Hybrid WOA-BAT Optimization for Performance Enhancement of Coexisting WBANs

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Research Article

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Hybrid WOA-BAT Optimization for Performance Enhancement of Coexisting WBANs

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***Abstract*:** The presence of multiple WBANs in any location leads to co-existence issues as multiple users occupy the same channel at the same time. In a real scenario due to mobility the co-existence issues arise intermittently depending on the closeness of the mobile WBAN and other static/mobile WBANs. Since WBAN's are used for monitoring the vital parameters of the human body, the performance of the system consisting of multiple WBANs gets affected whenever co-existence issues arise. Existing work deals with interference issues that arise in Intra WBAN communication. Very limited work is present in literature dealing with co-existence issues that arise from Inter WBAN interference due to varying mobility. In this work we evaluate the performance of the system consisting of static/mobile WBANs subject to interference under varying mobility of other WBANs passing by, thereby creating Body to Body Networks for random, intermittent time durations depending on the speed of the mobile WBANs. We consider two cases, a park area with surrounding paths and an old age home located on a roadside with passersby. We propose an optimization technique using WOA to determine closeness between the WBANs and evaluate the performance of the system. We also consider the case of the impact of passer-by WBAN mobility on static WBANs (elderly occupants of an old age home) and develop a hybrid WOABAT approach to determine the optimal positions for the static WBANs such that the entire system performance is optimized.

Keywords: WBAN, Mobility, Interference, Whale Optimization Algorithm, BAT Algorithm,

I. Introduction

A Wireless Body Area Network (WBAN) connects the sensor nodes on the body of a person through a wireless communication channel. These nodes are placed in a star or multi-hop topology with one of the nodes as a coordinator. In the medical field, for example, a patient can be equipped with a wireless body area network consisting of sensors that constantly measure specific biological functions, such as temperature, blood pressure, heart rate, electrocardiogram (ECG), respiration, etc. The advantage is that the person who is not critically ill does not have to stay in bed, but can move freely across the room and even leave the hospital for a while. This improves the quality of life of the patient and reduces hospital costs. In addition, data collected over a longer period in the natural environment of the patient, offers more useful information, allowing for a more accurate and sometimes even faster diagnosis.

In real scenarios, when many people equipped with WBANs are within a small area such as a bus station or hospital, the wireless signals in a WBAN may interfere with other WBANs. In addition, signal loss can be caused by the movement of the human body. WBAN mobility should be taken into account while designing the interference mitigation algorithms for co-existing WBANs [1]. Coexistence has been a hot issue with WBANs in recent years. The coexistence of multiple WBANs includes static, dynamic, and semi-dynamic environments. In [2], the inter-BAN interference was highlighted as the interference that was generated due to the communication of WBANs in the proximity of one another within the same operating frequency. In addition, mobility support in WBANs can be considered because the network topology changes frequently, according to the mobility of the person [3]. The problems surrounding mobility in WBANs are due to the distance between WBANs, the topology change in multiple WBANs, and the received power. When several nodes in different WBANs try to communicate data in their respective networks at the same time in the same vicinity, interference would increase significantly and therefore reducing the reception probabilities and throughput achieved by all the networks. In [4,5], inter-WBAN interference has been shown to degrade the network performance in terms of packet delivery ratio. Due to this, the connectivity between the nodes in WBAN is affected which causes failure in data delivery.

Existing work on WBANs is focussed on interference analysis and mitigation in coexisting WBANs, Sun et al. [6] presented a stochastic model to analyze the inter-user interference in IEEE 802.15.6 based WBANs and derived the optimal interference detection range to trade-off between outage probability and spatial throughput. Jameel et al.[7] analyzed the impact of co-channel interference on WBANs under generalized fading. The progress of interference generation between two deeply overlapped WBANs was introduced in [8]. Zhang et al. [9] described the necessity of classifying different types of health data for a WBAN. Moreover, different analytical models and proposed algorithms are used in the MAC performance analysis for WBANs. In the presence of inter-user interference, a stochastic model [10] was proposed to analyze the effects of IEEE 802.15.6 MAC. A superframe overlapping scheduling method based on beacon shifting and superframe interleaving interference mitigation techniques were developed for coexisting WBANs. The outage probability and spatial throughput of WBANs were derived from the spatial distribution of the interfering WBANs. Markov analytical models for WBANs have been developed[11]. A criticality index was introduced to identify the critical physiological parameter, using a Markov chain-based analytical approach to maximize the reliability of the critical node. Different User Priorities (UPs) of various traffic in a WBAN were considered in the analytical model. Scheduling techniques [11] were evaluated within various traffic rates and time slot lengths to improve WBAN reliability and energy efficiency.

