, the type of meta-heuristic algorithm, single-objective or multi-objective optimization, and the aim or application of the research. According to these indicators, a new classification of the applications of meta-heuristic algorithms in the IoT is proposed, which can be seen in Fig. 8.

a. First level: Discrete or continues optimization

As can be observed, the first level of classification includes two branches, discrete and continuous. Decision variables in discrete problems are discrete, in which optimal solutions are obtained using a countable set. In addition, decision variables in continuous problems are continuous, in which optimal solutions are obtained using continuous functions.

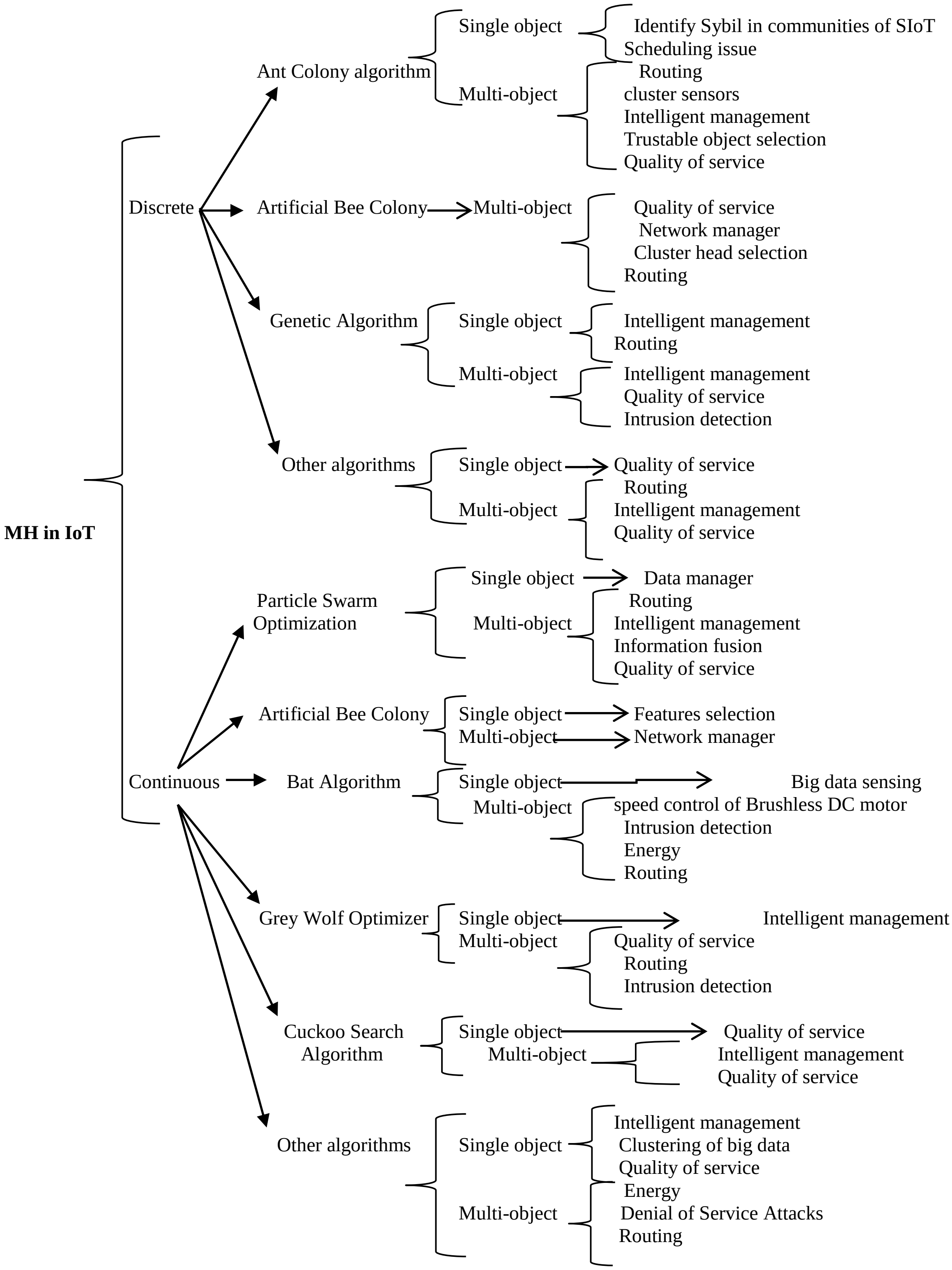

Fig. 8. Schematic diagram of meta-heuristic algorithms with the IoT.

b. Second level: Type of meta-heuristic algorithm

The second level of classification is based on the type of meta-heuristic algorithm used. According to research conducted in the IoT, the discrete branch is divided into four categories: ant colony (AC), artificial bee colony (ABC), Genetic algorithm (GA), and other algorithms. Moreover, the continuous branch is divided into six categories: particle swarm optimization (PSO), artificial bee colony (ABC), bat algorithm (BA), Gray wolf optimization (GWO), cuckoo search (CS), and other algorithms.

c. Third level: Single-objective or multi-objective

At the third level of classification, single-objective or multi-objective optimization is determined. In single-objective optimization problems, only one objective function needs to be optimized. Most applications of the IoT involve more than one objective function. Multi-objective optimization problem is an optimization problem in which different characteristics of the problem are optimized.

d. Forth level: Aim or application

At the fourth level, existing applications and problems of the IoT are considered. Some of the applications considered at this level are routing, intelligent management, quality of service. In the following, the existing literature in this category is discussed in detail.

Application of Genetic Algorithm in the IoT

The supply chain problem was solved by Wang et al. (2018). The GA was applied to obtain the optimal inventory cost of supply chains. Moreover, authors used this algorithm to control inventory cost.

Intrusion detection model based on improved GA and deep belief network was proposed by Zhang et al. (2019). In this study, the GA was used to diagnose attacks and increase the high detection rate. This model led to an improvement in the detection rate of intrusion attacks and a reduction in the complexity of the neural network structure.

The GA and dynamic clustering scheme with IoT were studied by Rani et al. (2020). This procedure was developed to choose the optimal sensor node in wireless sensor networks. Optimization of wireless sensor network (WSN) performance using dynamic cluster routing method based on GA was considered. In order to evaluate the performance, smart transportation network and smart city were investigated.

The service composition problem of IoT-based applications was studied by Kashyap et al. (2020). Dimensionless sorting GA was used to obtain the optimal solution of QoS in this problem. Also, GA was used to obtain Pareto frontiers in this problem.

A routing for blockchain-based IoT was considered by Abbas et al. (2021). For optimizing the energy consumption of nodes in the IoT network, the route calculation was performed by a network controller defined by the GA, which is used for on-demand routing. The efficiency of the proposed model was demonstrated in terms of gas consumption, which indicates the optimal use of resources.

Informed selection of QoS fluctuations was investigated by Khadir et al. (2022). For this purpose, a proposed method based on multi-objective GA was developed to solve the QoS problem. Then, local selection was performed using the resulting local constraints in a parallel and distributed manner. The performance of the proposed method was evaluated and validated through a series of experiments.

Virtual network embedding has been raised as a major challenge in the network virtualization problem. In (Lu et al., 2023), a method was designed to parallelize this problem using GAs and distributed machines. This method increased the chances of finding an optimal solution. The authors examined two methods of implementing the GA with different implementations of crossover and mutation.

In (Saiyed & Al-Anbagi, 2024), GA was applied to detect distributed denial of service attacks in IoT networks. Experimental results showed the effectiveness of the feature selection method in optimizing the system performance for detecting denial of service attacks. Also, the reduction in computational time compared to state-of-the-art methods was confirmed.

Application of Ant Colony Algorithm in the IoT

In (Cosido et al., 2013), a method for automatic routing cycle was proposed. This model used a combination of geographic information system and soft computing. This model was applied to improve traffic congestion in a smart city. The problem was solved using a method based on multi-objective AC algorithm.

