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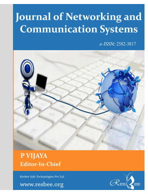

ChGOA: Advanced Grasshopper Optimization for Virtual MIMO-based Cross-Layer Design for WSN

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Abstract: Several sensor nodes connected by wireless media make up the Wireless Sensor Networks (WSNs). Long-distance dependable communication in WSNs is made possible by virtual MIMO (V-MIMO). V-MIMO guarantees dependable connection between intermediate nodes, making it challenging and resulting in energy requirements and transmission interference. Thus, this work suggests a novel optimization model for solving the issues in V-MIMO systems that greatly improves communication performance. This work designs a "multihop virtual MIMO communication protocol by cross-layer model" for improving the QoS, energy and reliability in WSN. Here, the throughput and latency were modeled based on BER efficacy of links. Chaotic Grasshopper Optimization (ChGOA) is a new optimization method used in this research to identify the enhanced BER performance of every link that satisfies the ETE QoS criteria with less energy usage. From analysis, the suggested ChGOA algorithm for 100 nodes acquired a less energy consumption of 5.86 Joules.

Keywords: Virtual MIMO; Quality Of Service; Energy Consumption; Bit Error Rate; Chaotic Grasshopper.

Nomenclature

Abbreviation	Description
ADV	Advertisement Message
AWGN	Additive White Gaussian Noise
BER	Bit-Error-Rate
BPSK	Binary Phase-Shift-Keying
BPSK-WOFDM	Binary Phase Shift Keying-Wavelet based Orthogonal Frequency Division Multiplexing
CH	Cluster Head
CMIMO	Cooperative Multiple-Input Multiple-Output
CSMA	Carrier Sense Multiple Access
CFIS	Clustering Fuzzy Inference System
CN	Cooperative Node
CSI	Channel State Information
CHS	Cluster Head Selection
DF	Decision Fusion
DA	DragonFly Algorithm
E2E	End-to-End
HV-MIMO	Hybrid V-MIMO
LEACH	Low-Energy Adaptive Clustering Hierarchy
LA	Lion Algorithm
MECR	Minimum Energy Consuming Route
MAC	Medium Access Control
PSD	Power Spectral Density
PAR	Packet Arrival Rate
PSO	Particle Swarm Optimization
RSS	Received Signal Strength
STBC	Space-Time Block Coding
TDMA	Time-Division Multiple Access
TCH	Target Cluster Head
V-MIMO	Virtual Multiple-Input Multiple-Output
WSN	Wireless Sensor Networks

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1. Introduction

Due to its energy efficiency across a wide range of networks, V-MIMO has garnered increasing attention in recent years [1] [2]. A collection of sensors works together to send and receive data in a V-MIMO networks. Long-range communications can save energy by using numerous receivers and transmitters during a transmission, but the consumption of power rises as the number of receivers and transmitters grows [3] [4]. Therefore, it is necessary to adjust energy optimization approaches to the environment. V-MIMO principles are used in WSNs for energy-efficient communication to save energy and boost reliability because of the circuitry complexity and challenge of combining different antennas [5].

For energy-aware communication in WSNs, several protocols and techniques are put forth. In order to increase data dependability in fading channels, V-MIMO involves several senders and receivers engaging in long-distance communication [6] [7]. The data link layer and network layer structures affect V-MIMO's performance in WSNs. Virtual antenna arrays may be implemented in WSNs in a number of ways. Several single-antenna nodes might be combined into a single entity in V-MIMO, and each node in the group combines its antenna with the others to work together as a single MIMO system [8]. Recently, V-MIMO systems with dynamic modulation and several source coding algorithms have been presented to attain almost perfect genuine MIMO performance [9] [10].

To cope up with the demands of a given environment, the network components in a cognitive network design should tune the operating parameters [11] [12]. In contrast, the MIMO approach is commonly employed in broadband and wireless systems because of its ability to take use of the huge theoretical capacity of multi-path fading channels. Examining if this method may be used to WSN energy conservation is an intriguing problem. All of these encourage us to suggest a novel plan to extend the lifetime of the WSN under these circumstances [13].