Several approaches were proposed to mitigate the intra- and inter- WBAN interference [12]. A two-layer interference mitigation MAC protocol (2L-MAC) was proposed based on IEEE 802.15.6 for WBANs [13]. Cheng and Huang [14] employed the TDMA method to reduce mutual interference of nearby WBANs. In [12], a horse racing scheduling scheme was raised to decrease single-WBAN interference. But the resource allocation scheme might degrade once the topology of WBAN changes due to human movements.

In this work, we study the influence of mobility on coexisting WBANs. We consider two cases: (i) A park area that has static WBANs inside and with surrounding paths that have mobile WBANs and a slightly modified case with a path midway through the park (ii) An old age home that has occupants with static WBANs located on a roadside with passers-by (mobile WBANs). We propose an optimization technique using WOA to determine the closeness in terms of distance between the static and mobile WBANs. The time for which different static and mobile WBANs remain close to each other depends on the speed of the mobile WBANs, hence the interference between them. We evaluate the performance of the system in terms of average system throughput, mean delay, and packet loss considering the interference. We also develop a hybrid WOABAT approach to determine the optimal positions for the static WBANs such that the entire system performance is optimized.

The paper is organized as follows: WOA and BAT optimization techniques are briefly described in sections II and III respectively. The proposed work is presented in Section IV. In Section V hybrid WOA-BAT algorithm is developed. Results and conclusion are summarized in sections VI and VII.

II. Whale Optimization Algorithm (WOA)

Whale Optimization Algorithm (WOA) is inspired by the survival and hunting behavior of humpback whales. WOA is based on the hunting behavior of humpback whales.

Humpback whales have a unique hunting method called the bubble-net feeding method which usually involves creating bubbles along a circle around the prey while hovering around the prey. Usually, there are two maneuvers associated with this hunting technique. The first one is 'upward spirals, where the whale dives 12m down and creates bubbles in spiral shape while swimming towards the surface and the other one is more complex and has three stages namely, lob tail, capture loop, and coral loop. This unique spiral bubble-net hunting behavior can only be seen in humpback whales [16]. WOA works in three phases listed below.

- Encircling prey,
- Bubble net attacking and
- Search for prey.

Encircling Prey

In this technique, the position of the search agent in the search space is not known. WOA assumes that the current position is the best position or near to the best solution and other search agents try to update their position. The optimum position can be updated by using the equations (1) and (2) below.

$$\vec{D} = \left|\vec{C} \cdot X^*(t) - X(t)\right| \qquad (1)$$

$$\vec{X}(t+1) = \left|\vec{X}^*(t) - \vec{A} \cdot \vec{D}\right| \qquad (2)$$

where 't's indicates about present iteration and X is the current position while X^* represents the best positions obtained in each iteration, A and C represent the coefficient vector and are calculated as given below.

$$\vec{A} = 2\vec{a} \cdot \bar{r} - \vec{a} \qquad (3)$$

$$\vec{c} = 2 \cdot \vec{r} \qquad (4)$$

where there is decay from 2 to 0 in both exploitation phase and exploration phases, r is an arbitrary vector [0 1].

Bubble-net attacking method (exploitation phase)

In this technique two approaches are designed as follows: shrinking encircling mechanism and spiral updating position. The humpback whales swim near to the prey in both mechanisms so we assume that there is a 50% possibility to choose either the encircling mechanism or spiral mechanism. When the probability is less than 50% encircling mechanism is used, otherwise, it uses a spiral.

$$\vec{X}(t+1) = \begin{cases} \vec{D}' \cdot e^{bl} \cdot \cos(2\Pi l) + \vec{X}^*(t), if\ p \leq 0.5 \\ \vec{X}^*(t) - \vec{A} \cdot \vec{D}, if\ p < 0 \cdot 5 \end{cases} \qquad (6)$$

The shape of the spiral depends upon the value of b and l is an arbitrary value [-1 1].

$$\vec{D}'(t) = \left|\vec{X}^*(t) - X(t)\right| \quad (7)$$

Search for prey (exploration phase)

In this method, the location of other whales is recognized by the humpback whales to search for the prey randomly. The fitness function is updated by a randomly chosen value instead of the best results. To update the position of the search agent in the search space equation given below is used.

$$\vec{D} = \left|\vec{C} \cdot \vec{X}_{rand} - \vec{X}\right| \quad (8)$$

where X_{rand} is a randomly generated position vector chosen from the current population of whales. The WOA optimization technique starts with a set of random solutions. Next, the random solutions are updated in each iteration to obtain the best solution so far. In the WOA algorithm, the optimization starts with a random solution. After each iteration, the WOA algorithm updates the position of the search agent by either a randomly chosen solution or the best solution obtained so far. The value of the parameter varies from 2 to 0 and decides to provide either exploration or exploitation phase. The position of the search agent depends upon the value of A. If |A| > 1 then a random solution is chosen else if |A| < 1 the best solution is chosen. The position updating method is pictorially represented in Fig 1.

