IoT Technology Enabled Heuristic Model With Morlet Wavelet Neural Network for Numerical Treatment of Heterogeneous Mosquito Release Ecosystem

ZULQURNAIN SABIR1, KASHIF NISAR2, (Senior Member, IEEE), MUHAMMAD ASIF ZAHOOR RAJA3,4, MUHAMMAD REAZUL HAQUE5, (Member, IEEE), MUHAMMAD UMAR1, AG ASRI AG IBRAHIM2, (Member, IEEE), AND DAC-NHUONG LE6,7

1Department of Mathematics, Hazara University, Mansehra 21300, Pakistan
2Faculty of Computing and Informatics, Universiti Malaysia Sabah, Jalan UMS, Kota Kinabalu Sabah 88400, Malaysia
3Department of Electrical Engineering, COMSATS Institute of Information Technology, Attock Campus, Attock 45550, Pakistan
4Future Technology Research Center, National Yunlin University of Science and Technology, Yunlin 64002, Taiwan
5Faculty of Computing & Informatics, Multimedia University, Persiaran Multimedia, Cyberjaya, Selangor 63100, Malaysia
6Faculty Institute of Research and Development, Duy Tan University, Danang 550000, Vietnam
7School of Computer Science, Duy Tan University, Danang 550000, Vietnam
Corresponding author: Kashif Nisar (kashif@ums.edu.my)

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ABSTRACT The utmost advancements of artificial neural networks (ANNs), software-defined networks (SDNs) and internet of things (IoT) technologies find beneficial in different applications of the smart healthcare sector. Aiming at modern technology’s use in the future development of healthcare, this paper presents an advanced heuristic based on Morlet wavelet neural network for solving the mosquito release ecosystem in a heterogeneous atmosphere. The mosquito release ecosystem is dependent of six classes, eggs density, larvae density, pupae density, mosquitoes searching for hosts density, resting mosquito’s density and mosquitoes searching for ovipositional site density. An artificial neural network with the layer structure of Morlet wavelet (MWNN) kernel is presented using the global and local search optimization schemes of genetic algorithm (GA) and active-set algorithm (ASA), i.e., MWNN-GA-ASA. The accurateness, reliability and constancy of the proposed MWNN-GA-ASA is established through comparative examinations with Adams method based numerical results to solve the proposed nonlinear system with matching of order $10^{-6}$ to $10^{-9}$. The accuracy and convergence of the proposed MWNN-GA-ASA is certified using the statistical operators based on root mean square error (RMSE), Theil’s inequality coefficient (T.I.C) and mean absolute deviation (MAD) operators.

INDEX TERMS Mosquito release ecosystem, IoT, SDN, artificial neural networks, heuristic algorithm, Adams’s method.

I. INTRODUCTION

The Internet of Things (IoT) is an innovation embedded with software, sensors, actuators, electronics, and network connectivity through which data can be collected and exchanged over the Internet. Artificial neural network (ANN) [1]–[4], software-defined networks (SDN) [5]–[7], and internet of things (IoT) [8]–[15] technologies find useful in different applications from the smart healthcare sector [16]–[21] to the satellite [22]. The exponential utilization of the Internet of Things (IoT) is expanding and is of ongoing interest as it is broadly utilized in numerous applications and devices like remote sensors, clinical devices, delicate home sensors, and other related IoT devices as shown in Fig. 1. The Internet of Things [23], [24] is an illustration of a new network that utilizes detecting units to gather ecological data. It is on a suitable server on the internet for decision-making utilizing ZigBee [25], WiMAX [26]–[29], and then some.
Software Defined Networking (SDN) presents centralized programmability [10], [30]–[35] that permits general control of the network. Thus, utilizing SDN is an undeniable answer for improving the presentation of IoT networking and beating existing complexity. IoT can implement using software-defined networking [36]–[43], named data networking (NDN) [44]–[46] and cloud computing network [47] with future applications such as voice over IP (VoIP) [48]–[51] fiber optic [52]–[54], worldwide interoperability for microwave access (WiMAX) [55]–[57], and artificial intelligence (AI) and machine learning (ML) [58].

The embedded sensing devices are employed in IoT-based systems to efficiently and economically gauge real-time environmental parameters [59], [60], [65]. A sensor is a device that can sense the change in its surrounding environment [66], [67]. The Internet of Things can fabricate and advance numerous areas of action we can discover the IoT eHealth Ecosystem [68]–[70], the IoT Intelligent Transportation Ecosystem [71], the IoT Smart Home Ecosystem [72]–[74], and mosquito release Ecosystem etc as shown graphically in Fig. 2.

However, he recognized that the public health community does not place a high priority on this issue. Ross stated that the density of mosquitoes depends on four variables in any region, which contain reproduction rates, mortality rates, immigration and emigration rates. Manga et al. [78] accessible that the spatial disparity in the spreading of possessions applied by mosquitoes affects their rate of dispersion and reproduction. This contributes to the variation in densities, human knowledge of vectors and the capacity to control disease communication [79], [80]. The characteristics of the resource on transport can be incredible. For example, even the presence of non-productive larval habitats can impact bite densities [81]. However, experimental investigations of mosquito dispersal are stimulating [82], [83]. Mathematical systems play a dynamic role in understanding and providing the phenomena’s solutions that are stimulating for the assortment of fields, however, insufficient systems have integrated dispersal or heterogeneity wide-ranging characteristic of a close population vector [84]–[86]. The researchers split the mature phase of the mosquitoes into various phases [87]. To discover the effects of dispersion and heterogeneity, a system can integrate mosquito life-cycle structures, spatial heterogeneity based on mosquito properties, distribution and feeding cycle. Space systems

![FIGURE 1. IoT applications.](image1)

