International Journal of Wireless Information Networks (2021) 28:175–198
https://doi.org/10.1007/s10776-021-00508-9

A Comprehensive Review on Swarm Intelligence-Based Routing Protocols in Wireless Multimedia Sensor Networks

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Received: 17 August 2020 / Revised: 24 October 2020 / Accepted: 11 February 2021 / Published online: 26 February 2021

Abstract

Wireless Multimedia Sensor Networks (WMSNs) have emerged as a new class of Wireless Sensor Networks (WSNs). They are applicable in several applications specific Quality of Service (QoS) requirements, like area monitoring and video surveillance. Recently, an intense research and considerable progress was conducted in solving numerous wireless sensor-networking challenges. However, the problem of enabling real-time quality-aware video streaming or scalar data transmission in WMSN is still open and largely unexplored. Unfortunately, transmitting multimedia data with reliability and in real time is a challenging task. WMSNs are dedicated for critical and sensitive applications, and the QoS is required and constitutes criterion to succeed the application. Routing protocols are then the building blocks of any WMSN transactions. Many WMSN routing protocols have been proposed previously. The categorization of these protocols is related to the number and type of QoS constraints. The eye-catching category in routing classification is the routing protocols based on Swarm Intelligence (SI). Bio-inspired techniques are very attractive and consider biology as a source of inspiration by mimicking the dynamics of natural species. The principle is to provide optimal routing solutions. In our work, we cover the details on how to define and build smart routes to accommodate QoS-aware applications. In this paper, we present a comprehensive review that specifically focuses on highlighting and describing all existing SI-based routing strategies for WMSNs. Moreover, detailed classification and comparative analysis based on relevant metrics are presented. Design challenges and possible directions for future research are also indicated.

Keywords Wireless multimedia sensor network (WMSN) · Swarm intelligence (SI) · Routing protocol · QoS

1 Introduction

Technological advances in embedded microprocessors, wireless communications and digital electronics have enabled the development of small and low-cost sensor nodes that made Wireless Sensor Networks (WSNs) one of the promising technologies during the past decade [1]. WSNs [2] consist of a substantial number of interconnected and self-organized sensors with limited processing and energy resources widely dispersed in a coverage area. The tasks of these tiny sensors are to sense, process, and transmit scalar data (i.e. Temperature, pressure, humidity), usually via radio transmitter to the sink either directly or through wireless multi-hops [2, 3]. WSN is deployed in numerous fields such as military, environmental monitoring, health care, security and surveillance in habitat and industry [4].

However, the integration of real time multimedia traffic in WSN applications imposes novel requirements about scalar sensors capabilities. Fortunately, the rapid development and progress of sensors, in addition to the availability of inexpensive Complementary Metal Oxide Semiconductor (CMOS) cameras and microphones, allowed for the emergence of so-called Wireless Multimedia Sensor Networks (WMSNs) [5]. WMSN is a new and emerging type of sensor networks that contain sensor nodes equipped with cameras, microphones, and other sensors producing multimedia content (see Fig. 1). It is a network of wirelessly interconnected devices that allow retrieving video and audio streams, still images, and scalar sensor data [6]. The network imposes new constraints related to the nature of the data captured and

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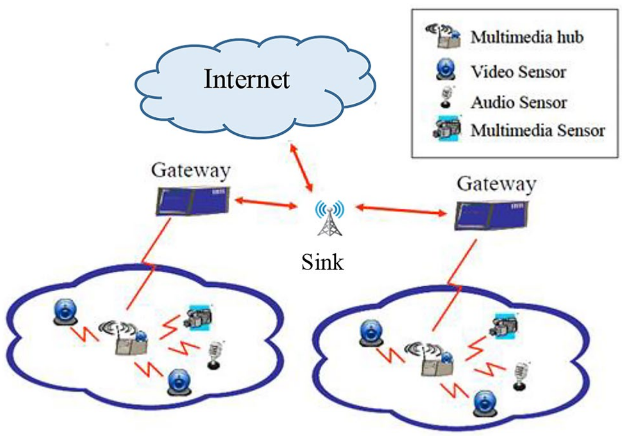

Fig. 1 WMSN architecture

manipulated. Indeed, the multimedia data are very largely voluminous compared to the scalar data and having in addition a time constraint (real time). Furthermore, WMSN is an exciting new technology that has not only extended the horizon of traditional sensor network applications, but also proliferated significantly to creating a series of new applications such as multimedia surveillance, traffic monitoring and enforcement, gaming, personal and health care, environmental and industrial [7].

In addition to the challenges raised by WSNs in terms of energy limitation, deployment, coverage, reliability, WMSNs have more functionalities and exigency, such as high bandwidth demand, limited delay, real-time delivery, acceptable jitter and low packet loss ratio. These characteristics impose more resource constraints that involve energy consumption, memory, bandwidth and processing capabilities [8]. The objective is to be able to meet Quality of Service (QoS) requirements for multimedia data that aim to confront the majority of the aspects described above. These mentioned constraints and requirements affect the design of WMSNs and lead to the need to develop protocols in order to maximize the network lifetime while satisfying the QoS requirements of the various applications [8].

Similar to the WSNs, the main task of sensor nodes in WMSN is to monitor the target area and transmit the collected information to the sink node in order to perform specific processing according to the needs of each application. In order to deliver data packets to the destination, sensor nodes require the routing protocols. Routing protocols are used for finding the best path to establish communication in the networks. However, designing an efficient routing protocol for WMSNs' applications is a challenging task due to the nature and abilities of sensor nodes such as energy supply, computation and communication abilities, deployment of nodes, communication architecture, the unreliability of the wireless links and the different performance requirements of the application in term of QoS. For all these reasons, the design of a routing protocol should take into account the requirements and resource constraints of the WMSN, in order to meet the stringent QoS requirements.

In the literature, several research initiatives exist to address the routing concerns in both WSNs and WMSNs. The classification of the different routing schemes can be done according to the classical approaches (reactive, proactive, flat and hierarchical) or biological-inspired approaches. In the last decade, bio-inspired routing emerged as an alternative to the classical approaches and attracted many researchers to improve the WSN/WMSN/Mobile ad hoc networks (MANET)/Vehicular Ad-Hoc Network (VANET)/Flying Ad-Hoc Networks (FANET) performance as well as increasing the energy efficiency and communications effectiveness. There are various bio-inspired and evolutionary approaches, including genetic programming, neural networks, evolutionary programming, particle swarm optimization (PSO) and ant colony optimization (ACO) used for routing protocols in ad hoc and sensor wireless networks [9]. In this paper, we particularly focus on the Swarm Intelligence (SI)-based routing protocols (ACO, PSO, ABC, etc.).

SI [10–13], which is an Artificial Intelligence (AI) discipline, is considered as an optimization technique used to solve various complex problems in diverse areas. It is a novel field, originated from the study of the collective behavior of decentralized, self-organized natural systems in interaction among themselves and with the environment. These multi-agent intelligent systems take inspiration from the collective behaviors of insect societies, flocks of birds, and schools of fishes, often observed in nature.

Studies have shown that routing protocols based on such bio-inspired methods bring many improvements and offer better performance in terms of energy efficiency, reliability, scalability, adaptability and robustness [14]. In fact, the design of most of these algorithms is inspired by the foraging behavior of insects to solve routing problems. They establish paths that can be used by individual insects to move back and forth efficiently from the nest of the colony to the food sources. These paths are the result of synergistic interactions between a large number of individuals that inform others of their characteristics using various communication schemes [15].

By going through the literature, most of existing routing-related surveys are for WSNs. So far, many survey papers that present and compare SI-based routing protocols for WSNs are published. However, over the past decade, very little researches have been done on WMSNs and in particular on WMSN routing protocols. Most of these are limited in the context of reviewing the classical routing protocols. Only few related surveys evoke SI-based routing protocols in their paper. For this purpose, and to our knowledge, we have not discovered any review that exclusively treats SI-based routing protocols for WMSNs. Therefore, and to bridge this gap, this research manuscript intends to present a comprehensive and state-of-the-art research work on SI-based routing in WMSNs.

The main contributions of this research are described as follows:

1. We carried out an in-depth research of various existing classical and SI-based routing protocols for WSNs and WMSNs since the appearance of the first to this day.
2. We give a taxonomy of the different SI-based routing protocols designing for WMSNs by classifying them according to their features. This categorization will help readers to further comprehend and analyze these approaches.
3. We provide a clear overall understanding of WMSNs by presenting their characteristics and outlining some design requirements that routing protocols should consider.
4. An exhaustive survey of emerging WMSN routing techniques based on SI is highlighted since the appearance of the first in 2008 until today. We explain in detail operation, objectives, features, limitations, simulation and experimental result of each algorithm.

