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Particle Swarm Optimization for Interference Mitigation of Wireless Body Area Network: A Systematic Review

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ABSTRACT

Wireless body area networks (WBAN) has now become an important technology in supporting services in the health sector and several other fields. Various surveys and research have been carried out massively on the use of swarm intelligent (SI) algorithms in various fields in the last ten years, but the use of SI in wireless body area networks (WBAN) in the last five years has not seen any significant progress. The aim of this research is to clarify and convince as well as to propose a answer to this problem, we have identified opportunities and topic trends using the particle swarm optimization (PSO) procedure as one of the swarm intelligence for optimizing wireless body area network interference mitigation performance. In this research, we analyzes primary studies collected using predefined exploration strings on online databases with the help of Publish or Perish and by the preferred reporting items for systematic reviews and meta-analysis (PRISMA) way. Articles were carefully selected for further analysis. It was found that very few researchers included optimization methods for swarm intelligence, especially PSO, in mitigating wireless body area network interference, whether for intra, inter, or cross-WBAN interference. This paper contributes to identifying the gap in using PSO for WBAN interference and also offers opportunities for using PSO both standalone and hybrid with other methods to further research on mitigating WBAN interference.

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1. INTRODUCTION

Wireless Sensor Networks (WSN) implementation, contains of some nodes spread over a certain zone. These sensor nodes are able to sense changes in environmentally friendly factors such as fever, heat, smoke, etc. WSN is a technology that has the potential to be used in various fields such as agriculture, earth, environmental monitoring, security, military, transportation, or IoT technology. To improve healthcare systems, WSN has a technology trend called Wireless Body Area Network.

WBAN is a type of wireless sensor network made up of tiny bio-medical plans, also known as nodes, that are dedicated to continuously observing patients by several crucial considerations. WBAN is made up of small-power modules that operate within or all over the human body to assist a diversity of requests, including those in the medical field. The sensor section is divided into implant nodes which are placed under a sink node in the humanoid physique; body outward nodes positioned on the outward of humanoid membrane. The body sensors on the WBAN capture signals from various parts of the body as operating networks. Standards used for body sensors can be in the form of RFID, ZigBee [1], Bluetooth, UWB, Zarlink, Sensiium, WPAN, WLAN, MICS, and ANT technology criterions with an ISM frequency of 2.4 GHz. For the communication architecture, there are three tiers, namely intra-WBAN, inter-WBAN, and beyond WBAN, so there are three categories of interference. One of the problems that arise in these technologies is interference. These disturbances most affect the performance of the communication system [2]. One example, is interference due to co-frequency can occur in both WSN and WBAN. For better network performance, interference mitigation techniques should be applied in designing WBAN systems [3]-[7]. Fig. 1 depicts the WBAN construction.

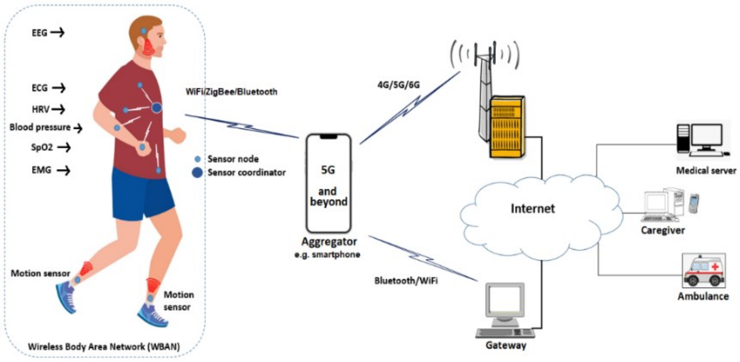


Fig. 1. Wireless body area network construction

We now know the swarm method. This makes sense because many animals are very intelligent in carrying out their daily mobility with swarm intelligence. There are various types of SI algorithms, some of which is particle swarm optimization (PSO), and genetic algorithm (GA) [8]. GA, among others, is used in the WSN model differentiation in research [9]. PSO was first introduced by Kennedy and Eberhart in 1995. The PSO algorithm can be used in a variety of continuous, discrete, linear, or non-linear optimization problems. This algorithm is inspired by collective social behavior in the intelligence of animal colonies such as birds and go fishing. This social behavior is in the form of individual actions or the influence of other individuals in a group. Each individual or particle behaves evenly by expending his own cleverness and is swayed by his mutual group activities. If a bird discovers the true path and the shortest technique to a food home, then the rest of the other group can also immediately trail that path even though their place is faraway between the groups. During the search process, each particle determines its own position based on its own best experience and based on the best experience of all particles [10]-[13]. There are uses of various SI methods in WSN i.e. in design and deployment, grouping, scheduling, localization, data aggregation, and quality of service (QoS) management [14] in this case the PSO algorithm is used to reduce the movement distance of nodes thereby reducing energy costs or for grouping choices related to WSN period maximation [15]. PSO is also used in optimizing WSN communiqué aspects [16] or on the WSN relay node [17].