Ebrahimi et. al. (2015), developed an ant clustering algorithm for cluster sensors. The aim of cluster sensors in this paper was clustered the similar context information in sensor semantic overlay networks. The AC algorithm was used to reduce the processing cost of sensor search.

The problem of vehicle routing under capacity constraints was studied by Yue & Yi (2016). The optimal logistics distribution route was given according to the combination of the improved GA with the AC algorithm. This algorithm reduced the number of network nodes used and increased the network efficiency.

The process of selecting a trusted object is based on the object's past activities or trust history, using a threshold value to check the object's trustworthiness. A modified AC algorithm was performed to calculate the trustable object in (Suryani et al., 2016). This was a way to improve policy, and the selection process was based on target activities.

In (Sabbani et al., 2016), the multi-agents AC algorithm was used to solve the urban traffic routing problem. In the proposed method of this research, each ant was represented by a computational vehicle unit and the network was shown by using the graph theoretical method.

Social IoT is a paradigm that integrates the IoT and social networks. There are several challenges in creating a social IoT. A new mechanism for detecting attacks in social IoT communities was investigated by Kowshalya & Valarmathi (2016). For this purpose, the authors applied AC algorithm to detect communities.

Based on the IoT and disturbance management, a real-time status analyzer was designed to detect disturbances by Jiang et. al. (2016). The aim of this study was to minimize the negative impact of participants. The participants included customers, managers of the manufacturing company, and workers who participated in production planning. An improved AC algorithm was presented to solve the scheduling problem in this model.

A technique according to AC algorithm was applied for the tourist guide system in (López-Matencio et al., 2017). This system can be helped for tourist routing. Moreover, tourists can decide by means of provided information by the server.

A routing algorithm was provided to select the optimal routing path with IoT in (Said, 2017; Mahalaxmi & Rajakumari, 2017). For this aim, the AC algorithm was utilized in each network to adjust the routing procedure. Finally, an algorithm was posed to control overlapped areas. In [59], each network has its own AC algorithm. The authors proposed an algorithm to control the use of AC algorithms and find a solution for overlapping regions. In additional, in (Mahalaxmi & Rajakumari, 2017), the IoT environment was divided into different regions. To find the optimal solution for each network, an AC algorithm was selected and investigated.

A smart management system based on IoT was designed by Oralhan et al. (2017). The road network was illustrated by a graph. Garbage collection container sensors were considered. All information was transmitted to the management software. Afterwards, the AC algorithm was applied to decide the optimal routing system.

A monitoring system based on IoT was considered by Bellini et al. (2018). Authors used AC algorithm to predict the optimal routing path. Also, they applied this procedure to solve the vehicle routing Problem. In this research, a solution was proposed for the problem of optimizing waste collection by smart machines in a smart city.

A modified AC algorithm was analyzed for cluster resource indexing in (Hong et al., 2019). This algorithm was performed to cluster data in IoT. By means of the ant colony's path, speed, and location information, the IoT cluster resource list was updated. Also, this approach was carried out global and local searches for resources.

An AC algorithm was proposed to select the optimal routing path for energy consumption in Thapar & Batra (2018). Authors considered energy consumption as the sum of energy consumed by the transmitting and listening nodes during transmission and listen processes, respectively.

The Internet of vehicles (IoV) as a branch of IoT was considered by Ebadinezhad et al. (2019). In order to optimization of routing with IoV, Ebadinezhad and et. al. applied AC algorithm. They used this algorithm to reduce traffic load.

In (Azizou et al., 2020), an routing optimization problem was investigated based on AC algorithm. This approach was discussed to solve a decentralized service discovery model. As a result, this algorithm was used in service discovery and finding the best solution with the optimal number of hops with a large network size.

The routing protocol was studied and simulated on the performance of the AC optimization in (Shi & Zhang, 2021). Clustering was performed by the routing method based on the criteria of energy level, collision reduction, distance from the cluster head to the destination, and neighborhood energy. It is worth noting that the cluster head was selected according to the maximum remaining energy, minimum distance to other clusters, and energy consumption. It was shown that the given method can be helped to save more than 40% energy compared to existing methods.

Application of Particle Swarm Optimization in the IoT

An improved PSO was presented by Sung & Chiang (2012). This algorithm was applied in a smart health care system. It was observed that this procedure helped to increase the measurement of the accuracy of the radio effect for multi-physiological signals fusion. It also helped people obtain timely medical care network services.

A monitoring system with several sensors in IoT systems was considered by Sung & Hsu (2013). A PSO algorithm was developed to carry out data fusion in a multi-sensor network. Also, in examining the experimental results, it was found that the resulting sensor data can produce excellent fusion results by eliminating noise interference.

Future IoT (FIoT) as a branch of IoT was investigated by Tsai et al. (2014). A smart data management frame was given in this paper. This framework was developed by means of PSO for FIoT. This model was applied in a smart home.

The improvement of the performance of the fault tolerance algorithm was studied by Luo et al. (2014). In order to reduce the physical damage, this algorithm was used to provide a fast recovery mechanism of the failed path. Also, the fault tolerance routing problem was solved using PSO. This model selected the optimal path based on the optimal sensor nodes.

The smart network of building energy management system was reviewed by Hurtado et al. (2015). This structure summarizes the information of the building environment into block information. The PSO was developed to improve the capacity of this system. Therefore, this algorithm increased the comfort and energy efficiency.

An improved PSO algorithm was presented by Fang et al. (2016). The retrieve end-use products problem was investigated in this study. For this purpose, this algorithm was used to measure the total revenue to obtain good solutions.

A multi-objective PSO was used to cloud brokering system in (Kumrai et al., 2016) This system is an intermediary for managing the connected things in cloud computing. Authors considered the maximum profit of the broker.

A method was reviewed to obtain the optimal situation of secondary base station in (Jinyi et al., 2017). Also, the optimal operating channel selection was proposed to maximize the secondary capacity. The goal was to maximize the number of sensor devices that can be supported. In order to find this location, a PSO algorithm was applied.

A computational resources allocation method was considered by Dai et al. (2018), based on improved PSO. Dai et al. used this algorithm to obtain the optimal decision for mobile-edge calculating of offloading. This algorithm resulted in speeding up the entire process and reducing the number of iterations.

The waterfall control system is controlled remotely using a microcontroller. This system was taken by Sangeetha et al. (2018). In this study, issues such as security, multi-user configuration, and time delay were considered. The PSO algorithm was applied to control the level and flow of the cascade. The responses of this system were validated by settling and rising times.

The QoS as one of the criterion to choose the suitable service was considered by Kashyap et al. (2020). The problem of minimizing service cost and execution time for each task in the service configuration was investigated. PSO was utilized to tackle QoS based on issues of combining service.

In (Liu et al., 2021), the PSO algorithm was studied to present an IoT intrusion detection model. For this aim, the PSO was used to extract data features and the support vector machine was applied to detect intrusions.

An intelligent intrusion detection system for detecting intruders in IoT-based WSNs was investigated by Subramani & Selvi (2023). For this purpose, a feature selection algorithm based on the multi-objective PSO was given. It was shown that the proposed method could detect intruders more accurately by increasing the detection accuracy and reducing the false positive rate.

A quantum PSO was presented to investigate the location of IoT services in (Bey et al., 2024). Quantum particles were designed to represent the IoT service. The quantum particle decryption was performed using the dual hash technique. Throughput, energy consumption, latency, and load balancing were considered in the fitting function.

Application of Artificial Bee Colony algorithm in the IoT

The radio frequency recognition network schematization problem was checked by Tuba & Bacanin (2015). A hybrid algorithm based on ABC and BA algorithms was presented to solve this problem. The performance of the BA was improved by the observer mechanism.

An improved ABC algorithm was developed by Huo & Wang (2016). Huo and Wang were built a service model. They applied this algorithm to obtain the optimal solution from the high accuracy and acceptable time in an IoT service.

The optimal service problem was considered by Xu et al. (2017). The strategy for determining configuration points to produce optimal service solutions was examined. To this end, this problem was solved in according to ABC algorithm and the impact of service features.