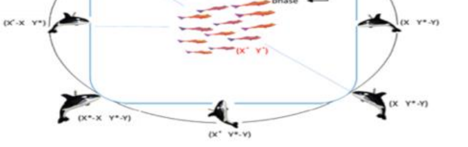

Fig 1. Position updating method for search agents

III Bat Algorithm

The bat algorithm is a metaheuristic algorithm developed by Xin She Yang in 2010[17]. It was based on echolocation. Bats can estimate the position of any surrounding object using the time delay of the returning pulse, and also, they determine the shape and the direction of the objects using comparative amplitudes of the sound pulses collected at each ear.

Based on the original paper by Yang [16], the mathematical equations for updating the locations x_i^t and velocities v_i^t can be written as

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (9)$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} - x^*)f_i \quad (10)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (11)$$

Each bat is encoded with a velocity v_i^t and a location x_i^t, at iteration t, in the solution space. Among the n bats in the population, the current best solution x^* found. Using the concept of bat echolocation, bats can determine the position of their prey, objects, or food exactly through very loud sound wave emission and receiving echo that comes back from these objects. Bats use the advantages of the time delay concept to find their prey, whereas the time delay is calculated as space between bats' ears and the echo wave variations. The velocity of the search agent is compatible with the frequency, and the position of the new solution is located depending on its new velocity. When a bat finds its prey or food, the rate of loudness reduces while the ratio of pulse emission rises.

IV. Proposed Work

We propose a hybrid WOA-BAT algorithm to improve the throughput of Coexisting WBANs. Two scenarios are considered I) A Park located in an area with pathways around and II) An Old age home located on a roadside with footpaths

Scenario I

The system considered is a park with an area of 2500 sq. m. There are roads on all the sides of the park. The Park boundary has pathways that are used by people for walking, running, and jogging. Elderly people in the park who need remote monitoring are assumed to be seated on benches thus constituting static WBANs as depicted in Fig 2.

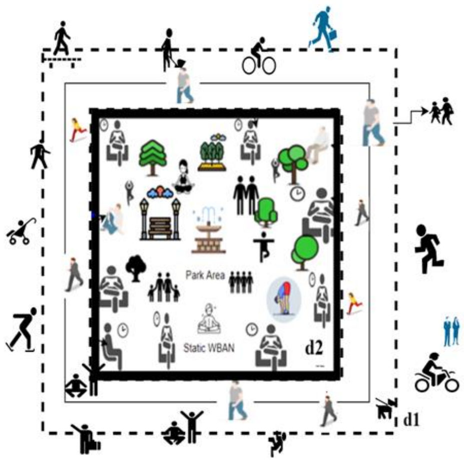

Fig 2 Park Area model

The Park pathways are occupied by people who are in motion (running, walking, and jogging). It is assumed that the number of people who do the exercises varies at random. The speed at which each person walks/runs/jogs depends on his/her strength and capacity (height, weight, and age). To determine the average speed of a person the 12-min Cooper test [2] is used as discussed below.

The Cooper test is a test of physical fitness. In the original form, the point of the test is to run as far as possible within 12 minutes. Pacing is important, as the participant will not cover a maximal distance if they begin with a pace too close to an all-out sprint. The outcome is based on the distance the test person ran, their age, and their sex. It is an easy test to perform in larger groups.

The distance covered by persons of different age groups in 12 minutes during a test and the corresponding speeds are listed in Table I below [2]

Table 1. Cooper Test Observations

Age (years)	Distance (m)	Speed(m/min)
20	312	26
30	299	23.33
40	290	20.83
50	280	16.66
60	189	15.75
70	158	13.10
80	120	10.75

To account for the influence of mobility. We consider the persons of different age groups moving (Running, Jogging, Walking) over an area of length 2500sqm We apply copper test over a runtime of 12 minutes. It is observed from the data obtained that the distance covered by a person is impacted by the person's age as shown in Table 1. Fig 5 shows the maximum distance covered by the mobile WBAN based on age using the Cooper test

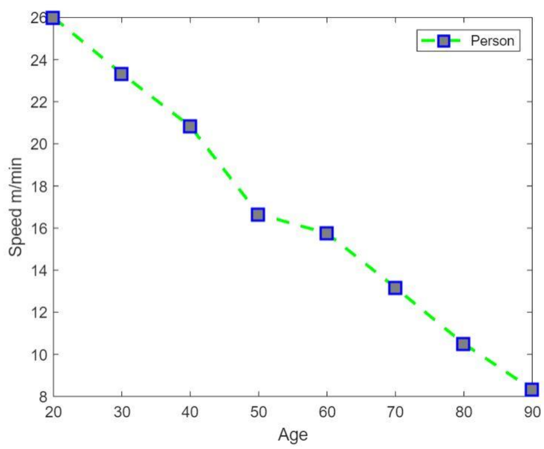

Fig 3. Speed vs Age

From Fig 3, it is clear that the person of lesser age will travel at maximum speed.