Equaled to other technologies of wireless system, WBAN has more strict practical requests and experiments in terms of the efficiency of power [18], security and confidentiality, QoS [19], [20], and other terms such as frequency issues [4]. Interference is one of the key problems in all wireless systems, and requires good interference management [21], [22]. Previously there were several studies related to interference mitigation on WBAN. Research [3] conducted a comparative study of various interference mitigation techniques on WBANs, namely for inter-WBANs and cross-WBANs with the Fuzzy algorithm. This study does not cover interference mitigation on intra-WBAN. Surveys have been conducted on the use of AI/SI algorithms in various fields in the last ten years, as in [23]-[25], but there has not been a progressive use of Swarm intelligence in WBAN in the last five years, especially on the use of Swarm Intelligence for all aspects of interference mitigation on WBAN.

The key aim of this study is to identify opportunities and topic trends using Particle Swarm Optimization as one of swarm intelligence for interference mitigation optimization of WBANs. As most WBANs operate in the universal industrial, scientific, and medical (ISM) frequency (2.4 GHz band), this has created challenges with respect to inter, intra and co-channel interference, specially in congested zones and movement situations. Various methods for interference mitigation have been implemented, and the role of optimization techniques is needed to produce more precise accuracy of WBAN technical parameters. The contribution of this research is in terms of identifying gaps in the use of PSO in mitigating WBAN interference and also offering opportunities for using PSO both standalone and hybrid with other methods to further research into mitigating WBAN interference.

2. METHODS

This research is a Systematic Literature Review (SLR) using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) method. SLR is a research method that aims to evaluate, identify, and analyze all previous research results that are related and relevant to a particular topic, particular research, or current phenomenon of concern. The facts presented are comprehensive and balanced because a systematic review was used to synthesize the relevant research findings. A systematic literature review includes the following steps: Formulating research questions, conducting a systematic literature review search, screening and selecting appropriate research articles, conducting analysis and synthesis of qualitative findings, implementing quality control, and preparing a final report [26]-[29]. This systematic review procedure consists of several steps, namely 1) Developing Background and Objectives, 2) Research Questions, 3) Literature Search 4) Selection Criteria 5) Data Extraction Strategy 6) Assessing Quality of Primary Studies, and 7) Data Synthesis [30] as the flow shown in Fig. 2.

Fig. 2. Flow of systematic review process

To help provide an overview of the scope and limitations of SLRs, we use the population, intervention, comparison, outcomes and context (PICOC) method in Table 1 which stands for Population, Intervention, Comparison, and Context.

Table 1. PICOC

Elements	Definitions
Population (P)	wireless body area network, wireless sensor network
Intervention (I)	particle swarm optimization, interference mitigation, interference cancellation, interference suppression
Comparison (C)	-
Outcomes (O)	signal-to-(interference+noise)-ratio (S/I+N or SINR) accuracy; bit error rate accuracy
Context (C)	wireless engineering

2.1. Research questions on literature review

To facilitate identification, research questions (RQ), and their motivations are summarized in Table 2.

Table 2. Research questions

#	Research questions	Motivations
RQ1	Which journal is the most significant as a journal related to interference mitigation optimization on WBANs?	Identification of the most significant journals for optimizing interference mitigation on WBANs
RQ2	What types of interference exist in the WBAN that have been studied?	Identify the type of interference on the WBAN that has been studied
RQ3	What are the most analyzed topics related to interference on WBANs?	Identify what topics or case studies have been raised the most regarding interference in WBANs
RQ4	What types of artificial intelligence (AI)/SI methods are used regarding interference mitigation on WBANs?	Identify opportunities and trends in AI/SI methods related to interference mitigation on WBANs
RQ5	What type of Swarm Intelligence optimization method is most often used regarding interference mitigation on WBANs?	Identifying the most widely used Swarm Intelligent optimization methods related to interference mitigation on wireless body area networks
RQ6	For what topics is the Particle Swarm Optimization method used in relation to WBANs?	Identify opportunities and topic trends using Particle Swarm Optimization related to WBANs
RQ7	What improvement methods have been proposed regarding interference mitigation?	Identify proposed improvement methods related to interference mitigation
RQ8	What are the most relevant methods that have been proposed regarding interference mitigation on WBAN?	Identify the most relevant methods that have been proposed regarding interference mitigation on WBAN

2.2. Searching the literature and selection criteria

In determining how to search the literature to be reviewed, we carried out the strategy in Table 3 and the selection criteria in Table 4 so that the PRISMA flowchart was obtained.

To store and manage search results, we use a reference manager in the form of the Mendeley software package (http://mendeley.com). We illustrate the complete flowchart in building the PRISMA diagram in Fig. 3.

