A Novel Intrusion Detection System in WSN using Hybrid Neuro-Fuzzy Filter with Ant Colony Algorithm

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Abstract: With the wide application of wireless sensor networks in military and environmental monitoring, security issues have become increasingly prominent. Data exchanged over wireless sensor networks is vulnerable to malicious attacks due to the lack of physical defense equipment. Therefore, corresponding schemes of intrusion detection are urgently needed to defend against such attacks. A new method of intrusion detection using Hybrid Neuro-Fuzzy Filter with Ant Colony Algorithm (HNF-ACA) is proposed in this study, which has been able to map the network status directly into the sensor monitoring data received by base station, accordingly that base station can sense the abnormal changes in network. The hybridized Sugeno-Mamdani based fuzzy interference system is implemented in both the NF filters to obtain more efficient noise removal system. The Modified Mutation Based Ant Colony Algorithm technique improves the accuracy of determining the membership values of input trust values of each node in fuzzy filters. To end, the proposed method was tested on the WSN simulation and the results showed that the intrusion detection method in this work can effectively recognise whether the abnormal data came from a network attack or just a noise than the existing methods.

Keywords: Hybrid Neuro-Fuzzy Filter, Ant Colony Algorithm, fuzzy filters, wireless sensor networks, security issues.

I. INTRODUCTION

Attacks in Wireless Sensor Networks (WSNs) aim in limiting or even eliminating the ability of the network to perform its expected function. WSNs are networks with limited resources and often deployed in uncontrollable environments that an intruder can easily access. WSN attacks target specific network layer's vulnerabilities but normally affect other layers as well. Local sensor activity at multiple sensor network layers should be monitored and evaluated to detect possible malicious intervention. Intrusion detection is the method of analyzing and checking for signs of potential accidents in a computer device or network and also of unauthorized access. Intrusion detection This normally occurs by gathering data from a number of devices and network sources automatically, again and reviewing the data for safety issues.

According to [1], the annual cost from cyber-crimes to the global economy is estimated

to be more than \$400 billion in 2014. This statistic stresses the importance of developing proper solutions to ensure the safety of information systems. In order to protect information systems against intruders, different preventive solutions have been deployed by organizations. Intrusion detection system, a type of security management system used to gather and analyze information on a computer network or on a website to help build a different attack safeguard mechanism [2]. Also it is recording massive research works on its system using data mining which have been flooded by many researchers recently as it have the potency of classifying and detecting anomalies within a network.

In many real-time applications, there is a need to secure the communication and perform an effective data transmission. Due to attacks and some hackers, various security issues may occur. A lot of researchers were focussed but since the tools such as anti-virus programs and firewalls are not sufficient to provide constant and reliable sources of information. There is a

need to test the IDS system by upgrading the features of the system and provide integrity.

This work focuses on Hybrid Neuro-Fuzzy Filter with Ant Colony Algorithm (HNF-ACA) helps to predict the malicious node with data authentication. This approach is distinct from the standard algorithms for intrusion detection that treat network traffic condition directly. The innovation is that the network status is mapped to a base station's measurements to reflect changes in network status.

The rest of the paper is structured as follows: In section 2 the related work of IDS in WSN is discussed. The proposed IDS detection mechanism using Hybrid Neuro-Fuzzy Filter with Ant Colony Algorithm (HNF-ACA) is described in section 3. The experimental results and discussion is discussed in section 4. The conclusion and future work is given in section 5.

II. RELATED WORK

In literature, there are a few works that aim to combine between anomaly-based approach and hybrid model to benefit from the advantages of both detection techniques. In [3] proposed a mechanism of Intrusion Detection System (IDS) created in a Cluster-based Wireless Sensor Network (CWSN). The method of feature selection is one of the important factors, which affects the performance of IDS. In the field of wireless sensor networks an IDS architecture inspired by the Human Immune System is proposed[4]. However, this intrusion detection systems are too resource-demanding.

A hybrid clustering method is introduced in [5], namely a density-based fuzzy imperialist competitive clustering algorithm (D-FICCA). However, studying a game-based evolutionary algorithm is considered extremely significant. In [6] proposed a lightweight, energy-efficient system, which makes use of mobile agents to detect intrusions based on the energy consumption of the sensor nodes as a metric. A linear regression model is applied to predict the energy consumption. In [7], a game theoretic method is introduced, namely cooperative Game-based Fuzzy Q-learning (G-FQL). G-FQL adopts a combination of both the game theoretic approach and the fuzzy Q-learning algorithm in WSNs. The energy consumption for intrusion detection and prevention should be focused.

