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Distance Vector-Hop (DV-Hop) and Differential Evolution (DE)-Based Interception Strategy for detecting Cross Border Infiltration in Underground Tunnel

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ABSTRACT

Securing the external border of a nation through potential surveillance is considered being highly essential, as the infiltration of trespassers and terrorists is considered to influence the harmony and peace of a nation. In this context, intensive human patrolling is required for safeguarding longer border areas. In specific, detecting the infiltration of terrorists in the underground tunnel is yet another challenge. Wireless sensor networks deployment is necessary for safeguarding the external borders through real-time monitoring with maximised accuracy and detection efficiency. Most of the existing approaches failed in adopting an optimal sensor node deployment strategy that prevents maximised overlapping of sensor nodes' coverage and struggled to localise the intruders with maximised accuracy and minimised error rate of positioning. In this paper, Distance Vector-Hop (DV-Hop) and Differential Evolution (DE)-based Interception Strategy (DV-Hop-DE-IS) are proposed for accurate detection of cross border infiltration in the underground tunnel. This proposed DV-Hop-DE-IS adopted the disk model of optimal sensor node deployment for concentrating on the sensing area of the underground tunnel despite overlapping regions realised during the coverage process. This proposed DV-Hop-DE-IS includes the merits of converting the discrete values of hop count into a highly accurate continuous value depending on the information received from the number of shared one-hop nodes that exist between neighbouring nodes. This problem of intruder detection is planned as the minimum optimisation problem that could be optimally solved through the utilisation of the Differential Evolution algorithm with maximised efficiency. The simulation results of the DV-Hop-DE-IS confirmed a better detection rate of 6.84 per cent, improved accuracy of 11.28 per cent with a reduced false-positive rate of 8.28 per cent, compared to the benchmarked intruder detection approaches.

Keywords: Differential evolution (DE); Distance Vector-Hop (DV-Hop); Cross border infiltration; Underground tunnel; Border surveillance systems

1. INTRODUCTION

In the recent past, border patrol systems are gaining maximised interest to handle the issues that possess immense challenges to national security[1]. In this border patrolling process, intensive human involvement is essential in the monitoring premises to protect the long stretches of the border in a more effective manner[2]. The traditional border patrolling systems comprise border troop and security checkpoints. The security checkpoints are established on the international roads where the complete vehicle traffic is stopped for apprehending and detecting illegal activity, drugs and illegal aliens[3]. In this context, every individual border troops check the predetermined time interval and route. With the manual patrolling process, extensive human resources are essential under the classical border patrolling system[4]. Now, multiple technologies that complement each other are essential for monitoring the border in real time with maximised accuracy and reduction in the need for human support[5]. Further, cross border infiltration through underground tunnels is considered a crucial challenge, as human involvement cannot be used[6]. Therefore, the underground nodes need to be thoroughly monitored through the deployment of sensor nodes that aids in establishing sensor networks to localise the intruder in the cross-border with no manual involvement[7]. The hybrid sensor network deployed for identifying the infiltration comprises three categories of sensor nodes: (i) The multimedia sensor nodes that possess night vision scopes and video cameras that are installed they are installed over the tunnel surveillance area. (ii) The sensor nodes that have the mobility to roam around the surface area of the tunnel with maximised optimality and scalar sensor nodes that incorporated seismic or vibration sensors buried underground[8]. These three categories of sensor nodes need to be cooperative inside the underground tunnel for facilitating localisation capabilities that were not guaranteed by the existing underground patrolling systems[9-14].

In this paper, Distance Vector-Hop (DV-Hop) and Differential Evolution (DE)-based Interception Strategy (DV-Hop-DE-IS) are proposed for accurate detection of cross border infiltration in the underground tunnel. This proposed DV-Hop-DE-IS includes the merits of converting the discrete values of hop count into a highly accurate continuous value depending

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on the information received from the number of shared one-hop nodes that exist between neighbouring nodes. This problem of intruder detection is planned as the minimum optimisation problem that could be optimally solved through the utilisation of the Differential Evolution algorithm with maximised efficiency. This intruder localisation is determined to be better than the existing approaches in five different ways:

- The localisation of intruders is made feasibly through a heterogeneous sensor that cooperative with one another to detect and report the intrusion to a remote administrator
- The used mobile sensors facilitate intruder localizing capability for determining the intruder movement before and after localisation
- The inclusion of underground sensors enabled the potential functionalities of the surveillance system and prevented the role of terrestrial devices from the purpose of concealment
- The incorporation of the multimedia sensor provided accurate detection of intruders with a wide range of detection
- The hidden intruder behind any obstacle can be detected through this localisation process. The simulation results of the DV-Hop-DE-IS confirmed better detection rate, accuracy with a reduced false positive rate compared to the benchmarked intruder detection approaches.

The remaining sections of the paper are structured as follows. Section 2 presents the comprehensive literature review of the existing intruder detection scheme proposed for protecting cross borders infiltration. Section 3 details the complete view of the proposed DV-Hop-DE-IS scheme with the advantages incorporated in the intruder's task localisation process. Section 4 demonstrates the simulation results and discussions of the proposed DV-Hop-DE-IS scheme and the benchmarked intruder detection scheme with justifications for their predominant performance. Section 5 concludes the paper with major contributions and future scope of enhancement.