Table 1. Search strategy

Item	Information type
Tools/software	Publish or Perish
Library sources	1. Elsevier (https://www.sciencedirect.com/) 2. Crossref (https://www.crossref.org/) 3. IEEE Xplore (https://ieeexplore.ieee.org/) 4. Springer (https://link.springer.com/)
Search keywords	*(particle swarm optimization OR pso) AND (interference cancellation OR interference mitigation OR interference suppression) AND (wireless body area network OR wban)*

Table 2. Selection criteria

Item	Criteria
Inclusion	1. Results of research in telecommunications and computer science or other relevant fields 2. Article of a reputable international journal 3. In English 4. Year of publication 2018-2023 5. Indexed in international databases 6. Optimization of Swarm Intelligence to mitigate interference on Wireless Body Area Networks
Exclusion	Books other than book chapters; indexes; repositories

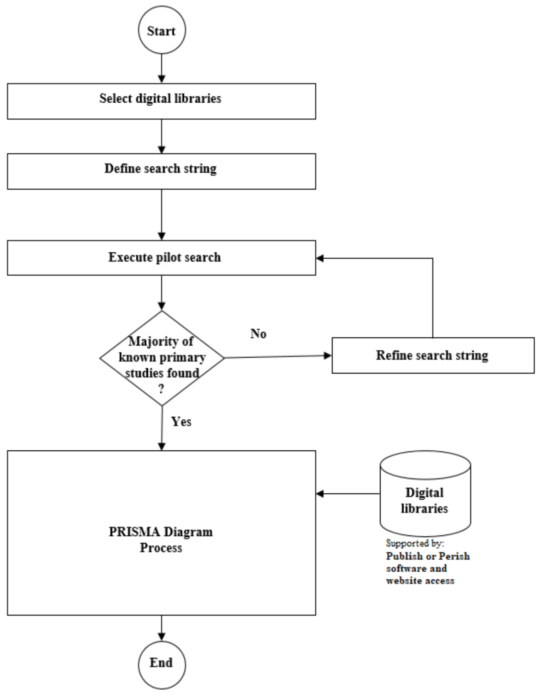


Fig. 3. Flowchart of building PRISMA diagram

2.3. Data Extraction, Assess Quality of Primary Studies, and Data Synthesis

The selected key studies were then mined to collect data that contributed to solving the research questions. Assessments of study quality can be used to guide the clarification of synthesis findings and to define the conclusions that are designated. Data synthesis aims to gather evidence from selected studies to answer research questions.

3. RESULTS AND DISCUSSION

For data tabulation in this chapter, we copied the existing metric results for Excel as search results from Publish or Perish software.

3.1. Results

The result is shown in some of the figures and tables, starting from Fig. 4 which describes the PRISMA flow diagram.

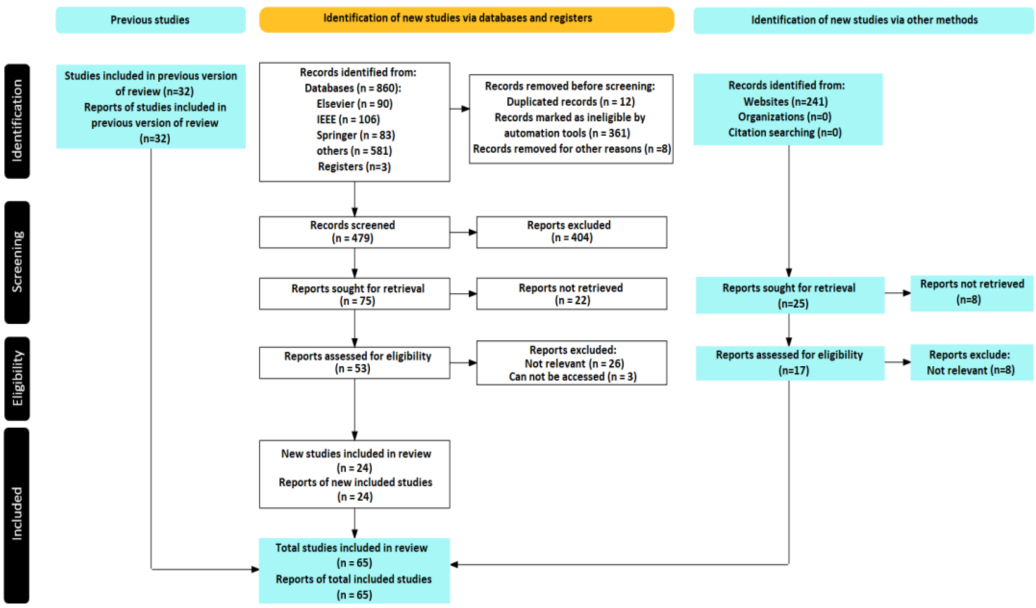


Fig. 4. PRISMA flow diagram

Digital searches were performed via Publish or Perish software. Previously, from the reference collection obtained from several website accesses, there were 3 articles that we entered as registers. With the PRISMA flow and the existing PICOC method, 860 articles were found in the specified database, and 836 were excluded because they did not meet the inclusion criteria so 24 articles were produced. Meanwhile, from previous studies, there were 32 articles, and through other methods, there were 9 articles. The total studies included in this review are 65 articles which we arranged in the order from [31] to [95].

The journals that are most relevant to the main topic of the literature review, you can see in Table 5. The selected journals have varying scimago journal rank (SJR) numbers which show their credibility, from 0.19 to 6.56, respectively. This figure is equivalent to the grade quartile Q4 to Q1 on the Scopus indexer. From the following table, it can be seen that only a few do not have SJR values.