In [8] proposed an appropriate probabilistic model which provides the coverage and connectivity in k-sensing detection of a wireless sensor network. However, when random deployment is required, determining the deployment quality becomes challenging. In [9] proposed a Trust Based Adaptive Acknowledgment (TRAACK) Intrusion-Detection System for WSN based on number of active successful deliveries, and Kalman filter used to predict node trust. Based on hybrid models this work is proposing an efficient hybrid system for sensor network. The goal in this research is to study and implement a new model of intrusion detection that combines the advantages of hybrid model in cluster wireless sensor environment, and surpassing other models proposed in the literature.

III. PROPOSED METHODOLOGY

Initially, the fuzzy based Hybrid Neuro-Fuzzy Filter with Ant Colony Algorithm (HNF-ACA) is considered here to evaluate the detection of malicious nodes presented in the wireless sensor nodes. Generally, the malicious node is stated as the node that does not follow the exact behavior, it means there is any malicious attack such as modifying the message, in some terms the packet may be dropped likewise it goes on. Initially, there is a need for establishing the cluster based routing along with the reputation of a node. Then it is necessary to identify the malicious nodes, these parameters are based on the trust recommendation value. If the process is selected then the routing process is made by maintaining the process of each route. It is necessary to update the neighbor node information to source and destination nodes. Finally, for encryption, the RSA (Rivest-Shamir-Adleman) scheme is used to provide the authentication to all nodes based on public and private keys. At last the HNF-ACA is used for classifying the normal and malicious nodes for efficient data transmission in WSN. The architecture diagram of HNF-ACA based IDS is illustrated in Figure 1.

3.1. Cluster Based Routing

The cluster based routing is one of the efficient routing methods, here the nodes are selected for processing as well as sending the data, it is done with the help of high energies. In this work, the Cluster is framed by the nodes that are based on the parameters of residual energy and the trust vector value of reliable nodes. The trust is evaluated based on the successful delivered of packets among source and destination. The routing table of each node consists of watch dog mechanism to monitor the neighbor nodes data and it is necessary to inform the activity. Normally, the routing table is made up of packet id, neighbor coverage range, packet information, cluster member id, link quality, a node to node connectivity etc. The residual energy Res of each node i at time t is calculated as in equation (2), for each and every node to improve the network lifetime [10].

$$Res_i(t) = \frac{[Initial - E_i(t)]}{reg} \quad (1)$$

where $Initial$ is the initial energy, $E_i(t)$ is the residual energy and reg is the current region of cluster formation. With respect to the high and medium trust vector value the process is determined, the processes of nodes are less energy consumption of the node are considered as a cluster head or cluster members. The trust value $Trust_i$ is calculated as in equation (2),

$$Trust_i = \frac{Deliv_i - packet_i}{recpacket_i} \quad (2)$$

where, $Deliv_i$ is described as the delivered packets from D_i , $packet_i$ describes the packets sent from D_i to S_i , $recpacket_i$ is describes received packets sent from S_i to D_i , D_i is the destination node and S_i is the source node.

The trust value evaluation is made here to check highest trust value node and find the trusted authenticator. This authenticator indicated as Cluster Head (CH) and other related trust value nodes are selected as cluster member nodes. In case, the selected node is already a member of another cluster region, then a node of high trust value is selected. Based on these CH and members, the cluster region is formed.

Authentication of Message by RSA: The message authentication is processed by RSA algorithm. One of the most popular methods for public key encryption is Ron Rivest, Adi Shamir and Leonard Adleman (RSA) and it is one of the secure publickey encryption methods [12].

3.2. Classification Using HNF-MMACA

To represent the original node representation the authenticate node is used and for misbehavior representation, the malicious node is considered. Based on these two factors the training class is defined. Consider a proposed HNF-MMACA system that has N number of nodes in the input samples. The two classes are considered here in the training example data, i.e., the process has two labels, as well as the proposed system use $K = 2$ like class groups of hidden nodes, and these nodes represents a Gaussian function midpoint with a correlated label. The process is a class grouped; each Gaussian has a different centre but the same label.