The proposed V-MIMO model for enhancing the energy efficiency comes up with the following contribution:

- Introduces Chaotic Grasshopper Optimization (ChGOA) for identifying the enhanced BER performance that satisfies the QoS criteria with less energy consumption.

The existing VMIMO systems for WSN are portrayed in section 2. System modelling and designing of protocol are elucidated in Section 3 and 4. QOS and energy consumption are described in Sections 5. Section 6 and 7 enumerates the results and conclusion.

2. Literature Review

2.1 Related works

Jong-Moon *et al.* [14] suggested a multihop HV-MIMO network scheme in 2012 that used the most effective CMIMO set up for each hop to establish a MECR that offered high connectivity while meeting e2e data rates and BER requirements. First, the source to target path was divided up into lengthy hops in the suggested scheme, and each hop was equipped with the least energy-intensive V-MIMO configuration. After then, each of the lengthy communication hops was assessed separately, and modifications were only made when a reduction in energy use was achievable. The hop config was not altered and the hop was no more assessed for replacement if no gain was achievable for that particular hop.

Askari *et al.* in 2017 [15] introduced a new MIMO CFIS-based model, which was derived directly from a family of fuzzy clustering techniques. Using fuzzy clustering, CFIS finds dense areas in the input data and then assigns a cluster to each of these areas. These fuzzy clusters served as fuzzy rules in the CFIS rule base, representing the real structure of the data. They also give MFs that precisely match the dense data areas, improving system interpretability and preventing redundant rules. By creating well-separated fuzzy clusters, the CFIS, a MIMO system, avoids inconsistent regulations.

An efficient V-MIMO-driven system for decentralized and cooperative WSNs was presented by Jayaweera *et al.* [16] in 2006. The delay and energy efficacies of the suggested strategy were calculated using semi-analytic methods, presuming a STBC driven MIMO system. Additionally, the effect of these parameters on fading time and the training time was examined. The findings demonstrated that, the V-MIMO approach can be engineered to offer notable energy and delay savings with careful selection of design parameters.

For energy-constrained WSNs, Naga Malleswari and Venkateswara [17] suggested a cluster-driven virtual MIMO communication technique in 2013. For both constant and variable rates, V-MIMO was analyzed. It was suggested to integrate a LEACH with an energy-efficient routing STBC driven V-MIMO approach. Furthermore, an analytical model based on the energy consumption of V-MIMO-based routing was found to be more energy-efficient.

In 2013, Zimran [18] examined the effects of various modulation strategies and conducted the analysis of V-MIMO system based on the V-BLAST architecture. The communication and computing energy consumption, BER, spectrum efficiency, and overall time delay of many cooperating nodes, each with a single antenna, were assessed by theoretical simulations utilizing actual hardware and environmental parameters.

2.2 Review

There are still important gaps in existing studies on V-MIMO in WSNs. One significant issue is the absence of energy-efficient coordination mechanisms as most V-MIMO designs anticipate frequent information transmission and tight synchronization across sensor nodes, which is impractical for energy-constrained WSNs. Practical synchronizing and channel estimates are another area where there is a gap. While real deployments are plagued by clock drift, inaccurate CSI, and dynamic topologies, many research depend on idealized or central assumptions. As most models take into account smaller, stationary clusters and fail to consider performance loss in massive or distributed networks, adaptability and node portability are similarly understudied. Furthermore, cross-layer design is still restricted; V-MIMO approaches are not sufficiently integrated with WSN-specific routing protocols.

3. System Model

The reference system framework for the multihop V-MIMO system that is being given is seen in Fig. 1. While data transfer, the SNs are grouped to h_c clusters. There are two main purposes for the transmission at each hop. First, CH in the local cluster will send data to CNs. In these kinds for transmitting with h^{th} power path loss, an AWGN channel is assumed due to the limited intra-cluster transmission range. The data bits are then encoded by the CNs and sent to CH on the next hop in accordance with the orthogonal STBCs. Furthermore, in these broadcasts, power path loss is considered for the Rayleigh fading channel. The number of CNs in every transmission is stated as κ, the distance between the destination and source cluster and sink is signified by D, H indicates the number of hops, and bw shows the bandwidth. Because of its great efficiency in the virtual MIMO paradigm, BPSK is used as a modulation technique [19].