In order to monitor physiological parameters or gather health-related data, compact, low-power sensor devices are put on or within the human physique to form WBANs. Interference on these networks has the potential to degrade the effectiveness and dependability of device-to-device communication. To enable accurate and timely data delivery in wireless body area networks, interference must be minimized. WBANs may use interference avoidance algorithms, which keep an eye on the wireless environment and dynamically change communication settings or channel selection to evade interference sources. These algorithms may be founded on methods for cooperative communication or estimate of interference. Simultaneous transmission by neighboring nodes is a major source of interference to the receiving sensor [52]. To model true interference that might interfere with packet reception at the physical layer, the SINR (or S/I+N) parameter is used. Basically, S/I+N is energy transmitted per bit/noise. Interference prevention systems can reach higher SINR rates, but the throughput is usually lesser. Also, in terms of computational complexity, interference prevention systems require fewer compound receivers, but more collaboration between coordinators is unavoidable. Specifically for WBANs, one of some issues in radio interference avoidance namely that interference at one node can be caused by the separate decisions of several coordinators so that the decisions of other coordinators and the surrounding environment are influenced by the individual decisions of each WBAN coordinator [86]. Then for maintaining the SINR threshold, interference is specified in terms of boundary network distance [68]. We describe these three types of interference in Fig. 5**.** The *first* is intra-WBAN interference which occurs among sensor nodes in the same network. The *second* is inter-WBAN interference occurs among WBANs working at the same frequency band. The *third* is cross-interference caused by other technologies transmitting in the same band.

For intra-WBAN, interference occurs amongst single WBAN sensor nodes; that's why it is said to be having intra-WBAN interference. Inter-WBAN coexistence and interference occur when there are several WBANs set up in the 2.4 GHz band then it is said to have inter-WBAN coexistence and interference. In some references, there are those who call it mutual WBAN or off-body interference. This mutual interference is mainly caused by packet collisions when the active periods of multiple WBSNs overlap.

Table 5. The most relevant journal (RQ1)

Id.	Sources	Publishers	SJR	Q
Mu20 [51]	IEEE Wireless Communications	IEEE	6.56	Q1
Mov18 [86]	ACM Transactions on Sensor Networks	ACM	1.23	Q1
Lyn18 [58]	IEEE Sensors Journal	IEEE	0.99	Q1
Yan20 [64]	IEEE Sensors Journal	IEEE	0.99	Q1
Geo20 [80]	IEEE Access	IEEE	0.93	Q1
Liu20 [42]	IEEE Access	IEEE	0.93	Q1
Mor20 [56]	Wireless Networks	Springer	0.71	Q2
Adh22 [74]	SN Computer Science	Springer	0.60	Q2
Deb19 [52]	Wireless Personal Communications	Springer	0.55	Q2
Shi22 [45]	International Journal of Information Technology	Springer	0.44	Q2
Mek20 [54]	International Journal of Biomedical Engineering and Technology	Inderscience	0.37	Q3
Xie20 [39]	Journal of Sensors	Hindawi	0.37	Q3
Suz20 [70]	TELKOMNIKA (Telecomm. Computing Electronics and Control)	IAES-UAD	0.29	Q3
Chau22 [92]	International J. of Sensors, Wireless Communications, and Control	Bentham Sc.	0.19	Q4
Ali19 [44]	International Journal of Recent Technology and Engineering	BEIESP	-	
Shi20 [50]	International Research Journal on Advanced Science Hub	RSP Sci. Hub	-	
Nas18 [62]	International Jour. of Adv. Research in Computer and Comm. Eng.	Tejass Pub.	-	
Adh18 [68]	Advanced Computing and Systems for Security	Springer	-	
Mil18 [33]	Wireless Engineering and Technology	Scientific Res.	-	

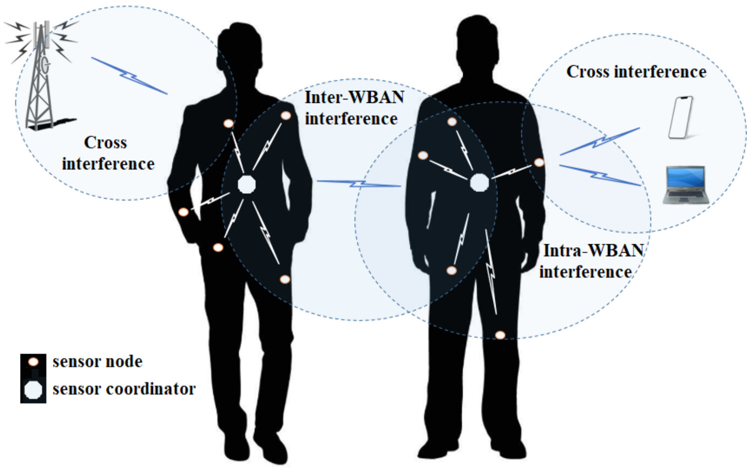


Fig. 5. WBAN interferences (RQ2)