![FIGURE 2. Ecosystem of IoT and mosquito release.](image2)
have usually implemented the diffusion scheme which reproduces space as a constant variable. Despite the reality of dissemination models that take heterogeneity into account, it is difficult to incorporate the many factors that disturb the movement [88], [89]. For example, in areas where possessions are located in discrete patches, mosquito dispersal is more appropriately modelled using a metapopulational technique, the population is allocated into isolated spots. At each location, the population is subdivided into subgroups, resulting in a set of subgroups corresponding to different states and multiple compartmentalized systems. There are various diffusion systems that incorporate the heterogeneity present in the atmosphere on the release of disease vectors [90], [91]. Nevertheless, each has understood the aquatic reality of disease vectors. In the atmosphere, it is difficult to incorporate the many factors that disturb the movement [90], [91]. The mathematical form of these classes based on the nonlinear mosquito’s dispersal system (NMDS) in the heterogeneous environment is given as [92]:

\[
E'(x) = b \rho_A A(x) - \rho_E E(x) - \mu_E E(x), \quad E(0) = i_1, \\
L'(x) = \rho_L L(x) L(x) - \rho_P P(x) - \mu_P P(x), \\
A_0'(x) = \rho_A A_0(x) + \rho_P P(x) - (\mu_A + \mu_P) A_0(x), \\
A_r'(x) = \rho_A A_r(x) - (\mu_A + \rho_P) A_r(x), \\
A_l'(x) = \rho_A A_l(x) - (\mu_A + \rho_A) A_l(x), \\
A_i'(x) = \rho_A A_i(x) - (\mu_A + \rho_A) A_i(x), \\
A_p'(x) = \rho_A A_p(x) - (\mu_A + \rho_A) A_p(x), \\
L(0) = i_2, \\
P(0) = i_3, \\
A_0(0) = i_4, \\
A_r(0) = i_5, \\
A_l(0) = i_6, \\
A_p(0) = i_7.
\]

The variables defined for each class of the NMDS in the heterogeneous environment (1) and the appropriate selections and ranges are given in Table 1 as reported in [92].

The motive of this work is to solve the above NMDS in the heterogeneous environment using the layer structure of Morlet wavelet (MWNN) kernel together with global and local search optimization schemes of genetic algorithm (GA) and active-set algorithm (ASA), i.e., MWNN-GA-ASA. Numerical stochastic approaches have been widely applied to solve a wide variety of applications, like delay singular functional model [93], [94], COVID-19 dynamical model [95], [96], singular fractional models [97], [98], prey-predator system [99], singular nonlinear higher order models [100]–[102], HIV infection system [103], multi-singular differential systems [104], [105] and dengue fever nonlinear system [106]. Based on these renowned applications, the authors are motivated to solve the NMDS with the help of the MWNN-GA-ASA. Some main factors of the MWNN-GA-ASA are briefly discussed as:

- The proposed MWNNs are designed and presented using GA-ASA optimization procedures to solve the nonlinear mosquito’s dispersal system in a heterogeneous atmosphere.
- Steady, constant and trustworthy outcomes for nonlinear mosquito’s dispersal system authenticate the value of the proposed MWNN-GA-ASA.
- The values of the absolute deviation from reference are found in the good agreement that further represents the dependability of the MWNN-GA-ASA.
- The MWNN-GA-ASA performance is certified using different statistics via root mean square error (RMSE), Theil’s inequality coefficient (T.I.C) and mean absolute deviation (MAD) observations to solve the NMDS in a heterogeneous atmosphere for 30 independent trials.
- The proposed MWNN-GA-ASA is smoothly implemented to solve the nonlinear mosquito’s dispersal system in a heterogeneous atmosphere with understandable processes, robust effective and stable.

The rest of the paper is organized as: Sect 2 presents the proposed MWNN-GA-ASA and statistical procedures. Sect 3 proves the simulation of the numerical outcomes. Sect 4 indicates the final explanations and future research reports.

### II. METHODOLOGY

To implement the proposed MWNN-GA-ASA, it is possible to use different IoT sensors and hardware components to detect six classes of mosquito release Ecosystem as shown in Fig. 3.

| Table 1: Variables defined for each class of the NMDS in the heterogeneous environment (1). |
|---|---|---|---|
| Index | Description | Chosen standards | Range |
| $\rho_i$ | Mature larvae rate into pupae | 0.12 | 0.08 to 0.17 |
| $h$ | Female eggs located per ovipositional | 60 | 50 to 300 |
| $\rho_{Ap}$ | Ovipositional rate | 3.2 | 3 to 4 |
| $\mu_{li}$ | Density-independent based larvae mortality rate (MR) | 0.4 | 0.30 to 0.58 |
| $\mu_k$ | MR of eggs | 0.5 | 0.32 to 0.8 |
| $\rho_{Pr}$ | Eggs rate producing into larvae | 0.4 | 0.33 to 1 |
| $\mu_{l2}$ | Density-dependent rate based on larval mortality | 0.02 | 0 to 1 |
| $\rho_{Ah}$ | Host searching mosquitoes rate for the latent state | 0.46 | 0.322 to 0.6 |
| $\mu_n$ | Pupae MR | 0.4 | 0.22 to 0.52 |
| $\rho_p$ | Pupae develop rate into mature | 0.7 | 0.33 to 1 |
| $\mu_{Ah}$ | Mosquitoes MR for hosts penetrating | 0.18 | 0.12 to 0.23 |
| $\mu_A$ | Mosquitoes MR pointed for ovipositional places | 0.41 | 0.41 to 0.56 |
| $\rho_A$ | Resting mosquitoes MR | 0.0043 | 0.03 to 0.01 |
| $\rho_A$ | Resting MR to enter ovipositional places | 0.5 | 0.30 to 0.56 |
The planned construction of the ANN-GA-ASA to solve NMDS in a heterogeneous atmosphere is designed in two phases:

**Step 1:** Introduce a merit function by operating the system of MWNN.

**Step 2:** Necessary explanations are provided to optimize the merit function to solve NMDS in a heterogeneous atmosphere (1) by the hybrid computing GA-ASA. The proposed MWNN-GA-ASA is accessible as demonstrated in Fig. 4.

