Int. J. Electron. Commun. (AEÜ) 111 (2019) 152882

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

Application of wireless sensor networks for Rhino protection against poachers in Kaziranga National Park

Tathagata Nath, Md Azharuddin *

Department of Computer Science and Engineering, Aliah University, Kolkata 700156, India

ARTICLE INFO

Article history:
Received 12 April 2019
Accepted 22 August 2019

Keywords:
Wireless sensor network
Routing
Energy consumption
Rhino
Kaziranga National Park

ABSTRACT

Last few decades many animals, birds, reptile and fish species were wiped out from the planet due to human activity. Many more species are likely to lose their existence because of lost their natural habitat, increased human land use and poaching. Rhino is one of them which can be found now only in few protected areas such as Assam, West Bengal etc. of India because of poaching. In this paper, we propose a model of wireless sensor network's application to protect the Rhino against poachers in Kaziranga National Park, Assam, India. In the model, we place the sensor nodes in the boundary region of the Rhino inhabited area to take necessary action upon detection of human movement. Then, we propose a routing algorithm for the model where a sensor node selects a next hop sensor node based on a fitness function. We also propose a linear programming formulation for the proposed algorithm. Finally, we simulate the proposed algorithm for varying number of sensor nodes and BSs and compare different results in terms of various performance metrics.

1. Introduction

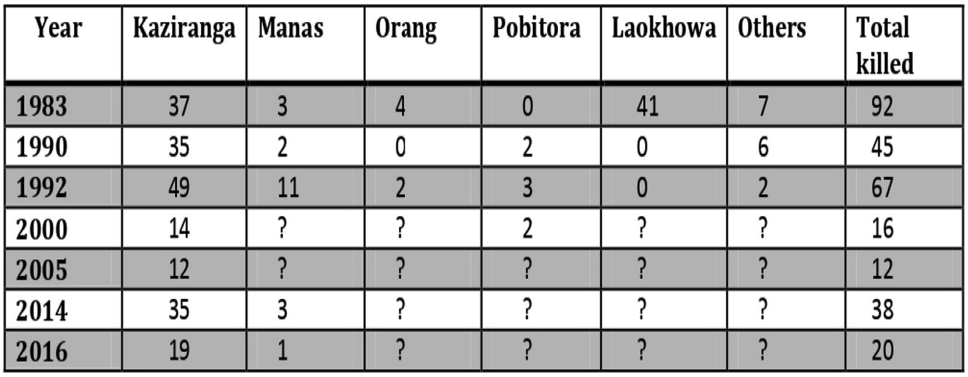
In the last few decades many types of birds (such as Dodo, Carolina, Parakeet etc.), mammals (such as Central rock rat, Scimitar oryx etc.), reptile(such as Pinta island tortoise, Martinique giant ameiva etc.) have been extinct from the world [1]. Recently, a study [1] have shown that in nearly 5 decades since 1970, 60% of mammals, birds, fish and reptile species were extinct from the planet due to human activity. Near about 1,700 species of amphibians, birds and mammals are likely to lose their natural habitats and face problem of extinction by 2070 due to increased human land use and poaching for their body parts etc. An Ecologists at Yale University has warned that in the next 50 years 886 species of amphibians, 436 birds and 376 mammals could go extinct due to habitat loss [1]. Rhino is one of them. There are many types of Rhinos such as White Rhino, Black Rhino, Indian Rhino, Javan Rhino, Sumatran Rhino etc. Many years ago Indian one horned Rhino inhabited many areas ranging from Pakistan to Myanmar and some part of China also. Now, they exist only in few protected areas such as Assam, West Bengal, and a few pairs in Uttar Pradesh of India, Nepal and Lal Suhanra National Park of Pakistan ([2]) due to irrevocable poachers influence. Rhino's horned, skin and nails are valuable, especially the horned which is used for traditional medicine in China and Vietnam. The size of the horn is around 20 cm to 60 cm long and its cost is around $300000, as it is used for medicine, especially for Cancer and Hangover [3]. Poaching of Rhino is a major environmental threat in India. 95% of Indian one-horned Rhino lives in various National Parks, forests and other grasslands of Assam such as Kaziranga National Park, Manas National Park, Pobitora, Orang National Park etc [2]. In India, the famous Rhino protected area is Kaziranga National Park and at present, two-third of the Indian Rhino can be found in Kaziranga National Park [2]. It is noticed that dehorning rate of Rhino is maximum in Kaziranga National Park which is shown in Fig. 1 (Detail table since 1962) and every year this rate is increasing due to illegal Rhino horn trade. Note that, in some forests, the year wise data is not available and it is marked as "?". Therefore, this is very essential to protect the Rhino from poachers against the illegal Rhino horn trade.

As the poaching rate of Kaziranga is very high, protecting the Rhino in Kaziranga National Park using wireless sensor networks (WSNs) would be a great idea. WSNs is very easy to implement, available and adaptable. It can be used in challenging areas where human intervention is not so easy. WSNs have been used for various applications like nuclear reactor control, health sector drug control, defence sector monitoring, surveillance the border enemy's vehicle detection, agriculture sector, soil measurement, pollution monitoring etc. However, WSN faces some challenges

---

* Corresponding author.
E-mail addresses: tathagatanath01@gmail.com (T. Nath), azhar_ism@yahoo.in (M. Azharuddin).

https://doi.org/10.1016/j.aeue.2019.152882
1434-8411/



Year	Kaziranga	Manas	Orang	Pobitora	Laokhowa	Others	Total killed
1983	37	3	4	0	41	7	92
1990	35	2	0	2	0	6	45
1992	49	11	2	3	0	2	67
2000	14	?	?	2	?	?	16
2005	12	?	?	?	?	?	12
2014	35	3	?	?	?	?	38
2016	19	1	?	?	?	?	20

Fig. 1. Year wise Rhino poaching in various Parks.

like node deployment, limited energy, security, limited bandwidth etc [4]. Therefore, our primary goal is to design a system which requires fewer nodes and longer lifetime of the nodes. The Kaziranga National Park is very large in area, thus the continuous monitoring of the whole area by human being may not be feasible. Hence, monitoring the area using WSNs is a reasonable solution.