2. RELATED WORK

An adaptive Immune system was proposed by Yang, *et al.*[15] for achieving border patrolling based on the merits of the TH1/TH2 Differentiation Mechanism. It was proposed a decentralised control approach that provides robustness independent of the adversarial conditions prevailing within the country's borders. It included adversarial conditions to handle the arbitrary motion period that make the intruders a complex task in determining the vulnerable spot on the border to launch possible kinds of attacks. It was also proposed with immuno-inspired control for the aim of recovering agent failure automatically and preventing collision in the patrolling region. Besides, the Border Sense mechanism was proposed by Sun, *et al.*[16] for deploying and operating resilient intruder detection in the country boundaries to prevent infiltrations of terrorists. This Border Sense mechanism was proposed with the architecture of a hybrid wireless sensor network. It included the merits of the most advanced sensor network technologies, such as wireless underground sensor networks and wireless multimedia sensor networks. It facilitated a coherent system that cooperated with diversified technologies that are used to enhance the accuracy of the system. It was also proposed for preventing the use of a single technique that handles significant problems of line-of-sight constraints and high false alarm rates. A border patrol decision support system is presented based on the Stackelberg Security Game (SSG) was proposed for representing the interaction between the intruders and the defenders[17]. This game model depicts the collaboration between defenders and intruders by pooling local resources that aids in controlling and monitoring the border patrols. It included a defender strategy by including a potential sampling method that aided in better problem formulation. It was developed as an automatic system that builds the Stackelberg game based on the data derived from different spatially located cross borders, topology and historical crime data. It also guaranteed clustering based on a logical probability distribution over historical crime data for allocating risk to areas of patrolling. The results confirmed that the computational efficiency of the model was comparatively better than it automatically constructed an instance to determine the sample solution quality. Then, the Panchendriya framework was proposed for detecting human intruders who infiltrate along the national borders that are covered by dry leaves[18]. It was proposed to minimise the cost and workforce required during the process of classical border surveillance. It integrated different wireless technologies and multiple sensors that aided in better localisation of human intruders at the borders. It specifically used a microphone sensor to detect the existence of a human intruder based on the information derived from the surveillance camera sensor and the merits of footstep signal detection. In specific, a surveillance camera sensor was used for determining solid evidence of the intruders at the border region based on potential visual information. The complete border patrolling system improved different sensors embedded into a microcontroller innovation board with the maximised capability of computation. It also included an early alert system, once the human infiltration at the border region under dry leaves is detected. However, the communication cost incurred during the implementation of this patrolling system is comparatively high.

A BLYNK smartphone application-based intruder detection system was developed to sense the existence of illegal immigrants by installing its sources of monitoring over the fences[19]. It senses the infiltration of the illegal immigrants and sends the signal to the soldiers who are patrolling around the fence. This intruder system has the capability of switching emergency lights and alarms based on the notified signal and the received signal. This strategy of alert included in the system had the potential of increasing the visibility of the patrolling soldiers such that accurate positions of the intruder can be positioned correctly and arrested when they are crossing the border illegally. But implementing the system was considered to be more complex and the dimension of coverage facilitated by this patrolling system is comparatively low, Also, a milky-way deployment strategy of border surveillance systems was proposed for intruder detection based on the arrangement of monitoring sensor nodes in a spiral fashion[20]. This strategy was developed with the deployment of three sink nodes at each of the classified zones of intrusion, such that no two sink nodes have the possibility of establishing reliable communication between them. But, this strategy supports the cooperation of intermediate sensor nodes between the sensor nodes and the base station, where the reactive decision of intrusions are determined. It was proposed with three base stations on both sides of the considered milky way to improve the network's lifetime. This deployment of three base stations concentrates on the motive of distributing the transmission of load uniformly along with the directions, rather than forcing one specific region and one sink node to handle the complete application scenario. This border surveillance system classified the region of monitoring into three zones termed Zone A, Zone B and Zone C. It achieved the idea of providing a better path profile during the process of early intruder detection such that monitoring can be determined along the direction more suitably.

3. PROPOSED DISTANCE VECTOR-HOP (DV-HOP) AND DIFFERENTIAL EVOLUTION (DE)-BASED INTERCEPTION STRATEGY (DV-HOP-DE-IS)

In this section, the detailed view of the proposed Distance Vector-Hop (DV-Hop) and Differential Evolution (DE)-based Interception Strategy (DV-Hop-DE-IS) contributed to the accurate detection of cross border infiltration is presented. In this scenario, the sensor node that detects the movement of a human in the tunnel is considered the anchor node as it transmits packets continuously with the information of hop-count and location information from itself to the complete deployed WSN.

In this proposed work, only the underground tunnel intrusion as the application area is considered. In the proposed DV-Hop-DE-IS approach, sensor node deployment is handled through disk model [21] in which the sensor nodes possess a fixed sensing radius, such that the complete area of sensing is featured by a regular field. In the incorporated disk model, it is considered that everything in the sensing area is completely observed and the region outside the sensing area cannot be estimated through the deployed sensors. If the sensor nodes are densely deployed in the sensing field, there is a huge possibility of overlapping between sensor nodes. This overlapping introduces redundant information in the sensor networks. If the sensor nodes are sparsely deployed in the sensing field, unsatisfactory coverage is realised in the network. Thus, the proposed DV-Hop-DE-IS approach concentrates on the deployment of optimal sensor nodes in the sensing region for determining maximised sensing information by a minimum number of sensor nodes deployed in the area of sensing.

