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# Monitoring Wild Life Passages across Transport Infrastructures using Delay Tolerant Wireless Sensor Network

AR.Arunachalam

Assistant Professor, Department of Computer Science, Bharath University, Chennai, Tamil Nadu, India

**ABSTRACT:** Wireless Sensor Networks have become a far-reaching technology with diverse potential applications for the monitoring different environments and to gather application specific parameters such as sound, vibration, temperature or pollutants. We are concerned about the wireless sensor networks which are used in wildlife monitoring. In these particular contexts, specimen protection and conservation is a challenge, especially in natural reserves, dangerous locations or hot spots of these reserves (*i.e.*, roads, railways, and other civil infrastructures). This paper proposes and studies a WSN based system for generic target (animal) tracking in the surrounding area of transportation infrastructures to establish safe ways for animals to cross these infrastructures. Here we can use a delay tolerant wireless sensor network where each node can cache a meticulous amount of data for a particular period of time. A mobile sink is used to assist the event collection by moving the mobile sink towards the static nodes to gather information. In a densely packed network the same event can be detected by multiple nearby sensors within a period of time. Thus, it is more energy-efficient if the mobile sink can selectively communicate with only a portion of static sensors, while still collecting all the interested events. Furthermore, an XOR operation is performed on the collected data in order to prevent the sending of the same data sensed by the nodes close to each other. This network can perform real time functions such as sending an alarm message which does not wait for the mobile sink to arrive but sends the message to the destination via multi-hop communication.

**KEYWORDS:** Event collection,sensornetworks, mobile sink,spatial-temporal correlation.

## I. INTRODUCTION

Highways which bisect wildlife habitat have direct and indirect ecological effects on local fauna. High traffic volumes can impair or prevent wildlife movements across the highways to meet daily or seasonal requirements for food, water, secure cover, dispersal of young and reproduction. The negative impacts of transportation on wildlife are dual. Primarily, they reduce the size of species populations as a consequence of road kills and the so-called edge effect, *i.e.*, the reduction of the population density in areas close to roads (due to animal aversion to the road system, human activities or traffic noise). Second, the movement of local fauna between populations fragmented by roads and other infrastructures on either side may be reduced. These concerns can be overcome by building wildlife passages across the highways. Therefore, the knowledge about the paths followed by animals would also be desirable in order to have a better understanding on where the wildlife passages have to be installed. Some of the traditional techniques used for wildlife tracking are binoculars, cameras, antennas or animal tagging. But these methods are proved to be inefficient.

Wireless Sensor Networks is a potential option in overcoming the limitations in traditional methods of wildlife monitoring. Some of the delay tolerant events which are monitored by WSN are such as temperature, humidity of forest for ecology monitoring or animal habitual tracking. The main task of a wireless sensor node is to sense and collect data from a certain region, process them and transmit them to a sink node. The sink nodes aggregate the information from the sensor nodes and make the decisions on the events. Wireless sensor networks have very limited energy in the form of battery which in most applications is expected to last for a long time.

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This paper proposes a framework to maximize the lifetime of a Wireless Sensor Network by taking advantage of sink mobility. Here the principal applications can tolerate delayed information delivery to the sink in an event collection region which is a forest region, where the static sensor nodes are deployed to monitor the environment and report the events. Since the sensor nodes have limited battery energy, it is inevitable to schedule the network so as to use the energy resources efficiently. Events may have spatial-temporal correlation, i.e., the same event may be detected by multiple nearby sensors within a period of time. Therefore, instead of collecting all the sensor readings from every static sensor node, selective querying performed by mobile sink is preferable. This helps in prolonging significantly the network lifetime. Also the same node may sense the same event simultaneously over a continuous period of time. Transmitting duplicated data depletes the precious battery energy of a sensor node. This depletion can be avoided by using suitable techniques to detect duplicate data and drop them. We also propose a method by which real time data such as critical data can be handled. For example a forest fire or human intervention in restricted wildlife area can be transmitted immediately to base station. Here the sensor nodes do not wait for the mobile sink but immediately send the data to destination in a multi-hop communication fashion.

The rest of the paper is organized as follows. In Section II we briefly describe some related work by other authors. In Section III we describe our proposed system architecture in detail. In Section IV, we provide our simulation results performed to analyze and evaluate our system In Section V; we give our conclusions and future work.