In this paper, we develop an application using WSNs for continuous monitoring of Rhino inhabited area of Kaziranga National Park against the poachers. Note that, the Kaziranga National Park is very large; however our focus is only the Rhino inhabited area which is given in the Fig. 2. First, we deploy some sensor nodes and some BSs (BSs) in the boundary of Rhino inhabited area to monitor the human movement. Therefore, necessary steps can be taken while sensing the presence of human movement. After that, we propose a routing algorithm to maximize the lifetime of the network, so that we can obtain the services from this application longer period of time. In the routing algorithm, first we develop a hop tree algorithm for forwarding the sense data only towards the nearest BS and then a specific sensor node selects its next hop node based on a fitness function to minimize the energy consumption. The fitness function is based on residual energy of the next hop node, the distance between the node and its next hop, and the distance between the next hop and its next hop node (i.e., next hop of next hop of the node). Then, we represent a LP formulation for the routing problem. Finally, we simulate the proposed algorithm extensively for various scenarios and demonstrate the results in terms of energy consumption, data packets received by BSs, No. of dead sensor nodes and standard deviations of remaining energy of the nodes.

The remaining of the paper is arranged as follows. The related works is represented in Section 2. The Section 3 represents the model and terminologies. The proposed work is described in Section 4. The simulation results are described in Section 5. Finally, we conclude the paper in Section 6.

2. Related works

There are many applications of WSNs in the modern world for environment monitoring such as forest fire protection, crop protection, animal protection from road accident etc. However, we discuss here only some of the relevant applications related to our proposed model. Damage of crops by the animal is a major issue for the fields situated nearby some forest areas. In [5], the authors have proposed a WSN model for protecting the crop fields nearby forests from the animal attacks. In this model, they placed the sensor nodes in the boundary reason of the field and place the BS in the centre of the field. The flasher light and sound system had been used for diverting the animal when coming to nearby the crop field. A good communication system like roads, railway tracks etc. are needed for making a good economical world. Many roads and railway tracks are situated beside or inside the forests or through the wildlife area. Every year many animals like elephant, deer etc. are died by the vehicle collisions. In [6], the authors proposed a WSN model in which sensor nodes are deployed beside the roads in the Alps region to prevent the collisions of vehicles and animals. Here, the sensor nodes capture the presence of animals and send a light signal to the approaching driver to take necessary action if find any dangerous situations. Trees and forests are one of the most important parts of the environment. Forests control the ecological balance. Wildlife animals live in forests and they depend on forests. If any forest destroys by any reason this is a threat for our environment. Forest fire is one of the most important reason for destroying the forest. Early detection of the forest fire is very crucial before it's become devastating. In([7–9]), the authors have

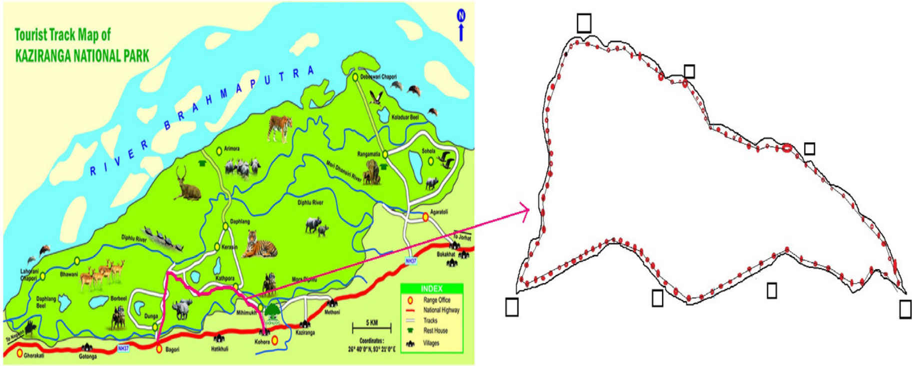


Fig. 2. (a) Kaziranga National Park, (b) only Rhino inhabited area where red dots are sensor nodes and black boxes are BSs.

deployed the sensor nodes to monitor the early detection of fire which can be monitored remotely.Water covered 70% of the earth so there is a need for extensive research in monitoring, detecting, and exploring various aspects of the ocean environment. Ocean pollution is a major threat. Authors in [10] have recommended a decentralized ad hoc WSN model where the nodes communicate through neighbours. They use short-range acoustic communication (50–500 m) to long-range communications (1–90 km). They have developed a novel node synchronization protocol for almost consistent battery wastage by the deployed sensors [10]. Clock synchronization is also an important metric for performing collaborative task among the sensor nodes for various WSN's applications which can be found in [11–13]. Crude oil, gas transporting from one location to another is also done through under ocean pipeline. Authors in [14] proposed a model for monitoring the Niger delta region which is oil rich region. They proposed a different type of sensors networks like underwater sensor networks, underwater acoustic sensor network, radio frequency WSN. The most important factors for the growth of plants are temperature, humidity, light and carbon dioxide. To measure these four environmental variables in greenhouse control is very important. In [15], a star topology in a tomato greenhouse has been set up, where three nodes have been integrated with Sensinode's sensor platform, temperature and luminosity. Humidity sensors measured climate variables and communicated directly with the gateway. In [16] authors proposed a prototype for a capsicum greenhouse (70 m × 150 m) where approximately 40 to 50 sensor nodes have been used and every sensor node may send the information to the central node. However, the model faces some intercommunication and data congestion problem between nodes. These problems overcome by some protocols and system on chip based hardware with programmable radio. Authors in [17] proposed an efficient WSNs framework to monitor the transmission line. They used a clustering algorithm in this framework to simplify this network management and balance the network's energy consumption. Routing is also important for maximizing the lifetime of the networks. Plenty of research have been carried out for routing which can be found in [18–20].