When several WBANs near each other send and receive information together, and there is no scheduling between WBANs, interference will occur between WBANs. Inter-domain coexistence or cross interference occurs when other wireless networks such as Wi-Fi, Zigbee or Bluetooth devices work at the same location of the WBAN and at the alike frequency at the matching time and place within the 2.4 GHz band of the WBAN, then it is said to be inter-domain coexistence and interference [50]. Another terminology used in literature is homogeneous and heterogeneous coexistence. In homogeneous coexistence, WBANs of the same technology are interfering with each other whereas in heterogeneous interference WBANs of different technologies are interfering with each other. Coexistence is also grouped as static or semi-dynamic or dynamic or no interference. WBAN co-existence is unavoidable because it is impossible to keep the human body stationary or confined in a special space where WBAN is less. Therefore, efforts should be made to detect and reduce interference [50], [51], [56], [62].

As a result of identifying the most frequently raised topics or case studies related to interference in wireless body area networks (RQ3), we present them in Fig. 6**.** It can be seen that the topic of interference mitigation or other designations of interference cancellation or interference suppression occupies the first position, namely as many as 19 studies. Other related topics include biosensors [48], node synchronization [55], healthcare monitoring [63], and dynamic resource management in WBAN [69].

The results of identifying opportunities and trends in AI/SI methods related to interference mitigation on the wireless body area network (RQ4), we display in the graphs in Fig. 7. Fig. 7(a) shows the composition of the number of PSO primary studies in SI. Meanwhile, Fig. 7(b) shows the entire primary study using AI where PSO is one part of the method.

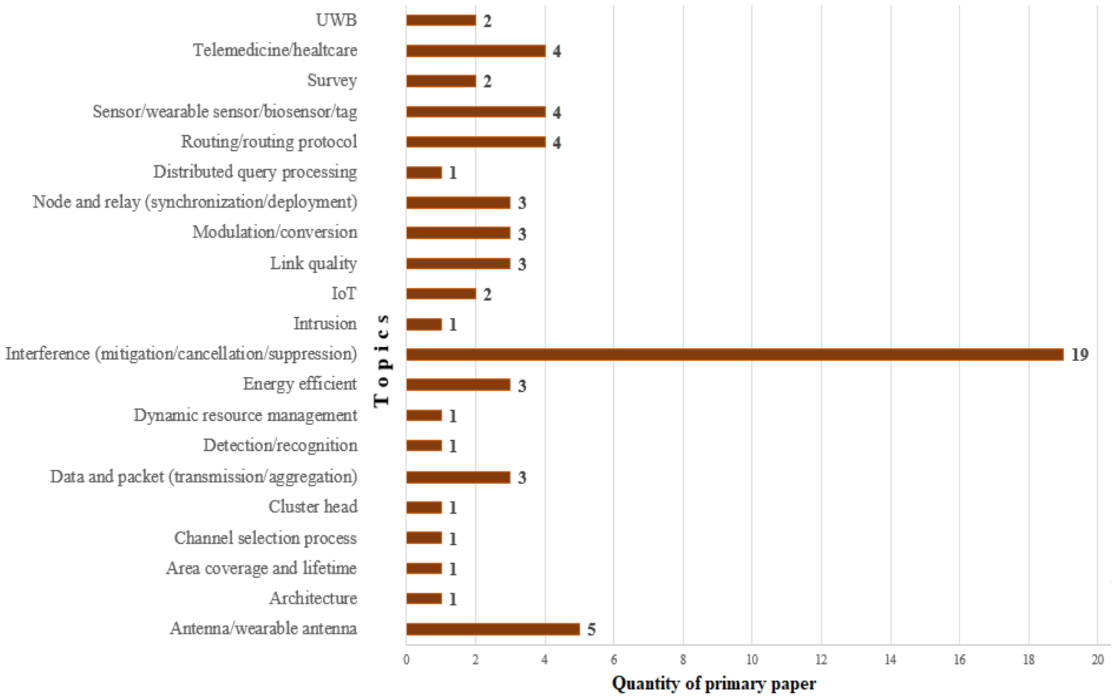
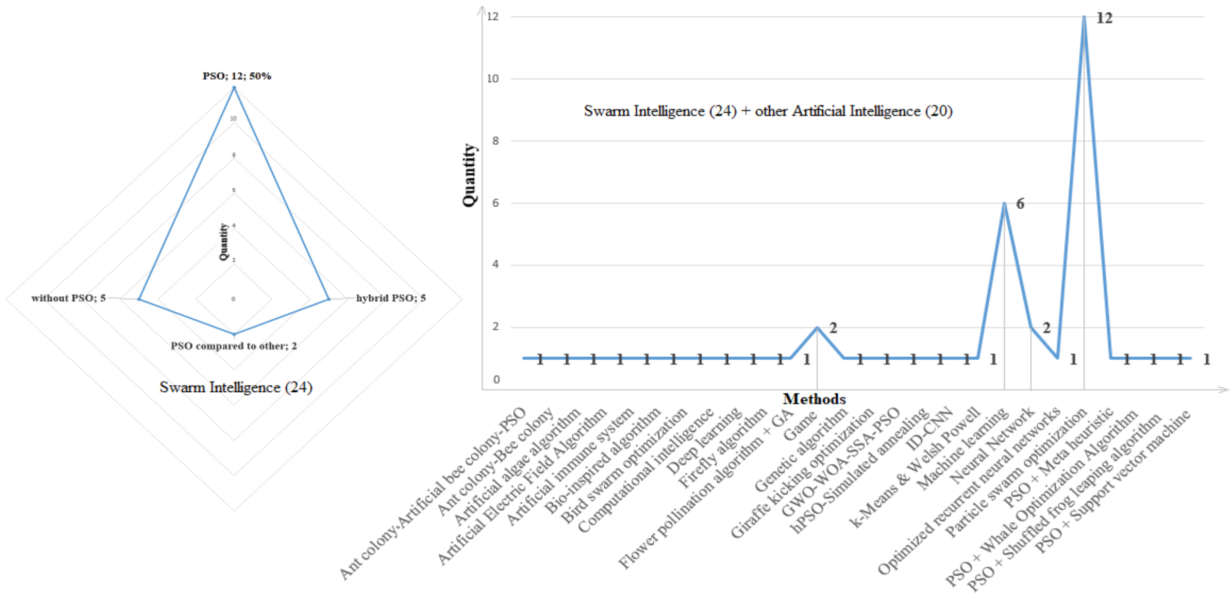