The persons inside the park are seated randomly with a minimum distance of 2m between them constituting static WBANs. The persons moving around the park on the pathways form the mobile WBANs. Mobile WBANs are assumed to have varying speeds. A person (mobile WBAN) who moves at less speed will have more chance of getting paired with the static WBAN and hence there will be more interference. The pairing of WBANs will affect the data transmissions of the static WBAN as well as the mobile WBAN due to interference. This leads to the loss of packets or storing of wrong data of the patients. At higher speeds, the interference exists for a very short time and is negligible

Let d1 indicate the position of a static WBAN and d2, the position of the mobile WBAN in Fig 2. The distance between the static WBAN and mobile WBAN is (d1-d2). When any mobile WBAN comes close to any static WBAN, the distance between the two is minimum and the static, mobile WBAN pair is known as the nearest neighboring pair. To determine the nearest neighboring pair, based on the nearest neighbor search(NNS), in a scenario with many static and mobile WBANs, the NP clustering technique where the closest point to a clustered point can be discovered and clustered to the same cluster of that point is implemented

The NNS problem is defined as follows: Given a set of N points in a metric space M, find the closest point from the set of points to a query point q ∈ M. Less distance between a point and another point implies more similarity between them. Similarity metrics, distance metrics, and the relationship between them are formalized by Chen et al. (2009). In the proposed technique, we consider the euclidean distance metric. The euclidean distance (ED) between points d1 and d2 can be defined by (12)

$$ED_{(d1,d2)} = \sqrt{\sum_{i=1}^{n}(d_{1i} - d_{d2i})^2} \quad (12)$$

where n is the no of mobile WBANs.

The NP clustering technique starts by assigning the points corresponding to the indices presented by the k genes of the initial population as initial points for the clusters. The algorithm tracks the number of nearest points selected for each elected point to prevent selecting the same nearest point every time the point is elected.

In the proposed model, the persons are grouped into three age groups, g1 (20-40 yrs), g2 (40-65 yrs), g3(65-80 yrs), and the corresponding average speeds are determined for each group. Let r1,r2, r3 be the probabilities of occurrence of each age group.

The average speed of all three age groups is calculated based on the probability of occurrence of each age group as

$$\lambda = \frac{g1(r1) + g2(r2) + g3(r3)}{3}$$

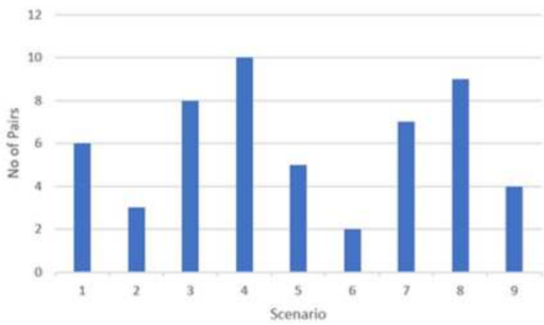

Fig 4. Scenario vs No of nearest neighboring pairs

Fig 4 shows the number of nearest neighboring pairs formed for the combination of varying numbers of each age group, namely Scenario 1, Scenario 2, etc., the numbers chosen at random.

Fig 5 shows the average throughput of the system when there is interference caused due to mobility of the three different age groups. Fig 5 clearly shows that the person belonging to g1 allows higher throughput to be achieved compared with the persons belonging to g2 and g3.

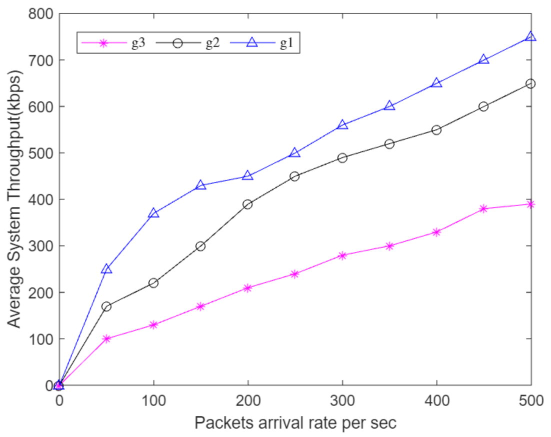

Fig 5. Average System Throughput

In another variation of the park scenario, i.e. (Scenario IA) we consider a pathway running through the center of the park with occupants (static WBANs) on either side. Interference occurs due to the formation of the nearest neighboring pair on either side due to the mobile WBANs in the pathway. The scenario is depicted in Fig 6.