Let us consider 'S_{Area}' as the area of sensing facilitated by each sensor node with r_{SA} as the radius of sensing, Then the three relationships that exist during the process of sensor node deployment with the spatial sensor coordinates (SN_i) and (SN_j) is expressed based on Eqns (1), (2) and (3):

$$SN_{(i)} \cap SN_{(j)} = S_{POC} \quad \text{If} \quad \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} < 2r_{SA} \tag{1}$$

$$SN_{(i)} \cap SN_{(j)} = POC \quad \text{If} \quad \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} = 2r_{SA} \tag{2}$$

$$SN_{(i)} \cap SN_{(j)} = \varphi \quad \text{If} \quad \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} > 2r_{SA} \tag{3}$$

Where 'POC' and 'S_{POC}' represents the point of contact and overlapping regions between the coverage of the individual sensor nodes.

In the forthcoming steps, we explain the involved in implementing the proposed DV-Hop-DE-IS approach are presented as follows:

Step 1: Initially, the packet transmitted from the anchor node is set to zero. The information packets will be delivered by the complete set of cooperating nodes through their propagation in the entire network. The sensing nodes construct a table for simultaneous recording of the associated values and locations of hop-count nodes from which the packets are forwarded to the anchor nodes. The minimum hop count associated with an anchor node is constantly changing in the process of data dissemination.

Step 2: Estimation of the mean distance

In this step, the parameters designated as mean distance are computed between an anchor node 'i' and any other sensor node 'j' in the network. The formula used for calculating this mean distance parameter is represented in Eqn (4):

$$M_{Dist} = \frac{\sum_{j=1}^{n} \sqrt{(x_i - x_j)^2 + (x_i - x_j')^2}}{\sum_{j=1}^{n} hp_{cnt(i,j)}} \tag{4}$$

where $hp_{cnt(i,j)}$ refers to the hop count between the anchor nodes 'i' and 'j' that determined the exact position of the intruder in the consecutive movement of time. (x_i, x_j) and (y_i, y_j) represents the current location of anchor nodes that recently determines the movement of the intruder in the tunnel. This information about mean distance is broadcasted to the other cooperating sensor nodes of the network.

Then, the location of the human activity instance is estimated based on the distance between all the anchor nodes as represented in Equn (5):

$$D_{i-n} = M_{Dist(k)} * hp_{cnt(i,j)} \tag{5}$$

Equation 6 represents the location of the intruders by coordinates that represent its distances from perpendicular lines that intersect at a point.

$$F_{Three-ed(i-n)} = \begin{bmatrix} (x_1 - x_k)^2 + (y_1 - y_k)^2 = D_{1.k}^2 \\ (x_2 - x_k)^2 + (y_2 - y_k)^2 = D_{2,k}^2 \\ ----------- \\ (x_n - x_k)^2 + (y_n - y_k)^2 = D_{n,k}^2 \end{bmatrix} \tag{6}$$

Converting Eqn (4) into a form of a matrix $XI_{LOC(x)}y$, where the value of and expressed using Eqn (7), (8) and (9), respectively:

$$X = 2\begin{bmatrix} (x_1 - x_{(1,k)}) & (y_1 - y_{(1,k)}) \\ (x_2 - x_{(2,k)}) & (y_2 - y_{(2,k)}) \\ ----- & ----- \\ (x_n - x_{(n,k)}) & (y_n - y_{(n,k)}) \end{bmatrix} \quad (7)$$

$$y = \begin{bmatrix} x_1^2 - x_{(1,k)}^2 + y_1^2 - x_{(1,k)}^2 + D_{(1,k)}^2 - D_1^2 \\ x_2^2 - x_{(2,k)}^2 + y_2^2 - y_{(2,k)}^2 + D_{(2,k)}^2 - D_2^2 \\ ------------------ \\ x_n^2 - x + y_n^2 - y + D^2 - D_n^2 \end{bmatrix} \quad (8)$$

$$I_{Loc(X)} = \begin{bmatrix} x_k \\ y_k \end{bmatrix} \quad (9)$$

In this situation, the method of least squares is used for solving the equation which represents the location of the intruder $I_{Loc(X)}$ at any point of time in the tunnel as presented in Eqn (10):

$$I_{Loc(X)} = (X^T X)^{-1} X^T Y \quad (10)$$

Once the method of multilateration is applied, the Differential Evolution Algorithm is applied for speeding up routing information from the source of the sense to the destination in which decision making is started.

Algorithm:-
Initialize:
Ind_N = Total Number of Sensor Nodes
A_N = Anchor Nodes
C_R = Communication Range

$S_N(E_{initial}) = 0$ // Initial energy of sensor nodes
Begin // Infiltrator's Crossover process
begins $For\ i = 1:N$

$For\ j = 1:N$

$if\ (S_N(E_i)) > 0$ // Condition that the Sensor Node's energy is greater than 0

$D_{mean} = S_N /\ hp_{cnt}(i,j)$ // Estimation of mean distance between an anchor node and any other anchor node

$D_{(i-n)} = D_{mean} *\ hp_{cnt}(i,j)$ // Location of human activity detected based on the distance between all anchor nodes

$D_{(j-n)} = D_{i-n} *\ hp_{cnt}(i,j)$ // Location of human activity detected based on the distance between all anchor nodes

$D_{(i-j)} = D_n * D_{j-n}$ // Location of the human activity detected to the tunnel based on the distance between the anchor node.

else

$f(S_N(E_i)) = 0$ // No Detection taken place

End simulation process
End

3.1 Inclusion of Differential Evolution Algorithm

The Differential Evolution (DE) was contributed as a metaheuristic approach that utilises the technology of stochastic search. This DE algorithm possesses three merits, such as fewer parameters, faster convergence and maximised robustness, compared to the other meta-heuristic algorithms. It included three potential operational phases of mutation, crossover, and selection.