## II. RELATED WORK

The most commonly used approach for the control of wildlife passages consists of employing cameras which are activated by an infrared motion detector [1]. It merely focuses on the detection of animals getting close enough to the detector. As a consequence, a very small area is covered and, thus, many animals are not detected. Also, having only one control point at the entrance of the passage makes it impossible to determine whether the animal finally avoided the structure under study or not. General tracking methods which offer valuable tracking results for scenarios other than wildlife passages can also be employed. This is the case of systems based on GPS receivers attached to animals [2]. Although they can be used for tracking animals over very large areas, they are not well suited for small areas as in the passage surveillance problem.
The model proposed in [4] introduced mobile sink, which move around and collected data from nearby sensor nodes on behalf of the immobile sink. It was assumed that the mobile agents have plenty of energy. However, the authors did consider using a sensor selection mechanism to enhance network lifetime. The WSN model proposed in [3] studied the maximum lifetime problem of the WSN where the mobile sink can visit only a small number of locations. They showed that the lifetime can be further increased by optimizing not only the schedule of sink visits but also routing of the traffic. However, they did not consider applications where delayed information delivery is allowed.
. The model proposed in [5], [6] includes the cost of moving the mobile sink (such as nodal energy consumption for route establishment/release when the sink moves to a new stop) and the sink mobility rate determined by the minimum sink sojourn time at the sink stops. Furthermore, the model incorporates a hop-length limit when the sink moves to next stop. TiNA [7] exploits temporal correlation in sensor data, and CAG [8] takes advantage of spatial correlation. These works only focus on gathering complete sensor readings without taking sink mobility into consideration. In short summary, our problem is the first one to leverage the advantages of both the mobile sink and the spatial-temporal correlation of event. We focus on controlling the mobile sink to selectively query static sensors' readings for event collection according to the delay constraints and the spatial-temporal correlation of event.
The Threshold sensitive Energy Efficient Network protocol (TEEN) was introduced in [9] and is essentially an interesting modification of the fundamental LEACH protocol (Low-Energy Adaptive Clustering Hierarchy, [10]) for reactive sensor networks [11]. The basic property of TEEN involves: (i) the clustering of nodes and (ii) the use of thresholds in order to decide whether the data should be transmitted to the sink. Hard threshold value: This is a threshold value for the sensed attribute. In order for the node to transmit the sensed value to the cluster head, the sensed value has to be above this hard threshold value. Soft threshold value: The sensed value is transmitted to the cluster head if there is a change compared to the previous sensed value that is greater than the soft threshold value. The nodes continuously sense their environment. When a value greater than the threshold value is sensed, it is stored in an internal variable in the node. In the subsequent sensing activities, it is checked whether the sensed value has changed by an amount greater or equal to the soft threshold value. If so, the data is transmitted to the respective cluster head. Our

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protocol also uses threshold values, but their use is different than in the TEEN protocol. We have a base threshold which is used to filter out the undesired data and in this way reduce the transmissions to the neighboring nodes (i.e., filtering is done at the sensor nodes). We also have a critical threshold that is used to expedite the delivery of the data from the sink node to the base station.

## III. GENERAL ARCHITECTURE

The following section gives an overview of WSNs and the technologies employed to monitor the local fauna to track the path used by them to cross the transport infrastructure. The sensor nodes are placed in the vicinity of the transport infrastructure to monitor the environment and it helps in analyzing the behavior of the animals in the neighborhood. The general architecture consists of a number of sensor nodes, a mobile node called the mobile sink and a base station. All the static sensor nodes are assumed to know their positions. The sensor nodes use a suitable communication protocol for communicating between the sensor nodes and the mobile sink. The mobile sink can be attached to a patrol vehicle which moves along the transportation infrastructure.

