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Editorial

Multiobjective Optimization Algorithms for Wireless Sensor Networks

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A Wireless Sensor Network (WSN), distributed within an area of interest, is a network that contains many wirelessly interconnected devices, with sensing, communication, and processing abilities called sensor nodes. A WSN also comprises of at least one sink node, called base station, which has enhanced energy, computational, and communication resources [1]. Based on the combined use of its constituting elements, a WSN is capable of monitoring the conditions existing at extensive regions of interest [2, 3]. For this reason, the domain of WSNs is considered the basis for Internet of Things (IoT) and Internet of Everything (IoE) and supports a continuously growing range of human activities [4–11].

On the other hand, the development of WSNs is obstructed due to both the restricted resources of sensor nodes in energy supply, memory and processing, and the inherent limitations of wireless communications, in terms of power, speed, and capacity of communication channels as well as resistance to interferences and intrusion detection and prevention to preserve data security.

Particularly, the most important weakness of WSNs is the extremely restricted energy sufficiency of sensor nodes that reduces their operational time and thus shortens the overall network lifetime [12]. Consequently, the achievement of energy conservation is vital for WSNs to remain operational. This is why all possible causes of energy waste in sensor nodes must be eliminated. Given that, the procedure of wireless communication is by far the most energy consuming task of a sensor node, and numerous research works have been proposed in order to accomplish power control and energy efficient routing of data among the sensor nodes themselves and the BS [13–18].

Also, several data aggregation methodologies that aim at eliminating redundant data in order to reduce the volume of the data transmitted have been developed [19, 20]. Their usage saves energy, under the condition that the energy expended for aggregation purposes is lower than the energy consumed for raw data transmission.

Additionally, the preservation of network connectivity in WSNs is an issue of crucial importance for both the execution of the routing process and the prolongation of network lifetime. This is because, as soon as a sensor node is disconnected from its neighboring nodes due to either a malfunction or the depletion of its energy reserves, the data routing is obstructed for them, and the corresponding communication cost is considerably increased, thus accelerating their depletion. For these reasons, various methods pursuing connectivity conservation are used [21, 22].

Another very important performance metric is that is that of coverage. Three types of coverage in WSNs are identified, namely, area coverage, point coverage, and barrier coverage. Specifically, area coverage expresses the ability of the network to monitor an area of interest, meaning that all points within this area are within the sensing range of at least one sensor node. Similarly, k-coverage refers to the ability of the network to assure that all points within an area of interest are always within the sensing range of at least k sensor nodes (where k is a positive integer number). Also, point coverage refers to the ability of the network to guarantee that a predetermined group of points are observed by at least one sensor node. Additionally, barrier coverage refers to the ability to detect the movement across a barrier of sensor nodes. The maximization of area coverage is the most widely referred case in WSNs. There are various factors that affect coverage. For example, the deployment of sensor nodes can be either random or deterministic. Likewise, the sensitivity of sensor nodes may be either Boolean or probabilistic. Also, the sensing area may be deterministic or probabilistic. Similarly, the communication range of sensor nodes may be invariable or variable. Additionally, sensor nodes may be either static or mobile. Moreover, the coverage scheme adopted may be either centralized or distributed [23]. Therefore, the maximization of coverage using the resource constrained sensor nodes in a WSN is a nontrivial problem. This is why sophisticated methodologies for coverage maximization are used [24–26].

Congestion is an additional problem for WSNs. Actually, two types of congestion may occur in WSNs. The first of them is the so-called node-level congestion that is caused by the overflow of sensor node buffers. The link-level congestion is the second type. It occurs when many sensor nodes try to use simultaneously the same communication channel [27]. Both types of congestion cause packet losses and consequently necessitate packet retransmissions thus depleting the energy reserves of sensor nodes and reducing communication throughput [28]. For these reasons, numerous methodologies for congestion avoidance [29–32] that aim at preventing the occurrence of congestion and congestion control [33–35] that try to alleviate existent congestion are used.

Likewise, in WSNs where multimedia data are transmitted, there is need to transfer huge volume of information in high rates, thus increasing the energy cost of communication and overloading the communication channels [36, 37]. The usage of appropriate schemes that have been proposed in order to accomplish compression and restoration of images [38–41] or video [42, 43], in such cases, provides considerable decrease of communication load.

The attainment of high QoS is very important not only for wireless multimedia sensor networks (WMSNs) but also for all kinds of WSNs. QoS in WSNs may consider collective parameters such as latency, packet losses, bandwidth, and throughput, which are also taken into account in conventional networks. Yet, there other QoS metrics too that are related with the distinctive features of WSNs such as the limitations of the sensor nodes, the unbalance of traffic, the heterogeneity of senor nodes, the scalability requirements, the dynamic nature of networks, the differences in message priorities, the variety of traffic types, and the coexistence of various sinks [44]. For these reasons, various methods for QoS preservation in WSNs have been proposed [45, 46].