   This contribution raises awareness among a large audience about the existence and the performance of the SI-based solutions.

5. After listing all SI-based WMSN routing protocols, we first established a comparative analysis of these protocols based on prominent metrics such as network topology (flat or hierarchical), route selection, multipath, location awareness, congestion control, classification service, energy efficiency, load balancing and QoS parameters considered. Then, we give a set of information on the simulation approach that was used for each solution studied.
6. We provide an insight into the promising future research directions that can improve the use of routing protocols in WMSNs. This will contribute to the development of this area of research.

The remainder of this paper is structured as follows (see Fig. 2). In Sect. 2, we present the main factors to consider in routing protocols design for WMSNs. After going through the literature, we report, in Sect. 3, the different surveys on SI-based routing protocols in WSNs and WMSNs. In Sect. 4, we first discuss the SI principle. Then we classify all existing SI-based routing protocols proposed in the literature for WMSNs and describe every protocol in detail. A comparative summary of these protocols is also provided in a tabular form in Sect. 5. An overview of future research directions is given in Sect. 6. Finally, we conclude the paper in Sect. 7.

2 Design Goals for WMSN Routing

The design of routing protocols must take into consideration the performance of WMSNs in terms of QoS and energy efficient.

Applications such as security surveillance, health systems and traffic management systems that involve multimedia content must be delivered in real-time. The multimedia data collected are voluminous and require high transmission rates and processing capabilities.

In WMSNs, requirements such as real-time multimedia traffic and handling data volumes raise many challenges and resource constraints to the routing protocols design. These problems are addressed by many researchers as surveyed in [6, 16, 17].

This section outlines the different challenges that should be considered for improving the communication efficiency in these networks.

- *Energy efficiency:* WMSNs deliver multimedia content consisting of high volumes of data, which require high transmission rates and processing capabilities. Sensors in WMSNs usually consume even more energy than in WSNs. Therefore, energy consumption is one of the most important performance metrics to consider when designing the routing protocol in order to prolong the network lifetime.
- *QOS requirement*: Delivering QoS and considering application-specific requirements remain significant challenges in the design of WMSNs applications. In

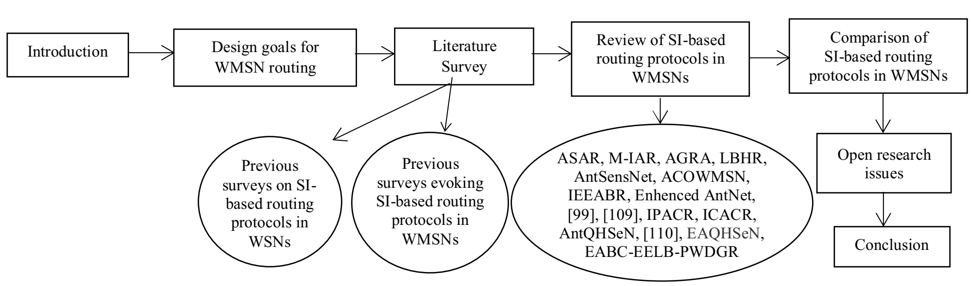

Fig. 2 Document structure

WMSNs, most applications require real-time multimedia data delivery. Therefore, different QOS metrics like delay, bandwidth, jitter and reliability will be imposed on WMSNs as a result according to the type of the application.

- *High bandwidth demand*: Multimedia content requires high transmission bandwidth. In order to optimize resource constraints of WMSN, new transmission techniques are needed to provide the required bandwidth with low power consumption.
- *Multimedia source coding techniques*: Coding must be taken into account as it is directly related to the size of the data. In WMSNs, multimedia devices such as cameras generate voluminous multimedia content that is why multimedia transmission requires a multimedia source coding techniques. One of the main aims of coding techniques is reducing the information amount sent in the network by using efficient compression techniques.
- *Multimedia In-network Processing*: In WMSNs, multimedia in-network processing algorithms are applied to the raw data sent from the environment. New architectures for collaborative, distributed, and resource-constrained processing are required in in-network processing for filtering and extracting information needed to the periphery of the network. Thus, the scalability of the system increases by decreasing redundant data transmission. Therefore, to enable flexibility in-network processing of multimedia content, it is important to develop application-independent architectures.

3 Related Work

There are many ways to classify routing protocols depending on different parameters. The classes and subclasses are not mutually exclusive as many protocols belong to more than one class or a subclass. Therefore, the classification of the different protocols can be done according to the classical approaches (based on path establishment, network structure or protocol operation) and based on SI.

Concerning WSNs, the bulk of research in the domain of routing has been done following a non SI-based approach. So far, several surveys of classical routing protocols exist in the literature on a variety of different research domains. The major important studies of routing schemes existing are described in [18–33]. While other surveys are more specific to certain aspects, such as energy-efficient routing [34–38], hierarchical/clustered-based routing [39–43], multipath routing [44, 45], and real time routing [46–48].

3.1 Previous Surveys on SI-Based Routing Protocols in WSNs

In the WSN, many surveys have focused on the SI approach and have only presented routing protocols based on SI [14, 15, 49–61]. While in other reviews, both classical and SI routing protocols have been studied [37, 62–65].

3.2 Previous Surveys Evoking SI-Based Routing Protocols in WMSNs

In WMSNs, most of surveys are limited in the context of reviewing the classical routing protocols [66–79]. Despite the considerable research on SI-based routing protocols in WMSNs, a very small number of surveys evokes some of these protocols in their investigation.

In Table 1, we discuss the reviews and surveys that evoked SI-based routing protocols that have been done so far in the literature.

Thus, there is no comprehensive paper that examines all the SI-based WMSN routing protocols in an appropriate classified manner. Therefore, the main objective of our review paper is to provide direct access and an initial reading point for future beginning researchers.

4 Review of SI-Based Routing Protocols in WMSNS

WMSNs require the delivery of multimedia content with a certain level of QoS. However, multimedia content is different from scalar data, especially with regard to the size of the data. Therefore, routing in WMSNs requires special attention because the large size of the data reduces the efficiency of data transmission. Some routing protocols have been developed according to the principles of SI. Thus, the majority of research in this area has focused on energy efficiency and QoS. In this section, we list all the existing SI-based routing algorithms dedicated for WMSNs and offered in the literature from the first in 2008 until today.

Figure 3 illustrates the proposed taxonomy. Bio-inspired routing applied to WMSNs is divided into three main categories: Evolutionary algorithms, Swarm intelligence algorithms and other biologically inspired algorithms.

The evolutionary algorithms [87] are computational techniques inspired by natural evolution using iterative progress such as inheritance, growth, development, reproduction, selection, and survival as seen in a population. They include Genetic Algorithms (GAs), Evolutionary Programming (EP) and Evolutionary Strategies (ES). These are population-based stochastic search algorithms operating with

Table 1 Description of previous surveys evoking SI-based routing protocols in WMSN

Year of survey	References	Survey characteristic	Survey description
2012	[80]	Energy-efficient QOS routing	Ehsan and Hamdaoui presented a classification and description of some energy-efficient QOS routing techniques for WMSNs. This paper was the first to have evoked the notion of routing protocols based on SI for WMSN in its classification. In this category, only three routing protocols were discussed briefly
2013	[17]	Classical routing	The paper published by Abazeed et al. proposes a classification and discussion concerning different routing protocols for WMSNs with their features and limitations. As well, a general comparison between them is made. SI routing protocol is a category in which four routing protocols have been defined (ASAR, ACOLBR, M-IAR, and Ant-like Routing Algo)
2014	[81]	ACO-based routing	Another paper from Abazeed et al. focused on ACO routing protocols designed for multimedia transmission. A description of the ACO principle and an explanation of the ACO-based routing protocols for WMSNs were done. Also, a comparison between them was realized. This review was the first to be interested in the SI approach and more particularly to ACO, but also to study a certain number of routing protocols based on ACO
2015	[82]	Secure routing approaches for next generation	In a third paper, Abazeed et al. addressed the concept of secure routing in WMSNs. A set of routing protocols based on SI (based on ACO) and on security was identified for WMSNs. A comparison between the mentioned routing protocols is summarized in a table according to various QoS parameters and others
2015	[83]	QOS routing	Aswale and Ghorpade proposed a classification of QoS routing protocols in WMSNs against a number of routing metrics as a categorization criterion and summarized the analysis in a comparative table by indicating the strengths and weaknesses of each protocol. The SI aspect has not been considered in this article. In the description of the different techniques, only five routing protocols based on SI are reviewed
2016	[84]	Classical and swarm intelligence routing	A survey of various existing protocols for WMSNs is presented by Bhandary et al. in which these are examined and categorized based on different characteristics into three main categories. An analytical comparison of protocols by category is carried out. SI-based routing is one of the categories in which a significant number of protocols have been listed and discussed, whose some are not intended for WMSNs
2016	[85]	Classical routing	Shen and Bai present an exhaustive study on WMSNs routing protocols classified into five major categories based on their design and optimization objectives. A detailed comparison of each solution is provided according to various parameters. SI-based routing is a sub-sub-category of one of the above mentioned categories called intelligent routing in which only two routing protocols have been reported
2018	[86]	Classical and swarm intelligence routing	Deb and Choudhury present a study of existing routing approaches used for WMSNs. The routing protocols cited were classified according to four categories and compared according to some characteristics. The biologically inspired category includes evolutionary based and certain SI algorithms (ASAR, M-IAR, ACOLBR, AntSensNet, AntHQSeN and AGRA)

best-to-survive criteria [88]. In WMSNs, A Crossover Game Routing Algorithm [89] has been proposed combining the genetic algorithm (GA) with game theory.