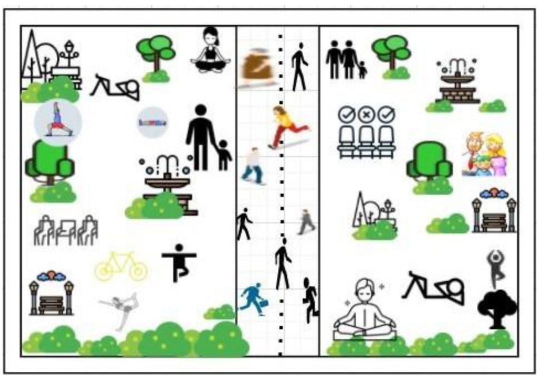

Fig 6 Park Scenario IA with a path midway

The mobile WBAN which is within the minimum distance of any static WBAN for a limited period gets paired with the static WBAN. To find the minimum distancing pair from the set of both static and mobile WBANs, the nearest point pair equation is used. As a slight modification of the park scenario discussed in Fig 2, the park area has a pathway in the center that is also used by mobile WBANs as indicated in Fig 6 (Scenario IA). The minimum distance in such a scenario is calculated on either side of the common pathway. From (12) it is clear that only when any mobile WBAN falls within the minimum distance for a limited time it will get paired with the nearest person (static WBAN) on either side of the park. It is observed that the average system throughput varies similar to Scenario I as shown in Fig 5 with g1 attaining a high value.

Though the WOA is good and fast in reduction of interference in the system, it does not provide the optimal position of the static WBAN that could be interference-free. A hybrid WOA-Bat Algorithm that converges faster than WOA is used to determine the optimal position of the static WBAN.

Scenario II:

We consider an old age home where the old people in the home constitute the static WBAN and people who are on the adjacent road form the mobile WBANs as shown in Fig 7.

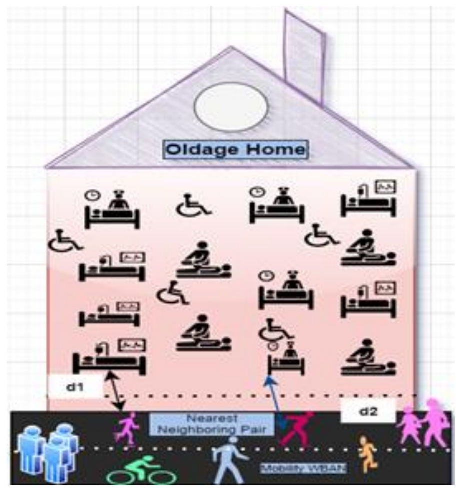

Fig 7 Old age Home Scenario

Using the hybrid WOA-BAT algorithm the new positions to which the elderly people in the old age home could be shifted to (positions where the mobile WBANs do not get paired with any static WBANs and cause interference when moving in the pathway) are determined.

V. Hybrid WOA-BAT Algorithm

To reduce the effect of inter-interference and improve the efficiency of the network, the hybrid WOA-BAT algorithm is implemented. WOA is an optimization algorithm, which provides improved performance when applied to many optimization problems. Despite the performance improvement, WOA has slow convergence while determining the global optimum. Therefore, the BAT algorithm is used to improve the exploration capability of WOA. The two considerations in this approach are:

(1) The BAT algorithm is partially embedded inside the WOA search phase and

(2) Technique is used after changing the position of each search agent.

We consider the old age home scenario to reduce the inter interference using the WOA-BAT algorithm as shown in Fig 7. Similar to the park scenario the mobile WBAN who gets paired with another will cause interference. The hybrid WOA-BAT algorithm will find the new position for the static WBAN which is better than the old position resulting in fewer iterations compared to WOA

The Hybrid WOA-BAT algorithm is explained as in the flow diagram below. Generally, the WOA consists of the Exploitation and Exploration phase. The Bat algorithm is used in the Exploration phase. In the Exploitation phase, the WOA algorithm finds the best position of the prey in the search space using the fitness function. The Bat algorithm in the Exploration phase will find the best position where each prey or object gets paired based on the echolocation concept.

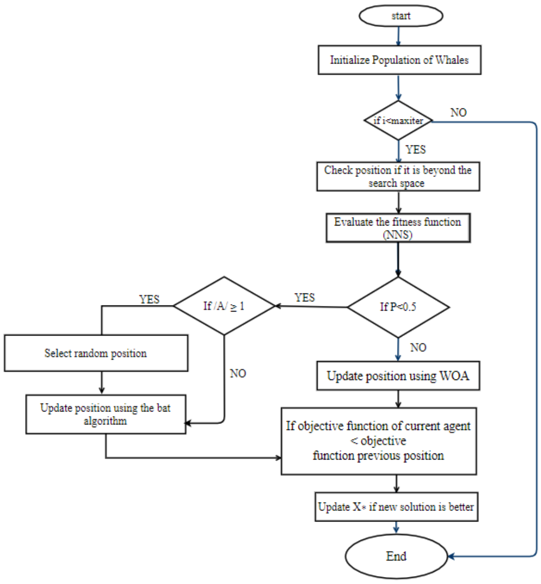

Fig 8. Hybrid WOA-BAT approach

Using this newly updated position, the position of the object or the patient bed in the old age home is shifted to the position where it does not get paired to any mobile WBAN. This will avoid interference in the system and improve the performance of the network compared to the performance observed with WOA

VI. Results and Discussion

The performance of the system under the scenarios described above is evaluated using simulation assuming that the pairing of the nodes between the static and mobile WBANs happens when the distance between them is <=2 meters.