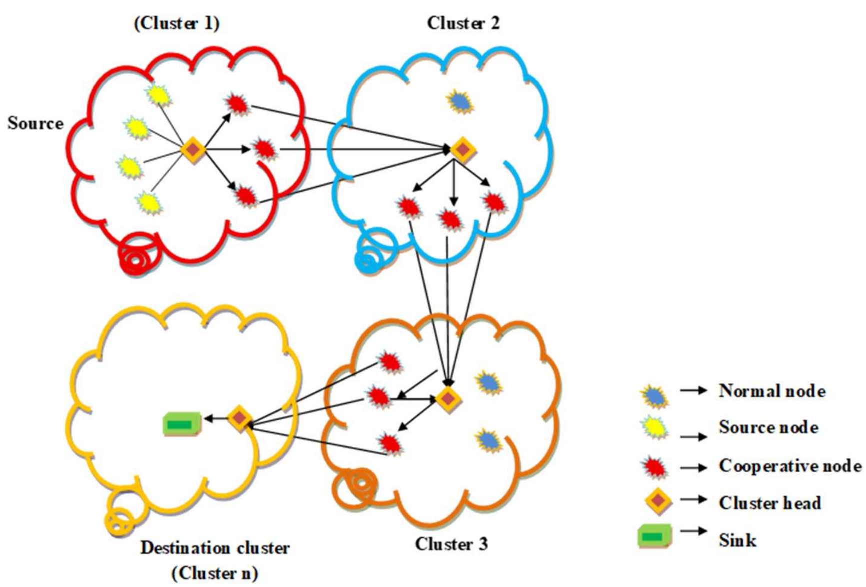

Fig. 1. *Architecture of virtual MIMO model*

3.1 Choosing CNs

The average energy used for each transmitted bit in BPSK is modelled using Eq. (1), where, M_1 signifies link margin, γ signifies power amplifier capacity, U_f signifies receiver noise value, U_0 signifies PSD, G_r

and G_t signifies receiver and transmitter antenna gains. , Γ_{cr} and Γ_{ct} indicates the power utilization of transmission and reception circuits and λ denotes wavelength.

$$Z_{bt} = (1+\gamma)\frac{U_0}{\Gamma_b^{\frac{1}{\kappa}}}\sum_{j=1}^{\kappa}\frac{(4\pi)^2}{G_t G_r \lambda^2} M_1 U_f + \frac{(\kappa\Gamma_{ct}+\Gamma_{cr})}{bw} \tag{1}$$

The following is an approximation of the node j's average channel attenuation. Eq. (2) provides the RSS Γ_{jt} at the node j when a signal with transmission power Γ_{out} is sent across a symmetric channel. Here, $G(D_j,k_j) = \Gamma_{out}/\Gamma_{jt} = (4\pi)^2 D_j^{k_j} M_1 U_f \big/ G_t G_r \lambda^2$. As a result, Eq. (1) is redesigned as Eq. (3). In Eq. (3), Γ_{out} node j for interacting with CH l is specified by Eq. (4).

$$\Gamma_{jt} = \Gamma_{out}\frac{G_t G_r \lambda^2}{(4\pi)^2 D_j^{k_j} M_1 U_f} = \frac{\Gamma_{out}}{G(D_j,k_j)} \tag{2}$$

$$Z_{bt} = (1+\gamma)\frac{U_0}{\Gamma_b^{\frac{1}{\kappa}}}\sum_{j=1}^{\kappa} G(D_j,k_j) + \frac{(\kappa\Gamma_{ct}+\Gamma_{cr})}{bw} \tag{3}$$

$$\Gamma_{out\ jt} = G(D_j,k_j)\frac{U_0 bw}{\Gamma_b^{\frac{1}{\kappa}}} \tag{4}$$

In Eq. (3), Z_{bt} is decreased by selecting a suitable collection of CNs with decreased $G(D_j,k_j)$. Furthermore, $\alpha_{jt} = en_j \big/ G(D_j,k_j)$ can be described as the selection criterion where the remaining energy is provided by en_j in order to balance the energy use. The rationale behind these requirements is that the node with a higher chance of being selected as the CN must use less power to interact with CH l. K Nodes with greatest α_{jt} score would thus be chosen as the CNs for communicating with l.