Besides swarm intelligence and evolutionary algorithms, which represent the two main categories of bio-inspired algorithms, a number of other biological processes have served as an inspiration for various algorithms. Cell biology and bacterial foraging are two interesting bio-inspired approaches used for WSN routing.

Works that apply cell biology [90, 91] are inspired by the similarities that exist between organisms and networks:

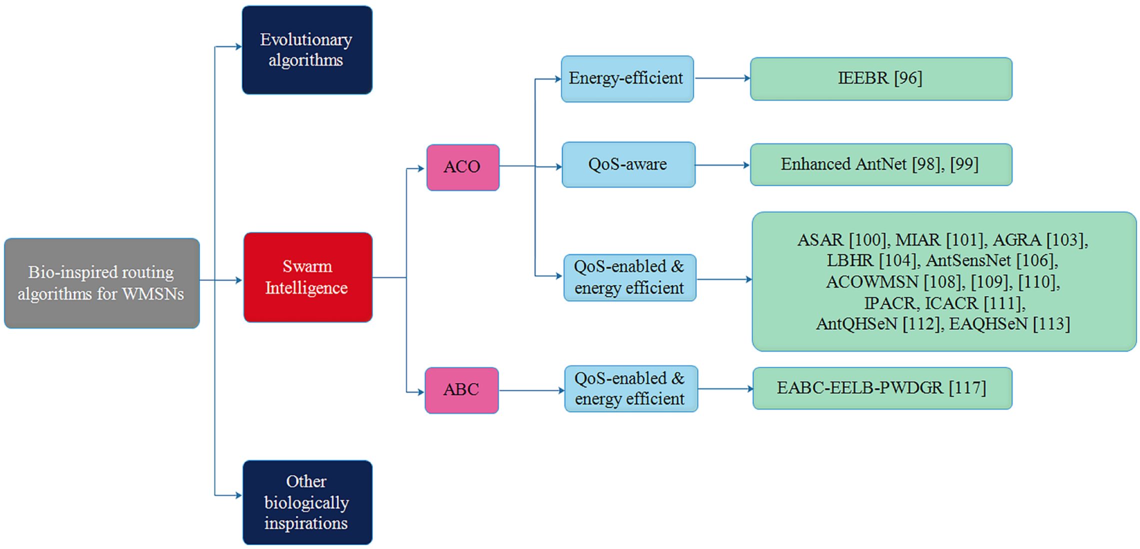

Fig. 3 Classification of SI-based routing protocols for WMSN

organisms consist of organs, tissues and cells, while a network consists of clusters and nodes.

Following the principle of swarm-based algorithms, the Bacteria Foraging Optimization Algorithm (BFOA) [92] is inspired by the foraging behavior of a group of *Escherichia coli* swarms (*E. coli*). It is a bacterium that lives in the intestines of some mammals and uses tumbling and swimming as it travels to the food source.

Our interest in this survey relates to the second category, as shown in Fig. 3, which consists of listing all the WMSN routing protocols inspired by SI such as Ants and Bees. Two sub-classes can be identified in this category, according to the existing routing protocols; Ant Colony Optimization (ACO) and Artificial Bees Colony Optimization (ABC). We established a taxonomy for ACO because the majority of the research work has been inspired by the behavior of ants. In this category, three sub-classes can be observed: A. Energy-efficient based, B. QoS-aware based and C. QoS-enabled and energy efficient based. Protocols fall under each category have also been listed in the figure. Concerning ABC, only one sub-class based on QoS-enabled and energy efficient includes only one routing protocol taken inspiration from Bee behavior.

4.1 The Concept of Swarm Intelligence

Considered as bio-inspired algorithms, Swarm Intelligence-based algorithms [10] are inspired by natural phenomena such as the collective intelligence of communities, observed in particular in social insects (such as ants, bees, animals evolving in groups such as migratory birds, schools of fish). Collective intelligence refers to the cognitive capacities of a community resulting from the multiple interactions between community members and the collaboration between them brings out possibilities for representation, creation and learning that are superior to those of isolated individuals. Swarm is used to refer to a finite set of particles or interactive agents. Thus, by imitating the social behavior of particles forming swarms capable of self-organizing, several algorithms have been proposed in recent decades among them, we find Ant Colony Optimization (ACO) [93] and Artificial Bee Colony (ABC) [94], the most widely used. These SI-based techniques are artificially simulated and used to solve routing problems in wireless networks.

Therefore, SI proposes efficient and robust metaheuristic algorithms to solve several problems in WSNs, as reviewed in [15, 62]. Routing constitutes an optimization problem, which, by analogy, can be solved with many swarm intelligence based algorithms.

4.1.1 Ant Colony Optimization (ACO)

ACO [93, 95] is the most famous SI inspired algorithm. It draws inspiration from the intelligent and foraging behavior of real ant colonies. Ants use indirect communication through the secretion of chemical pheromones, which allows them to find shortest paths from the food source to their nest. In their natural environment, ants move surrounding their nest in search of food. Once the food is found, the ant deposits pheromones, leaving behind traces of the path taken. The ants behind can smell these substances. When choosing its way, each ant tends to choose, in probability, the path with the highest pheromones. Therefore, the path likely to be taken by the majority of ants turns out to be the shortest path to the food source. This reinforcement of the path is due to strong pheromone concentrations deposited with each passage of an ant. Nevertheless, less visited paths will see their pheromone trail gradually evaporate over time, thereby reducing their attractive strength.

Most routing protocols intended for WMSNs are developed using ACO approach. These solutions are described below divided into three categories.

4.1.2 Energy-Efficient Routing Protocol

- **Improved Energy-Efficient Ant-Based Routing Algorithm (IEEABR)**

  Zungeru et al. [96] have developed an enhanced version of energy-efficient ant-based routing EEABR [97], energy-aware, based on ACO and designed for Visual Sensor Networks (VSNs). This protocol named IEEABR addresses the specific requirements of video and image applications that require high bandwidth. It uses the self-organization, self-adaptability of ACO to determine multiple optimal paths while avoiding using the energy of nodes on the optimal path. It considers the available power of nodes and improves memory usage. The modifications improve energy consumption of nodes and network performance. Therefore, the routing tables of each node are intelligently initialized, a priority is given to neighboring nodes of source, which must be the destination, and the congestion is controlled by reducing the flooding ability of ants in the network. As in EEABR, the protocol uses Fants to find a path to the destination. Each ant only carries the address of the last visited nodes. Every node saves the previous node, forward node, ant identification and a timeout value in a memory carried by the ant. Among the neighbor, the node, which falls to be the destination, is assigned the highest probability. The Bants are generated to update the pheromone trail of the path traversed by the Fant. The objective is that nodes near the sink have more pheromone levels and therefore force the distant nodes to find better paths.

  IEEABR approach has been compared to its predecessor EEABR and to some ant-based routing protocols such as Basic Ant-Based Routing (BABR) Algorithm, Sensor-driven and Cost-aware ant routing (SC), Flooded Forward ant routing (FF) and Flooded Piggybacked ant routing (FP). These algorithms use Routing Modeling Application Simulation Environment (RMASE) and the obtained results in each static or dynamic scenario are compared according to certain performance metrics like: latency, success rate, energy consumption and energy efficiency.

  The results showed that IEEABR has the lowest latency and a high success rate in packets delivery. In terms of energy consumption, EEABR consumes 31% and 29.66% of energy than IEEABR for static and dynamic scenario respectively. This means that IEEABR surpasses all protocols in term of low energy consumption. In summary, it outperforms its competitors in most of the assumed scenarios and metrics.