Among the most potential operational phases, the mutation operator is considered being more significant. The mutation process is attained by determining the deviation between the individuals selected from the complete population (the workable set of paths that aids in transmitting the information of human movement from the sensed node to the destination where the action needs to be initiated). Then, the process of mutation generates the candidate solution by performing the crossover operation between the mutation vector and the parent individual.

Moreover, the parent solution is replaced by the candidate solution and emerges as a new individual in the new population only when they are estimated to be better than the fitness potential of the parent solution. In the operation of mutation, the scale parameter and the difference vector are utilised for controlling the range of search and its directions towards the determination of optimal solutions. This DE algorithm included the benefits of crossover operation for depicting the genetic approach that aids in elucidating superior chromosomes from the parent solutions. Besides, the operation of the solution confirms the possibility of converging the complete population towards the solution of optimality.

The steps involved in the inclusion of the DE algorithm to speed up the process of routing information from the sensed source to the destination with maximised accuracy are presented as follows:

Step 1: Initialisation Process

In the given search space, the method of initialisation generates several individuals $'Ind_N'$(the feasible set of paths that aids in transmitting the information of human movement from the sensed node to the destination where the action needs to be initiated). Every individual from the Ind_N is explored based on $'d'$ dimensional vector (the dimensions used for exploring the quality or the fitness of the path determined from the source to the base station). At this instant, each individual in the k^{th} generation is represented as

$S_i^k = (s_{(i,1)}^k, s_{(i,2)}^k, s_{(i,3)}^k .... s_{(i,d)}^k)$, where $i = 1,2,3,............Ind_N$ and $k - 0,1.2...Max_{Gn}$.

In this context, the upper and lower threshold of search are

$S_{Max} = \left(S_{(Max,1)}, S_{(Max,2)}, \ldots S_{(Max,d)}\right)$ and

$S_{Min} = (S_{(Min,1)}, S_{(Min,2)}, \ldots S_{(Min,d)})$, respectively.

Thus the initial value of the individual is generated based on Eqn (11):

$$s^{d}_{(I,J)} = s_{(Min,j)} + rnd\,(0,1) * \left(s_{(Max,j)} - s_{(Min,j)}\right) \quad (11)$$

Where the value $rnd()$ ranges between 0 and 1.

Step 2: Mutation Process

In this step of mutation, the six significant six equations are most widely used in the mutation operator for the objective of generating the initial value corresponding to the i^{th} individual. In this process, the vector generated during mutation is termed the donor vector and the selected individual solution is designated as the target vector. The symbol "DEa/b" is used to represent the operators of mutation. Now, 'a' and 'b' depicts the primitive "n" number of deviation vectors that are utilised during mutation. The possible six equations that are commonly included in the operator of the mutation are represented using Eqns (12-19).

i) "DE" Best/1"

$$v_i^k = s^k_{Best} + P_{Scale} * \left(s^k_{r1} - s^k_{r2}\right) \quad (12)$$

ii) "DE/Best/2"

$$v_i^k = s^k_{"e"t} + P_{Sca"e} * \left(s^k_{r1} - s^k_{r2}\right) + P_{Scale} * \left(s^k_{r3} - s^k_{r4}\right) \quad (13)$$

iii) "DE/Rand/1"

$$v_i^k = s^k_{r1} + P_{Scale} * \left(s^k_{r2} - s^k_{r1}\right) \quad (14)$$

iv) "DE/Rand/2"

$$v_i^k = s^k_{r1} + P_{Scale} * \left(s^k_{r2} - s^k_{r3}\right) + P_{Scale} * (s^k_{r4} - s^k_{r5}) \quad (15)$$

v) "DE/Current-to-Rand/1"

$$v_i^k s_i^k + G_{Scale}\left(s^k_{Best} - s_i^k\right) + P_{Scale} * \left(s^k_{r1} - s^k_{r2}\right) \quad (16)$$

vi) "DE/ Current-to-Best/1"

$$v_i^k = s_i^k + P_{Scale}\left(s^k_{r1} - s_i^k\right) + P_{Scale} * \left(s^k_{r2} - s^k_{r3}\right) \quad (17)$$

Step 3: Crossover Process

In this process of crossover, the donor s_i^k and target vector (v_i^k) that are determined during the operation of mutation are included in the objective of generating the trial vector. This process of crossover is achieved based on Eqn (18):

$$CR\left(u^k_{(i,j)}\right) = \begin{cases} v^k_{(i,j)} & (j = j_{rnd}) \;\; Or \;\; rnd\,(0,1) \le Rate_{CR} \\ s^k_{(i,j)} & Otherwise \end{cases} \quad (18)$$

where, $Rate_{CR}$ is the rate of the crossover.