4. Designing Protocol

Here, we design "cluster-oriented multihop V-MIMO protocol". Three steps comprise the chosen protocol's functions: the cluster creation phase, the routing phase, and the transmission phase.

4.1 Formation of Cluster

Depending on their remaining energy, each node views them as a CH during this phase. After CHs are chosen, each CH will use a temporary CSMA MAC protocol to send an ADV by Γ_{out}. The message includes the head's ID. When CH receives the ADV from a separate head l and the RSS above a certain threshold Th, it registers ID of l and treats CH as a neighbour.

Each CH will select the optimal K CNs for CMIMO interactions with all of its adjacent CHs when clusters have formed.

Routing Phase: When building routing tables, the basic idea of "distance-vector-oriented routing" will be used. Additionally, the CH gets route ADV from other CHs, modifies its routing database depending on routing expense, and notifies neighbouring CHs of the updated routes. The routing tables of each CH are joined to create the desired one after many route exchanges and updates.

Data Transmission: Here, data is transmitted to CH by the cluster members using several frames. Data is sent according to the TDMA schedule in each frame. For all clusters, the frame duration and the number of frames sent to the CH in a slot are nearly identical. CH will perform data aggregation to eliminate data redundancy after receiving data frames. The CH sends the data packets to the TCH following the aggregation of the acquired data frames.

5. QOS and Energy Consumption

5.1 Energy Utilization

Eq. (5) displays the energy consumption for each packet transfer, where, D_0 indicates the transmitted distance in the local cluster and r defines a constant.

$$Z_0(D_0,\kappa) = mrD_0^2 + \frac{m\Gamma_{ct}}{bw} + \frac{m\kappa\Gamma_{cr}}{bw} \tag{5}$$

The block size of the STBC code is represented by d symbols, $p\kappa$ training symbols were considered in each block. Furthermore, as the inter- cluster distance is greater than the intra-cluster distance, it is considered that the differences between D_j, k_j of CNs are insignificant while designing. The Z at j^{th} hop is then represented by Eq. (6), which D_{hj} indicates the j^{th} hop's inter-cluster distance.

$$Z_1\left(\Gamma_b, D_{hj}, \kappa\right) = \frac{nd}{d - p\kappa}\left(\frac{\kappa U_0}{\Gamma_b} G\left(D_j, k_j\right) + \frac{\kappa\Gamma_{ct} + \Gamma_{cr}}{BW}\right) \tag{6}$$

The Z at j^{th} hop is modelled in Eq. (7).

$$Z_h\left(j\right) = Z_{code} + Z_0\left(D_0, \kappa\right) + Z_1\left(\Gamma_b, D_{hj}, \kappa\right) \tag{7}$$

Overall Consumption of Energy: According to the aforementioned study, the mean transmit interval must be examined in order to predict the total energy consumption for each packet transfer. For linear block code (m, y, l), word error probability is calculated by Eq. (8) [20].

$$\Gamma_w\left(\Gamma_b\right) = \sum_{i=t+1}^{m} \binom{m}{i} \Gamma_b^i \left(1 - \Gamma_b\right)^{(m-i)} \tag{8}$$

Therefore, the mean transmission period for each hop is depicted as $1/\left[1 - \Gamma_w\left(\Gamma_b\right)\right]$. Eq. (9) then provides the overall Z.

$$Z_{overall} = \frac{1}{\left[1 - \Gamma_w\left(\Gamma_b\right)\right]} \times \left\{H\left[Z_{code} + Z_0\left(D_0, \kappa\right)\right] + \sum_{j=1}^{G} Z_1\left(\Gamma_b, D_{hj}, \kappa\right)\right\} \tag{9}$$