4.1.3 QoS-Aware Routing Protocol

- **Enhanced AntNet Protocol for WMSNs**

  Bennis et al. [98] propose an optimization of the basic AntNet routing protocol to adapt it to WMSNs and provide better QoS in terms of delay and Packet Delivery Ratio (PDR). Several improvements of the initial version of the protocol were made such as the adaptation of the protocol in a wireless and mobile environment in order to make it more robust and more desirable for WMSNs. The goal is to minimize the number of hops, modify the way of choosing the next hop, make the protocol reactive and add lists that allow storing information such as an ancestor list, destination list, etc.

  The simulation results of the protocol with NS2 showed that compared to AODV, the proposed protocol has better packet delivery ratio, end-to-end delay and overhead and these improvements are more readable especially when the number of node increases.

  The disadvantage of this protocol is that it has not been compared to other routing protocols designed for WMSN to accurately evaluate its performance.

- **A Routing Optimization Based on Ant Colony for WMSNs**

  To transmit multimedia data, a routing optimization approach has been proposed by Putra et al. [99] based on ACO to guarantee the bandwidth or QoS in WMSN applications. The ACO proposed a technique that allows to determine best selected paths between sensor nodes and a sink. In spite of the variation of the bandwidth channels of WSNs, the goal of the protocol is precisely to adapt to the varying bandwidth conditions.

  The performance parameters that were taken into account to ensure the QOS were throughput and packet delivery ratio (PDR).

  The optimization process is done in relation to several levels of problems encountered. The number of layers represents the number of variables of the problems encountered and the number of nodes of a layer corresponds to the number of discrete values allowed for the linked variables. Thus, each node is associated with a possible discrete value for a variable.

  Pheromone tables are always updated by forward and backward ants. Thus, the routing tables will be updated according to the variable bandwidth conditions.

  The approach was simulated with the NS2 simulator. Two flows of UDP and TCP data were sent through the WMSN and three routing protocols were simulated namely the proposed protocol ACO, Ad hoc On-Demand

Distance Vector (AODV) and Destination Sequenced Distance Vector (DSDV). The results of the simulation show that routing optimization can provide better performance in terms of PDR and the throughputs and better QoS than DSDV and AODV routing protocols. Therefore, the ACO algorithm proposed allows to optimize routing techniques for multimedia applications on the WMSNs.

4.1.4 QoS-Enabled & Energy Efficient Routing Protocols

- **An ant-based Service-Aware Routing algorithm for Multimedia Sensor Networks (ASAR)**

  ASAR, proposed by Sun et al. [100], is a QoS hierarchical routing protocol for WMSNs based on the traditional ant algorithm. Routing selection involves the discovery of three service-aware accessible paths to meet different QoS requirements, thus optimizing network utilization, minimizing interference between the three types of services, balancing traffic distribution and improving network performance. It is a new service-oriented multipath routing selection scheme. This protocol is intended for three basic services provided by multimedia sensor networks and who are:

  - Event-driven service mode: R service must meet the requirements of real time and reliability. It is delay and error intolerant. This requires less bandwidth, a path with little traffic and high signal-to-noise ratio.
  - Data query service mode: the data received by service D must always be as reliable as possible. It is error intolerant but query-specific delay tolerant. This requires a path with significant congestion and a high signal-to-noise ratio on each link.
  - Stream query service mode: S services are delayed intolerant, but query-specific error tolerant. This requires a path with less traffic and lower signal-to-noise ratio.

  The proposed routing algorithm is designed based on the cluster-based architecture. In the cluster, nodes are able to collect and process multimedia data. The cluster head (CH) merges these multimedia data and then transfers them upstream. The sink node manages the status of CHs and broadcasts signals in the network. The CH connects the sink node via multi-hop wireless links.

  For each kind of service (R/D/S service), every CH generates ants to discover three different QoS paths from each CH to the sink. The QoS parameters used for the selection of the routing are latency, packet loss, energy consumption and bandwidth. So, the pheromone value is quantified on the sink in order to decrease the sending frequency of reverse ants to accelerate the convergence of ASAR.

  ASAR considers the routing scheme between the CH and the sink. It is made to run in all CHs. For each service, it searches three QoS routes by using a positive feedback mechanism adopted in Ant Colony Optimization (ACO) and the results are stored on CHs. For different services, all CHs manage three optimal path tables, three pheromone tables, the real time pheromone value and transition probability for its next hop.

  A simulation with NS2 was performed to evaluate the performance of ASAR with traditional ant-based algorithm, Dijkstra and conventional directional diffusion (DD) in WSN. The results show that the effectiveness of the ASAR algorithm depends on differentiated services. Also, it offers better convergence and better QoS for several types of services in WMSN.

- **Multimedia-Enabled Improved Adaptive Routing (M-IAR)**

  M-IAR, proposed by Rahman et al. [101], represents an extension of the Improved Adaptive Routing (IAR) algorithm [102], incorporating wireless multimedia sensors and targeting multimedia applications in WSNs. It is a flat multi-hop routing protocol that uses the geographic location of the sensor nodes, by assuming that each node knows its own position as well as that of its neighbors and the sink, in order to find the shortest path having the least number of nodes between the sending and receiving nodes. It uses the ACO concept to optimize some QoS parameters like end-to-end delay and jitter.

  The protocol considers two kinds of ants: Forward ant (Fant) and Backward ant (Bant). At the beginning, Fant is used by the source node to explore the route toward the sink. A probability is calculated for each of its neighbors in order to choose its best neighbor node taking into account the distance to the sink and the sender node. Based on this information, the node with the highest probability value is selected to become the next forwarder and the routing table is updated. In its packet header, every Fant has a set of global parameters like the nodes visited and their neighbors, the corresponding probability values, the total number of visited hops and the distance for each link. Intermediate nodes follow the same procedure until reaching the sink. Once the destination is reached, Fant generates Bant and sends it via the same visited path with the same global header information to reinforce the visited nodes by increasing the probability.

  The proposed protocol was simulated and the results demonstrate that it presents low jitter and low end-to-end delay what can be beneficial for multimedia traffic. Moreover, in 98% the cases, M-IAR can find the shortest path with only three route discovery attempts by consuming less energy, visiting less number of hops, and providing high packet success rate. Unfortunately, the simulation results obtained by M-IAR were not compared to any other routing protocols.

- **Ant-like Game Routing Algorithm for WMSNs (AGRA)**

  The ant-like game routing algorithm, namely AGRA [103] is a combination of ACO and game theory to solve the QoS routing problem of WMSNs. It is an energy efficient QoS routing algorithm that uses game theory to improve the performance of the ant colony algorithm. The goal is to find optimal routing path from source to sink node providing the QoS guarantee.

  Game theory uses three concepts: a set of players, strategies of each player and the payoff function of each one. The assumption is that each player tries to maximize his payoffs with minimum cost. The model uses mixed strategies game.

  In the proposed routing algorithm, the node uses local information to find a path according to the game result. When sending a packet from a sensor node, Fants are sent to find the path to the sink. Based on the pheromone trails left by ants, the probability is calculated using residual energy, delay and bandwidth to define payoffs of game players. All ants select next hop with the probabilities of mixed strategy Nash equilibrium of routing game.

  Once the Fants successfully reach the sink, a Bant is generated and takes the path found by Fants towards the source.

  A soon as, the Bants return to the source node, Fants are generated again, and each ant selects the next hop with the result of routing game until all ants select the same routing.

  The algorithm has not been simulated to be compared to others.

- **Load balancing-based hierarchical routing algorithm for WMSNs (LBHR)**

  Li and Wang proposed LBHR protocol [104] to improve the QoS of data transmission in WMSNs. The algorithm is inspired by ACOLBR (Ant Colony Optimization-based Load Balancing Routing Algorithm for WMSNs) [105].

  LBHR is a bio-inspired hierarchical routing protocol based on QoS used for load balancing and includes the clustering algorithm, the inter-cluster routing and the intra-cluster routing.

  First, the hierarchical architecture of the network is constructed from a new clustering algorithm, which allows both the selection of cluster heads and cluster formation. Each node within a cluster can become the cluster head if its weight is the smallest.

  Then, the inter-cluster routing is built by the improved ACO algorithm to find an optimal path with minimum cost and some suboptimal paths from the source cluster head to the sink. The suboptimal path is used by splitting the stream when the amount of data exceeds the path flow threshold. This improves the efficiency of the transmission and guarantees the QoS of the network.

  When a node sends its data to the next node, Fant updates the pheromone using the local pheromone update rule. Once in the sink, the Bant releases more pheromones on the selected path using the global pheromone update rule in order to reinforce the current optimal path. Thus, LBHR improves the ability to explore ants by introducing the maximum and minimum of pheromone density values. The same process is repeated until the second and third suboptimal paths are found. During the transmission, in the event of a node failure, the neighboring node will set the pheromone value to zero and send an error message to the source node. Then the source node will stop the transmission on this path and activate alternate path for transmission. However, if the next node finds that the end-to-end delay of a path from the source exceeds a certain threshold, it will send a congestion message to the source. Then the source node will reduce the data amount transmitted in this path and activate an alternate path to ensure the reliability.