Step 4: Selection Process

The selection process is attained through incorporating a selection operator, which is a potential greedy operation that derives the benefits of a one-to-one selection method based on Eqn (19):

$$s_i^{k+1} = \begin{cases} u_i^k & if \quad f\left(u_i^k\right) \le f\,(sk_i) \\ s_i^k & Otherwise \quad f\left(u_i^k\right) \end{cases} \quad (19)$$

4. SIMULATION RESULTS AND DISCUSSION

The simulation experiments of the proposed DV-Hop-DE-IS approach and the benchmarked schemes are conducted using Matlab R2018a. The performance evaluation of the proposed scheme

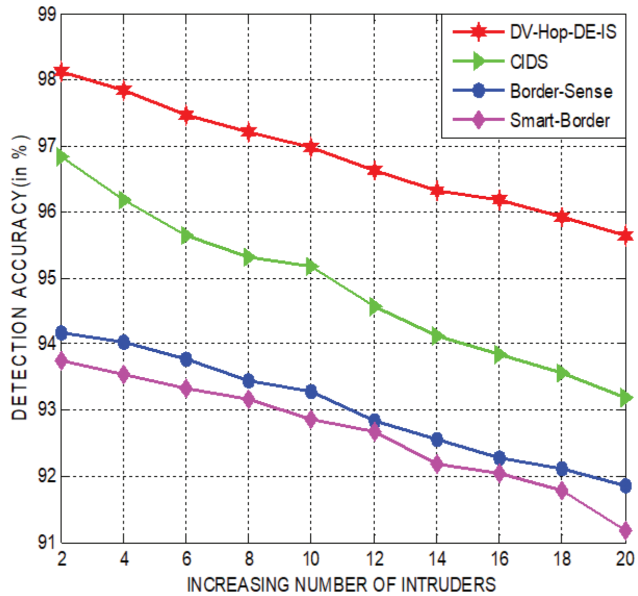

Figure 1. Proposed DV-Hop-DE-IS: Detection accuracy with number of intruders.

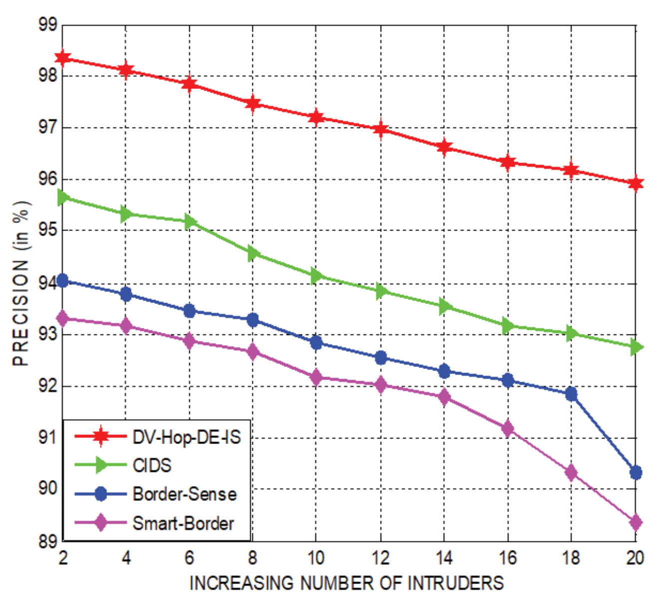

Figure 2. Proposed DV-Hop-DE-IS: Precision with number of intruders.

In the first part of the investigation, the proposed DV-Hop-DE-IS scheme, and the benchmarked approaches are explored based on Detection Accuracy, Precision, Recall, Energy consumption incurred during detection and the number of anchor nodes used for detection concerning the number of intruders.

Initially, Fig. 1 and Fig. 2 depict the Detection Accuracy, and Precision of the proposed DV-Hop-DE-IS scheme and the benchmarked CIDS, Border_Sense and Smart_Border approaches for the number of intruders. The detection accuracy and precision of the proposed DV-Hop-DE-IS scheme are considered getting decreased with a respective increase in the number of intruders.

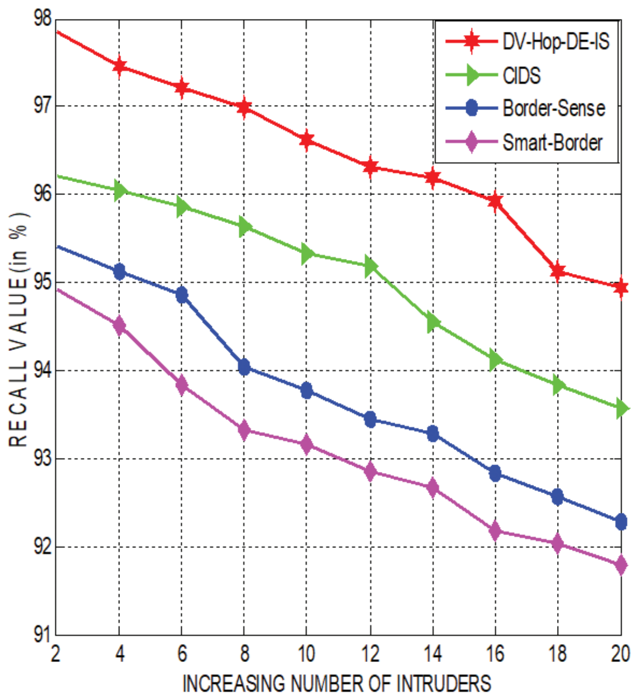

Figure 3. Proposed DV-Hop-DE-IS: Recall with number of intruders.