### A. MODELING: MWNN-GA-ASA

The mathematical relations in case of system (1) are provided with MWNN in the proposed results form $\hat{E}(x)$, $\hat{L}(x)$, $\hat{P}(x)$, $\hat{A}_h(x)$, $\hat{A}_r(x)$ and $\hat{A}_0(x)$ together with the $n^{th}$ derivatives are given as (2), shown at the bottom of the next page, where the unknown weight vector ($W$) is shown as:

$$W = [W_E, W_L, W_P, W_{A_h}, W_{A_r}, W_{A_0}]$$ for $W_E = [U_E, V_E, S_E]$, $W_L = [U_L, V_L, S_L]$, $W_P = [U_P, V_P, S_P]$, $W_{A_h} = [U_{A_h}, V_{A_h}, S_{A_h}]$, $W_{A_r} = [U_{A_r}, V_{A_r}, S_{A_r}]$ and $W_{A_0} = [U_{A_0}, V_{A_0}, S_{A_0}]$.

where

- $U_{E} = [U_{E,1}, U_{E,2}, U_{E,3}, \ldots, U_{E,m}]$,
- $U_{L} = [U_{L,1}, U_{L,2}, U_{L,3}, \ldots, U_{L,m}]$,
- $U_{P} = [U_{P,1}, U_{P,2}, U_{P,3}, \ldots, U_{P,m}]$,
- $U_{A_h} = [U_{A_h,1}, U_{A_h,2}, \ldots, U_{A_h,m}]$,
- $U_{A_r} = [U_{A_r,1}, U_{A_r,2}, \ldots, U_{A_r,m}]$,
- $U_{A_0} = [U_{A_0,1}, U_{A_0,2}, \ldots, U_{A_0,m}]$.  

![FIGURE 3. MWNN-GA-ASA, SDN, and IoT infrastructure.](image-url)  

![FIGURE 4. Proposed structure of the present MWNN-GA-ASM for solving the nonlinear Heterogeneous Mosquito Release Ecosystem model.](image-url)
\[ V_E = [V_{E,1}, V_{E,2}, V_{E,3}, \ldots, V_{E,m}], \]
\[ V_L = [V_{L,1}, V_{L,2}, V_{L,3}, \ldots, V_{L,m}], \]
\[ V_P = [V_{P,1}, V_{P,2}, V_{P,3}, \ldots, V_{P,m}], \]
\[ V_{Ah} = [V_{Ah,1}, V_{Ah,2}, \ldots, V_{Ah,m}], \]
\[ V_{A} = [V_{A,1}, V_{A,2}, \ldots, V_{A,m}], \]
\[ V_{A0} = [V_{A0,1}, V_{A0,2}, \ldots, V_{A0,m}], \]
\[ S_E = [S_{E,1}, S_{E,2}, S_{E,3}, \ldots, S_{E,m}], \]
\[ S_L = [S_{L,1}, S_{L,2}, S_{L,3}, \ldots, S_{L,m}], \]
\[ S_P = [S_{P,1}, S_{P,2}, S_{P,3}, \ldots, S_{P,m}], \]
\[ S_{Ah} = [S_{Ah,1}, S_{Ah,2}, \ldots, S_{Ah,m}], \]
\[ S_{A} = [S_{A,1}, S_{A,2}, \ldots, S_{A,m}], \]
\[ S_{A0} = [S_{A0,1}, S_{A0,2}, \ldots, S_{A0,m}], \]

The Morlet wavelet neural network \( f(x) = \cos(1.75x)e^{(-0.5x^2)} \) [107]. The updated form of the system (2) is given as (3), shown at the bottom of the page.

Using the network (3), a merit function \( E \) is written as:

\[ E = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7. \tag{4} \]
\[ E_1 = \frac{1}{N} \sum_{j=1}^{N} \left( \hat{E}_j - \rho_E \hat{E}_j + \rho_E \hat{E}_j - b \rho_{A0} (A_{0})_j \right)^2. \tag{5} \]
### TABLE 2. Pseudocode based on MWNN-GA-ASA for solving the NDMS in a heterogeneous atmosphere.

**Start of GA**

**Inputs:** The individual represents the identical elements as:

\[ W = [W_p, W_l, W_p, W_a, W_{sa}, W_{sh}], \]

for \( W_p = [U_p, U_p, S_p], W_l = [U_l, U_l, S_l], \)

\( W_{sh} = [U_{sh}, U_{sh}, S_{sh}], W_{sa} = [U_{sa}, U_{sa}, S_{sa}], \)

and \( W_{sh} = [U_{sh}, U_{sh}, S_{sh}] \) as given in system (3).

**Population:** The population is defined using the chromosomes number as:

\[ P = [W_{sa}, W_{sa}, ..., W_{sa}], \]

for \( j \)th component \( W_j = [W_{sa}, W_{sa}, W_{sa}, W_{sa}, W_{sa}, W_{sa}] \) with

**Output:** The global best decision variables \( W_{sa} \)

**Initialization:** Produce \( W \) and \( P \) with the initials of pseudo random numbers.

**Fit formulations:** Evaluate the FIT E as shown in system (4) and along with systems (5-11).

**Termination process:** Stop, if any of the criteria meets

- \[ \text{FIT} = E \to 10^{-21}, \text{Generations} \to 30, \]
- \[ \text{Tolerances:} \text{[ToCon} = 10^{-20} \text{ & TolFun} = 10^{-21}], \]
- \[ \text{GenLimit} \to 120, \text{Pop size} = 210, \text{Other: default} \]

Go to storage

**Ranking:** For each \( W \) of \( P \) shows the obtained FIT \( E \).

**Reproduction:** This process is completed using the four criteria of (Selection), (Mutations), (Crossover) & (Elitism).