  Finally, the intra-cluster routing is constructed using the minimal spanning tree (MST) algorithm with the cluster head as the root. Therefore, a hierarchical routing tree is established and the ability of each cluster member decreases from top to bottom.

  Thus, the cluster member sends the collected data after aggregation to cluster head through the intra-cluster hierarchical routing tree, while the cluster head sends the aggregated data to the sink using the inter-cluster routing scheme.

  The algorithm was simulated using the Network Simulator NS2 and was compared to clustered-control (CC) and M-IAR algorithms according to the following parameters: end-to-end delay, network lifetime, the transmission success rate and communication overhead. The results obtained demonstrate that LBHR reduces the end-to-end delay, increases the transmission success rate and achieves load balancing. Thus, the protocol has better adaptability and scalability, can in fact prolong the network lifetime and guarantee the QoS of data transmission in WMSNs.

- **Ant-based multi-QoS routing metric for WMSNs (AntSensNet)**

  AntSensNet protocol proposed in [106] by Cobo et al. is a QoS routing model specially designed for WMSN that combines the principles of ACO metaheuristic with hierarchical architecture, thereby improving network performance and optimizing its use. Moreover, it holds a power efficient packet scheduling scheme to achieve minimum video distortion during transmission through multiple paths. The proposed algorithm is a hybrid routing protocol that takes into account reactive and proactive components for efficient route establishment. It chooses the suitable path based on a combination of four QoS routing metrics: packet loss rate, available memory, queuing delay, and normalized remaining energy in order to meet the QoS requirements requested by the applications while minimizing the consumption of limited resources.

The authors take into account the network classification and believe that each class of traffic should be treated with its own appropriate QoS metrics. Thus, the aim of this algorithm is to determine accessible routes for each class of traffic from a transmitting CH node to the sink that satisfy various QoS requirements by introducing a packet scheduling policy which considers different priorities for each traffic class.

The algorithm works in three steps. The first is to create clusters in the network, drawing inspiration from the behavior of ants. Next, search for network routes between clusters satisfying the criteria of each application using ants. Finally, transfer different traffic using the routes previously discovered by the ants.

The clustering approach is used to ensure the scalability, improve network data aggregation mechanisms, thereby reducing node workloads, saving energy and increasing the network lifetime.

AntSensNet includes three operating phases: clustering process, route discovery and data transmission.

The clustering process is based on an improved ant colony algorithm T-ant [107] and is made up of rounds. Each round is divided into cluster setup phase and a steady phase. In the steady phase of the algorithm, data transmission takes place between sources and the sink. In the cluster setup phase, cluster ant (Cant) controls the selection of CHs in a totally distributed manner. A node with a Cant become a CH and the rest of the nodes join the cluster. An information update phase is carried out by the sensors before the cluster setup phase and consists of broadcasting a HELLO packet with the node's ID, its clustering pheromone value, and its state to its neighbors. On arrival, the stored information in a table of neighborhood is used then to decide how to join the cluster and route discovery. The suitability of a node to become CH depends on the clustering pheromone value. An adjustable factor called "cluster radius" determines the minimum distance between two CH nodes.

After clusters formation, the CH begins the route discovery process. Each CH maintains a pheromone table for its neighbors in each traffic class according to the QoS parameters. To find an appropriate path to the sink node for a specific traffic class, the CH source broadcasts Forward ants (Fant). Along the way, the Fants collect traversed nodes' IDs together with the four QoS metrics of the nodes passed by. When a CH relay node receives a Fant, its information is updated before sending it to the next hop. Once Fant arrives at the sink, the routes found are evaluated. When the route meets the application requirements, a Bant is generated and forwarded through the reverse path, updating the pheromone values. In case of congestion or link loss issues, the protocol generates a maintenance ant to inform neighborhood CHs to update their pheromone tables and to find alternative routes.

Data Ants (D ant) assist in route discovery and maintenance, their behavior is similar to that of FANTs. A Dant is assigned to transport urgent or real-time data from a node to the sink and is processed before all other traffic classes in each node.

Several simulations were performed with NS2 and the results showed that AntSensNet converges better and improves QoS for multiple types of services in WMSNs compared to ad hoc on-demand distance vector AODV and T-ant. Regarding the transmission of video packets, the video quality is much better with AntSensNet than with TPGF or ASAR because these do not handle video content correctly.

- **An Ant Colony Optimization-Based QoS Routing Algorithm for WMSNs (ACOWMSN)**

ACOWMSN is a routing algorithm based on ACO, presented by Yu et al. [108], for the transmission of video and imagery data in WMSNs based on QoS and energy efficiency. The algorithm is designed to find an optimal path that meets application-specific QoS constraints and aims to prolong the network lifetime. It is a reactive routing protocol using packet loss rate, queuing delay, bandwidth and remaining energy as QoS constraints to determine the path with minimum routing cost from the source to the destination. In routing modeling, the algorithm involves two phases: routing discovery and routing confirm, thus including two types of artificial ants: forward and backward ants. In routing discovery phase, Fants are sent to the destination node using unicast or broadcast. Broadcast approach is used only when current node does not have information about the sink. Fants collect information like minimum residual energy, cumulative queue delay, packet loss ratio and available memory of each node visited in order to find the next optimal neighbor node towards the destination. For each node, next forwarding node is selected by calculating the probability that combines the pheromone value with the residual energy. In routing confirm phase, when the Fant reaches the destination, it will be converted into Bant and return to the source node in the opposite direction along the same path. Bant updates the local node status and the pheromone concentration value of every visited node on the traversed path based on the path quality and the end-to-end delay.

The simulation of the proposed algorithm with NS2 shows that by comparing it to M-IAR and AODV according to the end-to-end delay, network lifetime and packet delivery ratio, the algorithm offers better performance than the other algorithms and increases the network lifetime. In addition, it is relatively more reliable and scalable than the other ACO-based protocols. Notwithstanding, it is not suitable for large-scale WMSNs because determining parameters is not easy and therefore the algorithm does not converge quickly.

- **Optimal routing protocol based on ant colony optimization in MWSNs**

An optimal routing protocol [109] that is energy-aware and QoS-aware based on ACO for WMSNs allows to find the optimal routing path between sensor nodes and the sink. The proposed algorithm minimizes energy consumption and prolongs the lifetime of the network while maximizing quality and reliability link.

The cost function of the link depends on the costs of energy consumption link, quality link and reliability link. However, each metric cited can be attributed to an importance that varies depending on the multimedia application requirements.

Thus, the optimal path is one that has the minimum cost in terms of energy consumption, link reliability and quality in addition to defining the delay as a constraint.

The energy consumption cost is calculated in term of the communication energy, transmission energy and a receiver node energy level. The quality link is the bit error rate on the link and the reliability link cost is the percentage of time that the link is up and functioning properly.

The Fants move from a node to its neighbor according to a transition probability that depends on the pheromone value deposited on the link and the heuristic value of the link, which is the inverse of the cost of the link. At first, the initial pheromone value is the same for all links. The pheromone value is updated only on the links found by all ants. The pheromone value evaporates at a certain rate on all links in the paths constructed by all ants.

Knowing that the simulation is run with different numbers of nodes. The parameters involved in the proposed algorithm are number of ants, pheromone value importance, the heuristic value importance and the evaporation rate. The purpose of the effected simulation is to see the impact of varying values of these parameters on the performance of the algorithm to determine the time taken to find the optimal path. The impact of the transmission bit rate, the event generation rate and the frame coding rate on various performance metrics are also taken into consideration.

The simulation results state that increasing the number of ants increases the probability of finding the optimal path, but results in increasing the computation time. Increasing the pheromone weight means increasing the importance of the following pheromone trails and would lead in unsatisfactory path. Increasing the heuristic weight means increasing the importance of the heuristic value which is the real cost of the path. In conclusion, to find the optimal path, the heuristic value must be more important than the pheromone value. An increase in evaporation rate would result in faster evaporation of pheromone trails and reduce the probability of finding the optimal path.

An increase in the transmission bit rate results in a decrease in the average queuing delay per node, end-to-end delay, delay jitter and loss percentage. On the other hand, an increase in the event generation rate leads to an increase in the queuing delay per node, end-to-end delay, delay jitter and loss percentage. In addition, good quality video requires a high frame encoding rate. Increasing this rate increases the percentage of loss. Thus to reduce this percentage, a high transmission bit rate is required for high frame coding rates.