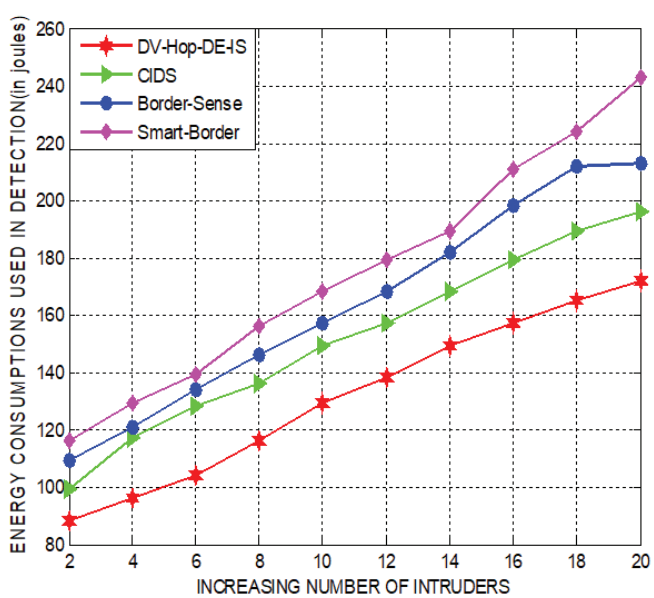

Figure 4. Proposed DV-Hop-DE-IS: Energy consumption with the number of intruders.

However, the detection accuracy and precision of the proposed DV-Hop-DE-IS scheme are substantially better than the benchmarked schemes, since it includes a hop count-detection approach and potential optimisation strategy that aided in better detection of intruders.

Thus, the proposed DV-Hop-DE-IS scheme improved the detection accuracy by 10.21%, 12.84% and 14.92%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches. The precision of the proposed DV-Hop-DE-IS scheme is also improved by 9.38%, 11.92% and 13.84%, compared to the benchmarked CIDS, Border Sense and Smart_Border approaches.

Figure 3 and Fig. 4 demonstrate the recall value and energy consumptions attained and incurred by the proposed DV-Hop-DE-IS scheme and the benchmarked CIDS, Border_Sense and Smart_Border approaches concerning the number of intruders. The recall value is also confirmed to get decreased with a corresponding increase in the number of intruders. However, the proposed DV-Hop-DE-IS scheme can sustain a better recall value on par with the baseline schemes, as they incorporated vital adaptive factors that facilitate accurate intruder detection.

Thus, the proposed DV-Hop-DE-IS scheme improved the recall value by 8.92%, 10.38% and 13.18%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches. Energy consumption incurred by the proposed DV-Hop-DE-IS scheme explodes with a respective increase in the intruders. But the proposed DV-Hop-DE-IS scheme is potential enough to sustain the energy by adapting the DE strategy that determined the optimal routing process in the network.

The energy consumption incurred by the proposed DV-Hop-DE-IS scheme is minimised by 9.36%, 11.41% and 14.28%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches.

Further, Fig. 5 and Fig. 6 portray the number of anchor nodes used for detection and latency in information reception incurred by the proposed DV-Hop-DE-IS scheme with

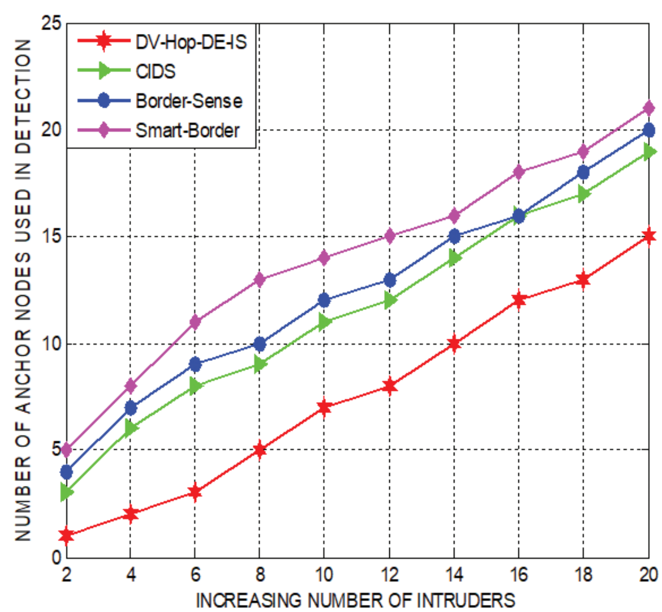

Figure 5. Proposed DV-Hop-DE-IS: Number of anchor nodes used for detection regarding the number of intruders.

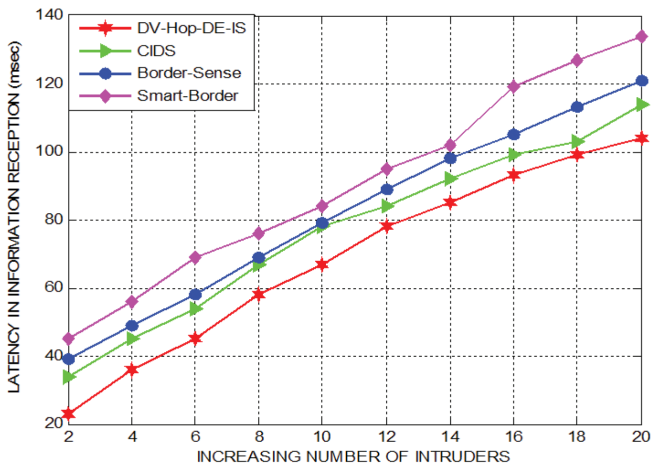

Figure 6. Proposed DV-Hop-DE-IS: Latency in information reception concerning the number of intruders.

an increase in the number of intruders. The parameters of anchor node count, as well as latency incurred in information reception, are considered getting potentially minimised in the proposed DV-Hop-DE-IS scheme as they utilised an improved multigenerational method that concentrated on the reduced use of anchor nodes. It also includes adaptive factors that determined the reliability of the sensor during the process of routing, reducing the latency incurred in the data dissemination process. The number of anchor nodes utilised by the proposed DV-Hop-DE-IS scheme is minimised by 6.12%, 8.29% and 10.14%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches. The latency in information reception used by the proposed DV-Hop-DE-IS scheme is reduced by 5.94%, 7.18% and 9.42%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches.