Go FIT evaluation.

**Storage:** \( W_{sa} \), FIT, generations, time and function counts for the GA.

**GA process End**

**ASA Start**

**Inputs:** Start point \( W_{sa} \)

**Output:** The best GA-ASA are signified as \( W_{sa} \)

**Initialize:** Regulate the iterations, bounded constraints and other limits in (optimset).

**Terminate:** ASA stops, if

- Iterations \( = 500 \), \( \text{FIT} = 10^{-19} \), \( \text{TolFun} = 10^{-22} \),
- \( \text{ToCon} = 10^{-20} \), \( \text{ToFun} = 10^{-20} \),

\( \text{MaxFunVal} \) = 268000.

While (Terminate)

**Fit Evaluations:** Calculate \( E \) of each \( W \) of \( P \)

by taking systems (4) to (11).

**Adjustments:** Regulate “fmincon” with ‘ASA’ to adjust \( \text{‘W’} \) and the FIT values by taking systems (4) to (11).

**Store:** Accumulate FIT, \( W_{sa} \), time, iterations and weight vector.

**ASA process End**

**Data Generations**

Repeat 30 times ASA process to find an enlarge data-set using the optimization MWNN variables to solve the NDMS in a heterogeneous atmosphere.

**FIGURE 5.** Decision variables of MWNN-GA-ASA for 15 number of variables for solving NDMS in a heterogeneous atmosphere.

\[ E_4 = \frac{1}{N} \sum_{j=1}^{N} \left( \hat{A}_{h} - \left( \mu_{Ah} + \rho_{A} \hat{A}_{h} \right) - \rho_{p} \hat{P}_j - \rho_{A} \hat{A}_{0} \right)^2, \]

\[ E_5 = \frac{1}{N} \sum_{j=1}^{N} \left( \hat{A}_{r} + \mu_{Ar} \hat{A}_{r} - \rho_{A} \hat{A}_{0} \right)^2, \]

\[ E_6 = \frac{1}{N} \sum_{j=1}^{N} \left( \hat{A}_{0} - \rho_{A} \hat{A}_{r} \hat{A}_{r} + \mu_{A0} + \rho_{A0} \hat{A}_{0} \right)^2, \]

\[ E_7 = \frac{1}{6} \left( \left( \hat{E}_0 - i_1 \right)^2 + \left( \hat{L}_0 - i_2 \right)^2 + \left( \hat{P}_0 - i_3 \right)^2 \right) \]

\[ + \left( \hat{A}_{h0} - i_4 \right)^2 + \left( \hat{A}_{r} - i_5 \right)^2 + \left( \hat{A}_{0} - i_6 \right)^2 \],

where \( Nh = 1, x_j = jh, \hat{E}_j = \hat{E} \left( x_j \right), \hat{L}_j = \hat{L} \left( x_j \right), \hat{P}_j = \hat{P} \left( x_j \right), \hat{A}_{h} \left( x_j \right), \hat{A}_{r} \left( x_j \right), \hat{A}_{0} \left( x_j \right) \) and \( \hat{A}_{0} \left( x_j \right) \).

The approximate solutions of eggs density (\( E \)), larve density (\( L \)), pupae density (\( P \)), mosquitoes searching based hosts density (\( A_h \)), density of resting mosquitoes (\( A_r \)) and mosquitoes searching based on ovipositional site density (\( A_0 \)), respectively signified as \( \hat{E}_m, \hat{L}_m, \hat{P}_m, \hat{A}_{hm}, \hat{A}_{rm} \) and \( \hat{A}_{0m} \). Accordingly, \( E_1, E_2, E_3, E_4, E_5 \) and \( E_6 \) are the merit functions.
FIGURE 6. AE values based on best and mean solutions for each category of the heterogeneous mosquito release ecosystem.

associated with NDMS in a heterogeneous atmosphere and $E_7$ represents the initial conditions of the system (1).

B. OPTIMIZATION PROCESS: GA-ASA

In this section, a brief explanation of GA-ASA combination to optimize the merit function as shown in system (4) is provided for solving the NDMS in a heterogeneous atmosphere.

Genetic algorithm is an efficient global optimization tool introduced by Holland in the last century [108]. GA is mathematical genetic procedure of humans, which is applied broadly using the optimization of decision variables in various domains. The process of GA is implemented in many applications include expenditure system of the hospitals [109], brain tumor models [110], feature collection in cancer systems [111], bismuth-borate glasses optimizations [112], prediction based differential systems [113], air blast systems of prediction [114], monorail vehicle networks [115], prediction of liver diseases [115], optimization through cloud services [117] and periodic boundary values networks [118].

Active-set approach is known as a local search process, rapidly optimize to solve the constrained/unconstrained systems generally. ASA is used to execute various stiff, complex and nonlinear systems. Recently, ASA is executed to pricing the American option [119], the actual control through optimization [120], pressure-dependent system of water distribution [121], embedded model predictive control [122], overcurrent relays in microgram optimization [123] and frictional contact models based on electrodynamic [124].

The pseudocode detail of MWNN-GA-ASA based procedures is given in Table 2, while the procedure construction is shown in Figure 4.