The Heterogeneous wireless networks management was studied by Khan et al. (2017). The network choice is done by means of ABC. This procedure was used to choose the goal network with least delay.

A hybrid ABC algorithm was presented by Muhammad et al. (2017). This scheme was applied to search the optimal disjoint subsets. These subsets increase the lifetime of a smart devices network. They also provided the optimal solution in a shorter time.

A combination algorithm based on ABC and Gravitational Search Algorithms was developed by Praveen Kumar Reddy & Rajasekhara Babu (2017). This algorithm was implemented for selecting the efficient cluster head in the IoT devices. Energy, latency, temperature, and distance of IoT devices were considered in the proposed cluster head selection process. To verify the accuracy of the proposed method, the performance of these factors was compared with the obtained results.

Ahmad et. al. (2018) presented an improved ABC algorithm for selection of feature in e-health large data IoT. This algorithm was applied to process big data sets and gain an efficiency processing.

Energy-optimized routing using improved ABC for cluster-based WSNs was proposed by Santhosh & Prasad (2023). The proposed model was presented in order to achieve energy optimization and increase the network lifetime. The ABC algorithm was used to select energy-efficient cluster heads in large-scale WSNs.

Application of Cuckoo Search algorithm in the IoT

A visible light communication power coverage problem in smart home was considered by Sun et al. (2017). For this purpose, an improved CS algorithm was applied to solve this problem. This algorithm improved the quality of initial solutions as chaotic distributions in order to avoid a uniform distribution of solutions.

Improving the QoS of ad hoc cognitive radio network routing was studied by Mulya et. al. (2020). The aim of this research was to obtain optimal signal overhead and improve the quality of service. For this purpose, thet used the CS algorithm to find the final optimal path.

The binary CS algorithm was investigated by Kaur et. al. (2020). Human activity recognition in smart home was studied. For this purpose, activities were considered in a categorical manner. The binary cuckoo search algorithm based on the stacking model was used to recognize information from accelerometer sensors installed on wearable and mobile devices.

The multi-objective optimization problem was modeled based on QoS requirements and service requests in (Liu et al., 2022). Also, an evolutionary algorithm based on cuckoo search was proposed to solve this problem. Simulation results showed that the proposed method provided better performance compared to its counterparts in terms of various criteria such as fog usage, energy consumption, number of services performed, response time, and service latency.

In order to increase the accuracy of the intrusion detection system and prevent the spread of cyber threats in the IoT, a combined method of CS algorithm and K-means was proposed by Hassan et al. (2024). The CS algorithm and K-means were used for feature selection for dimensionality reduction, respectively. The model was evaluated by an available intrusion dataset.

Application of Bat algorithm in the IoT

The brushless DC motor with IoT was modeled by Balamurugan & Mahalakshmi (2018). Also, speed control and parameter estimation of this model were presented. In order to estimate the optimal parameters, the BA and deep neural network were used.

An modified BA was designed by Cui et al. (2019). The convergence speed, optimization performance, and global search space of the proposed algorithm were increased. This algorithm was utilized to select cluster-head node. Furthermore, authors applied this procedure to save the energy cost.

Minimizing the security risks of distributed denial of service attacks in the IoT was investigated by Alharbi et al. (2021). In this study, a hybrid approach of the BA and neural networks was proposed for feature selection and parameter determination for effective attack detection. The proposed algorithm was tested on a dataset with extensive real-world traffic data with malicious and malicious target classes.

The process of maximizing comfort and minimizing energy consumption in smart homes was considered by Malek et al. (2022). The authors presented a solution based on the BA to solve this problem. Three main parameters affecting occupant comfort were considered, namely temperature, illumination, and indoor air quality. The algorithm was optimized towards the best set of values for the three parameters.

Achieving Exposure Path in WSNs was investigated by Jagadeesh et al. (2024). The goal was to obtain optimal coverage and minimize the sensor node balance. For this purpose, a modified BA was used. The search process was conducted to identify routes that not only provide comprehensive coverage of the desired area, but also minimize the number of exposed sensors along the route.

Application of Grey Wolf Optimization in the IoT

A hybrid algorithm of GWO and Bacterial Foraging (BF) algorithms was presented by Anwar et al. (2017). Hassan et. al. used this technique to evaluate the performance of home energy management system. For this aim, household appliances were classified into two categories based on their consumption patterns. The goal was to reduce energy load during peak hours. The GWO provided optimal results and faster convergence.

Software defined mobile networke was considered by Farshin & Sharifian (2017). Furthermore, an improved GWO was proposed. Authors developed a controller framework based on this network and improved GWO. The goal was to reduce the total cost of the cloud data center and achieve better quality of service by the best controller allocation.

An intelligent data routing mechanism based on multi-objective GWO for WSNs was proposed by Ojha & Chanak (2021), which prevents premature network death. The presented method divides the entire network into clusters with different optimal sizes and selects optimal rendezvous points. This mechanism has significantly improved the network lifetime performance.

Two modified GWO algorithms for energy-efficient routing in WSNs and decentralized systems were presented by Seyyedabbasi et al. (2023). The main objectives of this research were to minimize traffic, improve fault tolerance in related systems, and increase reliability and lifetime.

The aim of Alqahtany et al. (2025) was to find key features to provide reliable and efficient intrusion detection systems. Therefore, the generalized GWO was implemented for the feature selection problem. The function of this algorithm was to remove unnecessary features from the dataset used for intrusion detection.

Application of other algorithm in the IoT

A recommendation mechanism was presented by Horng (2015) to modify the QoS in the data center for IoT. Horng gave an optimal hybrid algorithm based on the Artificial Fish Swarm Algorithm and chaos searching theory. This algorithm was used in a smart parking mechanism.

A honey Bee mating (HBM) optimization was developed to improve QoS by Fadel et al. (2017). The algorithm was used for cognitive radio sensor networks. This algorithm led to improved QoS in smart environments.

A gossip-based algorithm was presented to progress urban drainage network by Garofalo et al. (2017). The aim was to reduce sewage flooding and overflow. Therefore, this method ensures fault tolerance even in cases of damage and blockage.

The BF algorithm was studied in (Reddy& Babu, 2017; Khalid et al., 2018). In (Reddy& Babu, 2017), a modified BF algorithm was applied to obtain an optimal energy routing. The performance of the method was analyzed in terms of latency, power, and energy. In addition, a hybrid algorithm based on GA and BF was used to obtain the optimal electricity cost in (Khalid et al., 2018). The goal was to minimize the electricity cost and user comfort through the coordination of household appliances. For this purpose, a home energy management system was checked.

The clustering algorithm for IoV according to dragonfly optimization was designed by Aadil et al. (2018). The clustering metrics of this paper to compare the performance of the optimization method are reclustering delay, clustering time, dynamic transfer range, direction, and speed.

Firefly algorithm was presented to determine the stochastic resonance parameters for getting the optimal parameter value in (Reda et al., 2020). The proposed system had low time complexity and high detection accuracy. This system achieved a feasible design for cognitive radio-based IoT applications.

The project scheduling problem with multi-level resource constraints was studied by Quoc et al. (2020). It was a combinatorial optimization problem that had many advantages in network resource management. This scheduling problem was solved using the differential evolution algorithm (EA) by Quoc et al. (2020). The results were also compared with real data from a well-known textile factory.

The marine predators algorithm was developed to improved QoS by Abdel-Basset et al. (2020). This algorithm was investigated to improve the QoS. Also, the task scheduling problem in Fog computing was solved using these algorithms. To evaluate the performance of the proposed methods, the duration, energy consumption, and execution time metrics were investigated.

In (Tripathi et al., 2020), a parallel military dog algorithm (MD) was studied to solve the big data problems. The performance of this method was investigated in three industrial IoT-based complexes with real data. The developed algorithm performed better in terms of clustering accuracy and computation time.

In (Mohamed et al., 2020), network clustering techniques were studied to improve energy consumption and increase the lifetime of WSNs. A modified Coyote (CO) optimization was considered to obtain optimal energy cost and throughput in WSNs.