In the second part of the investigation, the proposed DV-Hop-DE-IS scheme, and the benchmarked approaches are explored based on the percentage increase in detection rate, the percentage decrease in energy consumption and the percentage decrease in network latency under a different number of hop lengths between the nodes of the network. The proposed DV-Hop-DE-IS scheme confirmed a superior performance in terms of the percentage increase in detection rate with different hop lengths by 4.82%, 5.19% and 6.91%, compared to the CIDS, Border_Sense and Smart_Border approaches. The percentage decrease in energy consumption of the proposed DV-Hop-DE-IS scheme is also decreased by 5.19%, 6.16% and 7.22%, superior to the baseline approaches. This predominant performance visualised in terms of detection rate and energy consumption with increasing hop length is mainly because of the accurate localisation and routing process inherited by the proposed DV-Hop-DE-IS scheme

Figure 7 depicts the percentage decrease in network latency of the proposed DV-Hop-DE-IS scheme and the benchmarked approaches with varying amounts of hop lengths. The proposed DV-Hop-DE-IS scheme included the merits of the disk model for optimal sensor node deployment, such that overlapping region between the nodes is prevented from guaranteeing maximised network coverage. It adopted the merits of DE to balance exploration and exploitation involved during the process of localisation. Thus, the proposed DV-Hop-DE-IS scheme confirmed an improvement in percentage decrease in network latency with different hop lengths by 4.58%, 5.92% and 6.46%, compared to the CIDS, Border_Sense and Smart_Border approaches.

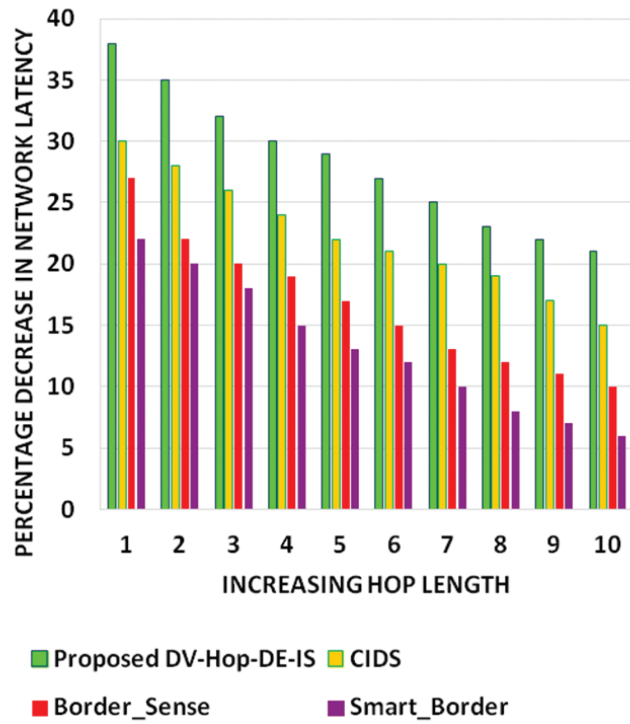

Figure 7. Proposed DV-Hop-DE-IS: Number of anchor nodes used for detection of the number of intruders.

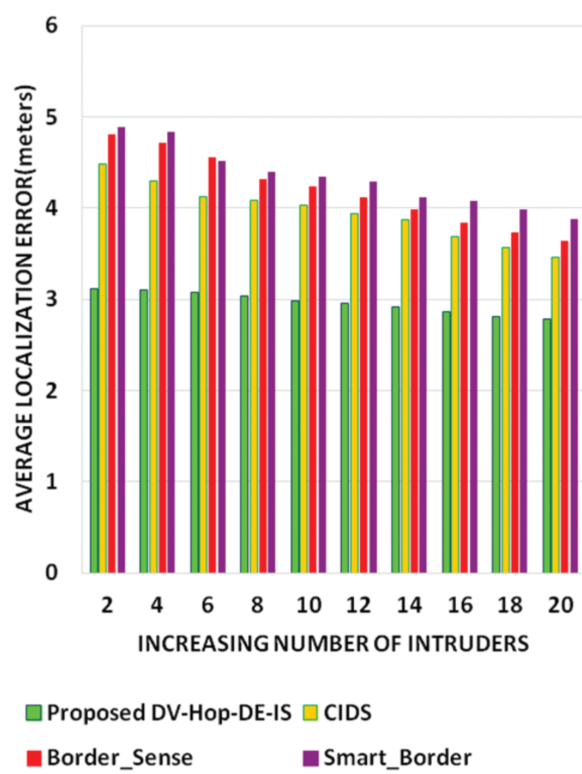

Figure 8. Proposed DV-Hop-DE-IS: Average localization error with number of intruders.