C. PERFORMANCE MEASURES

The performance operators to solve the NDMS in a heterogeneous atmosphere are presented using the root mean square error (RMSE) operator, mean absolute deviation (MAD) operator and Theil’s inequality coefficient (TIC) operator, mathematically given as (12) and (13), shown at the bottom of the next page.
III. RESULTS AND DISCUSSION

In this section, the considerations of the results to solve the NDMS in a heterogeneous atmosphere given in system (1) are described. The relative investigations with the Adams methods precise the exactness of the proposed MWNN-GA-ASA. Moreover, statistical outcomes are plotted to authenticate the accuracy of the proposed MWNN-GA-ASA.

A. PRESENTATIONS OF NDMS IN A HETEROGENEOUS ATMOSPHERE

The efficient form of NDMS in a heterogeneous atmosphere given in system (1) using the suitable values is given as:

\[
\begin{align*}
& E'(x) = 192A_0(x) - 0.9E(x), & & E(0) = 0.00001, \\
& L'(x) = 0.4E(x) - (0.02L(x)) + 0.52L(x), & & L(0) = 0.00001, \\
& P'(x) = 0.12L(x) - 1.11P(x), & & P(0) = 0.0003, \\
& A_0'(x) = 0.7P(x) + 3.2A_0(x), & & A_0(0) = 0.0001, \\
& A_0'(x) = 0.46A_0(x) - 0.5043A_r(x), & & A_r(0) = 0.00001, \\
& A_0'(x) = 0.5A_r(x) - 3.61A_0(x), & & A_0(0) = 0.0003.
\end{align*}
\]

(14)

A merit function of the model (14) is written as:

\[
E = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{\hat{E_i} - 0.9\hat{E_i} - 192(\hat{A}_0)}{100000} \right)^2 + \frac{1}{6} \left( \frac{\hat{L_i} - 0.4\hat{E_i} + (0.02\hat{L_i} + 0.52)\hat{L_i}}{100000} \right)^2 + \frac{1}{6} \left( \frac{\hat{P_i} + 1.11\hat{P_i} - 0.12\hat{L_i}}{100000} \right)^2 + \left( \frac{\hat{A}_h - 0.7\hat{P}_i - 3.2(\hat{A}_0) + 0.64(\hat{A}_h)}{100000} \right)^2 + \left( \frac{\hat{A}_r + 0.5043(\hat{A}_r) - 0.46(\hat{A}_h)}{100000} \right)^2 + \left( \frac{\hat{A}_0 + 3.61(\hat{A}_0) - 0.5(\hat{A}_r)}{100000} \right)^2.
\]

(15)

The optimization of the NDMS in a heterogeneous atmosphere given in system (1) is accomplished by the hybrid based computing structure GA-ASA for 30 trials to achieve the MWNNs parameter with 15 variables of the system. The best weight values of the MWNN through GA-ASA are
TABLE 3. Statistics performances for $E(x)$ and $L(x)$. 

| Index | $x$ | Statistical indices |
|-------|----|----------------------|
|       | Min | Max | Med | S.I.R |
| $E(x)$ | 0.576E-06 | 3.497E-05 | 1.000E-05 | 5.665E-10 |
| 0.1 | 4.605E-03 | 4.650E-03 | 4.626E-03 | 1.293E-11 |
| 0.2 | 7.451E-03 | 7.479E-03 | 7.457E-03 | 3.748E-14 |
| 0.3 | 9.083E-03 | 9.110E-03 | 9.087E-03 | 8.674E-19 |
| 0.4 | 9.913E-03 | 9.946E-03 | 9.918E-03 | 8.674E-18 |
| 0.5 | 1.020E-02 | 1.026E-02 | 1.022E-02 | 8.674E-19 |
| 0.6 | 1.028E-02 | 1.028E-02 | 1.028E-02 | 8.674E-19 |
| 0.7 | 9.971E-03 | 9.946E-03 | 9.974E-03 | 8.674E-19 |
| 0.8 | 9.632E-03 | 9.699E-03 | 9.653E-03 | 8.674E-19 |
| 0.9 | 9.235E-03 | 9.301E-03 | 9.241E-03 | 8.674E-19 |
| 1 | 8.765E-03 | 8.922E-03 | 8.831E-03 | 5.258E-09 |
| $L(x)$ | 0.7 | 7.098E-07 | 8.184E-05 | 1.009E-05 | 1.099E-09 |
| 0.1 | 9.873E-05 | 1.284E-04 | 1.076E-04 | 6.802E-12 |
| 0.2 | 3.433E-04 | 3.573E-04 | 3.428E-04 | 6.720E-14 |
| 0.3 | 6.432E-04 | 6.626E-04 | 6.513E-04 | 4.224E-15 |
| 0.4 | 9.832E-04 | 1.002E-03 | 9.909E-04 | 2.929E-15 |
| 0.5 | 1.371E-03 | 1.347E-03 | 1.335E-03 | 2.392E-15 |
| 0.6 | 1.395E-03 | 1.398E-03 | 1.366E-03 | 3.936E-17 |
| 0.7 | 1.968E-03 | 1.992E-03 | 1.973E-03 | 3.996E-16 |
| 0.8 | 2.251E-03 | 2.278E-03 | 2.257E-03 | 2.392E-13 |
| 0.9 | 2.504E-03 | 2.533E-03 | 2.511E-03 | 8.778E-11 |
| 1 | 2.662E-03 | 2.764E-03 | 2.736E-03 | 3.360E-10 |

These weights are used in set of equation (3) to derive the approximate solution. Accordingly, the mathematical representations of the approximate solutions of MWNNGASA are given as (16)–(21), shown at the bottom of the page.

The trained weight vectors for 15 variables based MWNNGASA system are plotted in subfigures 5(i), 5(ii), 5(iii), 5(iv), 5(v) and 6(vi) for the classes $E(x)$, $L(x)$, $P(x)$, $A_P(x)$, $A_r(x)$ and $A_0(x)$, respectively. The equations (16-21) are used to show the outcomes of the NDMS in a heterogeneous atmosphere using the MWNNGASA and plot of results are given in Figures 6-10 for 15 weights or decision variable in the networks.