Fig. 6. Topics related to the interference in wireless body area networks (RQ3)



(a) (b)

Fig. 7. Methods of AI/SI (RQ4)

As for identifying the most widely used Swarm Intelligent optimization methods related to interference mitigation on wireless body area networks (RQ5 and RQ6), we summarize them in Table 6 as well as answering RQ6 specifically for topics that use the particle swarm optimization method. This is consistent with Fig. 7(a). In this figure it can be seen that half of it is for the percentage of PSO; also 5 studies for hybrid PSO with other methods.

In identifying improvement methods that have been proposed specifically related to interference mitigation (RQ7), from the search results with PRISMA we found 19 studies. The results or findings for each existing method from each of these studies, we present in Table 7.

Table 6. Topics that use the particle swarm optimization (RQ5 & RQ6)

Topics	Methods	Rmrks.
Link quality parameter optimization, Routing protocol, Research on range-free location algorithm, Energy efficient target tracking, Data aggregation, Cluster head management, Near-field to far-field conversion, LNA of wideband application, Interference-limited UAV-assisted networks, Heart sound interference, Biosensor-Detection of blood glucose	Particle swarm optimization [37], [87], [34], [76], [41], [47], [83], [89], [42], [54], [84]	RQ5 & RQ6
Novel optimization	PSOBAN [49]	RQ5 & RQ6
Relay node selection	hPSO + Simulated annealing [31]	RQ5 & RQ6
Wearable sensor	PSO + SVM [79]	RQ5 & RQ6
Energy-efficient fuzzy-optimized routing	PSO + WOA [82]	RQ5 & RQ6
Energy-efficient and reliable multipath transmission	PSO + SFLA [88]	RQ5 & RQ6
Area coverage and lifetime	PSO + Metaheuristic [53]	RQ5 & RQ6
Node deployment	Flower PA + GA [40]	RQ5
IoT	Ant colony (ACO): Bee colony (BC) [95]	RQ5
IoT	ACO : Artificial BC : PSO [36]	RQ5 & RQ6
Comparison of GWO-WOA-SSA-PSO on antenna design	GWO: WOA : SSA: PSO [78]	RQ5 & RQ6
Perform optim. ch. selection process in the second tier	Bird swarm [43]	RQ5
IoMT antenna	Genetic algorithm [67]	RQ5
EEG-based emotion recognition	Firefly algorithm [66]	RQ5

Table 7. Primary studies that focus on interference mitigation (RQ7)