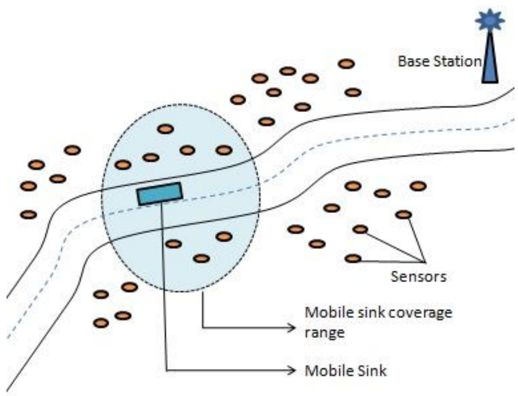


Fig 1 System Architecture

The mobile sink is a sensor node which can collect data from the sensor nodes which are within its coverage area .The velocity with which the mobile sink moves to gather data is not considered in this paper. This paper proposes a system which mainly focuses on maximizing the lifetime of the wireless sensor network to the full extend as possible. The use of delay tolerant sensor network assists in improving the lifetime of the network considerably. In a delay tolerant sensor network each node does not need to send the data immediately as it becomes available, instead the node can store the data temporarily and transmit the data when the sink is at the most favorable location for achieving the longest WSN lifetime. The lifetime can be increased significantly when a mobile sink in implemented in the network. It moves around the network and collects the data from various static nodes. The static sensor nodes need not send the data to the sink in a multi-hop fashion but the nodes can wait until the sink arrives to collect their data. We also perform event selection where the sink can selectively collect data from particular sensors to avoid any duplicate data. In a densely placed sensor network usually the same event may be detected by multiple nearby sensors over a period of time. Thus it is more energy efficient if the mobile sink can selectively communicate with only a portion of static sensors, while still collecting all interested events. Another example is in military applications where a rival’s military activities can be monitored. A mobile sink which is attached to an unmanned spy aircraft can be used to survey and to collect information from the sensor nodes installed in enemy territory which could be air dropped by a spy aircraft. Here each node does not send the sensed data immediately to the sink as it becomes available instead, the nodes aggregate the data temporarily for a prescribed delay tolerance level and transmit it when the mobile sink is at the most favorable location so as to achieve the longest network lifetime.

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### A. *Functional architecture*

The Functional Architecture for the proposed system is given in Figure 2. The functional architecture shows the modules of the stationary sensor node, mobile sink node and the base station are specified. The sensor node is installed to sense the environment and collect the data[2]. The collected data is buffered queued in node until the mobile sink arrives. The node is made more intelligent by using the duplication detector and the crisis detector. The duplication detector looks for any duplication in the sensed data and make sure that all the duplications are filtered out using suitable techniques.

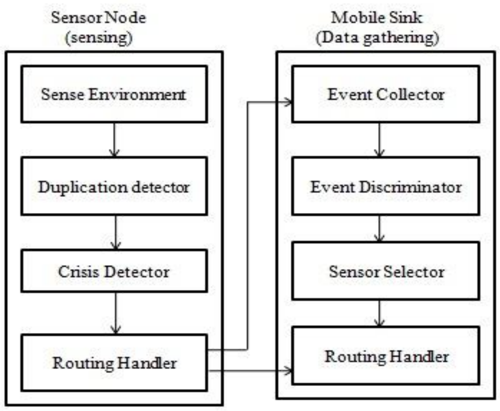


Fig 2 Functional Architecture

The Crisis Detector looks for any critical data among the sensed data. This is possible with the use of thresholds which are discussed later in this paper. Crisis detector sends the critical data immediately to the mobile sink in a multi-hop communication fashion. This data doesn't wait for the mobile sink to arrive. The mobile sink moves around the network in a fixed route and the Event collector performs data gathering from the static sensor nodes. The mobile sink performs the spatial and temporal correlation to find sensors sensing similar data. From the group of sensors belonging to an event region which are sensing similar data; only one sensor is selected which has the highest amount of energy is left in it. Hence it helps in reducing the transmission power of the sensor nodes considerably. The communication module helps in performing communication between the sensor nodes and the mobile sink[1].

### B. *Lifetime maximization by using delay tolerant network*

In this section, we consider how the life time of the networks is maximized by using applications that can tolerate a certain amount of delay. In this setting, each node can postpone the transmission of data until the sink is at the most favourable location for extending the network lifetime. This helps the nodes to collectively achieve a longer network lifetime in contrast to other models which do not exploit this possibility.