Proposed Hybrid Neuro - Fuzzy: Structure of the Hybrid Neuro - Fuzzy, the fuzzy system is classified into Mamdani and Sugeno, which is associated with fuzzy rules. The structures of the two hybrid NF are identical to each other. Each filter is a combination of first order Sugeno and Mamdani fuzzy interference system. Therefore, the general form of the output function is given by equation (3),

$$Y = \sum_{k=1}^K \frac{a_k v_k}{\sum_{k=1}^K a_k} b_k(X) \quad (3)$$

Where a_k is the degree, the input x matches the rule computed, b_k for the Sugeno model and volume of the output fuzzy set is represented as v_k and the centroid of the output fuzzy set is denoted as N_k . The outcome of both the hybridized NF filter is computed by equation (10), represents the generalized fuzzy interference model which is hybridized the both Sugeno model and Mamdani model. Therefore, the hybridized model is defined as in equation (4)

$$\begin{aligned} & \text{Rule } k: \text{ if } x_1 \text{ is } M_1^k; x_2 \text{ is } M_2^k; \\ & \quad x_3 \text{ is } M_3^k \text{ and } x_4 \text{ is } M_4^k \\ & Y \text{ is } N_k (v_k, b_k(X)) \end{aligned} \quad (4)$$

Where the N_k for Mamdani model, or b_k for the Sugeno model. The M_i^k is represented [13] the membership function of the i th input of the k th rule. The essential features are preserved the interpretable capability of the Mamdani model and also enhance the accuracy of the Sugeno model as in equation (5). The hybrid NF outcome fetched into the post processor Y_{post} is truncated to the 8 bit integer values.

The final outcome of the proposed filter Y_{Final} is determined by the average output of the two hybrid NF filters. The function round (), rounds the element x to the nearest integer.

$$Y_{Final} = \text{round} \left(\frac{1}{2} \sum_{post=1}^2 Y_{post} \right) \quad (5)$$

The outcome is fetched into the post processor $post$ to produce the final output of the filter. The internal parameters of the hybridized NF filters are optimized using hybrid learning rule to reduce the error. The antecedent and the consequent parameters are optimized using gradient descent and least mean squares algorithm respectively.

MACA based optimization of Membership values: The membership values are assigned for further optimizing the input to improve the accuracy of the system as it decides the efficiency of IDS [14].

Table 1. Algorithm for optimal membership value Selection using ACA for HNF based IDS

Input: Initial Membership values for nodes, N that represents the number of features (i.e nodes parameters)

Output: Optimized Membership values

Formulate the optimization problem as a graph that is fully connected.

Assign, initial values of membership to the nodes in the network model.

Let number of membership values be m ;

While best membership value is not optimum do

Assign the parameter Residual energy function is minimum

Spread the membership values on the construction graph.

Update the visited membership values with their error functions.

While optimal membership value is not met do

Initialize ACA

For each ant do

Choose next node by applying state transition rule

Apply step by step pheromone update

End for

Repeat step 10 to 13 until met stopping criterion

Update best solution

Apply offline pheromone update

Check stopping condition not satisfied do

Position each ant in a starting node

For

. Check the Residual energy function of the value

End for

. End while

. Select best membership value in the values m as M_{best} ;

- . Update the global best solution
- . End while
- . Return M_{best} .
- Do IDS using HNF
- . Calculate the overall feature vector pairs with minimal distance MD
- . Calculate the vectors of MD for all classes

- . Input can be classified based on the conditions using equation (4)
- If the classification is made for all inputs, then the function is terminated,
- . Else forward it to the Step 31 process.
- . Produce the classification results of normal and malicious node

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the proposed HNF-ACA performance is carried out with the traditional methods such as D-FICCA [5], G-FQL [7] and TRAACK [9] in presence of malicious node environment in terms of Detection Rate Comparison, communication overhead, End to End delay and network lifetime. The proposed IDS are simulated with Network Simulator tool (NS 2.34). The simulation settings and parameters of the proposed scheme are given in Table 2 [15].