- **QoS Enabled Probabilistic Routing for Heterogeneous Wireless Sensor Networks**

Kumar et al. [110] presented a QoS distributed routing algorithm based on ACO in Heterogeneous Wireless Sensor Networks (HWSNs). It takes into consideration heterogeneous characteristics of nodes and allows better packet delivery. The protocol was designed to meet various QoS requirements posed by different types of traffic generated by heterogeneous nodes, thereby maximizing network performance and usage. The network considers scalar and multimedia sensor nodes supporting scalar and multimedia data traffic respectively.

Each node maintains two tables: a pheromone table containing the neighbor information such as pheromone value required to reach a destination and an average hop count and a neighbor table in which QoS metrics are stored as available bandwidth and remaining energy of the node. When selecting QoS aware route, the protocol uses three ants: Hello ants, Forward ants (FA) and backward ants (BA). Hello ants are short messages broadcast by all the nodes at each interval and are used for neighbor discovery, pheromone diffusion and link failure detection. To find a path from source to destination, the source node generates control packet FA. A FA stores intermediate nodes encountered on its way and network status information for determining the QoS-aware routes. On receiving the FA, every intermediate node updates the residual bandwidth and energy. At each intermediate node, depending on whether the routing information for destination is available or not, FA is either unicast or broadcast. In the first case, the next hop is selected based on a probability calculation.

Upon arrival at destination, each FA is converted into BA. The destination computes the pheromone released by BA. This pheromone value is determined by the route status information carried by the ant, hop count and delay. The BA is unicast, thus taking the same path in the opposite direction to the source. When the source node receives BA, it begins to send data packets stochastically on different paths. The probability of selecting the next hop is determined according to the heuristic function and the pheromone value deposited on each node for the destination. For multimedia traffic, the protocol considers residual bandwidth as heuristic factor. For scalar traffic, residual energy is considered as the heuristic factor.

The simulation results of the proposed protocol with NS2 show that in terms of packet delivery fraction, end-to-end delay, jitter and percentage packets loss, the proposed solution reveals a significant improvement in performance compared to AODV standard in HWSNs with dynamic topology. However, in terms of normalized routing load, the proposed protocol has higher routing overhead than AODV.

- **A QOS-aware routing algorithm based on ant-cluster in WMSNs**

  Huang et al. [111] offer two multi-path routing algorithms based on ACO in WMSNs and propose a generalized QoS-aware routing model that integrate priorities of packets and multiple routing metrics such as end-to-end delay, packet loss rate, bandwidth and energy consumption. The first, called an improved ant-based routing algorithm IPACR, a flat routing protocol that consists in improving the standard ant colony routing algorithm (SACR) through optimizing the initial pheromone distribution thus aiming to accelerate the convergence rate of the algorithm. While SACR is based on the principle that each link has the same initial pheromone value between nodes and their neighbors, IPACR establishes a neighbor-list, which stores information about adjacent nodes and guarantees at least one feasible path. The optimal path is chosen according to the first hello packet, arriving at the node. Log SEQ also allows to define the optimal path. Hence, the initial pheromone value of each link depends on log SEQ. Each Fant has a table that contains all the visited nodes in order to prevent looping. The probability equation of selecting the next node is based on the pheromone value and the heuristic function that depends largely on the remaining energy. Local and global pheromone values are updated by Fants and Bants.

  The second, called ICACR is a QoS-aware, hierarchical and ant based routing protocol that uses IPACR and adapts it to the clustering topology to support large-scale WMSNs. Clusters are formed according to the Leach protocol. To enhance the scalability of the network, ICACR uses the "divide and conquer" principle. The network is divided into clusters and each can be considered as a sub-networks. The additional sub-network is the backbone composed of the sink node and all the CHs. The cluster head can communicate with the sink node, while the other nodes communicate with each other within the cluster.

  IPACR protocol first searches for the local optimal path set inside each cluster then searches for the local optimal path set which is connected through each cluster heads until the sink node. Finally, ICACR protocol searches for the approximate global optimal path from paths found by IPACR.

  Both algorithms were simulated with NS2 and the results show that by increasing the network scale, the convergence rate of IPACR is better than the standard ant colony algorithm. Moreover, ICACR outperforms the IPACR and Dijsktra in all routing performance metrics and in network lifetime, so it is more scalable. Nonetheless, if the source node is located near to the sink, ICACR is less efficient. For the transmission of the real video data, the quality of the video in ICACR is good.

  The two algorithms are not applicable in the case of real-time data transmission.

- **ACO Based QoS Aware Routing for WSN with Heterogeneous Nodes (AntQHSeN)**

  Based on their previous work [110], Kumar et al. [112] present a reactive ant-based QoS routing protocol for HWSN called AntQHSeN working according to two phases: route discovery phase and route maintenance phase. Fants are created by the source node to find multiple paths to the destination node. Each ant collects information to assess the quality of the path by using some QoS parameters of the intermediate nodes lying on the path. The pheromone concentration is calculated using residual bandwidth, minimum residual energy and route cost. The route cost is computed according to hop count and end-to-end delay. In AntHQSeN, hello ants allow the discovery of immediate neighbor nodes and carry the bandwidth, timestamp, energy, and pheromone concentration information. When a link failure occurs, route maintenance phase is activated.

  While in previous work, on receiving the Fant, each intermediate node updates the residual bandwidth, here the update of residual bandwidth is made depending upon the status of a flag bit and its residual bandwidth, thus either it forwards the ant or drops it. When the destination node receives Fant, it sends a Bant to the source node, containing the status information of the route carried by Fant. To improve reliability, AntQHSeN used another method to calculate the pheromone value deposed on the node.

Simulating AntQHSeN with NS-2 and comparing it with EEABR and AODV protocols, the results showed that in terms of packet delivery fraction, end-to-end delay and routing overhead, the solution outperforms its competitors for dynamic topology environments.

However, AntQHSeN initially lacks sufficient information to determine paths. The algorithm converges after a certain time, discovering better quality routes than those of AODV. AntQHSeN also provides consistent performance due to its reactive route discovery mechanism as compared to EEABR.

- **Enhanced ant-based QoS-aware routing protocol for heterogeneous WSNs (EAQHSeN)**

  EAQHSeN [113] is an improved QoS-aware routing protocol for heterogeneous WSNs based on ACO supporting multimedia and scalar data traffic. This proposal meets the differentiated QoS requirements defined by heterogeneous traffic generated by the nodes. The routing path is established according to each type of traffic (control traffic, scalar traffic and multimedia traffic) and its QoS constraints. This protocol is based on the work done in [110] with some improvements. Before updating the bandwidth by the intermediate node and on receiving several ants of the same generation, it must compare the bandwidth field of each ant to that of the previously received ants of the current generation to decide to accept or reject the ant packet using an acceptable factor. This improvement reduces routing overhead while keeping only the best paths. In addition, each Fant received at the destination is not necessarily converted to Bant. Only Fants received within a stipulated time interval are converted to Bant to limit end-to-end delay and avoid extra routing overhead while selecting a route. In addition, for multimedia traffic, EAQHSeN protocol considers both residual bandwidth and end-to-end delay as heuristic factors.

  A series of simulations were carried out with NS2 to assess performance of the proposed EAQHSeN protocol and thus compare it to AODV and EEABR protocols. In the two scenarios taking into account the variation of pause time and maximum node speed respectively, the results showed that significant optimizations were observed compared to EEABR and AODV concerning packet delivery fraction, end-to-end delay, routing overhead and minimum remaining energy.

  EAQHSeN improves minimum residual energy by 4% compared to EEABR, which indicates an extended lifetime.

  After the comprehensive analysis of reviewed ACO-based routing protocols, it can be seen that most of the routing protocols developed for WMSNs use ACO as a bio-inspired technique. We note that the majority of works try to reduce energy consumption in order to maximize the network lifetime, apart from Enhanced AntNet protocol [98] and [99]. Also, with the exception of the IEEBR [96] protocol, all studied protocols employ at least one or multiple metrics to meet QoS requirements. Moreover, most use multipath routing to distribute the network traffic load between the different sensor nodes.

  Knowing that for a protocol intended for WMSN, real time represents a primary constraint that most of routing protocols have not taken into account. The same goes for the bandwidth, which is an essential measure of QoS.

  In summary, ACO is the most widely adopted SI approach by researchers because it provides QoS support to heterogeneous traffic load through multipath and multi-constraint routing.