We consider a WBAN to be composed of Wavenis Sensor Nodes with a coordinator [18]. The simulation parameters are listed in Table 2.

Sensor	Wavenis Sensor Node
Range	2m-5m
Channel Bandwidth	50kHz
Packet Size	512 bits
Target area	1250sqm

No of Static WBANs	10
No: of mobile WBANs	10 – 50 approximately

Table 2. Simulation Parameters

The system performance is evaluated in terms of the mean delay, average system throughput, and packet loss. The performance of the system with the WOA-BAT optimization technique is compared with WOA and PSO techniques

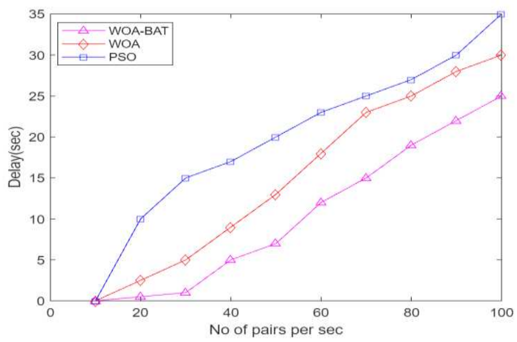

Fig 9. Delay vs No of pairs

The mean delay of a network specifies how long it takes for n number of packets to be transmitted through the network. Fig 9 shows the variation of mean delay for varying numbers of pairs per sec. It is observed from Fig 9 that the delay of the network reduces with the Hybrid WOA-BAT technique by 5% and 22% compared to WOA and PSO techniques respectively when the number of pairs is 80 approximately.

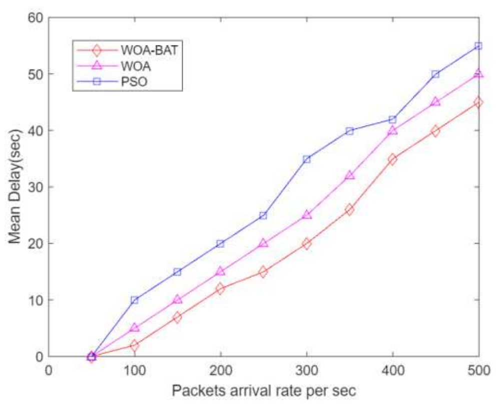

Fig 10. Mean delay vs Packet Arrival Rate

Fig 10 shows the mean delay of the system when WOA, PSO, and Hybrid WOA-BAT algorithms are implemented for varying packet arrival rates. From Fig 10 that the Hybrid WOA-BAT implementation provides reduced Mean delay by 12% and 25% compared to WOA and PSO implementations respectively for a packet arrival rate of 400 packets per sec.

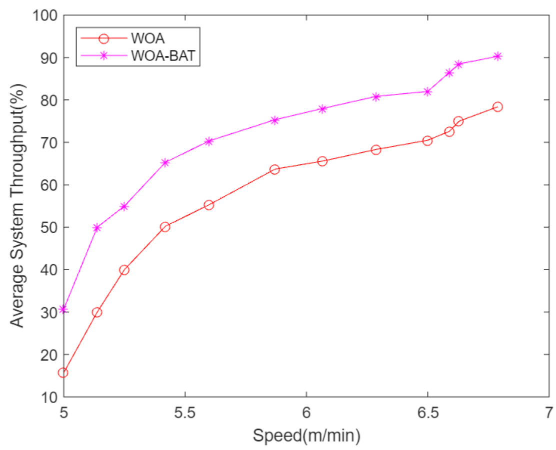

Fig 11Average System Throughput vs Speed(m\mins)

Fig 11, Fig 12, and Fig 13 represent the variation of the average system throughput against the speed of the mobile WBAN for Scenario I, Scenario IA, and Scenario II respectively. It is observed from Fig 11 that the average system throughput improves with WOA-BAT implementation compared to WOA considering Scenario I. From Figures 12 and 13, it is observed that the WOA-BAT technique provides improved performance compared to WOA and PSO implementations considering Scenarios IA and II respectively

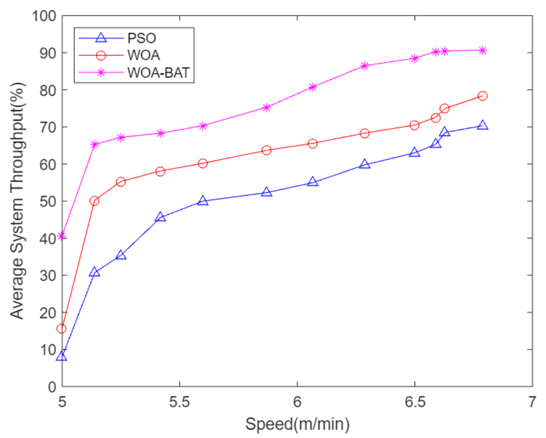

Fig 12 Average System Throughput vs Speed(m\mins)

From Fig 12 it is observed that for Scenario I, the Hybrid WOA-BAT provides an improvement in average system throughput by 6% and 24%of throughput compared with WOA and PSO implementations respectively.