5.2 QoS

The average packet transmission time is provided by $l_f = md/bw\left(d - p\kappa\right)$. Consequently, Eq. (10) may be used to describe the throughput.

$$G = \frac{1 - \Gamma_w\left(\Gamma_b\right)}{l_f} \tag{10}$$

QoS Performance: Every link's BER performance in SPT is taken into consideration while modeling it. Intra-cluster PAR is given in Eq. (11), where, U_{si} signifies the set of children CHs in SPT, and λ_c signifies PAR, and $\mu_j\left(\Gamma_{bj}\right) = \left(1 - \Gamma_w\left(\Gamma_{bj}\right)/l_f\right)$.

$$\lambda_i = \begin{cases} \lambda_c, \left(i \in V_s\right) \\ \sum_{j \in U_{si}} \mu_j\left(\Gamma_{bj}\right)\left(1 - \Gamma_0\left(\mu_j\left(\Gamma_{bj}\right), \lambda_j\right)\right) + \lambda_c, \left(i \in V_r\right) \end{cases} \tag{11}$$

Eq. (13) and (12) provide the e2e delay and throughput for the path from CH j to sink. Additionally, Eq. (14) and (15) provide the average e2e throughput and latency for the whole network. The total energy consumption of all CHs is displayed in Eq. (16).

$$Th_j = \prod_{i \in J_j}\left(1 - \Gamma_U\left(\mu_i\left(\Gamma_{bi}\right), \lambda_i\right)\right) \tag{12}$$

$$L_j = \sum_{i \in J_j} \varpi\left(\mu_i\left(\Gamma_{bi}\right), \lambda_i\right) \tag{13}$$

$$Th\left(\left\{\Gamma_{bj}\right\}\right) = \frac{\sum_{j \in V_s \cup V_r} \lambda_j Th_k}{\sum_{j \in V_s \cup V_r} \lambda_j} \tag{14}$$

$$L\left(\left\{\Gamma_{bj}\right\}\right) = \frac{\sum_{j \in V_s \cup V_r} \lambda_j L_j}{\sum_{j \in U_s \cup U_r} \lambda_j} \tag{15}$$

$$Z_{overall} = \sum_{j \in V_s \cup V_r} \frac{1}{1 - \Gamma_w\left(\Gamma_{bj}\right)} \times \left[Z_{code} + Z_0\left(D_0, \kappa\right) + Z_1\left(\Gamma_{bj}, D_j, \kappa\right)\right] \tag{16}$$

5.3 ChGOA Algorithm

The ChGOA is used in the current study for the virtual MIMO-based CHS model since the required latency and lower energy consumption are important factors. As a significant addition, a novel ChGOA method is used to optimize the BER $\left(\Gamma_b\right)$ and $\left(\Gamma_{bj}\right)$ of Eq. (9) and (14) and (15), potentially resulting in lower energy usage.

Solution Encoding and Objective: During optimization, the algorithm receives Γ_b and Γ_{bj} as input. Eq. (17) provides the objective function Ob, in which, Z signifies energy usage.

$$Ob = Min\left(Z\right) \tag{17}$$

GOA [21] is based on the swarming habits of grasshoppers [7]. Eq. (18) illustrates the swarming actions, in which, A_i indicates i^{th} grasshopper position, S_i indicate social interaction, Q_i indicates gravity force and w_i signifies wind advection," illustrates the swarming actions of GOA.

$$A_i = S_i + Q_i + w_i \tag{18}$$

In order to create a random behavior, Eq. (6) is modelled as in Eq. (19), where arbitrary factors ϕ_1, ϕ_2, ϕ_3 lies among 0 and 1.

$$A_i = \phi_1 S_i + \phi_2 Q_i + \phi_3 w_i \tag{19}$$

As per ChGOA, instead of randomly choosing ϕ_1, ϕ_2, ϕ_3, we chose ϕ_1, ϕ_2, ϕ_3 using chaotic maps, especially, logistic map formulation. This logistic map generates chaotic sequences rather than random integers for better diversity.