Plenty of researches have been carried out for environment monitoring and wildlife species protection using WSNs discussed above [5–7,10,14,15,17]. However, more research is needed for the unexplored area of environmental monitoring and wildlife species protection. In this paper, we consider the Rhino protection against poachers using WSNs in the large area of a forest like Kaziranga National Park which is unexplored till now as per our knowledge.

3. Models and terminologies

Here we describe the whole network model, terminologies and other important part of this proposed model.

3.1. Network model

Here, we assume a wireless sensor network model in which we manually deploy non portable same type (homogeneous) of sensor nodes and BSs. Sensor nodes capture the raw data and transmit to the corresponding BSs. The distance between two sensors or one sensor and BS is considered the euclidean distance. Initially the energy of all sensor nodes is same, however their energy consumption rates are different depending upon the routing load. The communication between the nodes or nodes and BSs take place over wireless links, established only when they exist communication range of one another. The wireless links are symmetric which is useful to compute the approximate distance using received signal strength [21]. We use the time division multiple access (TDMA) [21] to impart medium access control (MAC) layer communication.

3.2. Terminologies

Some important notations are described in Table 1.

Some other useful terminologies for the proposed model are defined as follows.

- **Round:** The time period in which all the sensor nodes successfully send their collected data to their nearest BSs is called a round.
- **ComS(s_i):** This is set of all sensor nodes and BSs within the R_{max} range of s_i.
  Therefore,
  $$ComS(s_i) = \{s_k \cup b_k \mid \forall s_k \cup b_k \in \{S + B\}\} \tag{1}$$
- **Hop message:** A message which contains the hop value. Initially the message is broadcast by the BSs by setting the hop value equal to zero within the range R_{max} and latter on it flooded by the sensor nodes.
- **Nhop(s_i):** The set of sensor nodes those might be selected as a next hop node of s_i. The next hop node must be towards the BSs. So,
  $$Nhop(s_i) = \{s_k \in ComSN(s_i)\} \tag{2}$$
- **HCount(s_i):** Denotes the number of next hops required to reach a BS from s_i. If s_i directly communicates with a BS, then HCount (s_i) is one. Therefore,
  $$HCount(s_i) = \begin{cases} 1, & \text{Nhop}(s_i) = b_j \in \text{B} \\ 1 + \text{HCount}(s_j), & Nhop(s_i) = s_j \in S \end{cases} \tag{3}$$
- **Average hop count:** Denotes average of hop counts of all the sensor nodes in the network. i.e.,
  $$Avg\_hop\_count = \frac{\sum_{i=1}^{n} HCount(s_i)}{n} \tag{4}$$
  Note that, decreasing the Avg_hop_count reduces the total energy consumption as the travelling distance for all the data packets from each sensor node reduces.
- **Lifetime of sensor node ($LT(s_i)$):** The lifetime of a sensor node s_i is calculated as $Energy(s_i)$ divided by the energy consumption of s_i for forwarding data to its next-hop sensor node per round, i.e.,
  $$LT(s_i) = \frac{Energy(s_i)}{\text{Total energy consumption of } s_i \text{ for a round}} \tag{5}$$

4. Proposed work

The procedure of the proposed model is given as follows. Initially, all the sensor nodes and BSs go through the bootstrapping process in which all the BSs broadcast HELLO message and all

Table 1
Notations and descriptions.

Notations	Descriptions
n	Number of sensor nodes
S	$\{s_1, s_2, s_3, \ldots, s_n\}$ Set of sensor nodes
m	Number of base stations
B	$\{b_1, b_2, b_2, \ldots, b_n\}$ Set of base stations
$alive(s_i)$	check whether the sensor node s_i alive or not
R_{max}	Maximum communication range of a sensor node.
$Nhop(s_i)$	Next hop sensor node of s_i
$Energy(s_i)$	Remaining energy of s_i.
$dis(s_i, s_j)$	Represent distance between sensor node s_i and s_j

sensor nodes reply a response to that message. Finally the BSs provide unique IDs for the sensor nodes. Next, the network setup phase is build which made up of setup phase and steady state phase. Initially at the set up phase, the BSs build a hop tree using the sensor nodes by allocating a hop value to each sensor node and then, the final route setup is accomplished with the help of proposed algorithm. The steady state phase consists of some pre-specified rounds say 50 or 75 rounds. Every round the sensor nodes forward their collected data to either next hop sensor nodes or BSs. This phase is continued until and unless there is a path from a sensor node to a BS.

Now we represent first the hop tree setup phase and then the proposed routing algorithm. Finally we represent the LP formulation for the routing problem.

4.1. Hop tree setup phase

Here, we discuss the formation of hop tree as follows. First, the BSs broadcast a hop message containing a hop value equal to zero to all the sensor nodes in the R_{max} communication range. After receiving the message, If a sensor node does not have any hop value then the node sets its hop value by increasing the hop value of hop message by one. For example, if a node s_i receive a hop value of 2, then s_i sets its hop value 3. After fixing the hop value, a sensor node again floods the hop message in the communication range R_{max}. This flooding process will continue until all the sensor nodes get a hop value. Note that, during this flooding process a sensor which already have the hop value may receives multiple hop messages flooded by all the BSs, however it keeps only the smallest hop value by incrementing one. The hop tree formation algorithm for multiple BSs is shown in Algorithm 1. The Fig. 3 shows the creation of hop tree for a single BS.