Table 2. Simulation Settings

Number of nodes	101
Area size	1000×1000
Mac	802.11
Radio range	250m
Simulation time	100sec
Packet size	80bytes
Mobility model	Random way point
Protocol	LEACH

4.1. Detection Rate Comparison

From the figure 4, when increasing the number of features the detection rate is increased twice that of the initial conditions. It is concluded that the detection rate of the proposed HNF-ACA method has improved with rate of 95%. In exiting methods such as D-FICCA, G-FQL and TRAACK attains low rate of 90%, 89% and 87% respectively. The numerical results of detection rate comparison is shown in Table 3.

Table 3. The numerical results of detection rate comparison

No.of features	HNF-ACA	D-FICCA	G-FQL	TRAACK
150	89	85	80	79
300	91	87	82	82
450	92	88	84	85
600	94	89	86	86
750	95	90	89	87

4.2. Communication Overhead Comparison

Communication overhead is a process of integrating an additional or indirect measure of resource that includes time, memory, bandwidth and a few other resources that are necessary to obtain the objective. From the figure 4, when increasing the time the communication overhead rate is increased. The communication overhead rate of the proposed HNF-ACA method has improved with rate of 24. In exiting methods such as D-FICCA, G-FQL and TRAACK attains low rate of 16, 14 and 12 respectively. The numerical results of communication overhead Comparison is shown in Table 4.

Table 4. The numerical results of communication overhead Comparison

Time (ms)	HNF-ACA	D-FICCA	G-FQL	TRAACK
10	14	12	10	8
20	16	13	11	9
30	18	14	12	10
40	20	15	13	11
50	24	16	14	12

4.3. End to end delay Comparison

Figure 6 shows the result of an end to end delay by varying nodes mobility. The obtained delay graph shows that the delay taken by data packets to reach the destination is less for proposed HNF-ACA methodology with 0.2ms when comparing with the traditional D-FICCA, G-FQL and TRAACK attains low rate of 0.24ms, 0.25ms and 0.31ms respectively. The graph proves that the end to end delay is reducing if the mobility of the nodes gets increased.

Figure 6. Representation of End to end delay Comparison

Hence, it is summarized that, if nodes get increased then the end to end delay decreased, it is stated as the transmission is effective. The numerical results of End to end delay Comparison is shown in Table 5.

Table 5. The numerical results of End to end delay Comparison

Mobility	HNF-ACA	D-FICCA	G-FQL	TRAACK
20	0.29	0.35	0.40	0.45
40	0.28	0.33	0.35	0.40
60	0.26	0.29	0.32	0.35
80	0.24	0.25	0.27	0.33
100	0.20	0.24	0.25	0.31

4.4. Network Lifetime Comparison

Figure 6 shows the result of Network lifetime by varying nodes time. The obtained delay graph shows that the delay taken by data packets to reach the destination is less for proposed HNF-ACA methodology with 1.21s when comparing with the traditional D-FICCA, G-FQL and TRAACK attains low rate of 1s, 0.9s and 0.8s respectively.

Figure 6. Representation of Network lifetime Comparison

Hence, it is summarized that, the proposed HNF-ACA is highly recommended for IDS in WSN. The numerical results of Network lifetime Comparison is shown in Table 7.

Table 7. The numerical results of Network lifetime Comparison

Time (ms)	HNF-ACA	D-FICCA	G-FQL	TRAACK
20	0.6	0.55	0.52	0.4
40	0.8	0.7	0.6	0.5
60	0.9	0.8	0.7	0.6
80	1	0.9	0.8	0.7
100	1.21	1	0.9	0.8

V. CONCLUSION AND FUTURE WORK

In this work, HNF-ACA based anomaly detection scheme is proposed for large scale sensor networks. The proposed filter hybridizes the Mamdani and Sugeno fuzzy interference model which offers the effective filtering mechanism. Furthermore, the proposed mechanism improves the performance of Sugeno model as well as Mamdani model. The ACA technique greatly improves the membership values to the input. It exploits the stability in their neighborhood information. Initially, the cluster based routing is selected with the trust vector and residual energy of neighbor nodes in the random topology. In this system, the packet transmission from a source node to a destination node is encrypted using the RSA scheme. After that, the identification of malicious nodes is made by using trust recommendation value. Finally, the normal and malicious nodes are classified by using HNF-ACA. An experimental performance result proved that the HNF-ACA provides maximum detection efficiency and high network lifetime, an end to end

delay and overhead is minimized than the existing D-FICCA, G-FQL and TRAACK.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The authors confirm that the data supporting the findings of this research are available within the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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