![3-D bar plots in Figure 5.](image-url)

The graphs of AE are shown in Figure 3. The classes $E(x)$, $L(x)$ and $P(x)$ plots are given in the subfigures 6(a), while, the plots of the rest of the classes $A_P(x)$, $A_r(x)$ and $A_0(x)$ of the NDMS in a heterogeneous atmosphere are given in subfigures 6(b). The best AE shown in subfigure 6(a) for the classes $E(x)$, $L(x)$ and $P(x)$ lie around $10^{-02}$ to $10^{-03}$, $10^{-03}$ to $10^{-06}$ and $10^{-04}$ to $10^{-05}$, respectively. While, the best AE shown in subfigure 6(b) for the classes $A_P(x)$, $A_r(x)$ and $A_0(x)$...
lie about $10^{-03}$ to $10^{-05}$, $10^{-04}$ to $10^{-06}$ and $10^{-03}$ to $10^{-05}$, respectively.

The performance of the MWNN-GA-ASA is observed through the statistical based TIC and RMSE operators using the histograms and boxplots provided in Figures 7-10. The performance of TIC operator for the classes $E(x)$, $L(x)$ and $P(x)$ is plotted in figure 7, while the rest of the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ of the NDMS in a heterogeneous atmosphere are illustrated in figure 8.

The best RMSE performances shown in figure 9 for the classes $E(x)$, $L(x)$ and $P(x)$ lie around $10^{-02}$ to $10^{-03}$, $10^{-02}$ to $10^{-04}$ and $10^{-03}$ to $10^{-04}$, respectively. While, the best RMSE performances as presented in figure 10 for the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ lie about $10^{-03}$ to $10^{-04}$, $10^{-03}$ to $10^{-04}$ and $10^{-04}$ to $10^{-05}$, respectively. These accurate results, i.e., values in good agreement with the desire level.
for the near to perfect modelling, on different performance operator calculated for 35 trials of MWNN-GA-ASA show that most of the executions achieved higher level of accuracy for TIC and RMSE operators, which further prove the worth of the designed MWNN-GA-ASA for solving the system model.

Measure of central tendency and variations are exploited for better analysis of the precision and accuracy of the numerical outcome of MWNN-GA-ASA. The statistical results/observations for minimum (MIN), maximum (MAX), median (MED) and semi interquartile range (S.I.R) using the proposed MWNN-GA-ASA for solving the NDMS in a heterogeneous atmosphere are calculated. The statistical observation in terms of MIN, MAX, MED and S.I.R for $E(x)$ and $L(x)$ are provided in Table 3, while these indices for $P(x)$ and $A_r(x)$ are provided in Tables 4 and 5, respectively.

### TABLE 4. Statistics performances for $P(x)$ and $A_r(x)$.

| Index | $x$ | Statistical indices |
|-------|-----|---------------------|
|       | Min | Max | Med | S.I.R |
| $P(x)$ | 0 | 6.32E-05 | 3.49E-04 | 3.00E-04 | 1.24E-07 |
| | 0.1 | 1.67E-04 | 2.69E-04 | 2.69E-04 | 5.64E-10 |
| | 0.2 | 1.49E-04 | 2.47E-04 | 2.43E-04 | 9.54E-11 |
| | 0.3 | 1.38E-04 | 2.26E-04 | 2.23E-04 | 3.03E-11 |
| | 0.4 | 1.32E-04 | 2.10E-04 | 2.10E-04 | 8.03E-14 |
| | 0.5 | 1.31E-04 | 2.01E-04 | 2.01E-04 | 2.66E-15 |
| | 0.6 | 1.35E-04 | 1.97E-04 | 1.97E-04 | 1.89E-13 |
| | 0.7 | 1.43E-04 | 1.97E-04 | 1.97E-04 | 2.34E-12 |
| | 0.8 | 1.55E-04 | 2.02E-04 | 2.02E-04 | 2.15E-12 |
| | 0.9 | 1.69E-04 | 2.27E-04 | 2.07E-04 | 1.18E-11 |
| | 1   | 1.49E-04 | 2.99E-04 | 2.15E-04 | 1.79E-10 |

### TABLE 5. Statistics performances for $A_r(x)$ and $A_0(x)$.

| Index | $x$ | Statistical indices |
|-------|-----|---------------------|
|       | Min | Max | Med | S.I.R |
| $A_r(x)$ | 0 | 8.28E-06 | 1.85E-04 | 1.00E-04 | 6.76E-08 |
| | 0.1 | 1.81E-04 | 3.64E-04 | 1.91E-04 | 6.63E-10 |
| | 0.2 | 2.56E-04 | 4.13E-04 | 2.51E-04 | 1.16E-15 |
| | 0.3 | 2.88E-04 | 4.42E-04 | 2.89E-04 | 1.11E-12 |
| | 0.4 | 3.10E-04 | 4.56E-04 | 3.13E-04 | 2.78E-15 |
| | 0.5 | 3.20E-04 | 4.61E-04 | 3.27E-04 | 2.71E-20 |
| | 0.6 | 3.21E-04 | 4.60E-04 | 3.35E-04 | 1.02E-16 |
| | 0.7 | 3.13E-04 | 4.56E-04 | 3.39E-04 | 4.35E-17 |
| | 0.8 | 2.97E-04 | 4.49E-04 | 3.40E-04 | 2.43E-15 |
| | 0.9 | 2.79E-04 | 4.42E-04 | 3.40E-04 | 9.12E-11 |
| | 1   | 2.63E-04 | 4.39E-04 | 3.40E-04 | 4.85E-11 |

Convergence performances through RMSE for $A_h(x)$, $A_r(x)$ and $A_0(x)$ classes histograms and boxplots for 15 variables.
and $A_r(x)$ are shown in Table 4 and the other two classes for $A_r(x)$ and $A_0(x)$ these metrics are tabulated in Table 5. The MIN and MAX values shows the best and worst results and a relatively small variation exist in these parameter which show the consist accuracy of MWNN-GA-ASA. The S.I.R is the difference of third and first quartiles and near to zero value of this metric is consistently achieved by MWNN-GA-ASA. The statistical performances of central tendency, i.e., mean and MED values, are found in reasonably accurate ranges for each class of the NDMS in a heterogeneous atmosphere consistently.