In (Iwendi et al., 2021), the authors used a hybrid algorithm of whale optimization and simulated refrigeration to optimize the energy consumption of sensors in the IoT network. Also, several performance criteria such as the number of live nodes, load, temperature, residual energy, and cost function were used to select the optimal cluster head in the IoT network clusters.

The hybrid optimization algorithm of lion-firefly was investigated by Krishna & Thangavelu (2021). This algorithm was used to detect denial of service attacks in the IoT. Also, the random forest method was applied for attack classification and feature selection.

In (Mir et al., 2023), an energy-aware or efficient approach was presented for routing in the IoT. The chaos fuzzy grasshopper optimization algorithm was used. In this algorithm, the initial population of grasshoppers is generated by Lorenz chaos theory and the input and output parameters of the algorithm are adjusted with a fuzzy approach. Three evaluation criteria of residual energy, network lifetime, and coverage rate were used to evaluate the efficiency of the proposed method.

Overview of applications

In this subsection, a summary of research on the applications of metaheuristic algorithms in the IoT is presented according to the year of publication and the number of citations. The results are proposed separately in Tables 1 and 2 for discrete and continuous problems, respectively. Also, some of the main objectives of this research are mentioned.

Table 1 shows the year of research, the number of citations, the type of metaheuristic algorithm used, and the main research objective based on discrete-type applied problems. The number of citations is calculated up to February 2025. The table is sorted by year of publication. As can be seen, the main topics of interest in each article are briefly presented. In this table, the most cited reference is (Zhang et al., 2019) with 400 references, which investigated multi-objective genetic algorithms for intrusion detection.

Table 2 shows the year of research, the number of citations, the type of metaheuristic algorithm used, and the main research objective based on continuous-type applied problems. The number of citations is calculated up to February 2025. Similar to Table 1, Table 2 is sorted by year of publication and the main discussed topics of interest in each paper are briefly presented. In Table 2, the most cited reference is (Tsai et al., 2014) with 385 references, which analysed single-objective particle swarm algorithms for data mining.

Table 1: Summary of research on the applications of metaheuristic algorithms in the IoT for discrete problems

Year	Study	Citations	Algorithm	Objective	Main discussed topic
2013	Cosido et al. (2013)	20	AC	Multi	Find a bike route automatically
2015	Ebrahimi et al. (2015)	18	AC	Multi	Cluster sensors
2016	Yue & Yi (2016)	-	AC	Multi	Optimize route
	Suryani et al. (2016)	25	AC	Multi	Choose a reliable object
	Sabbani et al. (2016)	11	AC	Multi	Routing problem

Year	Study	Citations	Algorithm	Objective	Main discussed topic
	Kowshalya& Valarmathi (2016)	13	AC	Single	Sybil attacks in the community
	Huo & Wang (2016)	39	ABC	Multi	Optimize service instantiation
2017	Mahalaxmi & Rajakumari (2017)	22	AC	Multi	Improve the routing problem
	Oralhan et al. (2017)	66	AC	Multi	Smart waste management
	Thapar & Batra (2018)	13	AC	Multi	Optimize route
	Xu et al. (2017)	65	ABC	Multi	Optimize Service
	Muhammad et al. (2017)	35	ABC	Multi	Solve scheduling problem
	Praveen Kumar Reddy & Rajasekhara Babu (2017)	51	ABC	Multi	Select Cluster head
	Fadel et al. (2017)	93	HBM	Multi	Identify radio frequency sensor networks routing
	Garofalo et al. (2017)	124	GB	Multi	Decrease sewer flooding
2018	Wang et al. (2018)	58	GA	Multi	Control inventory cost in supply chain
	Bellini et al. (2018)	6	AC	Multi	Smart waste management
	Aadil et al. (2018)	118	DO	Multi	Optimize internet of vehicles
2019	Zhang et al. (2019)	400	GA	Multi	Intrusion detection
	Ebadinezhad et al. (2019)	35	AC	Multi	Optimizeinternet of vehicles
	Hong et al. (2019)	14	AC	Multi	Optimize the sources indexing
2020	Rani et al. (2020)	221	GA	Multi	Optimize energy in smart city
	Kashyap et al. (2020)	46	GA	Multi	Optimize service composition
	Quoc et al. (2020)	3	EA	Multi	Schedule network resources
	Reda et al. (2020)	11	FA	Single	Sense spectrum in cognitive radio
	Abdel-Basset et al. (2020)	197	MP	Multi	Optimize energy
2021	Abbas et al. (2021)	44	GA	Single	Gas network energy optimization
	Shi & Zhang (2021)	26	AC	Multi	Optimize scheduling of multiple tasks
2022	Khadir et al. (2022)	19	GA	Multi	Fluctuating Quality of Servic Aware Selection
2023	Lu et al. (2023)	21	GA	Multi	Online virtual network
	Santhosh & Prasad (2023)	31	ABC	Multi	Energy optimization in Wireless sensor network
2024	Saiyed & Al-Anbagi (2024)	14	GA	Single	High-precision attack detection in IoT networks

Table 2: Summary of research on the applications of metaheuristic algorithms in the IoT for continuous problems

Year	Study	Citations	Algorithm	Objective	Main discussed topic
2012	Sung & Chiang (2012)	89	PSO	Multi	Signal processing of remote medical care system
2013	Sung & Hsu (2013)	25	PSO	Multi	Data fusion
2014	Tsai et al. (2014)	385	PSO	Single	Data mining
	Luo et al. (2014)	10	PSO	Multi	Fault Diagnosis routing problem
2015	Hurtado et al. (2015)	116	PSO	Multi	Smart home energy management
	Tuba & Bacanin (2015)	56	ABC	Multi	RFID problem
	Horng (2015)	28	AFS	Single	Smart parking
2016	Jiang et al. (2016)	10	AC	Multi	Recognize the disorder
	Kumrai et al. (2016)	81	PSO	Multi	Optimize the profit of broker
	Fang et al. (2016)	117	PSO	Multi	Resumption of the end-of-use productions
2017	López-Matencio et al. (2017)	13	AC	Multi	Mobility tourists
	Said (2017)	71	AC	Multi	Routing
	Jinyi et al. (2017)	6	PSO	Multi	Find the optimal position of secondary base stations
	Khan et al. (2017)	36	ABC	Multi	Select Network
	Sun et al. (2017)	33	CS	Multi	Optimizevisible light connection in smart building
	Anwar ul Hassan et al. (2017)	16	GWO	Single	Optimize energy
	Farshin & Sharifian (2017)	32	GWO	Multi	Control Software Defined Mobile Networking
	Reddy & Babu (2017)	55	BF	Multi	Energy efficient routing protocol
2018	Dai et al. (2018)	17	PSO	Multi	Optimize the mobile-edge calculation offloading
	Sangeetha et al. (2018)	44	PSO	Multi	Tuning waterfall control
	Ahmad et al. (2018)	103	ABC	Single	Selection of features in e-health system
	Balamurugan & Mahalakshmi (2018)	-	BA	Multi	Brushless DC motor parameter estimation
	Khalid et al. (2018)	230	GA and BF	Multi	Demand side management in smart homes
2019	Cui et al. (2019)	269	BA	Single	Sense big data system
2020	Azizou et al. (2020)	5	AC	Multi	Discover decentralized services
	Kashyap et al. (2020)	37	PSO	Multi	Quality of service
	Moila et al. (2020)	4	BA	Single	Identify radio ad hoc network
	Kaur et al. (2020)	31	CS	Multi	Recognize human activity in smart building
	Tripathi et al. (2020)	96	MD	Single	Identify IndustrialIoT
	Mohamed et al. (2020)	33	CO	Single	Optimize energy in wireless sensor network
2021	Liu et al. (2021)	115	PSO	Multi	Designing a secure intrusion detection model
	Alharbi et al. (2021)	101	BA	Multi	Botnet attack detection
	Ojha & Chanak (2021)	29	GWO	Multi	Improve wireless sensor network longevity
	Iwendi et al. (2021)	280	WOA and SA	Multi	Energy efficiency in the IoT networks
	Krishna & Thangavelu (2021)	25	Li and FA	Multi	Designing a secure intrusion detection model
2022	Liu et al. (2022)	101	CS	Multi	Designing a secure intrusion detection model
	Malek et al. (2022)	38	BA	Multi	Comfort and energy consumption optimization in smart homes
2023	Subramani & Selvi (2023)	43	PSO	Multi	Intelligent intrusion detection system