Algorithm 1. Hop tree formation

```
   Input  : Set of sensor node $S=\{s_1,s_2,s_3,...,s_n\}$
            alive($s_i$) $\forall\ s_i \in S$
   Output: $HCount(s_i)$: $\forall\ s_i \in S\ \rightarrow Z^+$
1  for each $s_i$, $1 \leq i \leq n$ do
2      if (alive($s_i$)) then
3          HCount ($s_i$) = TH // Some thresold value
4      else
5  end
6  for each sensor $s_i$, $1 \leq i \leq n$ do
7      for each base station $b_j$, $1 \leq j \leq m$ do
8          $d = dis(s_i, b_j)$
9          if ($d \leq R_{max}$ & & $HCount(s_i)$==TH && alive($s_i$)) then
10             $HCount(s_i\ ) = 1$
11         else
12     end
13 end
14 for each sensor $s_i$, $1 \leq i \leq n$ do
15     if ((alive($s_i$) && $HCount(s_i)$==TH)) then
16         temp = TH
17         for each sensor $s_j$, $1 \leq j \leq n$ do
18             $d = dis(s_i, s_j)$
19             if ($d \leq R_{max}$ && temp >$HCount(s_j)$) then
20                 temp = $HCount(s_j)$
21             else
22         end
23         if (temp $\neq$ TH) then
24             $HCount(s_i)$= temp+1
25         else
26     else
27 end
```

Lemma 1. *The worst case running time complexity of the hop tree formation algorithm is $O(n^2)$ for n sensor nodes and m base stations.*

Proof. For the line 1–5, initializing the value of $HCount(s_i)$ to some threshold value (TH) is $O(n)$ as in the worst case the all the sensor nodes remain alive. In the line 6–13, each sensor node checks whether it is in the communication range R_{max} of any BSs or not. Therefore, in the worst case time complexity of this section (line 6–13) is $O(m * n)$ for m BSs and n sensor nodes. In the line 14–27, each sensor node checks is there any sensor node in its communication range R_{max} which is already having a hop value or a hop value less than its own hop value. Therefore, each sensor node for the worst case checks with all of its neighbours i.e., the worst case complexity of this section of $O(n * (n-1))$ or $O(n^2)$. Therefore, the worst case complexity of the hop tree formation is $O(n) + O(m * n) + (n^2)$ or (n^2). $\square$

4.2. Routing phase

Now we discuss the routing algorithm. Here every sensor node selects the next hop node or BS in such a way that the lifetime of the network is maximized. This is implemented as follow. Initially, all the sensor nodes which are within the R_{max}range of any BS $b_j, \forall b_j \in B$, they transmit the data directly to their corresponding nearest BSs, i.e., $Nhop(s_i) = b_j$. Otherwise, a sensor node has to find some other sensor node as next hop node. During this next hop selection process, a sensor node s_i always selects a node $s_j$from its $ComS(s_i)$ having the hop value one less than the hop value of s_i, i.e., $HCount(s_i) = HCount(s_j) + 1$. But, still the node s_i may have many possible next-hop nodes with same hop value within its communication range. In that scenario, the node s_i selects a next hop node $s_j$based on maximum fitness value of a fitness function (say, $Fitnessfun(s_i, s_j)$) which is given as follows.

$$Fitness\ fun(s_i, s_j) = \frac{Energy(s_j)}{dis(s_i, s_j) * dis(s_j, s_k)} \tag{6}$$

Note that, a sensor node (s_i) should select another next hop sensor node (s_j) which has maximum energy (i.e.,Fitnessfun$(s_i, s_j) \propto$ Energy(s_j)). A sensor node losses maximum energy to communicate with other sensor node. So sensor node (s_i) should select the nearest next hop sensor node (s_j) (i.e., Fitnessfun(s_i, s_j) $\propto$1/dis(s_i, s_j)) Similarly, s_i should select that s_j whose distance between s_j and next hop sensor node of s_j (say, s_k) is minimum (i.e., Fitnessfun$(s_i, s_j) \propto 1/$dis(s_j, s_k). The next hop selection in routing phase is shown in Algorithm 2.

Algorithm 2. Routing

```
Input  : Set of sensor nodes $S=\{s_1,s_2,s_3,...,s_n\}$
         alive($s_i$) , HCount($s_i$) $\forall s_i \in S$
Output: Nhop($s_i$): $\forall s_i \in S \rightarrow$ {S + B}
for each $s_i$, $1 \le i \le n$ do
    if (alive($s_i$)) then
        $Nhop(s_i)$ = TH
    else
end
for each sensor $s_i$, $1 \le i \le n$ do
    if (alive($s_i$)) then
        for each $b_j$, $1 \le j \le m$ do
            $d = dis(s_i, b_j)$
            if ($d \le R_{max}$ && $Nhop(s_i)$==TH) then
                $Nhop(s_i) = b_j$
            else
            end
        end
    else
end
for each sensor $s_i$, $1 \le i \le n$ do
    if (alive($s_i$) && $Nhop(s_i)$==TH) then
        temp = 0 ; k=TH
        for each sensor $s_j$; $1 \le j \le n$ do
            $d = dis(s_i, s_j)$
            calculate $Fitnessfun(s_i, s_j)$ using (eq.6)
            if ($i \neq j$ && $d \le R_{max}$ && Nhop(j)$\neq$ TH && alive(j)&&
              HCount($s_j$)<HCount($s_i$)&& temp<$Fitnessfun(s_i, s_j)$ ) then
                temp = $Fitnessfun(s_i, s_j)$
                $k = s_j$
            else
        end
        if k$\neq$ 0 then
            $Nhop(s_i) = k$
        else
    else
end
```

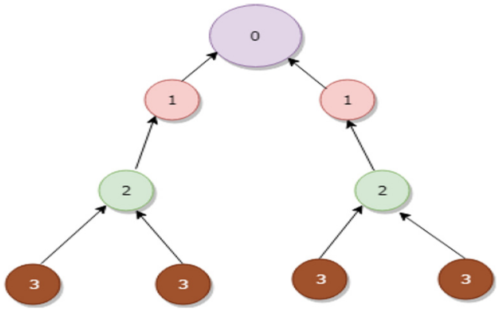


Fig. 3. Hop tree.