The logistic map for computing ϕ_1, ϕ_2, ϕ_3 is modelled as in Eq. (20), where, ϕ_1, ϕ_2, ϕ_3 signifies present value, x_{k+1} signifies next chaotic value, X signifies controlling parameter and k signifies iteration index.

$$x_{k+1} = \mathrm{X}.x_k.(1 - x_k) \tag{20}$$

Eq. (21) displays the social communication, wherein, $\mathbb{Q}_{ij}$ signifies distance among i^{th} and j^{th} grasshopper, and it is evaluated as $\mathbb{Q}_{ij} = |\mathrm{X}_j - \mathrm{X}_i|$, and . $\hat{\mathbb{Q}}_{ij} = \frac{\mathrm{X}_j - \mathrm{X}_i}{\mathbb{Q}_{ij}}$ .indicated a unit vector, which displays the social communications.

$$S_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} r(\mathbb{Q}_{ij}) \hat{\mathbb{Q}}_{ij} \tag{21}$$

Eq. (22) illustrates the power of social force, wherein, q specifies the attraction degree and a define attraction on length scale.

$$r(g) = qe^{\frac{-g}{a}} - e^{-g} \tag{22}$$

Two grasshoppers are separated by a distance of $[1,4]$. Consequently, the factor Q is computed as shown in Eq. (23), wherein, q implies gravitational constant and $\hat{e}_q$ reveals a unity vector.

$$Q_i = -q\hat{e}_q \tag{23}$$

W is determined using Eq. (24), wherein, v signify steady drift and $\hat{e}_w$ indicate unity vectors in wind orientation.

$$w_i = v\hat{e}_w \tag{24}$$

On replacing S, w and Q in Eq. (6), it become Eq. (25), wherein, N indicates grasshopper counts.

$$A_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} r\left(\left|\mathrm{X}_j - \mathrm{X}_i\right|\right) \frac{\mathrm{X}_j - \mathrm{X}_i}{l_{ij}} - q\hat{e}_q + v\hat{e}_w \tag{25}$$

The final formulation of the theoretical framework is found in Eq. (26) where, υ_a and ℓ_a signify upper and lower limits. Additionally, $\hat{\delta}_a$ denotes the finest number in l^{th} dimension. Here, α acts as a constraint; as the iteration goes on, it improves the regional precision search while decreasing global exploration.

$$A_i^l = \alpha \left(\sum_{\substack{j=1 \\ j \neq i}}^{N} \alpha \frac{\upsilon_l - \ell_l}{2} r\left(\left|\mathrm{X}_j^l - \mathrm{X}_j^l\right|\right) \frac{\mathrm{X}_j - \mathrm{X}_i}{l_{ij}} \right) + \hat{\delta}_l \tag{26}$$

Therefore, in ChGOA, the value with the best goal is referred to as the targeted value. Furthermore, the more accurate target is selected as the search space's ideal value.

6. Results and Discussion

6.1 Simulation Set Up

Python was used for implementing the V-MIMO model for WSNs. The proposed ChGOA algorithm was compared over existing LA, PSO and DA algorithms. The analysis was done by considering energy consumption (in Joules) for varied iterations (0, 10, 20, 30, 40 and 50). The energy consumption was examined for 4 sets of nodes, (100, 200, 300 and 400).

6.2 Performance Analysis

An analysis on V-MIMO model based on energy consumption for 4 sets of nodes is shown in Fig. 2. LA, PSO and DA algorithms models are used for comparison. The findings demonstrate that when it comes to energy consumption in V-MIMO networks, the proposed ChGOA algorithm performs better than LA, PSO and DA algorithms. For 100 nodes, the suggested ChGOA algorithm acquired a less energy consumption of 5.86 Joules at 50th iteration, while the conventional LA, PSO and DA algorithms produced high energy consumption values of 6.19 Joules, 6 Joules and 6.1 Joules. For 200 nodes, the proposed ChGOA algorithm performs better with less energy consumption of 5.85 Joules at 50th iteration. In contrast, LA, PSO and DA algorithms consumed high energy. For 300 nodes and 400 nodes, the proposed ChGOA algorithm performs better with less energy consumption of 5.84 Joules at 50th iteration. Thus, the better energy efficiency of V-MIMO systems using proposed ChGOA algorithm is shown to be effective over existing LA, PSO and DA algorithms.