	Seyyedabbasi et al. (2023)	60	GWO	Multi	Optimal resource utilization in wireless sensor networks
	Mir et al. (2023)	23	CFG	Multi	Energy-aware routing design in the Internet of Things
2024	Bey et al. (2024)	25	PSO	Multi	Efficient IoT service placement in edge computing systems
	Hassan et al. (2024)	3	CS	Multi	Designing a secure intrusion detection model
	Jagadeesh et al. (2024)	1	BA	Multi	Minimal Exposure Path
2025	Alqahtany et al. (2025)	-	GWO	Single	Designing a secure intrusion detection model

FUTURE WORK

According to the reviewed research in the previous sections, it can be seen that many studies have applied meta-heuristic algorithms in various IoT topics. Some features of meta-heuristic algorithms can be used to solve IoT-based systems by means of these algorithms, including scalability, flexibility, and robustness. In the following, some research areas in this field are presented for future work.

Introducing the new methods based on the proposed classification

The provided classification demonstrates that there are very classifications in which no investigation has been presented yet. For example, more research needs to be done on the application of meta-heuristic algorithms to solve discrete or continuous IoT problems. In addition, according to the efficiency of methods for combining multiple meta-heuristic algorithms, research on hybrid meta-heuristic algorithms to solve discrete and continuous IoT problems should be conducted. Also, other meta-heuristic algorithms can be used to examine the IoTs. In addition, a new classification based on these algorithms can be used.

Pay more attention to new and improved algorithms

According to the methods studied in this review article, it can be derived that most of the research in the field of optimization were based on genetic algorithm (GA), ant colony (AC), particle swarm optimization (PSO), artificial bee colony (ABC), gray wolf optimization (GWO), bat algorithm (BA) and cuckoo search (CS). It is possible to use other algorithms to study the IoT, including the flower pollination algorithm (Bozorg-Haddad, 2018), the Moth-Flame optimization algorithm (Kaveh & Bakhshpoori, 2019), the fireworks algorithm (Kaveh & Bakhshpoori, 2019), the elephant herd optimization (Vasuki, 2020) and so on. Also, improved and hybrid IoT algorithms can be used, such as the modified ant colony algorithm (Yang et al., 2006), the improved artificial bee colony algorithm (Eskandar et al., 2012), and etc. In addition, most of the proposed algorithms are based on multi-objective problems. It is suggested that in future works, the application of these algorithms in single-objective problems be further investigated.

Application of meta-heuristic algorithms in other usages

Meta-heuristic algorithms are appropriate for optimization, planning, management and design issues. These kinds of issues are everywhere, including investment, health, manufacturing, vehicles, and so on. These algorithms can be suitable methods to investigate the IoT systems. In many studies, methods have been proposed to solve a particular problem. In addition to the issues raised, these algorithms can be used in various applications. Applications of meta-heuristic algorithms in the IoT include the following areas: routing in wireless sensor networks, estimating water resources, estimating travel time, increasing image contrast, optimizing energy, selecting high-dimensional features, and etc.

Research challenges

The use of meta-heuristic algorithms in IoT environments is inevitable. Despite the very good efficiency of meta-heuristic algorithms in the IoT, there are still challenges that need to be addressed in the articles. Including:

• Hardware and software challenges of the IoT in meta-heuristic algorithms: In recent years, the IoT has attracted a lot of attention in various fields using smart devices. The application of meta-heuristic algorithms is essential for the intelligent management of infrastructure, health systems, agriculture, financial risk, etc. However, the lack of professional sensors and network communications in some areas are very important challenges in systems with an IoT-based framework. In addition, it is necessary to provide a practical system to examine the performance of problems with computational complexity under different conditions.

• Security challenges: So far, in most countries, there is no single organizational structure that can manage dynamic and high-dimensional data. Therefore, there are security challenges such as eavesdropping, data manipulation and repeated attacks. Hence, it is necessary to provide optimization methods to manage some of the problems in investing in this area.

• Big Data Management: Due to the generation of large amounts of data from IoT devices, we need intelligent infrastructure to process, analyze and store data in automation of various tasks. In non-stationary environment and dynamic problems where data is not static, the use of meta-heuristic algorithms helps to solve these problems.

CONCLUSION

The IoT has attracted the attention of many researchers. Recently, we have witnessed the growth of IoT-enabled devices. The IoT has provided new opportunities in the field of technology. Many important issues in the IoT include routing, quality of service, intelligent management, etc. In addition, in recent years, meta-heuristic optimization algorithms have been considered in various fields. One of the application areas of meta-heuristic optimization is the application of these methods in the IoT. Therefore, many studies have addressed the issue of the application of these methods in the IoT. The purpose of this review study was to provide a classification of the application of meta-heuristic algorithms in IoT systems. It is clear that meta-heuristic algorithms are one of the most efficient models for solving dynamic systems such as IoT systems. These algorithms can provide robust and acceptable solutions for these systems. To address this issue, first, definitions and concepts of the IoT and its applications were provided. In addition, some meta-heuristic algorithms were briefly reviewed. Also, pseudocodes of these algorithms were presented. Then, categorization was presented in four levels. At the first level, the problems were identified as discrete or continuous. In the second level, the meta-heuristic algorithms used to solve the problem were expressed. In the third level, IoT systems solved using meta-heuristic algorithms were mentioned. Finally, in the fourth level, aim or application of the research was checked. With this classification, researchers can get an overview of the applications of meta-heuristic algorithms in the IoT.

REFERENCES

Banker, R. D., Charnes, A., Cooper, W. W., & Schinnar, A. P. (1981). A bi-extremal principle for frontier estimation and efficiency evaluations. *Management Science*, *27*(12), 1370-1382.

Aadil, F., Ahsan, W., Rehman, Z. U., Shah, P. A., Rho, S., & Mehmood, I. (2018). Clustering algorithm for internet of vehicles (IoV) based on dragonfly optimizer (CAVDO). *The Journal of Supercomputing*, 74, 4542-4567.

Abbas, S., Javaid, N., Almogren, A., Gulfam, S. M., Ahmed, A., & Radwan, A. (2021). Securing genetic algorithm enabled SDN routing for blockchain based Internet of Things. IEEE Access, 9, 139739-139754.

Abdel-Basset, M., Mohamed, R., Elhoseny, M., Bashir, A. K., Jolfaei, A., & Kumar, N. (2020). Energy-aware marine predators algorithm for task scheduling in IoT-based fog computing applications. IEEE Transactions on Industrial Informatics, 17(7), 5068-5076.

Ahmad, A., Khan, M., Paul, A., Din, S., Rathore, M. M., Jeon, G., & Choi, G. S. (2018). Toward modeling and optimization of features selection in Big Data based social Internet of Things. Future Generation Computer Systems, 82, 715-726.

Alaa, M., Zaidan, A. A., Zaidan, B. B., Talal, M., & Kiah, M. L. M. (2017). A review of smart home applications based on Internet of Things. Journal of network and computer applications, 97, 48-65.

Alaba, F. A., Othman, M., Hashem, I. A. T., & Alotaibi, F. (2017). Internet of Things security: A survey. Journal of Network and Computer Applications, 88, 10-28.

Ali, U., & Calis, C. (2019, October). Centralized smart governance framework based on iot smart city using ttg-classified technique. In 2019 IEEE 16th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT) (pp. 157-160). IEEE.

Alharbi, A., Alosaimi, W., Alyami, H., Rauf, H. T., & Damaševičius, R. (2021). Botnet attack detection using local global best bat algorithm for industrial internet of things. Electronics, 10(11), 1341.