Lemma 2. *The worst case running time complexity of the routing algorithm is* $O(n^2)$ *for* n *sensor nodes and* m *base stations.*

Proof. For the line 1–5, first we check the aliveness of sensor nodes. If a node is alive then initializing the $Nhop(s_i)$ to some threshold value (TH). In the line 6–16, each sensor node checks whether it is in the communication range R_{max} of any BSs or not. If any BS is in the communication range then $Nhop(s_i)$ equals to the corresponding BS. Therefore, in the worst case time complexity of this section (line 6–16) is $O(m*n)$ for m BSs and n sensor nodes. For the line 17–32, each sensor node checks is there any sensor node in its communication range R_{max} and calculate the fitness function. Therefore, each sensor node for the worst case checks with all of its neighbours i.e., the worst case complexity of this section of $O(n*(n-1))$ or $O(n^2)$. Therefore, the worst case complexity of the routing algorithm is $O(n) + O(m*n) + (n^2)$ or (n^2). □

4.3. LP formulation for routing problem

In the proposed model, the lifetime of the network means the number of rounds until the first sensor node dies. The objective of the proposed model is to enhance the lifetime of the network and that is only possible when we maximize the lifetime of the fast energy drainage sensor node. Therefore, this can be achieved by properly distributing the routing overload among the sensor nodes. If we consider the average number of next hop nodes for a sensor node s_i is k, then there is k^n possible way to create the paths towards the BSs for n number of sensor nodes. Thus, routing problem is an optimization problem which can also be solved using LP formulation. Let $X_{i,j}$be a Boolean variable such that,

$$X_{i,j} = \begin{cases} 1, & \text{if } Nhop(s_i) = s_j \mid \forall s_i \in S \text{ and } s_j \in \{S+B\} \\ 0, & Otherwise \end{cases} \tag{7}$$

Hence, the LP formulation for routing problem to maximize the lifetime of the network can be written as follows.

$$fitness = min\{LT(s_i) \mid \forall s_i \in S\} \tag{8}$$

$$\text{Objective} = \text{Maximize } fitness \tag{9}$$

Subject to

$$\sum_{j=1}^{n+m} a_{i,j} = 1, \forall i1 \leqslant i \leqslant n, \forall s_i \in S, \forall s_j \in \{S+B\} \\ \text{and } HCount(s_j) < HCount(s_i) \tag{10}$$

$$\sum_{j=1}^{n+m} dis(s_i, s_j) * X_{i,j} \leqslant R_{max}, 1 \leqslant i \leqslant n, \\ \forall s_i \in S, \forall s_i \in \{S+B\}, i \neq j \text{ and } HCount(s_j) \tag{11}$$

Note that, the first constraint (Eq. (10)) guarantees that each sensor node $s_i$selects only one next hop node $s_j$or BS $b_j$towards the BS. On the other hand, second constraint (Eq. (11)) guarantees that a sensor node $s_i$select a next hop node $s_j$only if it is within the maximum communication range R_{max}.

4.4. An illustration of the proposed model

For better understanding of the proposed model, we assume a small wireless sensor network scenario with 10 sensor nodes $S = \{s1, s2, s3 \ldots, s10\}$ and 3BS $B = \{b1, b2, b3\}$ shown in Fig. 4. The sensor nodes (shown in image red circle) and the BSs (blue square) are deployed in the boundary line of the target area. After that, the hop value (say h_1, h_2, h_3 etc.) for every sensor node is calculated using the Algorithm 1. The sensor node whose hop value is 1 (e.g., $s_1, s_4, s_5, s_7, s_8, s_{10}$) can send data directly to the BSs and whose hop value is greater than 1 (e.g., s_2, s_3, s_6, s_9) can send data via the intermediate next hop nodes. During the next hop selection process, a sensor node s_i always selects a next hop node s_j whose hop value is one less than the hop value of s_i i.e., HCount(s_i) = HCount(s_j)+1. Thus, the node s_6 with hop value h_2 will select either s_5 or s_7 since their hop value is h_1. Now whether s_6 selects s_5 or s_7

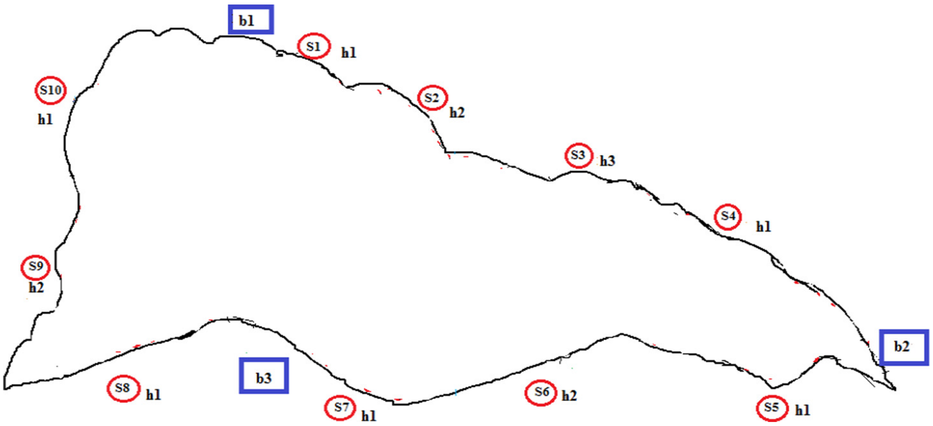


Fig. 4. An illustration of the proposed model.

that is depends on maximum fitness value using the Eq. (6). When a sensor node senses the presence of human movement around the boundary area, immediately the captured data is forward to the nearest BS so that immediate action can be taken against them.