Fig 3 Two Nodes and Location

Let's take an example to show how our framework can outperform other ones. Consider the two-node example shown in Figure 3. Node1 ($N_1$) and Node2 ($N_2$) are two sensor nodes and the two locations $L_1$ and $L_2$ are the candidate stops of the mobile sink where the mobile sink can gather data. Both nodes $N_1$ and $N_2$ generate data at 1 bps and have 100 units of energy initially. When the sink is at $L_1$, mobile sink gathers data from $N_1$ and latter the mobile sink gathers data from $N_2$ when it is at $L_2$. In this method, the nodes do not always participate in the communication for all the sink stops; they each wait until the sink's location is most favourable for energy saving, and then send data at the higher rate. Unlike the others, the sink in our model can collect data from only a subset of the set of all sensor nodes, N, at each stop. Let $R_{L1}$ be the subset of N such that only nodes in $R_{L1}$ can participate in the communication when the sink is at $L_1$. We call $R_{L1}$

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the coverage area of the sink at that location $L_1$. Note that the union of all $R_L$ over every L must be the set of all sensor nodes, N. In other words, any sensor node should be covered by at least one sink location. In previous methods the sink collects data from each node i at the same rate at which node i generates the data. However, in our model the data transmission rates at node i during the collection time is no longer the same as the constant data generation rate $d_i$. When node i is not active (i.e., not covered by the current sink location), it continues to gather data and should store the newly generated data. Hence, data buffering is required by our framework.

*C. Sensor selection to avoid duplicate data gathering*

Sensor readings can have spatial-temporal correlation, i.e., neighbouring sensors may have similar sensor readings and one sensor's readings do not change acutely in a period of time. Since the interested event is defined as a range of sensor readings, we believe that the event may also have spatial temporal features. A good understanding of this characteristic plays an important role in developing a cost-effective system. Let us regard sensor reading *Rt* at space-time point (*Xi, Yi, t*). Let $Kt_i$ indicate the event happens on location (*Xi, Yi*) at time slot *t*. For two happened events $Kt_\alpha$ and $Kt_\beta$ we call them *identical* if one of the following conditions holds:
$|Xi_\alpha - Xi_\beta| \le 1$, $|Yi_\alpha - Yi_\beta| \le 1$ and $|t_\alpha - t_\beta| \le 1$.
Two events are called *individual* if they are not *identical*. All the identical events form one *event region[3]*. This actually helps in verifying the spatial-temporal correlation of an event that is happening in a region simultaneously and last for a period of time. To collect the event information from one static sensor node, the query action $Qt_i$ would wake up and consume the energy of sensor $S_i$. To simplify the energy consumption model, we ignore the energy cost for sleeping and assume that the energy cost to respond a query action $Qt_i$ is *one* unit. We take into account that the network lifetime, which is defined as the time instant when the first sensor runs out of energy. The objective of our problem is to select a sensor with the maximum amount of residual energy in an event region. Only one sensor with maximum residual energy is queried for data collection in an event region from a group of sensors with spatial-temporal correlation. The mobile sink can move along the transport infrastructure from one static sensor node to another to complete the selected query actions[4].

*D. Filtering node level duplication*

In a sensor network, close-by nodes may fall into the same region and sense same data moreover. This will result in sensor nodes sending duplicated data to the base station. This results in transmitting more and unwanted data to the mobile sink by a node, which eventually depletes the node energy. In our proposed solution, as a node senses data from the environment, an XOR operation is performed on the sensed data with the buffered data in queue in order to check if they are the same. If the newly received data already exists among the previously sensed data, the latter is ignored, because the same data has been sensed before and is being kept waiting at the node to be sent to the mobile sink.

In this way, we sense a data and compare the incoming data with the waiting data, to prevent redundant transmissions (transmitting the same data). This reduces the volume of traffic transported across the resource-scarce wireless sensor network hence reducing the depletion of precious battery energy. It also means less processing at the mobile sink. If all the received data is the same with the first waited data, none of the new data is sent to the mobile sink. In this way, the whole network consumes less energy.

There are various methods that can be used to compare the new data with the waiting data. If the information is ON/OFF information (*i.e.*, it can be represented with a single bit), then we can apply simply an XOR operation (Table 1). It will XOR a new incoming bit together with the already existing bit (waiting data); if the result is one, then the new data will also be queued besides the waited data in the node buffer.