Alqahtany, S. S., Shaikh, A., & Alqazzaz, A. (2025). Enhanced Grey Wolf Optimization (EGWO) and random forest based mechanism for intrusion detection in IoT networks. Scientific Reports, 15(1), 1916.

Anwar ul Hassan, C. H., Khan, M. S., Ghafar, A., Aimal, S., Asif, S., & Javaid, N. (2017). Energy optimization in smart grid using grey wolf optimization algorithm and bacterial foraging algorithm, in: Advances in Intelligent Networking and Collaborative Systems, Springer International Publishing, 166-177.

Azizou, A. Z., Boudries, A., & Amad, M. (2020). Decentralized service discovery and localization in Internet of Things applications based on ant colony algorithm. International Journal of Computing and Digital Systems, 9(5), 941-950.

Balamurugan, K., & Mahalakshmi, R. (2018). Mathematical analysis of BLDC motor parameter estimation using internet of things (IoT).

Bangui, H., Ge, M., & Buhnova, B. (2018). Exploring Big Data Clustering Algorithms for Internet of Things Applications.In IoTBDS (pp. 269-276).

Bellini, V., Di Noia, T., Mongiello, M., Nocera, F., Parchitelli, A., & Di Sciascio, E. (2018). Reflective internet of things middleware-enabled a predictive real-time waste monitoring system. In Web Engineering: 18th International Conference, ICWE 2018, Cáceres, Spain, June 5-8, 2018, Proceedings 18 (pp. 375-383). Springer International Publishing.

Bey, M., Kuila, P., Naik, B. B., & Ghosh, S. (2024). Quantum-inspired particle swarm optimization for efficient IoT service placement in edge computing systems. Expert Systems with Applications, 236, 121270.

Bozorg-Haddad, O. (2018). Advanced optimization by nature-inspired algorithms (Vol. 720). Singapore: Springer.

Cosido, O., Loucera, C., & Iglesias, A. (2013). Automatic calculation of bicycle routes by combining meta-heuristics and GIS techniques within the framework of smart cities. In 2013 International conference on new concepts in smart cities: Fostering public and private alliances (SMARTMILE) (pp. 1-6). IEEE.

Cui, Z., Cao, Y., Cai, X., Cai, J., & Chen, J. (2019). Optimal LEACH protocol with modified bat algorithm for big data sensing systems in Internet of Things. Journal of Parallel and Distributed Computing, 132, 217-229.

Dai, S., Liwang, M., Liu, Y., Gao, Z., Huang, L., & Du, X. (2018). Hybrid quantum-behaved particle swarm optimization for mobile-edge computation offloading in internet of things. In Mobile Ad-hoc and Sensor Networks: 13th International Conference, MSN 2017, Beijing, China, December 17-20, 2017, Revised Selected Papers 13 (pp. 350-364). Springer Singapore.

Donoso, Y., & Fabregat, R. (2016). Multi-objective optimization in computer networks using metaheuristics. Auerbach Publications.

Dorigo, M. (1992). Optimization, learning and natural algorithms. Ph. D. Thesis, Politecnico di Milano.

Ebadinezhad, S., Dereboylu, Z., & Ever, E. (2019). Clustering-based modified ant colony optimizer for internet of vehicles (CACOIOV). Sustainability, 11(9), 2624.

Ebrahimi, M., Shafieibavani, E., Wong, R. K., & Chi, C. H. (2015, June). A new meta-heuristic approach for efficient search in the internet of things. In 2015 IEEE International Conference on Services Computing (pp. 264-270). IEEE.

Eskandar, H., Sadollah, A., Bahreininejad, A., & Hamdi, M. (2012). Water cycle algorithm–A novel metaheuristic optimization method for solving constrained engineering optimization problems. Computers & Structures, 110, 151-166.

Fadel, E., Faheem, M., Gungor, V. C., Nassef, L., Akkari, N., Malik, M. G. A., & Akyildiz, I. F. (2017). Spectrum-aware bio-inspired routing in cognitive radio sensor networks for smart grid applications. Computer Communications, 101, 106-120.

Fang, C., Liu, X., Pardalos, P. M., & Pei, J. (2016). Optimization for a three-stage production system in the Internet of Things: procurement, production and product recovery, and acquisition. The International Journal of Advanced Manufacturing Technology, 83, 689-710.

Farshin, A., & Sharifian, S. (2017). A chaotic grey wolf controller allocator for Software Defined Mobile Network (SDMN) for 5th generation of cloud-based cellular systems (5G). Computer Communications, 108, 94-109.

Fausto, F., Reyna-Orta, A., Cuevas, E., Andrade, Á. G., & Perez-Cisneros, M. (2020). From ants to whales: metaheuristics for all tastes. Artificial Intelligence Review, 53, 753-810.

Garofalo, G., Giordano, A., Piro, P., Spezzano, G., & Vinci, A. (2017). A distributed real-time approach for mitigating CSO and flooding in urban drainage systems. Journal of Network and Computer Applications, 78, 30-42.

Ghayvat, H., Mukhopadhyay, S., Gui, X., & Suryadevara, N. (2015). WSN-and IOT-based smart homes and their extension to smart buildings. sensors, 15(5), 10350-10379.

Glover, F. (1986). Future paths for integer programming and links to artificial intelligence. Computers & operations research, 13(5), 533-549.

Hassan, M. Y., Najim, A. H., Al-Sharhanee, K. A., Kadhim, M. N., Soliman, N. F., & Algarni, A. D. (2024). A Hybrid Cuckoo Search-K-means Model for Enhanced Intrusion Detection in Internet of Things.

Hong, Y., Chen, L., & Mo, L. (2019). Optimization of cluster resource indexing of Internet of Things based on improved ant colony algorithm. Cluster Computing, 22, 7379-7387.

Horng, G. J. (2015). The adaptive recommendation mechanism for distributed parking service in smart city. Wireless Personal Communications, 80, 395-413.

Huo, L., & Wang, Z. (2016). Service composition instantiation based on cross-modified artificial Bee Colony algorithm. China Communications, 13(10), 233-244.

Hurtado, L. A., Nguyen, P. H., & Kling, W. L. (2015). Smart grid and smart building inter-operation using agent-based particle swarm optimization. Sustainable Energy, Grids and Networks, 2, 32-40.

Iwendi, C., Maddikunta, P. K. R., Gadekallu, T. R., Lakshmanna, K., Bashir, A. K., & Piran, M. J. (2021). A metaheuristic optimization approach for energy efficiency in the IoT networks. Software: Practice and Experience, 51(12), 2558-2571.

Jagadeesh, K., Kumar, A. S. P., Kumar, A., Srikar, J. P., Babu, P. S., & Aravinth, S. S. (2024). Efficient Path Planning for Wireless Sensor Networks: Minimizing Exposure with a Modified Bat Algorithm. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1454-1459). IEEE.

Jiang, Y., Ding, Q., & Wang, X. (2016). A recovery model for production scheduling: combination of disruption management and Internet of Things. Scientific Programming, 2016(1), 8264879.

Jinyi, W., Qin, Y., Shrestha, A. P., & Yoo, S. J. (2017, October). Optimization of cognitive radio secondary base station positioning and operating channel selection for IoT sensor networks. In 2017 International Conference on Information and Communication Technology Convergence (ICTC) (pp. 397-399). IEEE.

Kalarthi, Z. M. (2016). A review paper on smart health care system using internet of things. International Journal of Research in Engineering and Technology, 5(03), 8084.

Karaboga, D., & Basturk, B. (2008). On the performance of artificial bee colony (ABC) algorithm. Applied soft computing, 8(1), 687-697.

Kashyap, N., Kumari, A. C., & Chhikara, R. (2020). Multi-objective Optimization using NSGA II for service composition in IoT. Procedia Computer Science, 167, 1928-1933.

Kashyap, N., Kumari, A. C., & Chhikara, R. (2020). Service Composition in IoT using Genetic algorithm and Particle swarm optimization. Open Computer Science, 10(1), 56-64.