Security is also an issue of critical importance, because cyberattacks have become one of the most challenging problems that organizations must face, and WSNs are not the exemption to this. General methods have been proposed for the optimization of cybersecurity controls [47, 48]. Yet, such methods are not directly applicable to WSNs. This is because, in WSNs, sensor nodes may operate unattended and connected in a ubiquitous manner with a number of devices within the context of zero-trust security. This makes WSNs a challenging infrastructure to secure against numerous threats. The application of cyber controls to WSNs at operational level is not a straightforward process not only due to the above reasons but also due to the limited resources that sensor nodes have available. Numerous works have investigated secure data transmission in WSNs or device-to-device communications in general [49–53].

Scientific literature is rich in approaches that aim at achieving performance optimization in terms of individual metrics, like the aforementioned ones. However, meeting desired requirements in terms of more than one of these metrics is much more difficult, due to the fact that in many cases, the conditions required to optimize each one of these metrics may conflict with each other.

Thus, the combinational use of conventional single-objective optimization algorithms may be unsuitable for real applications, since they act to the detriment of the rest of the performance parameters. For instance, the coverage maximization objective in a WSN requires the sparse placing of nodes, which increases the energy cost of communication and thus obstructs the pursuit of maximizing the network lifetime. Similarly, the sparse deployment of sensor nodes worsens connectivity. Also, in order to save energy, it is preferable to transmit sensed data over reduced distance at each hop. Yet this increases the accumulative time for data transmission from source to final destination. So the minimization of energy cost of communications in a WSN contradicts the objective of minimizing the end-to-end latency. Similarly, the objective of attaining high QoS obstructs the conservation of energy. Likewise, the increase of the number of sensor nodes is beneficial for the connectivity, the coverage, and the overall network operability at the expense of increasing energy consumption. In the same way, the accomplishment of high security standards acts to the detriment of numerous nonsecurity requirements, like the abovementioned ones, that may occasionally or always be more critical than protecting a WSN infrastructure against cyberattacks [54]. For these reasons, the development of multiobjective optimization algorithms which aim at simultaneously achieving various goals, subject to a set of constraints in order to enhance the performance of WSNs, is a critical challenge [54–60].

Metaheuristic search methods have been very promising in this area, as most of them can approximate multiple elements of the Pareto front in a single evaluation, due to their population-based nature. Another important advantage of these methods is their ability to avoid getting trapped in local minima, which makes them suitable for global optimization [60]. Some of the most popular metaheuristic search methods are based on evolutionary computation [61–63], where the objective is to imitate biological evolution, and on swarm intelligence methods [64–66], which mimic the collective behavior exhibited by swarms of birds. Hybrid methods, combining the advantages of both worlds, have also been proposed [67].

Within this line of research, Kong and Yu, in their work entitled *Modeling and Optimization of RFID Networks Planning Problem*, presented a mathematical model that considers the tag coverage and the reader interference, in order to solve the planning problem at Radio Frequency Identification (RFID) Networks. For this reason, they introduced the DEEPSO algorithm, which adds Differential Evolution (DE) and Evolutionary Strategies (ES) to the standard Particle Swarm Optimization (PSO) algorithm. It was shown that DEEPSO improves global convergence ability and particle diversity, while also avoiding local convergence.

A different approach involves decentralized schemes which make use of cooperative agents, where data are partitioned and processed in individual clusters, thus avoiding the need of solving the optimization problem in a centralized way [68]. Within this context, Aznaoui et al., in their work entitled *A Heuristic Algorithm of Cooperative Agents Communication for Enhanced GAF Routing Protocol in WSNs* proposed a novel routing protocol. This protocol, named the Cooperative Agents GAF (CAGAF) protocol, uses a heuristic method based on cooperative agent communication, in order to find an optimal path in terms of energy to transmit data collected until reaching the base station. The proposed protocol was found to outperform GAF protocol in terms of considering important data, energy consumed, and dead nodes.

Jadoon et al., in their work entitled *Performance Evaluation of Zone-Based Routing with Hierarchical Routing in Wireless Sensor Networks*, also focus on data routing protocols in WSNs. Precisely, they made a comparative study among zone-based and static cluster hierarchical routing protocols in terms of three performance criteria, namely, energy efficiency, network throughput, and overall network lifetime. It was shown that in zone-based protocols, contrary to what happens in static cluster hierarchical protocols, no extra control information is needed while selecting the next hop nodes, thus achieving better performance in terms of the three abovementioned criteria.

Last but not least, Mo et al. in the research work entitled *Transmit Power Allocation with Connectivity Probability for Multi-QoS in Cluster Flight Spacecraft Network* proposed a transmit power allocation strategy to minimize the average packet error rate at the access point in cluster flight spacecraft networks (CFSNs). By using Monte Carlo method for the validation of the analytical model developed, the influence of node transmit power on the QoS performance of cluster flight spacecraft network was simulated and analyzed under the assumption of finite overall network transmit power and low traffic load. It was verified that the proposed transmit power allocation strategy allows to minimize the packet error rate for a given total network transmit power at any time slot for CFSNs.

Based on the ceaseless evolution of WSNs, and the ever growing range of their applications, it is logical to suppose that more and more challenges will arise for the development of sophisticated algorithms that will be able to achieve the performance optimization of WSNs in terms of multiple objectives.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

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