TABLE 1
XOR Truth Table

| X | Y | Z |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

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Other data filtering techniques can be used as well for different data types. XOR is good for Boolean data. For byte or integer data, binary comparison can be performed and filtering out can be decided if the difference is less than a certain value.

*E. Handling critical data*

We propose the use of two threshold values to reduce the amount of data sent to the mobile sink, but still react to emergency cases as quickly as possible. The two thresholds we propose are: (1) High threshold (2) Low threshold.

High Threshold is the critical value above which we assume that there is an emergency situation that has to be handled as quickly as possible. Hence, when the network senses a value above this threshold, the data will be sent to the sink node without being kept waiting at the respective sensor node. It is transported towards the base station as soon as possible. The critical threshold in our application can be human intervention in restricted areas or a forest fire. Critical threshold is important for the rescue teams to detect the emergency situation as soon as possible so that the best emergency decisions could be taken in the environment without much delay. The precautions taken on time will be very important for the rescue.

Low Threshold is the minimum value desired to be sensed and to be reported to the mobile sink. The sensed values above the low threshold will be delivered to the base station, but there is not much hurry in delivering them. Hence the sensor nodes can store such data for a while. A value below the low threshold will be ignored at the sensor nodes and will neither be delivered to the nearby nodes nor to the mobile sink[5][6].

The nodes constantly sense their environment. But not all sensed data is delivered across the network. The sensor nodes know the low threshold (they are configured initially to know the low threshold) and filter out all sensed data below the low threshold. Only values above the low threshold are sent to the neighboring nodes. Therefore, a 1-hop neighbor will only receive values above the low threshold. Each node collects the incoming values between the low and high thresholds for certain amount of time. Then node compresses (or filters out with a filtering function like XOR) the different collected values and sends them to the mobile sink. If there is an incoming data above the high threshold, it is not aggregated or compressed; it is sent to the sink node immediately. Only the values above the high threshold are treated like that (sent immediately). The use of high and low threshold is suitable for applications requiring periodic reports and also requiring quick response to emergence cases[7]-[9].

## IV. SIMULATION

We have experimented with different parameters extensively, such as the number of nodes and the parameters for the energy consumption model. In Table 2, we provide the system parameters and their values for the reported experiments in this paper. In this section, we evaluate the network lifetime as a key metric of our scheme in different scenarios by comparing it to other schemes[10][11].

TABLE 2
EXPERIMENTAL PARAMETERS AND VALUES

| | |
|---|---|
| # of sensors | 100 |
| Channel Type | Wireless Channel |
| Radio Propagation Model | Two ray ground |
| Antennae Model | Omni Antenna |
| Energy Model | Battery |
| Initial energy($E_i$) | 500 J |
| Data generation rate($d_i$) | 500 bps |
| Simulation Area | 800 x 800 |
| Communication Model | Bi-directional |
| # of mobile sinks | 1 |
| Packet size | 512 Bytes |

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*A. General Performance of Entire System*

In our scheme, the mobile sink selects sensors to query using the sensor selection. In our scheme, the mobile sink does not need predicted knowledge of events but just moves in a fixed route periodically with a fixed velocity. The results show that our scheme outperforms other schemes on network lifetime. We would like to mention the impact of the radius of coverage of the sink on the performance of our scheme[12].

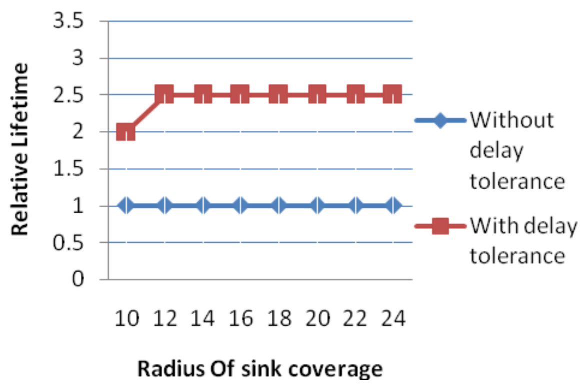


Fig. 4 Comparison of lifetimes of network with delay tolerance and without delay tolerance under the various radii of coverage