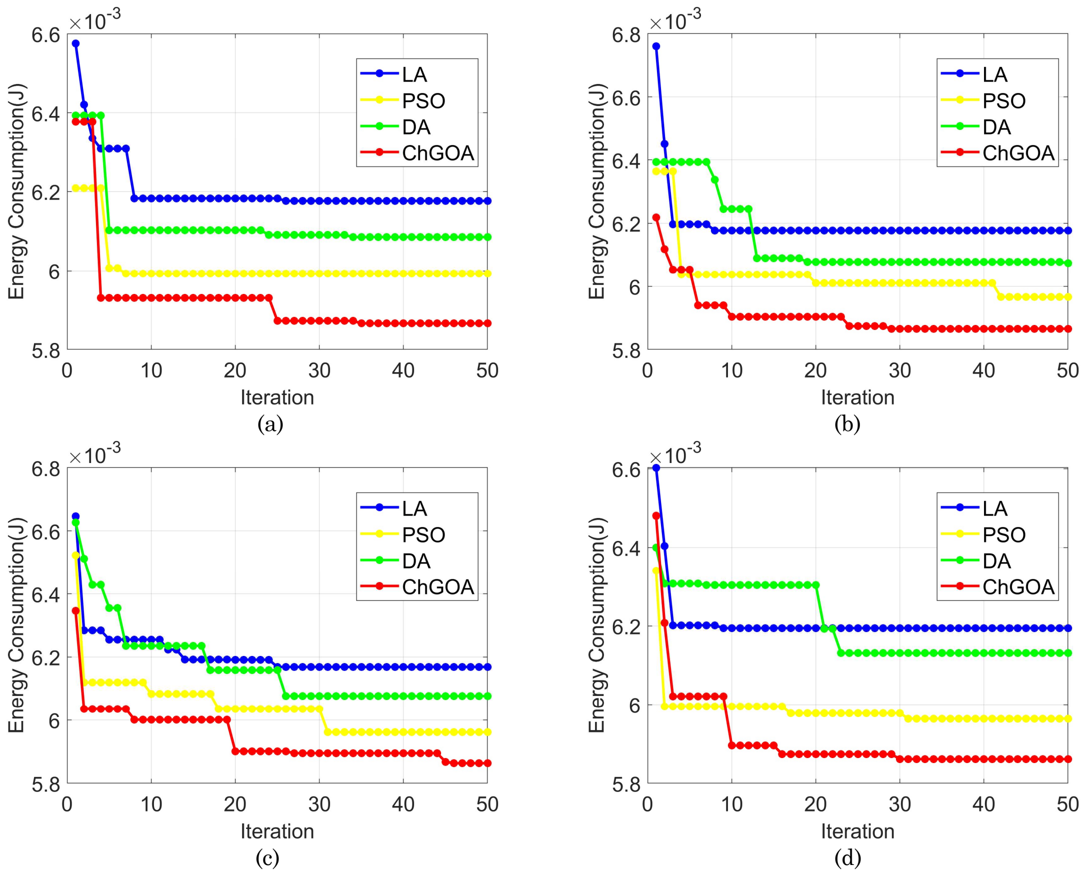

Fig. 2. *Analysis on energy consumption using proposed ChGOA algorithm for V-MIMO systems over existing algorithms for (a) 100 nodes (b) 200 nodes (c) 300 nodes (d) 400 nodes*

7. Conclusion

This work suggested a novel optimization model for solving the issues in V-MIMO systems that greatly improved communication performance. This work designed a "multihop virtual MIMO communication protocol by cross-layer model" for improving the QoS, energy and reliability in WSN. Here, the ETE latency and throughput of the protocol were modeled based on BER efficacy of links. ChGOA was a new optimization method used in this research to identify the enhanced BER performance of every link that satisfies the ETE QoS criteria with less energy consumption. From analysis, the suggested ChGOA algorithm for 100 nodes acquired a less energy consumption of 5.86 Joules. In future, delay issues can be considered for V-MIMO systems for WSNs.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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