5. Simulation results

The simulations of proposed algorithm were performed using Matlab R2014a on Intel CORE i3 processor, 4 GB RAM and 2.40 GHz CPU running on the Microsoft Windows 8.1 platform. As per our knowledge we have not found any WSN's scenarios similar to our proposed model where sensor nodes are placed in the perimeter of large boundary of Rhino inhabited area for the fair comparison. We have created our own scenario for the comparison of the proposed model by varying number of sensor nodes (60, 90) and varying number of BSs (3, 5, 7). For simulations, we have used the energy equations ([22–24]) given in the Eqs. (12) and (13). We assume that each node's initial energy was 2j and BSs have unlimited energy ([22–24]). We have used the following values of parameter as in ([25,26]) shown in Table 2.

$$E_{T}(p,dis)=\begin{cases} p.E_{elec}+p.e_{fs}.dis^{2} & dis \leqslant dis0 \\ p.E_{elec}+p.e_{mp}.dis^{4} & dis \geqslant dis0 \end{cases} \tag{12}$$

$$E_{R}(p)=p.E_{elec} \tag{13}$$

Multi-path fading channels and the free space are used based on the distance between sender and receiver. When threshold value is greater than distance $dis0$ then free space model is used, otherwise multi path model. If E_{elec} is the energy required by the electronics circuit, e_{fs} and e_{mp} are the energy required by amplifier in free space and multi-path respectively, energy required by the radio to transmit an p-bit over a distance dis is given in Eqs. (12) and (13).

Table 2
Parameters for experiments.

Parameters	Value
Sensor nodes	60/90
Base Stations	3/5/7
Initial energy of nodes	2 j
R_{max}	100 m
E_{elec}	50 nJ/bit
E_{mp}	0.0013 pJ/bit/m^4
E_{fs}	10 pJ/bit/m^2
Packetsize	4000 bits
Messagesize	200 bits

5.1. Energy consumption

First, we discuss the algorithm for total energy consumption of 60 sensor nodes and 90 sensor nodes in the Fig. 5(a-b). In both the figures, we observed that total energy consumption is very less for 7 BSs in comparison to 5 and 3 BSs. This is because of (i) the fitness function (Eq. (6)) in which each sensor node carefully selects its next hop node to send the data packet towards BS with minimum energy consumption, (ii) due to the formation of hop tree, each sensor nodes always send data to its nearest BS which reduces the data packets travel distance from each sensor nodes to the BS for the 7 BSs scenario, (iii) when the number of BSs increase the average hop counts for each sensor node towards the BS are decreased and as a result, the data packet from each sensor node has to travel less distance to reach the BS, and (iv) Increasing the number of BSs reduce data forwarding load for each sensor nodes towards BSs, hence less energy consumption for 7 BSs. On the other hand, the average hop counts as well as the travel distance for each data packet from each sensor node to the BS for the 5 BSs are greater than 7 BSs but less than 3 BSs, that's why the energy consumption for 5 BSs is greater than 7 BSs but less than 3 BSs and 3 BSs has the highest energy consumption among all. Note that, in Fig. 5(a), the energy consumption for the 7 BSs is lowest through the lifetime, but for the 3 BSs the energy consumption is highest up to 2000 rounds and after that it is lower than 5 BSs. This is due to the sudden death of large number of sensor nodes (see Fig. 6(a)) at around 2000 rounds for the 3 BSs, however for the 5 BSs, the number of dead sensor nodes at around 2000 rounds is lower than 3 BSs and hence more sensor nodes are alive and hence, more energy consumption. Similarly for the Fig. 5(b), the energy consumption for the 7 BSs at around 2500 rounds is higher than 5 BSs because of large of dead sensor nodes (see Fig. 6(b)) for 5 BSs reduces its energy consumption, but at the same time number of dead nodes is very less (see Fig. 6(b)) for 7 BSs at around 2500 rounds, i.e., higher number of alive sensor nodes and hence high energy consumption.

5.2. Dead sensor nodes

Now we represent the number of dead sensor nodes for the same scenario in Fig. 6(a-b). As we have seen earlier that the increased in the number of BSs reduces the energy consumption for each sensor nodes, thus the lifetime of each sensor nodes increased too. Therefore, the sensor nodes die in the network due to energy depletion after very longer period of time. In Fig. 6(a), we can observe that the number of dead sensor node is very less for the 7 BSs followed by 5 BSs and 3 BSs, because

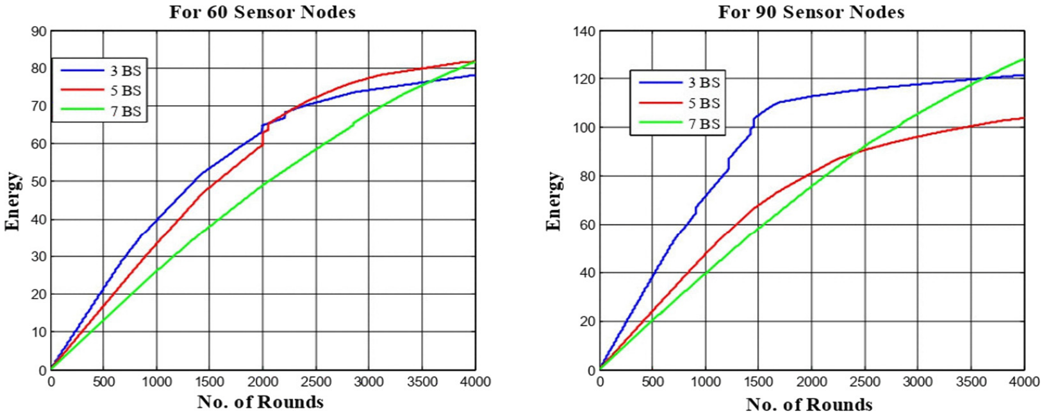


Fig. 5. Comparison in terms of (a) Energy consumption for 60 sensor nodes. (b) Energy consumption for 90 sensor nodes.