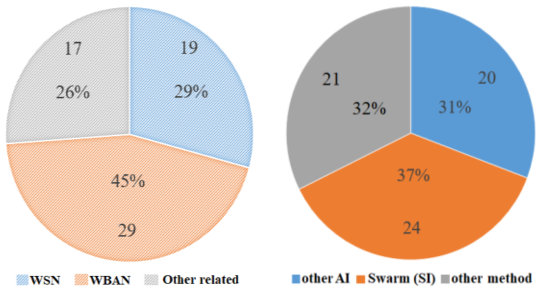
Ref	Methods	Area	Result / Relevant Findings
[33]	Hybrid WBAN interference mitigation model	WBAN	The model of hybrid overtakes the IEEE 802.15.6-based CSMA/CA protocol in bandwidth efficiency, net. throughput area, and network delay
[39]	OBTIM	Inter WBAN	Energy consumption performance over the 802.15.4 scheme
[42]	PSO+ k-Means clustering	UAV-assisted networks	Location optimization is evaluated by the resulting SINR values of all users
[44]	IAPFB scheme	WBAN	Improves the performance of WBAN
[45]	CShILPeA	WBAN	CShILPeA is capable of detecting and mitigating interference; increasing throughput; reducing delay and energy consumption
[50]	N2S platform	WBAN	It is proved that interference causes a decrease in throughput and an increase in delay and energy consumption
[51]	Machine learning (ML)	Inter WBAN	Able to maintain network reliability and stability
[52]	MAC scheme	WSN	There decoding probability increase is about ~39% for sensor density
[54]	Particle swarm optimization	Heart sound	An enhanced particle swarm algorithm can be used to find the optimal forgetting factor (λ) of recursive least square (RLS) based adaptive noise/interference cancellation.
[56]	DPS scheme	Inter WBAN	Frequency adaptation strategy combined with a phase adaptation approach improves the performance of WBANs in the presence of mutual interference in a dynamic environment
[58]	Machine learning	WSN	ML can predict the level of transmit power req. to outgrow the interference
[62]	Hungarian minimum matching algorithm	Inter WBAN	Protocol effectiveness is obtained in terms of throughput, latency, and energy consumption
[64]	SVM-KNN	WSN	SVM-KNN class. has the highest accuracy for human body posture recog.
[68]	Bio-inspired algorithm	Intra WBAN	PSO is able to solve problems that are modeled mathematically as linear programming problems
[70]	Machine learning	WSN	3% less memory is obtained compared to the logistic regression-based ML model
[74]	k-Means++ & Welsh Powell	Inter WBAN	Higher throughput and reduced interference between WBANs
[80]	SLA, SELA, and Q-learning	Inter WBAN	Improves the performance of WBANs
[86]	Smart Channel Assign. Algo.	Inter WBAN	An increase in the density of sensor nodes within each WBAN, and an increase in the number of coexisting WBANs
[92]	Game theory	WBAN	Improves the performance of WBAN

3.2. Discussion

There are three categories of interference in WBANs, namely intra-WBAN interference occurring between sensor nodes in a single WBAN; then inter-WBAN, and cross-WBAN interference. Inter-WBAN interference is also called mutual interference or off-body interference due to one WBAN to another adjacent

WBAN with the same equipment and working on the same frequency band. Several factors are of concern to inter-WBAN interference, namely the location of nodes on the body, number of sensors per WBAN, number of WBANs in the area, dynamic traffic, and velocity of body movement. Cross-WBAN interference occurs when different wireless networks (Bluetooth, ZigBee, or WiFi) are operated within the similar frequency band. Cross-interference scenarios are tricky to deal with in real time because different wireless standards usage different packet sizes, power settings, and protocols. Mutual and cross-interference will also degrade WBAN performance. Intra-WBAN and/or inter-WBAN nodes can potentially become a source of interference, namely intra-WBAN and/or inter-WBAN interference working on the same frequency band (co-channel), or on different frequency bands (adjacent-channel). Many studies only conduct interference mitigation tests for inter-WBAN coexistence, not for intra and cross-WBANs, and even then without mentioning the use of optimization techniques. Indeed, it has been stated that there is a solution to mitigate intra-WBAN interference, namely by using time division channel access; while the solution to inter-WBAN and cross-WBAN is by canceling interference with adaptive methods at physical and MAC layers. However, these solutions have not demonstrated the use of optimization techniques, especially swarm intelligence. All of these paragraphs are closely related to our RQ2 of the systematic review article.

Discussing WBAN is inseparable from WSN because WBAN is one of the most trending WSN technology applications. From the search results of 65 primary studies, we depict the related technology areas obtained in Fig. 8(a) and the types of methods in Fig. 8(b). For efficiency, we put the two side by side. Therefore, from the search results with PRISMA, 29% of primary studies were found in the WSN class; 45% were WBAN and the remaining 26% other related primary studies as chart (a) in Fig. 8, meanwhile chart (b) in the figure shows a 37% portion for the swarm intelligence method; 31% for other artificial intelligence methods, including in this last portion including the use of Bayes theory [32], Artificial immune system [35], Game [46], Optimized recurrent neural network [59], Deep learning [60], Convolutional neural network [72], Artificial algae algorithm [75], Deep neural network [77], Machine learning [81], [85], Computational intelligence [90], and Giraffe kicking optimization [93]. Then the remaining 32% for other methods including studies [57], [65], [73], [91] and [94].



(a) (b)

Fig. 8. Map of primary studies

Then by paying attention to the existing tables and figures as a result of the study search, we can describe the following after this. Fig. 6 (related to RQ3) shows the topic composition of the 65 primary studies obtained. Indeed, the topic of interference mitigation or other designations of interference cancellation or interference suppression occupies the first position, namely as many as 19 studies. But of that number, only 3 studies used the particle swarm optimization method (Adh18, Liu20 & Mek20), the remaining 5 studies used other types of AI, 7 studies used non-AI/SI, and 4 studies did not even include the method.