4.1.5 Artificial Bee Colony (ABC)

Artificial Bee Colony (ABC) algorithm [94, 114] is an optimization algorithm based on SI that simulates the intelligent foraging behavior of a honeybee swarm living inside a hive and possessing individual cognitive capacities and self-organization. Depending on the model, foraging bees can be organized into employed and unemployed forager bees. The employed forager bee is associated with a specific food source that it is currently exploiting. An unemployed forager bee searches for a food source to exploit. It could be an onlooker trying to find a food source using the information providing by the employed bee or a scout who searches the environment randomly for food. The position of a nourishment source depicts a possible solution to the multi-constrained optimization issue, and its nectar amount is related to the quality of the associated solution. The employed forager bee exploits a nourishment source (solution) based on local information and the nectar amount (fitness cost). These bees will remember the new position and neglect the old one if the nectar amount associated with the new food source (new solution) is better than the previous one. Once they have all completed the search process, they start sharing the nectar information of the nourishing source like: direction, distance, and profitability with the onlooker bees through a waggle dance. Therefore, an onlooker bee evaluates the nectar amount information provided by each employed bee and selects a food source with a higher probability to find the nectar. After few existing food sources have been abandoned by the bees after many forages, scout bees begin to randomly search for new food sources around the hive. Accordingly, ABC algorithm achieves global optimization through investigation carried out by artificial scouts, whereas local optimization is obtained through exploitation, which is executed by onlookers and employed bees [61].

4.1.6 QoS-Enabled & Energy Efficient Routing Protocol

- **An Enhanced Artificial Bee Colony Based EELB-PWDGR (EABC-EELB-PWDGR)**

  Based on EELB-PWDGR protocol, which is itself based on EE-PWDGR [115] created to overcome the limitations of PWDGR [116], Al-Ariki et al. [117] first proposed the ABC-EELB-PWDGR protocol based on the Artificial Bee Colony (ABC) to reduce the time consumed during the path selection process in order to select the optimal path satisfying QoS constraints. However, the ABC algorithm presents unsatisfactory performance. Therefore, the use of an enhanced ABC algorithm has enabled the development of An Enhanced Artificial Bee Colony Based EELB-PWDGR protocol called EABC-EELB-PWDGR for optimized route selection in WMSNs.

  EABC-EELB-PWDGR reduces both time consumed during the classification of the routing paths based on QoS priority and energy consumption based on QoS-based load balancing between paths using two new improved solution search equations such as employed bee and onlooker bee. In addition, to reduce the search time and increase the convergence of ABC, the protocol uses the chaotic search method and the opposition-based learning mechanism in population initialization. Thus, an initial population is constructed in order to enhance the solution search.

  The proposed EABC-EELB-PWDGR protocol and its predecessor, ABC-EELB-PWDGR were evaluated using NS2 and compared with PWDGR, EE-PWDGR, and EELB-PWDGR in terms of end-to-end delay, Peak signal-to-noise ratio (PSNR), energy per-packet, hop count and network lifetime. The outcomes show that the proposed solution provides better delay with 20% less, reduced energy consumption by 60%, longer lifetime by 17%, a PSNR higher by about 8db and a number of hop reduced by 30%.

  In this category, an energy-efficient multipath routing protocol has been developed guaranteeing the QoS through several metrics. In principle, the bio-inspired ABC algorithm is designed to optimize multivariable and multimodal continuous functions. It is best suited for implementing multi-objective clustering in WMSN. The relevant drawbacks of these algorithms are the slow convergence and the local optimum [60].

  In summary, designing an efficient routing protocol for the WMSN consists of taking into account all the criteria, or at least the most relevant for multimedia needs.

  To conclude, the main motivation behind the deployment of bio-inspired networking techniques stems from the analogy that exists between communication scenarios in network routing and the natural communication of species.

5 Performance Comparison

In this section, we establish two comparative analytical tables that contain all these protocols and their main characteristics. Tables 2 and 3 contain the 15 SI-based routing protocols for WMSN listed in the previous section.

Firstly, in Table 2, we choose various parameters to compare these surveyed protocols, according to their network topology (flat or hierarchical), route selection, multipath, location awareness, congestion control, classification service, energy efficiency, load balancing and QoS parameters considered.

Then, in Table 3, we give for each routing protocol cited above, its advantages and disadvantages, but also an overview of the simulation approach that was used such as: the type of simulator used, the protocols with which they were compared, the performance parameters taken into account in the simulation and finally the results of the comparison.

6 Open Research Issue

WMSN stills a constantly evolving area of research. It is important to note that, in spite of the abundant research undertaken in the field of routing protocols in recent years, several open issues remain unresolved and require special attention. In this section, these research issues are highlighted for current and future explorations [71, 75, 80, 82–84].

Energy efficiency: Energy efficiency plays an important role in the design of routing protocol for WMSNs. Thus, the main challenge of routing protocols is to reduce network power consumption in order to achieve reliability in data delivery packets, extend network lifetime and ensure load balancing in the network.

Multi-constrained QoS Guarantee: In WMSNs, real-time multimedia data transmission requires some QoS parameters to be taken into account. So, to ensure this, a routing protocol must support different application-specific QoS requirements such as end-to-end delay, delay jitter, bandwidth consumption, reliability, energy efficiency.

Security: WMSNs are usually deployed in unattended or hostile environments. Therefore, they are vulnerable to various attacks. Current routing protocols focus essentially on the QoS and energy efficiency and do not consider security. In this respect, henceforth, secure routing requires additional attention to protect against interceptions and malicious behavior. Ensuring network security while saving energy is another area of WMSN research [82].

Table 2 Comparison of SI-based routing protocols for WMSNs

SI-routing protocols	Architecture		Route selection	Multipath	Location awareness	Congestion control	Classification service	Energy efficiency	QoS parameters	Others	Load balancing
	Flat	Hierarchical									
ASAR 2008		✓	Proactive	✓			✓	✓	Delay, bandwidth Packet loss ratio	ACO	✓
M-IAR 2008	✓		Proactive		✓			✓	Delay and jitter	ACO	
AGRA 2008	✓							✓	Delay Bandwidth	ACO Game theory	
LBHR 2010		✓	Hybrid	✓		✓		✓	Bandwidth Delay	ACO The minimum spanning tree algorithm	✓
AntSensNet 2010		✓	Hybrid	✓		✓	✓	✓	Delay Packet loss rate Available memory	ACO	✓
ACOWMSN 2011	✓		Reactive	✓				✓	Delay, bandwidth, packet loss rate	ACO	✓
[109] 2011	✓				✓		✓	✓	Link quality Link reliability	ACO	
IEEABR 2011		✓	Proactive	✓		✓		✓		ACO	
Enhanced AntNet 2013	✓		Reactive						Delay, packet delivery ratio (PDR)	ACO	
[110] 2013	✓		Reactive				✓	✓	Bandwidth	ACO	✓
IPACR, ICACR 2014		✓		✓				✓	Delay, bandwidth Packet loss rate	ACO	
AntQHSeN 2014	✓		Reactive				✓	✓	Bandwidth, end to end delay	ACO	✓
[99] 2016	✓			✓					Bandwidth	ACO	
EAQHSeN 2016	✓		Reactive				✓	✓	Bandwidth, end-to-end delay	ACO	✓
EABC-EELB-PWDGR 2018				✓	✓			✓	Average delay, Link Quality, packet loss rate, path reliability	ABC	✓

Table 3 Simulation scenario of SI-based routing protocols for WMSNs

Routing protocol	Simulation	Simulator type	Performance metrics	Compared to	Advantages	Disadvantages	Comparison results
ASAR 2008	✓	NS-2	Queuing delay, received packet rate, dropped packet rate	Traditional ant-based, Dijkstra, Directional diffusion routing algorithm DD	Fast convergence Better QoS for multiple types of WMSN services	Performances degradation due to bottleneck problem and repetitive usage of optimal paths	ASAR has better convergence then Dijkstra and traditional ant-based algorithms It outperforms Dijkstra and DD It select the optimal paths to meet their individual QoS requirements, thus improving network performance
M-IAR 2008	✓	Java	Delay, Jitter	Not compared	Self-organized, fault tolerant, adaptive	Limited scalability No load balancing	M-IAR shows good performance, which achieves acceptable delay, jitter and energy consumption
AGRA 2008	Not simulated						
LBHR 2010	✓	NS-2	End-to-end delay, network lifetime, Transmission success rate, communication overhead	A novel clustered-control algorithm CC M-IAR	Prolonged network lifetime Efficient load balancing Congestion control support	Complex calculations to find optimal route Heavy load results in a bottleneck situation	LBHR reduces the end-to-end delay, increases the transmission success rate and achieves load balancing Thus, it has better adaptability and scalability, can in fact prolong the network lifetime and guarantee the QoS of data transmission in WMSNs
AntSensNet 2010	✓	NS2	End to end delay, Packet delivery ratio, routing overhead	Traditional ant-based (T-ANT), AODV, ASAR, TPGF	Supports energy efficient video transmission Prevents network Congestion	High complexity	AntSensNet outperforms AODV in terms of delivery ratio, end-to-end delay and routing overhead The quality video is better than ASAR and TPGF It has better convergence and provides significantly better QoS for multiple types of services in WMSN