Kaur, M., Kaur, G., Sharma, P. K., Jolfaei, A., & Singh, D. (2020). Binary cuckoo search metaheuristic-based supercomputing framework for human behavior analysis in smart home. The Journal of Supercomputing, 76, 2479-2502.

Kaveh, A., & Bakhshpoori, T. (2019). Metaheuristics: Outlines, MATLAB Codes and Examples.doi:10.1007/978-3-030-04067-3

Kennedy, J., & Eberhart, R. (1995, November). Particle swarm optimization. In Proceedings of ICNN'95-international conference on neural networks (Vol. 4, pp. 1942-1948). IEEE.

Khadir, K., Guermouche, N., Guittoum, A., & Monteil, T. (2022). A genetic algorithm-based approach for fluctuating QoS aware selection of IoT services. IEEE Access, 10, 17946-17965.

Khalid, A., Javaid, N., Guizani, M., Alhussein, M., Aurangzeb, K., & Ilahi, M. (2018). Towards dynamic coordination among home appliances using multi-objective energy optimization for demand side management in smart buildings. IEEE access, 6, 19509-19529.

Khan, M., Din, S., Gohar, M., Ahmad, A., Cuomo, S., Piccialli, F., & Jeon, G. (2017). Enabling multimedia aware vertical handover Management in Internet of Things based heterogeneous wireless networks. Multimedia Tools and Applications, 76, 25919-25941.

Kowshalya, A. M., & Valarmathi, M. L. (2016). Detection of sybil's across communities over social internet of things. Journal of Applied Engineering Science, 14(1).

Krishna, E. P., & Thangavelu, A. (2021). Attack detection in IoT devices using hybrid metaheuristic lion optimization algorithm and firefly optimization algorithm. International Journal of System Assurance Engineering and Management, 1-14.

Kumrai, T., Ota, K., Dong, M., Kishigami, J., & Sung, D. K. (2016). Multiobjective optimization in cloud brokering systems for connected Internet of Things. IEEE Internet of Things Journal, 4(2), 404-413.

Laghari, A. A., Wu, K., Laghari, R. A., Ali, M., & Khan, A. A. (2021). A review and state of art of Internet of Things (IoT). Archives of Computational Methods in Engineering, 1-19.

Lessmann, S., Caserta, M., & Arango, I. M. (2011). Tuning metaheuristics: A data mining based approach for particle swarm optimization. Expert Systems with Applications, 38(10), 12826-12838.

Liu, J., Yang, D., Lian, M., & Li, M. (2021). Research on intrusion detection based on particle swarm optimization in IoT. IEEE Access, 9, 38254-38268.

Liu, C., Wang, J., Zhou, L., & Rezaeipanah, A. (2022). Solving the multi-objective problem of IoT service placement in fog computing using cuckoo search algorithm. Neural Processing Letters, 54(3), 1823-1854.

López-Matencio, P., Vales-Alonso, J., & Costa-Montenegro, E. (2017). ANT: Agent Stigmergy-Based IoT-Network for Enhanced Tourist Mobility. Mobile Information Systems, 2017(1), 1328127.

Lu, Q., Nguyen, K., & Huang, C. (2023). Distributed parallel algorithms for online virtual network embedding applications. International Journal of Communication Systems, 36(1), e4325.

Luo, S., Cheng, L., & Ren, B. (2014). Practical swarm optimization based fault-tolerance algorithm for the internet of things. KSII Transactions on Internet and Information Systems (TIIS), 8(3), 735-748.

Mahalaxmi, G., & Rajakumari, K. E. (2017). Multi-agent technology to improve the internet of things routing algorithm using ant colony optimization. Indian Journal of Science & Technology, 10(31), 1-8.

Malek, M. R. A., Aziz, N. A. A., Alelyani, S., Mohana, M., Baharudin, F. N. A., & Ibrahim, Z. (2022). Comfort and energy consumption optimization in smart homes using bat algorithm with inertia weight. Journal of Building Engineering, 47, 103848.

Marietta, J., & Chandra Mohan, B. (2020). A review on routing in internet of things. Wireless Personal Communications, 111(1), 209-233.

Meng, Z., Li, G., Wang, X., Sait, S. M., & Yıldız, A. R. (2021). A comparative study of metaheuristic algorithms for reliability-based design optimization problems. Archives of Computational Methods in Engineering, 28, 1853-1869.

Mir, M., Yaghoobi, M., & Khairabadi, M. (2023). A new approach to energy-aware routing in the Internet of Things using improved Grasshopper Metaheuristic Algorithm with Chaos theory and Fuzzy Logic. Multimedia Tools and Applications, 82(4), 5133-5159.

Mirjalili, S., Mirjalili, S. M., & Lewis, A. (2014). Grey wolf optimizer Advances in Engineering Software. 69 46–61.

Mohamed, A., Saber, W., Elnahry, I., & Hassanien, A. E. (2020). Coyote optimization based on a fuzzy logic algorithm for energy-efficiency in wireless sensor networks. IEEE Access, 8, 185816-185829.

Moila, R. L., Velempini, M., & Madiba, M. S. (2020, September). Optimisation of cuckoo search algorithm to improve quality of service routing in cognitive radio ad hoc networks. In 2020 6th IEEE International Energy Conference (ENERGYCon) (pp. 951-957). IEEE.

Muhammad, Z., Saxena, N., Qureshi, I. M., & Ahn, C. W. (2017). Hybrid artificial bee colony algorithm for an energy efficient internet of things based on wireless sensor network. IETE Technical Review, 34(sup1), 39-51.

Mukadam, Z., & Logeswaran, R. (2020). A cloud-based smart parking system based on IoT technologies. Journal of critical reviews, 7(3), 105-109.

Nakib, A., & Talbi, E. G. (2017). Metaheuristics for medicine and biology (Vol. 704). Berlin Heidelberg: Springer.

Ojha, A., & Chanak, P. (2021). Multiobjective gray-wolf-optimization-based data routing scheme for wireless sensor networks. IEEE Internet of Things Journal, 9(6), 4615-4623.

Oralhan, Z., Oralhan, B., & Yigit, Y. (2017). Smart city application: internet of things (IoT) technologies based smart waste collection using data mining approach and ant colony optimization. Int. Arab J. Inf. Technol., 14(4), 423-427.

Praveen Kumar Reddy, M., & Rajasekhara Babu, M. (2017). Energy efficient cluster head selection for internet of things. New Review of Information Networking, 22(1), 54-70.

Priyan, M. K., & Devi, G. U. (2019). A survey on internet of vehicles: applications, technologies, challenges and opportunities. International Journal of Advanced Intelligence Paradigms, 12(1-2), 98-119.

Quoc, H. D., The, L. N., Doan, C. N., Thanh, T. P., & Xiong, N. N. (2020). Intelligent Differential Evolution Scheme for Network Resources in IoT. Scientific Programming, 2020(1), 8860384.

Rani, S., Ahmed, S. H., & Rastogi, R. (2020). Dynamic clustering approach based on wireless sensor networks genetic algorithm for IoT applications. Wireless Networks, 26(4), 2307-2316.

Rani, R., Jain, S., & Garg, H. (2024). A review of nature-inspired algorithms on single-objective optimization problems from 2019 to 2023. Artificial Intelligence Review, 57(5), 1-51.

Reda, H. T., Mahmood, A., Diro, A., Chilamkurti, N., & Kallam, S. (2020). Firefly-inspired stochastic resonance for spectrum sensing in CR-based IoT communications. Neural Computing and Applications, 32(20), 16011-16023.

Reddy, P. K., & Babu, R. (2017). An Evolutionary Secure Energy Efficient Routing Protocol in Internet of Things. International Journal of Intelligent Engineering & Systems, 10(3).

Reddy, M. P. K., & Babu, M. R. (2019). Implementing self adaptiveness in whale optimization for cluster head section in Internet of Things. Cluster Computing, 22, 1361-1372.

Sabbani, I., Youssfi, M., & Bouattane, O. (2016, September). A multi-agent based on ant colony model for urban traffic management. In 2016 5th International Conference on Multimedia Computing and Systems (ICMCS) (pp. 793-798). IEEE.