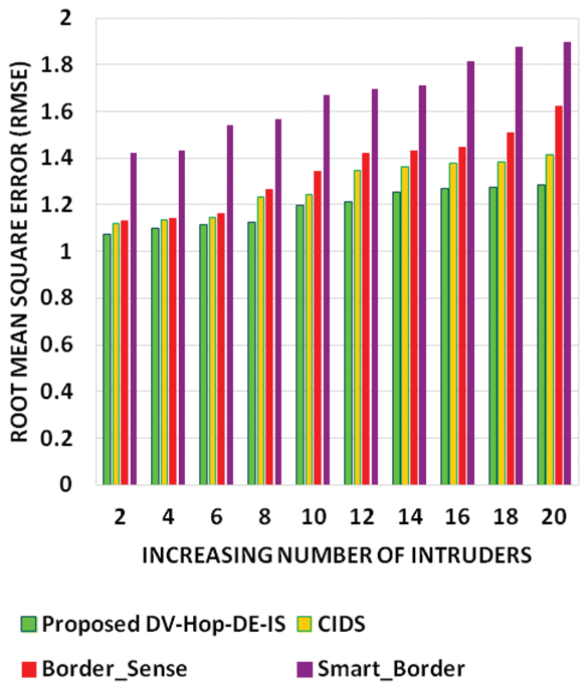

Figure 9. Proposed DV-Hop-DE-IS: Root Mean Square Error (RMSE) with number of intruders.

In addition, performing the proposed DV-Hop-DE-IS scheme, the benchmarked approaches are evaluated using average localisation error, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) with a different number of intruders.

Figure 8 and 9 demonstrate the plots of average localisation error and RMSE achieved by the proposed DV-Hop-DE-IS scheme and the benchmarked approaches with an increasing number of intruders.

The results confirmed that the proposed DV-Hop-DE-IS scheme is vital enough to ensure better localisation of intruders by an adaptive change of ranges included during the process of optimal sensor node deployment. This improved performance of the proposed DV-Hop-DE-IS scheme is also noted because of the sustained exploration facilitated by DE and multilateration introduced by the DV-Hop localisation process.

Thus, the proposed DV-Hop-DE-IS scheme with a different number of intruders confirmed minimised average localisation error of 3.21%, 6.19% and 9.32%, better than the CIDS, Border_Sense and Smart_Border approaches.

The value of RMSE attained by the proposed DV-Hop-DE-IS scheme with a different number of intruders is also minimised by 5.68%, 7.52% and 10.21%, better than baseline approaches.

Moreover, Fig. 10 depicts the plots of MAE determined for the proposed DV-Hop-DE-IS scheme and the benchmarked approaches with a varying number of intruders. The MAE attained by the proposed DV-Hop-DE-IS scheme is realised to be potentially minimised due to the use of disk model-based optimal sensor node deployment to maximise network coverage. Thus, the proposed DV-Hop-DE-IS scheme confirmed reduced MAE with a different number of intruders by 6.78%, 9.12% and 12.54%, better than the competitive CIDS, Border_Sense and Smart_Border approaches.

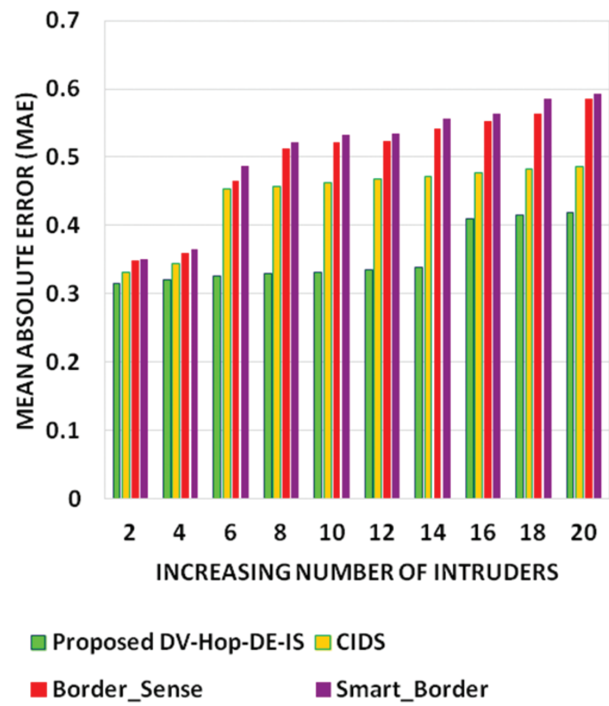

Figure 10. Proposed DV-Hop-DE-IS: Mean Absolute Error (MAE) with number of intruders.

5. CONCLUSION

The proposed DV-Hop-DE-IS scheme achieved accurate detection of cross border infiltration in the underground tunnel by transforming discrete values of hop count into a highly accurate continuous value depending on the information received from the number of shared one-hop nodes. The proposed DV-Hop-DE-IS scheme included a disk model of optimal sensor node deployment and prevented the problem of coverage region overlapping between sensor nodes. It adopted the merits of the Differential Evolution algorithm with maximised efficiency between exploration and exploitation, confirmed intruder detection with maximised localisation accuracy and minimised false positive rate. The simulation results confirmed that the proposed DV-Hop-DE-IS scheme minimised the network latency with different hop lengths by 4.58%, 5.92% and 6.46%, compared to the CIDS, Border_Sense and Smart_Border approaches. The results also proved that the number of anchor nodes used by the proposed DV-Hop-DE-IS scheme is minimised on an average by 8.12%, compared to the benchmarked CIDS, Border_Sense and Smart_Border approaches. In particular, the latency in information reception utilised by the proposed DV-Hop-DE-IS scheme is reduced by an average of 7.56%, better than the baseline approaches. As part of the plan of research, it is planned another intruder detection scheme based on a Harris hawk optimisation algorithm is planned to compare with the proposed DV-Hop-DE-IS scheme.

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