For this experiment, we deploy 100 nodes in a 2D region. We need to find the minimum radius of coverage. At each sink location, we increase the radius of coverage from 0 simultaneously until the union of all coverage's contains all sensor nodes. At that point, we have reached the minimum radius of coverage required to cover all nodes[13]. The result of the experiment is plotted in Figure 4. Note that, in the figure, the lifetime is normalized to the optimal lifetime of network without delay tolerance. As shown in the figure, the lifetime of the network with delay tolerance increases as the radius of coverage increases. The increase is the sharpest when the radius just exceeds the minimum radius required to cover all nodes. After that, further increase of the radius has a negligible effect. It is generally desirable for region to have as few nodes as possible, since this reduces the communication and coordination complexity[14].In Figure 5, we show the lifetimes of the two models under various values for the transmission range. The transmission range determines whether a link exists between a pair of nodes. When radius of the coverage of mobile sink is minimum, the effective transmission range is limited according to the dimension of coverage of mobile sink.

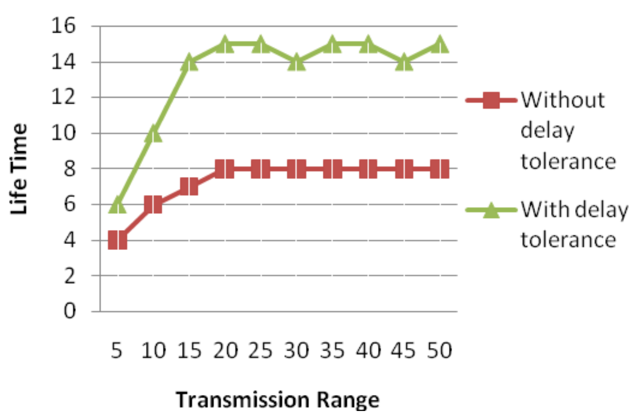


Fig 5 Lifetimes versus transmission range

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Both the methods exhibit a sharp lifetime increase when the transmission range is small but increasing. However, when the transmission range becomes large, the lifetime increase comes to a stop for the 2 models. The result implies that long-distance wireless links are not beneficial for improving the system lifetime[15][16].
We also consider the energy balance among static sensors as a metric to evaluate the lifetime of the network. We use the standard deviation σ of the residual energy to depict the energy balance among the static sensors:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Pi - P)^2}$$

Fig. 6 illustrates that our scheme better balances the energy. The energy balance of other scheme grows in linear-like way which is much quicker than ours.

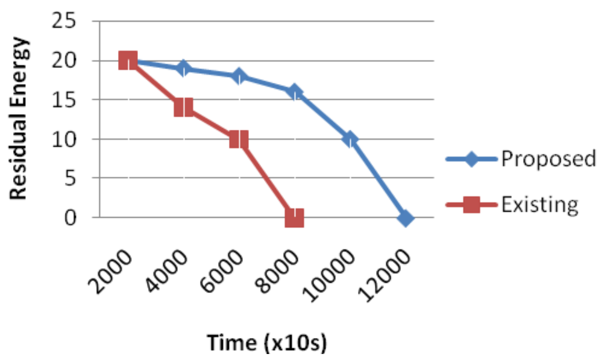


Fig 6 Residual Energy calculations

With more and more query actions initiated, the standard deviation is even flattened in our scheme, implies a good balancing of query burdens[19-21].

## V. CONCLUSION

This paper presents a WSN-based system for wildlife monitoring in areas of special interest. In particular, it has been applied for tracking animals approaching transport infrastructure and to check if already installed wildlife passages across the infrastructures are been used efficiently. We proposed a new framework for using the mobile sink to improve the network lifetime. It is expected to be useful in this applicationn which can tolerate a certain amount of delay in data delivery. We formulated the sensor selection problem by which the mobile sink can selectively communicate with only a portion of static sensors to collect the data. This helps to maximize the network lifetime with a guaranteed event collection rate. Also XOR operation is proposed to filter out duplicated/redundant data received at the nodes. In the future, the system can be deployed in a larger number of sites with the purpose of acquiring biologically valuable information. The system can also be used to monitor other facilities, like feeders or water troughs. The inclusion of new features into the system is also considered, for example, the possibility of automatically extracting gathered information from nodes via cellular 3G or 4G mobile networks. Also in this paper, only one mobile sink is exploited for event collection. If multiple mobile sink nodes are available, a suitable algorithm to control their movement and let them cooperatively collect events can be considered[17-18]

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