Sahlmann, K., Scheffler, T., &Schnor, B. (2017). Managing IoT device capabilities based on oneM2M ontology descriptions. Proceedings of the 16. GI/ITG KuVSFachgesprächSensornetze, ser. Technical Reports. Hamburg, Germany: HAW Hamburg, 23-26.

Said, O. (2017). Analysis, design and simulation of Internet of Things routing algorithm based on ant colony optimization. International Journal of Communication Systems, 30(8), e3174.

Saiyed, M. F., & Al-Anbagi, I. (2024). A Genetic Algorithm-and t-Test-Based System for DDoS Attack Detection in IoT Networks. IEEE Access, 12, 25623-25641.

Sakthivel, S., &Vidhya, G. (2021). A Trust-Based Access Control Mechanism for Intra-Sensor Network Communication in Internet of Things.Arabian Journal for Science and Engineering, 46(4), 3147-3153.

Santhosh, G., & Prasad, K. V. (2023). Energy optimization routing for hierarchical cluster based WSN using artificial bee colony. Measurement: Sensors, 29, 100848.

Seyyedabbasi, A., Kiani, F., Allahviranloo, T., Fernandez-Gamiz, U., & Noeiaghdam, S. (2023). Optimal data transmission and pathfinding for WSN and decentralized IoT systems using I-GWO and Ex-GWO algorithms. Alexandria Engineering Journal, 63, 339-357.

Shah, S. H., & Yaqoob, I. (2016). A survey: Internet of Things (IOT) technologies, applications and challenges. 2016 IEEE Smart Energy Grid Engineering (SEGE), 381-385.

Shi, B., & Zhang, Y. (2021). A novel algorithm to optimize the energy consumption using IoT and based on Ant Colony Algorithm. Energies, 14(6), 1709.

Singh, M., & Baranwal, G. (2018). Quality of service (QOS) in internet of things. In 2018 3rd International Conference On Internet of Things: Smart Innovation and Usages (IoT-SIU) (pp. 1-6). IEEE.

Soler-Dominguez, A., Juan, A. A., & Kizys, R. (2017). A survey on financial applications of metaheuristics. ACM Computing Surveys (CSUR), 50(1), 1-23.

Subramani, S., & Selvi, M. (2023). Multi-objective PSO based feature selection for intrusion detection in IoT based wireless sensor networks. Optik, 273, 170419.

Sun, G., Liu, Y., Yang, M., Wang, A., Liang, S., & Zhang, Y. (2017). Coverage optimization of VLC in smart homes based on improved cuckoo search algorithm. Computer Networks, 116, 63-78.

Sun, G., Li, J., Dai, J., Song, Z., & Lang, F. (2018). Feature selection for IoT based on maximal information coefficient. Future Generation Computer Systems, 89, 606-616.

Sung, W. T., & Chiang, Y. C. (2012). Improved particle swarm optimization algorithm for android medical care IOT using modified parameters. Journal of medical systems, 36, 3755-3763.

Sung, W. T., & Hsu, C. C. (2013). IOT system environmental monitoring using IPSO weight factor estimation. Sensor Review, 33(3), 246-256.

Sangeetha, A. L., Bharathi, N., Ganesh, A. B., & Radhakrishnan, T. K. (2018). Particle swarm optimization tuned cascade control system in an Internet of Things (IoT) environment. Measurement, 117, 80-89.

Suryani, V., Sulistyo, S., & Widyawan, W. (2016). Trust-based privacy for Internet of Things. International Journal of Electrical and Computer Engineering, 6(5), 2396.

Thangaramya, K., Kulothungan, K., Logambigai, R., Selvi, M., Ganapathy, S., & Kannan, A. (2019). Energy aware cluster and neuro-fuzzy based routing algorithm for wireless sensor networks in IoT. Computer networks, 151, 211-223.

Thapar, P., & Batra, U. (2018). Implementation of ant colony optimization in routing protocol for internet of things. In Innovations in Computational Intelligence: Best Selected Papers of the Third International Conference on REDSET 2016 (pp. 151-164). Springer Singapore.

Torre, I., Adorni, G., Koceva, F., & Sanchez, O. (2016). Preventing disclosure of personal data in IoT networks. In 2016 12th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS) (pp. 389-396). IEEE.

Tripathi, A. K., Sharma, K., Bala, M., Kumar, A., Menon, V. G., & Bashir, A. K. (2020). A parallel military-dog-based algorithm for clustering big data in cognitive industrial internet of things. IEEE Transactions on Industrial Informatics, 17(3), 2134-2142.

Tsai, C. W., Lai, C. F., & Vasilakos, A. V. (2014). Future internet of things: open issues and challenges. Wireless Networks, 20, 2201-2217.

Tuba, M., & Bacanin, N. (2015, May). Hybridized bat algorithm for multi-objective radio frequency identification (RFID) network planning. In 2015 IEEE congress on evolutionary computation (CEC) (pp. 499-506). IEEE.

Umair, M., Cheema, M. A., Cheema, O., Li, H., & Lu, H. (2021). Impact of COVID-19 on IoT adoption in healthcare, smart homes, smart buildings, smart cities, transportation and industrial IoT. Sensors, 21(11), 3838.

Vasuki, A. (2020). Nature-inspired optimization algorithms. CRC Press

Villa-Henriksen, A., Edwards, G. T., Pesonen, L. A., Green, O., & Sørensen, C. A. G. (2020). Internet of Things in arable farming: Implementation, applications, challenges and potential. Biosystems engineering, 191, 60-84.

Wang, Y., Geng, X., Zhang, F., & Ruan, J. (2018). An immune genetic algorithm for multi-echelon inventory cost control of IOT based supply chains. IEEE Access, 6, 8547-8555.

Xu, X., Liu, Z., Wang, Z., Sheng, Q. Z., Yu, J., & Wang, X. (2017). S-ABC: A paradigm of service domain-oriented artificial bee colony algorithms for service selection and composition. Future Generation Computer Systems, 68, 304-319.

Yang, X. S., Lees, J. M., & Morley, C. T. (2006). Application of virtual ant algorithms in the optimization of cfrp shear strengthened precracked structures. In International Conference on Computational Science (pp. 834-837). Berlin, Heidelberg: Springer Berlin Heidelberg.

Yang, X. S., & Deb, S. (2009). Cuckoo search via Lévy flights. In 2009 World congress on nature & biologically inspired computing (NaBIC) (pp. 210-214). Ieee.

[41] Yang, X. S. (2010). A New Metaheuristic Bat-Insspired Algorithm. Nature Inspired Cooperative Strategies for Optimization. Studies in Computational Intelligence (Springer). pp-65-74.

Yang, X. S. (2020). Nature-inspired optimization algorithms: Challenges and open problems. Journal of Computational Science, 46, 101104.

Yang, X. S. (2020). Nature-inspired optimization algorithms: Challenges and open problems. Journal of Computational Science, 46, 101104.

Yue, S., & Yi, S. (2016). Study of logistics distribution route based on improved genetic algorithm and ant colony optimization algorithm. Internet of Things (IoT) and Engineering Applications, 1(1), 11-17.

Zarpelão, B. B., Miani, R. S., Kawakani, C. T., & de Alvarenga, S. C. (2017). A survey of intrusion detection in Internet of Things.Journal of Network and Computer Applications, 84, 25-37.

Zedadra, O., Guerrieri, A., Jouandeau, N., Spezzano, G., Seridi, H., & Fortino, G. (2018). Swarm intelligence-based algorithms within IoT-based systems: A review. Journal of Parallel and Distributed Computing, 122, 173-187.

Zhang, K., Liang, X., Lu, R., & Shen, X. (2014). Sybil attacks and their defenses in the internet of things.IEEE Internet of Things Journal, 1(5), 372-383.

Zhang, Y., Li, P., & Wang, X. (2019). Intrusion detection for IoT based on improved genetic algorithm and deep belief network. IEEE Access, 7, 31711-31722.