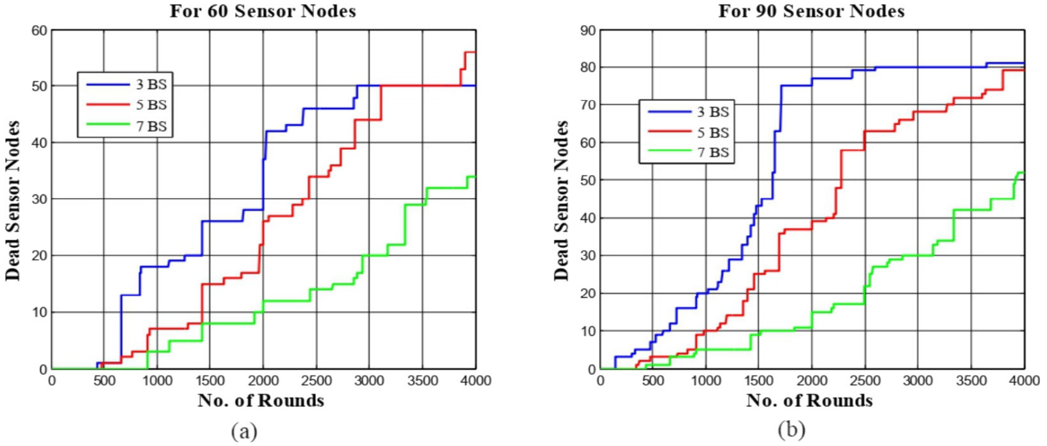


Fig. 6. Comparison in terms of (a) Number of dead sensors for 60 sensor nodes (b) Number of dead sensors for 90 sensor nodes.

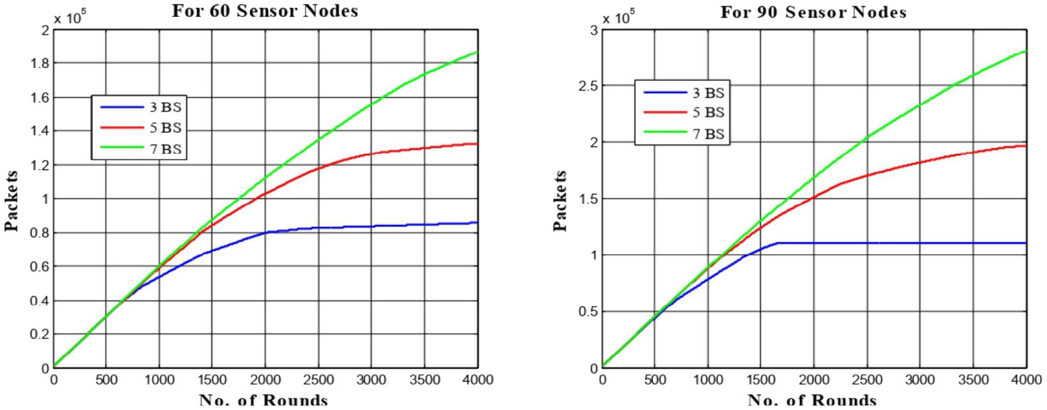


Fig. 7. Comparison in terms of (a) Packet received by BSs for 60 sensor nodes (b) Packet received by BSs for 90 sensor nodes.

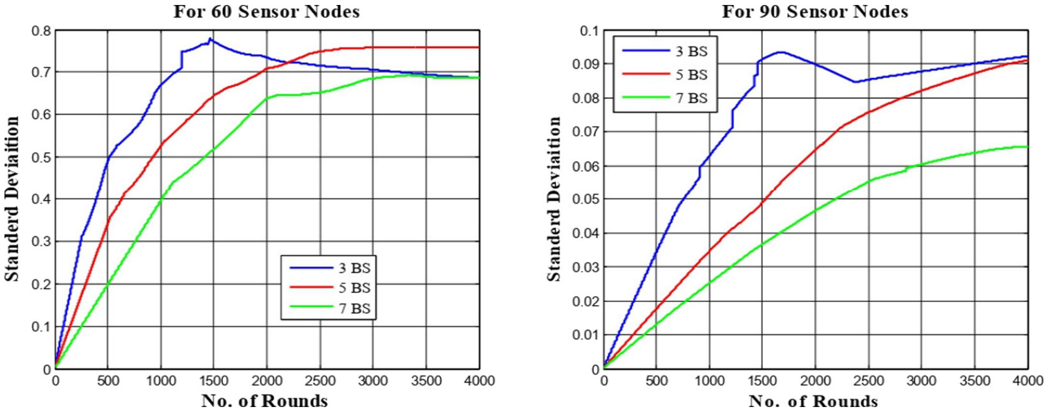


Fig. 8. Comparison in terms of (a) Standard deviation for 60 sensor nodes (b) Standard deviation for 90 sensor nodes.

the data forwarding load as well as energy consumption for each sensor node is lowest in 7 BSs scenario. Thus a large number of nodes remain alive in the network for longer period of time. On the other hand energy consumption rate for each sensor node in 5 BSs higher than 7 BSs, that's why the number of dead nodes is higher for the 5BSs and it is highest for 3 BSs. Same can also be seen in the Fig. 6(b).

5.3. Packets received

In this section, we compared the total data packets received at the BSs for 60 sensor nodes and 90 sensor nodes which is shown in Fig. 7(a-b). In both the scenarios, the packets received at BSs are very high for 7 BSs compare to others. It can be observed from Fig. 7(a) that the number of data packets received at BSs for 7BSs is very high compared to 5 BSs and 3 BSs. The reasons behind them are when we use more BSs then energy consumption rate of nodes are very less, so the large number of sensor nodes remains alive (see Fig. 6(a-b)) in the network for long time in the network which results large number of data packets received at BSs. However, the sensor nodes in the 5 BSs and 3 BSs scenario remain alive less time compared to 7 BSs and hence less number of data packets received at BS for these two scenario.

5.4. Standard deviation

Now we compare the results in terms of energy balancing. Fig. 8(a-b) shows the standard deviation of remaining energy of all the sensor nodes after each round. It can be observed from the Fig. 8(a-b) that the standard deviation for the 7 BSs scenario is lowest among the others two. Moreover it is increasing for all the scenarios with increasing rounds. Since the energy consumption rate for each sensor node is different in a particular scenario due to their different hop counts. The energy consumption rate the very high for the nodes near to the BSs and very low for the node furthest from the BSs. Also with increasing rounds the number of dead sensor nodes is also vary for different scenarios (see Fig. 6(a-b)) which reflects the standard devotion which can be seen in the Fig. 8(a-b).