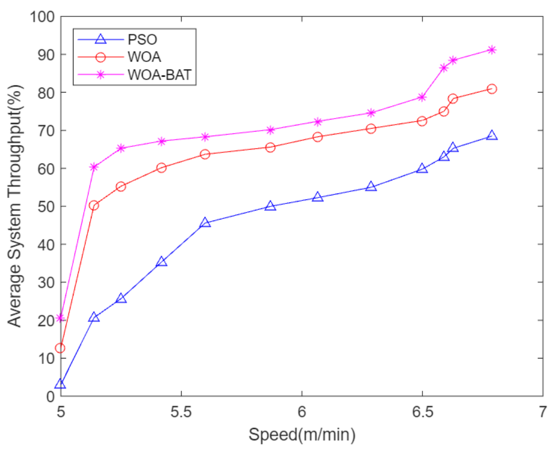

Fig 13 Average System Throughput vs Speed(m\mins)

From fig 13 it is observed that in Scenario IA the throughput of the Hybrid WOA-BAT technique is improved by 17% and 30 % compared to WOA and PSO implementations respectively.

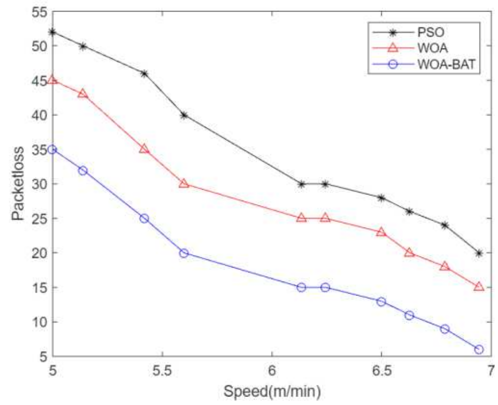

Fig 14 Packet loss vs Speed (m\mins)

Fig 14 and Fig 15 show the performance in terms of packet loss for Scenario I and Scenario II respectively. From Fig 14, it is observed that the Hybrid WOA-BAT technique reduces packet loss by 9% and 38% compared to WOA and PSO implementations respectively for Scenario I

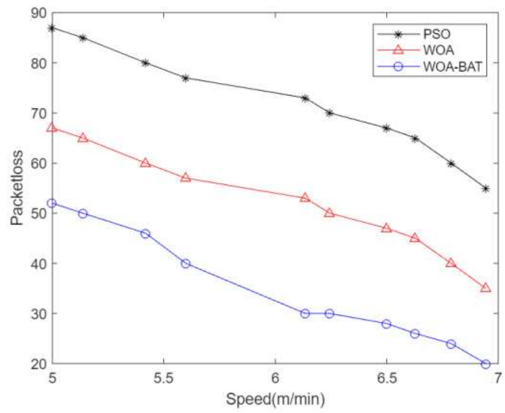

Fig 15 Packet loss vs Speed(m\mins)

From Fig 15 it is observed that for Scenario II the packet loss of the hybrid WOA-BAT is reduced by 17% and 44% compared to PSO and WOA implementations respectively. WOA-BAT technique reduces packet loss compared to WOA and PSO implementations for both scenarios.

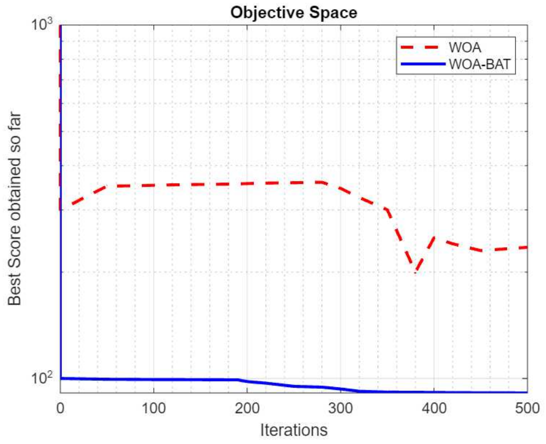

Fig 16. Convergence curve of WOA-BAT, WOA

The convergence curve for WOA-BAT and WOA algorithms is presented in Fig 16. It is observed from Fig 16 the WOA-BAT algorithm converges faster than the WOA algorithm.