IV. CONCLUSION

The design of IoT technology enabled Morlet wavelet neural network is presented viably and effectively for solving a class of nonlinear mosquito’s dispersal system in the heterogeneous atmosphere. A merit function is considered in accordance with the representation of differential system of mosquito’s dispersal system and corresponding initial conditions with MWNNs. The optimization of merit function to solve the nonlinear biological system is performed by using the global and local search techniques, GA-ASA. One can observe that the proposed results through MWNN-GA-ASA are overlapped with the Adams results that shows the accurateness of the scheme for solving the nonlinear mosquito’s dispersal system. The comparison through AE is also observed in good ranges for each class of the mosquito’s dispersal system. The mosquito’s dispersal system is proficiently measured by the numerical MWNN-GA-ASA along with the layer construction neural networks using 15 numbers of variables. The stability of the solver MWNN-GA-ASA is examined with a reasonable level of accuracy for solving each class of the nonlinear mosquito’s dispersal system in the heterogeneous atmosphere. Statistical explanations for 35 executions of MWNN-GA-ASA using the MIN, MAX, MED and S.I.R operators show the precision of the designed MWNN-GA-ASA. The MIN and MAX operators show the best and worst performances of the MWNN-GA-ASA. Moreover, the TIC and RMSE operators authenticate the worth and values of the proposed MWNN-GA-ASA for solving the nonlinear mosquito’s dispersal system in the heterogeneous atmosphere.

In future, the accessible MWNN-GA-ASA is promoted to solve the singular higher order, fractional models, smart cities model, and fluid dynamics systems [20], [99], [125]–[140].

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KASHIF NISAR
(Senior Member, IEEE) received the Ph.D. degree from Auckland University of Technology, Auckland, New Zealand. He is currently pursuing the Ph.D. degree with Universiti Teknologi PETRONAS, Malaysia with a major in computer networks and information technology. In 2014, he worked as a Guest Professor with Fernuniversität Hagen, Germany, fully funded by DAAD. He holds a number of visiting professor positions at well-known universities, such as McMaster University, Hamilton, ON, Canada, University of Auckland, New Zealand, Waseda University, Tokyo, Japan, and Hanyang University, Seoul, South Korea. He is also working as an Associate Professor with the Faculty of Computing and Informatics, University Malaysia, Sabah, Kota Kinabalu, Malaysia. He is also working on machine and deep learning for IoT security and API security and he is also working closely with Industry. He has published over more than 200 research papers in many high impact journals and well reputed international conference proceedings in the area of computer science and computer network. His research interests include future internet (FI), information centric networks (ICN), content-centric networking (CCN), named data networking (NDN), software-defined networking (SDN), the Internet of Things (IoT), internet of everything (IoE), industrial Internet of Things (IoT), fourth industrial revolution (IR 4.0), quantum network, information security and privacy, network/cyber security, digital forensics, applied cryptography, vehicular clouds, cloud and edge computing, and blockchain. He is a member of many professional organizations from academia and industry, including the Founding Vice-Chair, IEEE Sabah Subsection, Malaysia, a member of ACM, ACM-SIGMOBILE, ISOC, Engineers Australia, IAENG, and Park Lab. and a fellow of APAN and ITU. He is serving as an editorial board member for various high impact factor journals, including Computer Communications (Elsevier), an International journal Kybernetes (Emerald U.K.), and an International journal of Wireless Personal Communications (Springer). Additionally, he is serving as a reviewer for most of the IEEE TRANSACTIONS, IEEE ACCESS, IEEE INTERNET INTELLIGENCE, INTERNET TECHNOLOGY LETTERS, Journals (Wiley, Springer, and Elsevier). Furthermore, he is serving as a Steering Committee Member, the PC Chair, the Track Chair, a Technical Program Committee (TPC) Member of over more than 100 international conferences as IEEE GLOBECOM, IEEE R10 TENCOM, IEEE TrustCom, IEEE ICC, IEEE VTC, IEEE VNC, IEEE ICCVSE, and ICCCN. He has delivered keynote talks at international conferences and universities. He is also serving as a Guest Editor for more than a dozen special issues in journals and magazines, such as IEEE, Elsevier, Springer and Wiley. He would contribute to your mission by bringing credibility to high quality of modern creative technologies research. He has extensive experience in teaching, research, and industry at key positions. He also conduct interdisciplinary research in academic and industry, integrating digital technologies in teaching at undergraduate and postgraduate levels, demonstrate his ability to convey complex information and thrive on providing a classroom experience that facilitates a high level of engagement with students of all levels. He will develop an active research program in creative technologies, and supervise postgraduate research students. He also bring international grants, local grants, collaboration with universities and industries. He has experienced and an ability to work well with students and staffs from differing academic and cultural backgrounds and at all levels.