Table 3 (continued)

Routing protocol	Simulation	Simulator type	Performance metrics	Compared to	Advantages	Disadvantages	Comparison results
ACOWMSN 2011	✓	NS2	End-to-end delay, network lifetime, packet delivery ratio	M-IAR AODV	Low delay Improve network lifetime	Not suitable for large-scale networks due to heavy traffic Slow convergence	ACOWMSN increases network lifetime, ensuring a lower delay and high packet delivery ratio when compared to AODV and M-IAR
[109] 2011	✓	Not specified	Number of ants, pheromone value importance, heuristic value importance, evaporation rate	Not compared	Prolonged network lifetime Maximized quality and reliability link	No load balancing Good quality video increases the percentage of loss	The simulation studies the effect of changing the number of ants, pheromone value importance, the heuristic value importance, and the evaporation rate on the probability of finding the optimal path The effects of transmission bit rate, event generation rate and frame encoding rate on various performance metrics are also examined
IEEABR 2011	✓	RMASE	Latency, success rate, energy consumption, energy efficiency	BABR, SC, FF, FP, EEABR	Energy efficient Congestion control support	QoS parameters not considered	IEEABR has the lowest end-to-end delay followed by EEABR It outperforms all protocols in terms of low energy consumption It has a high success rate in packets delivery and surpasses all the routing protocols in terms of energy efficiency
[110] 2013	✓	NS-2	Packet delivery fraction, average end to end delay, Jitter, % Packets lost, normalized routing load	AODV	Better packet delivery Maximization of network performance and use	High routing overhead	The proposed algorithm achieves a higher packet delivery ratio than AODV protocol, especially when the traffic load is high. It has a lower jitter compared to AODV for highly loaded networks It offers better end-to-end delay and lesser packet loss rate than AODV

Table 3 (continued)

Routing protocol	Simulation	Simulator type	Performance metrics	Compared to	Advantages	Disadvantages	Comparison results
Enhanced AntNet 2013	✓	NS-2	Packet delivery ratio (PDR), overhead, end-to-end delay	AODV	Protocol adapted to a wireless and mobile environment	No comparison with WMSN routing protocols Energy no considered	The protocol has better packet delivery ratio, end-to-end delay and overhead than AODV
IPACR, ICACR 2014	✓	NS-2	Average delay, energy cost, packet loss rate, throughput, number of hops	Standard ant colony routing SACR, Dijkstra	Scalable Good quality of video data transmission	Real-time data transmission not applicable	In a large-scale network, IPACR converges faster than SACR ICACR outperforms the IPACR and Dijkstra in all the considered performance metrics and in network lifetime, so it is more scalable. It is less efficient when the source node is located near to the sink, For the transmission of the real video data, the quality of the video in ICACR is good
AntQHSeN 2014	✓	NS-2	Packet delivery fraction (PDF) end-to-end delay (EED), routing overhead	EEABR AODV	Work fine in both static and dynamic topologies Improve reliability	Long setup time Lacks sufficient information at the beginning to find routes	The PDF of AntQHSeN is significantly higher compared with AODV and EEABR It has considerably lower average EED than AODV It also provides consistent performance due to its reactive route discovery mechanism as compared to EEABR

Table 3 (continued)

Routing protocol	Simulation	Simulator type	Performance metrics	Compared to	Advantages	Disadvantages	Comparison results
[99] 2016	✓	NS-2	Received packets, packet delivery ratio PDR, throughput	AODV DSDV	Guaranteed bandwidth Transmit multimedia data with guaranteed QoS	Energy no considered	The routing algorithm can deliver multimedia data within an average throughput of 164.65 kbps It provides better performance in terms of PDR and the throughputs than the DSDV and AODV Thus, it has an ability to optimize routing techniques for multimedia applications over the WMSNs
EAQHSeN 2016	✓	NS-2	Packet delivery fraction end-to-end delay, routing overhead, minimum remaining energy	EEABR AODV	Prolonged network lifetime Reduce routing and control overheads	Scalability cannot be assured	EAQHSeN performs very well irrespective of the node's pause time and outperforms AODV and EEABR in terms of packet delivery fraction, average end to-end delay and routing overhead It has better lifetimes than EEABR
EABC-EELB-PWDGR 2018	✓	NS2	End-to-end delay, PSNR, energy per-packet, hop count, Network lifetime	PWDGR, EE-PWDGR, EELB-PWDGR, ABC-EELB-PWDGR	Less delay Energy efficient Load balancing Improve ABC convergence	Node failure event	EABC-EELB-PWDGR provides better routing performance than ABC-EELB-PWDGR, which in turn outperforms EELB-PWDGR EABC-EELB-PWDGR offers 17% longer lifetime, 20% less delay, 60% lesser energy consumption, approximately 8 dB higher PSNR and reduced number of hop by 30%

Multiple Sources and Base Stations: Most WMSN routing protocols are designed to transmit data from a single source to a unique base station. Some situations involve using multiple sources and sinks, for example, to simultaneously obtain different information about events. Therefore, multi-sink and/or multi-source oriented routing may be considered for achieving higher performance in WMSNs.

Support for Node Mobility: Originally, in WMSNs, sensor nodes are immobile. Recent advances have enabled the integration of mobile sensors to improve the performance, including coverage and energy efficiency [70]. In addition, the mobility of sensors and sinks allows real-time delivery. In WSNs, there are already works that support the mobility of sinks such as [118, 119]. However, the majority of existing WMSN routing solutions in the literature do not consider mobility. Hence, routing that supports node mobility is a relatively unexplored field and can be considered as an interesting area for future research and investigation.

New Class of Algorithms: QoS is an important constraint in the design of routing protocols in WMSNs. QoS routing is a multi-objective problem. It is therefore necessary to design and develop routing protocols that can increasingly focus on several metrics. Routing approaches based on computational intelligence as biologically inspired such as swarm intelligence (ACO, PSO, ABC, etc.), evolutionary algorithms (EA such as genetic algorithm), machine learning (ML), reinforcement learning (RL), fuzzy logic (FL), and artificial neural networks began to emerge and have shown promising results as they are adaptive and multi-objective. Consequently, these techniques remain very little exploited and require more investment in order to achieve further technological advances in WMSN.

Also, another concept that the future research should consider and not overlook is hybrid intelligence algorithms. This involves using more than one algorithm to solve a problem. The interest of this concept is to be able to use the advantages of one solution to fill the gaps of another to solve or improve some optimization problems in WMSNs.

Cross-layer design: Very few protocols are designed according to the cross-layer functionality. To improve QoS routing in WMSNs, one of the solutions to be considered is the use of a cross-layer approach for an efficient routing.

7 Conclusion

Over the last decade, many research works about WMSNs have focused on improving the network performance as well as increasing the energy efficiency and communications effectiveness. SI is one of these new and promising techniques that enables a considerable increase in performance, scalability, robustness and efficiency by providing solutions to complex problems.

In a wireless communication system, routing still a big challenge problem. The SI techniques are applied to solve routing problems in sensor networks due to their fast convergence, simplicity, high-quality and optimized solution. Thus, these techniques have widened the scope in the area of WSN. Studies have proved that the SI-based routing protocols perform better in terms of energy efficiency, reliability, scalability, robustness and can enhance the QoS performances of routing.

This paper has elucidated that research is very active in WSNs field, as opposed to WMSNs, where there is still much to discover. Therefore, a comprehensive analysis of all existing SI-based routing protocols applied to WMSNs has been provided. A classification of these protocols has been developed according to the existing SI algorithms, which include ACO and ABC. The basic concepts of these SI techniques have also been described. Then, a comparison of these routing protocols has been offered according to some primary metrics.

According to this review, we note that the majority of proposed works have used the ACO approach in their routing protocols and very few have used the bee colony algorithm. The PSO-based technique was ignored. This is due to the fact that routing protocols based on ACO and ABC are very efficient in various parameters such as energy, robustness, scalability and therefore perform best in complex transmission environments. Therefore, significant efforts have been made to develop effective and efficient routing protocols for WMSNs. Thus, we conclude that SI being a novel and bio-inspired field has contributed a lot to the improvement of routing issues of sensor networks.

For this first attempt, the goal of our contribution is to provide, on the one hand, a single document gathering all existing SI-based routing protocols designed for WMSNs to encourage research in this direction and to allow direct access as an initial reading point for researchers. On the other hand, providing beginners or researchers with a reference support that includes all previously published routing surveys for WMSNs by avoiding time-consuming and spending less effort.

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