VII. Conclusion

The work presents a study of the impact of mobility on Co-existing WBANs under various scenarios. A hybrid optimization technique, namely the WOA-BAT is applied to improve the performance of the system with coexisting WBANs. Compared to optimization algorithms such as PSO and WOA, the hybrid WOA-BAT algorithm is observed to perform better. Such investigations are helpful for remote patient monitoring, particularly in places where there is a possibility of people equipped with WBAN are close to one another. The study can be extended to crowded areas with multiple WBANs and the performance of such co-existing WBANs could be analyzed.

Declaration

We declare that this manuscript is original, has not been published before, not currently being considered for publication elsewhere. We know of no conflicts of interest associated with this work, and there has been no significant financial support for this work. Data sharing does not apply to this article as no datasets were generated or analyzed during the current study. Matlab tool is used for the simulation results. As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

References

1. Jon Louis Bentley. Multidimensional divide-and-conquer. *Communications of the ACM*, vol.23(4), pp.214-229.
2. Monique M. Samson, Ingrid B. A. E. Meeuwsen, Alan Crowe, Jos A. G. Dessens, Sijmen A. Duursma, Harald J. J. Verhaar: Relationships between physical performance measures age, height and healthy weight in healthy adults, *Age and Aging*, 2000, vol-29, pp-235-242.
3. Kim, B.-S.; Kim, K.H.; Kim, K.-I. A Survey on Mobility Support in Wireless Body Area Networks. *Sensors* **2017**, vol.17, pp. 797.
4. IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs), IEEE Standard 802.15.4, *IEEE Computer Society*, Sep. 2011
5. Patel, M.; Wang, J. Applications, Challenges, and Perspective in Emerging Body Area Networking Technologies. *IEEE Wireless. Communications.* **2010**, vol 17, pp.80–88.
6. IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs), IEEE Standard 802.15.4, *IEEE Computer Society*, Sep. 2011.
7. F. Jameel, A. Butt, and U. Munir, "Analysis of interference in body area networks over generalized fading," *in*

Proc. IEEE ICET, Islamabad, Pakistan, Oct. 2016, pp. 1–6. [21]

8. M. N. Anjum and H. Wang, "Optimal resource allocation for deeply overlapped self-coexisting WBANs," in Proc. IEEE GLOBECOM, Washington, DC, USA, Dec. 2016, pp. 1–7.
9. K. Zhang, X. Liang, M. Baura, R. Lu, and X. Shen, "PHDA: A priority-based health data aggregation with privacy preservation for cloud-assisted WBANs," *Information. Science*., vol. 284, pp. 130–141, Nov. 2014.
10. W. Sun, Y. Ge, Z. Zhang, and W.-C. Wong, "An analysis framework for inter-user interference in IEEE 802.15.6 body sensor networks: A stochastic geometry approach," *IEEE Transactions Vehicle Technology*, vol. 65, no. 10, pp. 8567–8577, Oct. 2016.
11. S. Rashwand, J. Miši´c, and V. B. Miši´c, "Analysis of CSMA/CA mechanism of IEEE 802.15.6 under the non-saturation regime," *IEEE Transactions Parallel Distribution System*, vol. 27, no. 5, pp. 1279–1288, May 2016.
12. S. H. Cheng and C. Y. Huang, "Coloring-based inter-WBAN scheduling for mobile wireless body area networks," *IEEE Transactions Parallel Distribution System*, vol. 24, no. 2, pp. 250–259, Feb. 2013.
13. S. Moulik, S. Misra, and D. Das, "AT-MAC: Adaptive MAC-frame payload tuning for reliable communication in wireless body area networks," *IEEE Transactions Mobile Computation*., vol. 16, no. 6, pp. 1516–1529, Jun. 2017
14. Y. Tselishchev, A. Boulis, and L. Libman, "Variable scheduling to mitigate channel losses in energy-efficient body area networks," *Sensors*, vol. 12, no. 11, pp. 14692–14710, 2012.
15. S. Sarkar, S. Misra, B. Bandyopadhyay, C. Chakraborty, and M. S. Obaidat, "Performance analysis of IEEE 802.15.6 MAC protocol under non-ideal channel conditions and saturated traffic regime," *IEEE Transactions Computations*, vol. 64, no. 10, pp. 2912–2925, Oct. 2015.
16. Hardi M. Mohammed, Shahla U. Umar, and Tarik A. Rashid. "A Systematic and Meta-Analysis Survey of Whale Optimization Algorithm" *Computational Intelligence and Neuroscience*, 2019, Vol.3, pp. 1-25.
17. X.-S. Yang. A new metaheuristic bat-inspired algorithm. In Nature inspired cooperative strategies for optimization (NICSO 2010), pp. 65–74. *Springer*.
18. Mohammad Ghamari, Balazs Janko, R. Simon Sherratt, William Harwin, Robert Piechockic and Cinna Soltanpur, "A Survey on Wireless Body Area Networks for eHealthcare Systems in Residential Environments", *Sensors* 2016, Vol-16, pp-830-833.