6. Conclusions and future work

In this paper, we have proposed an application of WSNs to avoid the Rhino poaching in Kaziranga National Park. In this application, first a hop tree formation algorithm is proposed and then a routing algorithm has been proposed to maximize the lifetime of the network. We have measured the time complexity of both the algorithms. Then a LP formulation for the routing problem has been proposed. Finally, we enormously have simulated the proposed algorithm and justified the results in terms of various performance metrics such as energy consumption, standard deviation of remaining energy of nodes etc. In our propose application, we have not considered fault tolerance issue of the sensor nodes, however our future work will be made to develop algorithms considering the fault tolerant issue.

Declaration of Competing Interest

None.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.aeue.2019.152882.

References

[1] Powers RP, Jetz W. Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios, Nature. Clim Change 2019:1.

[2] Foose TJ, Khan MKBM, van Strien NJ. Asian rhinos: status survey and conservation action plan, vol. 32. IUCN; 1997.

[3] https://www.theatlantic.com/business/archive/2013/05/why-does-a-rhino-horn-cost-300-000-because-vietnam-thinks-it-cures-c; 2013.

[4] Karthik S, Kumar AA. Challenges of wireless sensor networks and issues associated with time synchronization. In: Proceedings of the UGC sponsored national conference on advanced networking and applications.

[5] Bapat V, Kale P, Shinde V, Deshpande N, Shaligram A. Wsn application for crop protection to divert animal intrusions in the agricultural land. Comput Electron Agric 2017;133:88–96.

[6] Viani F, Robol F, Giarola E, Benedetti G, De Vigili S, Massa A. Advances in wildlife road-crossing early-alert system: New architecture and experimental validation. In: 2014 8th European Conference on Antennas and Propagation (EuCAP). IEEE; 2014. p. 3457–61.

[7] Zhang J, Li W, Yin Z, Liu S, Guo X. Forest fire detection system based on wireless sensor network. In: ICIEA 2009. 4th IEEE conference on industrial electronics and applications, 2009. IEEE; 2009. p. 520–3.

[8] Bouabdellah K, Noureddine H, Larbi S. Using wireless sensor networks for reliable forest fires detection. Procedia Comput Sci 2013;19:794–801.

[9] Kułakowski P, Calle E, Marzo JL. Performance study of wireless sensor and actuator networks in forest fire scenarios. Int J Commun Syst 2013;26:515–29.

[10] Khan A, Jenkins L. Undersea wireless sensor network for ocean pollution prevention. In: COMSWARE 2008. 3rd International conference on communication systems software and middleware and workshops, 2008. IEEE; 2008. p. 2–8.

[11] Lévesque M, Tipper D. A survey of clock synchronization over packet-switched networks. IEEE Commun Surv Tutor 2016;18:2926–47.

[12] Xiong Y, Wu N, Shen Y, Win MZ. Cooperative network synchronization: Asymptotic analysis. IEEE Trans Signal Process 2017;66:757–72.

[13] Yuan W, Wu N, Etzlinger B, Wang H, Kuang J. Cooperative joint localization and clock synchronization based on gaussian message passing in asynchronous wireless networks. IEEE Trans Veh Technol 2016;65:7258–73.

[14] Obodoeze FC, Nwobodo LO, Nwokoro SO. Underwater real-time oil pipeline monitoring using underwater wireless sensor networks (uwsns): Case study of niger delta region. Sensors 2015;2.

[15] Ahonen T, Virrankoski R, Elmusrati M. Greenhouse monitoring with wireless sensor network. In: 2008 IEEE/ASME international conference on mechtronic and embedded systems and applications. IEEE; 2008. p. 403–8.

[16] Chaudhary D, Nayse S, Waghmare L. Application of wireless sensor networks for greenhouse parameter control in precision agriculture. Int J Wireless Mobile Networks (IJWMN) 2011;3:140–9.

[17] Lin J, Zhu B, Zeng P, Liang W, Yu H, Xiao Y. Monitoring power transmission lines using a wireless sensor network. Wireless Commun Mobile Comput 2015;15:1799–821.

[18] Tyagi S, Kumar N. Journal of network and computer applications a systematic review on clustering and routing techniques based upon leach protocol for wireless sensor networks. J Netw Comput Appl 2013;36:623–45.

[19] Tanwar S, Kumar N, Rodrigues JJ. A systematic review on heterogeneous routing protocols for wireless sensor network. J Network Comput Appl 2015;53:39–56.

[20] Al-Karaki JN, Kamal AE. Routing techniques in wireless sensor networks: a survey. IEEE Wireless Commun 2004;11:6–28.

[21] Azharuddin M, Jana PK. Particle swarm optimization for maximizing lifetime of wireless sensor networks. Comput Electr Eng 2016;51:26–42.

[22] Heinzelman WB, Chandrakasan AP, Balakrishnan H, et al. An application-specific protocol architecture for wireless microsensor networks. IEEE Trans Wireless Commun 2002;1:660–70.

[23] Kaswan A, Nitesh K, Jana PK. Energy efficient path selection for mobile sink and data gathering in wireless sensor networks. AEU-Int J Electron Commun 2017;73:110–8.

[24] Nitesh K, Azharuddin M, Jana P. Minimum spanning tree–based delay-aware mobile sink traversal in wireless sensor networks. Int J Commun Syst 2017;30:e3270.

[25] Azharuddin M, Kuila P, Jana PK. Energy efficient fault tolerant clustering and routing algorithms for wireless sensor networks. Comput Electr Eng 2015;41:177–90.

[26] Kia G, Hassanzadeh A. A multi-threshold long life time protocol with consistent performance for wireless sensor networks. AEU-Int J Electron Commun 2019;101:114–27.