Fig. 7 (related to RQ4) depicts 44 primary studies using methods in the AI/SI group, with 12 PSO studies and 6 machine learning studies. Of the 12 studies using the PSO, only 2 studies covered the topic of interference mitigation, the rest carried other topics namely routing, link quality, energy efficiency, data transmission, cluster head, modulation, UWB, and bio-sensors.

From Table 6 (related to RQ5 and RQ6) it can be seen that 19 studies used PSO, both standalone and hybrid with other methods. However, of these, only 2 studies covered the topic of interference mitigation, the rest covered other topics such as telemedicine, wearable sensors, relay nodes, energy efficiency, cluster nodes, area coverage, and data aggregation. All of this shows that the use of PSO optimization is still very rare in interference mitigation, especially in wireless body area network areas.

Next, to provide a complete description of RQ7 and RQ8, we include pictures and tables after this. Fig. 9 depicts the nineteen primary studies that focus on interference mitigation obtained within the 2018-2023 search range. Fig. 9 is a summary of Table 7. It can be seen that there are only three methods that are very relevant to the search with each of the three reference sources i.e. the one we gave the ID to Adh18, Liu18, and Mek20. We present this in Table 8 which is accompanied by limitations of previous research or opportunities for future research.

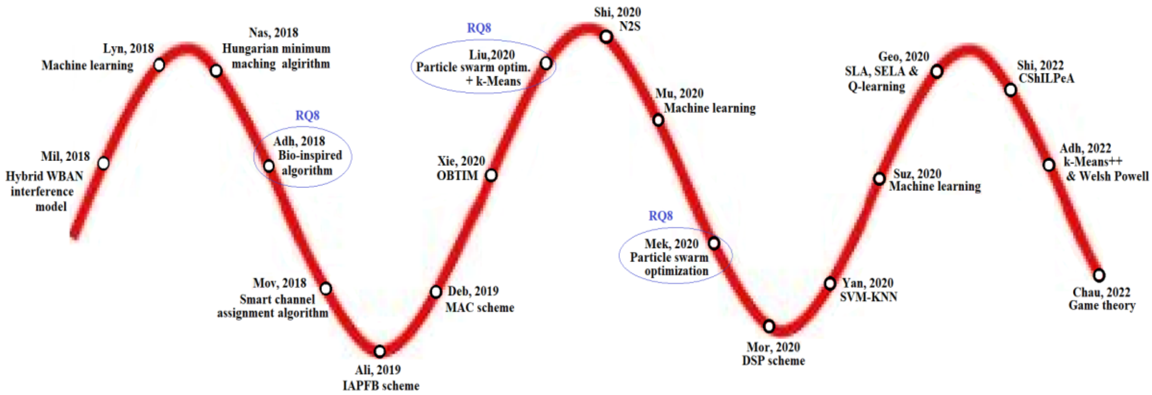


Fig. 9. Primary studies that focus on interference mitigation

Table 8. Most relevant primary studies (RQ8)

Ref	Methods	Limitations
[68]	Bio-inspired algorithm	The simulation with PSO was carried out only on the AWGN channel, not yet on the Rayleigh and Rician channels; PSO has not been tested for inter-WBAN and cross-WBAN interference mitigation; Haven't tried the hybrid-PSO yet
[54]	Particle swarm optimization	PSO has not been utilized for interference mitigation on WBAN
[42]	Particle swarm optimization + k-Means clustering	PSO has not been utilized for interference mitigation on WBAN

Associated with Ultra-Wideband (UWB), this technology is one of the body sensor standards used in WBAN [5], [96], [97]. One of the advantages of UWB wireless technology is the data transmission range between 850 Mbps and 20 kbps and can be used to simultaneously observe many physiological signals that are continuously sent such as ECG/EEG [38]. UWB faces several regulations due to interference problems with co-existing narrowband communication systems, as effective use of bandwidth is not possible resulting in lower data transmission rates [71]. So the BER performance of a UWB-based WBAN depends on the signal power of interfering networks such as IEEE 802.15.4a (piconet) or IEEE 802.15.4f (RFID) systems [50]. And a pulse-shape design method is proposed that can reduce interference on co-existing band communication lines [71]. Meanwhile, for the modulation side, UWB uses differential quadrature phase-shift keying modulation (DQPSK) [6], [61], where one of the uses of DQPSK is in ECG monitoring [4], [6], [98]-[100]. From the primary studies in this systematic review, there are matters related to UWB including its modulation aspect (DQPSK) but there is no research that specifically utilizes PSO optimization. This is certainly an opportunity as well as a challenge for research.

4. CONCLUSION

What is expected in this study is to identify opportunities and topic trends using Particle Swarm Optimization as one of swarm intelligence for interference mitigation optimization of wireless body area networks in the end can provide "Result and Discussion", so that there is compatibility. From the identification, it was found that there were still very few researchers including optimization methods for the type of swarm intelligence, especially the particle swarm intelligence in mitigating wireless body area network interference. Some of them are the use of PSO in mitigating inter-WBAN interference which has not been seen in the 2018-2023 period; also for intra-WBAN and cross-WBAN. Also, other parts supporting the physical transmission layer such as the modulation technique, the opportunity is still very wide open.

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