KASHIF NISAR
(Senior Member, IEEE) received the M.Sc. degree in mathematics from Punjab University, Lahore, Pakistan, and the M.Phil. degree in mathematics from Preston University Kohat, Islamabad Campus, Pakistan. He is currently pursuing the Ph.D. degree in mathematics from Hazara University, Mansehra, Pakistan. He has published more than 50 articles in prestigious international WoS journals with Impact Factors. His research interests include mathematical modeling, unsupervised neural networks, supervised neural networks, artificial intelligence, and implementation of computational techniques based on traditional and heuristic methodology. He is famous to solve singular models, functional models, fractional models, biological models and fluid models. He is a pioneer to design and solve second order pantograph Emden-—Fowler model, prediction differential model, nonlinear fifth order Emden-Fowler model, nervous stomach model, and nonlinear multi-singular SIR model based on coronavirus (COVID 19).

MUHAMMAD ASIF ZAHOOR RAJA
received the M.Sc. degree in mathematics from Forman Christen College Lahore, Pakistan, in 1996, the M.Sc. degree in nuclear engineering from Quaid-e-Azam, University, Islamabad, Pakistan, in 1999, and the Ph.D. degree in electronic engineering from International Islamic University, Islamabad, Pakistan, in 2011. He was involved in research and development assignment of Engineering and Scientific Commission, Pakistan, from 1999 to 2012. He is currently working as an Assistant Professor with the Department of Electrical Engineering, COMSATS Institute of Information Technology, Attock Campus, Attock, Pakistan, and associated with the Future Technology Research Center, National Yunlin University of Science and Technology, Douliou, Yunlin, Taiwan, for the research work. He has developed the Fractional least mean square algorithm and computational platform is formulated for the first time for solving fractional differential equation using artificial intelligence techniques during his Ph.D. studies. He has been author of more than 275 publications, out of which more than 225 are reputed journal publications with impact factor $ more than 850. He acts as a Resource Person and gives invited talks on many workshops and conferences held at the national level. His research interests include solving linear and nonlinear differential equation of arbitrary order, active noise control systems, fractional adaptive signal processing, nonlinear system identification, direction of arrival estimation, and bioinformatics problems.
MUHAMMAD REAZUL HAQUE (Member, IEEE) received the B.Sc. Engg. degree in computer science and engineering from Queens University, Dhaka, Bangladesh, and the M.Sc.Engg. degree (Hons.) in computer systems engineering (UAV-AI) from the University of East London (UEL), England, U.K., in 2013. He is currently pursuing the Ph.D. degree in information technology (SDN-AI-Satellite) from Multimedia University, Malaysia. He is also an Artificial Intelligence and Computer Scientist, an Inventor, and a Mathematician. He is also the Principal Inventor of the RUSPEEI Green Technology (RGT). He completed Mobile and Wireless Communication (MWC) from Bangladesh University of Engineering and Technology (BUET), Bangladesh. He enlisted as a Young Scientist and a Researcher by the Science and ICT Ministry of Bangladesh for the “Auto Fire Protector System.” He received a “Gold Medal” from Dr. Muhammad Monjurul Islam Siddiquee Sir for the project “The Great Thought Reflects (Mohavabna Protibimba).” He worked as a Senior Software Programmer with Axcell Pte. Ltd., in Singapore, from 2014 to 2015. He joined as a Research Scholar with Multimedia University for the project of Telekom Malaysia Research and Development (TM R&D), in December 2016. He has published many research papers in IEEE conferences, international journals, two patents, PCT, and several book chapters published by Springer International Publishing AG, Switzerland, USA, and Singapore, Part of Springer Nature. His research interests include mathematical modeling, algorithm, scientific and mathematical models, software programming, simulation, emulation, and publish in peer-reviewed journals and conferences worldwide. He created several course materials and provided practical training to Government Staff of Malaysia, and a mentor of UG and PG international researchers. He has been serving as a reviewer for many IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE/ACM TRANSACTIONS ON NETWORKING, IEEE ACCESS, COMPUTER COMMUNICATIONS, (Elsevier B.V., Tech Science Press USA), and IET Networks.

MUHAMMAD UMAR was born in Kala Gujran, Jhelum, Pakistan. He received the M.Sc. and M.Phil. degrees from Preston University Kohat, Islamabad, Pakistan. He is currently pursuing the Ph.D. degree in mathematics from Hazara University, Mansehra, Pakistan. He has published more than 25 papers in reported international WoS journals with impact factors. His research interests include mathematical modeling, neural networks, artificial intelligence and implementation of computational techniques based on traditional, and heuristic solvers.

AG ASRI AG IBRAHIM (Member, IEEE) received the bachelor’s and master’s degrees in computer science from the University of Malaya, Malaysia, and the Ph.D. degree in electronics from The University of York, U.K. He is currently working as the Director of JTMK, University Malaysia Sabah, Labuan Campus and Kota Kinabalu Campus, Sabah, Malaysia. His research interests include sonification, Kansei engineering, and human–computer interaction. He has been a member of the university senate for more than ten years. He is the Chairperson of the Malaysia Association of Kansei Engineering (MAKE) for the Sabah Region.

DAC-NHUONG LE received the M.Sc. and Ph.D. degrees in computer science from Vietnam National University, Vietnam, in 2009 and 2015, respectively. He is currently an Associate Professor in computer science, the Deputy-Head of the School of Computer Science, Duy Tan University, Danang, Vietnam. He has a total academic teaching experience of more than 12 years with many publications in reputed international conferences, journals, and online book chapter contributions (Indexed by SCI, SCIE, SSCI, Scopus, ACM, and DBLP). His research interests include soft computing, network communication, security and vulnerability, network performance analysis and simulation, cloud computing, the IoT, and image processing in biomedical. His core work is in network security, soft computing, and the IoT, and image processing in biomedical. Recently, he has been the Technique Program Committee, the Technique Reviews, the Track Chair for international conferences under Springer-ASIC/LNAI Series. He is serving in the editorial board of international journals and he authored/editored more than 15 computer science books by Springer, Wiley, and CRC Press.