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Research article

Dual sensing scheduling algorithm for WSN based road network surveillance

Farhan Khan*and Sing Kiong Nguang

Department of Electrical, Computer, and Software Engineering, Faculty of Engineering, The University of Auckland, 20 Symonds Street, Auckland CBD, Auckland, New Zealand

* **Correspondence:** Email: fkha113@aucklanduni.ac.nz; Tel: +64-22-6421275.

Abstract: In this paper, a dual sensing scheduling algorithm is proposed which is a modified version of VISA technique for sensing scheduling in road networks where targets can enter from both sides of the road. VISA and similar algorithms are based on the idea of designated entrance points and protection points and are very suitable for military scenarios. In comparison, civilian applications mostly use two-way roads and dual carriageways with entrance points on both ends of the roads calling for a modification of the VISA technique to make it suitable for two-way detection. The proposed algorithm achieves detection on a two-way road by using two parallel scan waves originating from the midpoint sensor on the road segment but in opposite directions. The proposed modification of the VISA algorithm improves the detection time by reducing it to half as compared to VISA but at the cost of decreased network lifetime. The proposed algorithm is also compared to Duty Cycling and Always-Awake schemes. In addition, a very simple hole handling method is proposed which applies a comprehensive labeling scheme on all the sensors of the road network represented as vertices in an undirected graph of road network.

Keywords: wireless sensor networks; road segment surveillance; duty cycling; always-awake; virtual scanning

1. Introduction

As discussed in [1], wireless sensor network based road segment surveillance is one of the key operations in military applications and with the rise of road traffic monitoring applications in civilian contexts, there is a renewed interest in this application area [2]. Traditional methods have mostly focused on full coverage, Always-Awake based techniques [3–6]. Always-awake techniques generally have very limited network lifetime because the sensors do not sleep during network operation, but they provide the smallest average detection time usually denoted by zero in literature. In order to increase network lifetime, the Duty Cycling based approaches allow all sensor nodes to start their sensing operation simultaneously for w seconds and after that the whole network goes to sleep for D seconds [7–10]. One of the earliest works which utilized scan waves for detection of intruding vehicles was proposed by Jeong et al. and is known as Virtual Scanning Algorithm (VISA) [16, 17]. The work proposed in this paper is based on a modification of VISA. VISA uses the concepts of entrance points and protection points in a road network and sends waves of scan to detect vehicles as shown in Figure 1.

In Figure 1, the left end of the road segment is the entrance point where the vehicle can get into the road network and the right end of the road segment is protection point which needs to be protected from intruding vehicles. In VISA design, all sensors are waked up one by one for a certain working time w from the direction of protection point towards entrance point after a network-wide silent time. This wave of sensing activities guarantees the detection of target and allows additional sleeping time for individual sensors. Jeong et al. also argue that the virtual scan of the opposite direction i.e., from the entrance point to the protection point cannot guarantee target detection if a very fast target enters just after the start of the network-wide silent time. VISA is very suitable and appropriate for military applications where there is a concept of designated entrance points and designated protection points, but the design of VISA does not consider detection in the case of two-way roads which is the most common type of roads in civilian applications. This paper proposes a dual sensing scheduling algorithm. The basic idea of dual sensing scheduling algorithm is to ensure detection of vehicles on two-way roads by using two scan-waves in opposite directions initiating from the midpoint sensor of a road segment. In simplest terms, dual sensing scheduling can be thought of as two parallel VISA scan waves but in opposite directions with midpoint sensor as the starting point of both of the scans or in terms of VISA terminology, midpoint sensor can be thought of as a protection point for both of the scans. This is illustrated in Figures 2 and 3 for the same road segment of length d which is shown in two sub-segments of length $d/2$ each. This type of parallel dual sensing puts quite a stringent demand on network lifetime but greatly reduces the average detection time.

The main contributions of the work presented in this paper are as follows:

- This work proposes DSSA scheme which extends VISA scheme so that sensing can be performed for two-way roads.
- This work provides analytical and simulation based results to compare network lifetime and average detection time of DSSA with VISA, duty cycling, and always awake schemes.
- The proposed hole handling scheme uses labeling to detect sensing hole locations and updates the schedule to guarantee sufficient sensing with remaining sensors.
- The hole handling scheme allows identification of simple as well as compound holes.

The rest of this paper is organized as follows: Section 2 briefly discusses related work followed by problem formulation in Section 3. In Section 4, comparison of analytical network lifetime and average detection time is described, followed by discussion of a simple hole handling algorithm in Section 5, which is followed by performance comparison in Section 6 and a discussion in Section 7. The paper is concluded in Section 8.

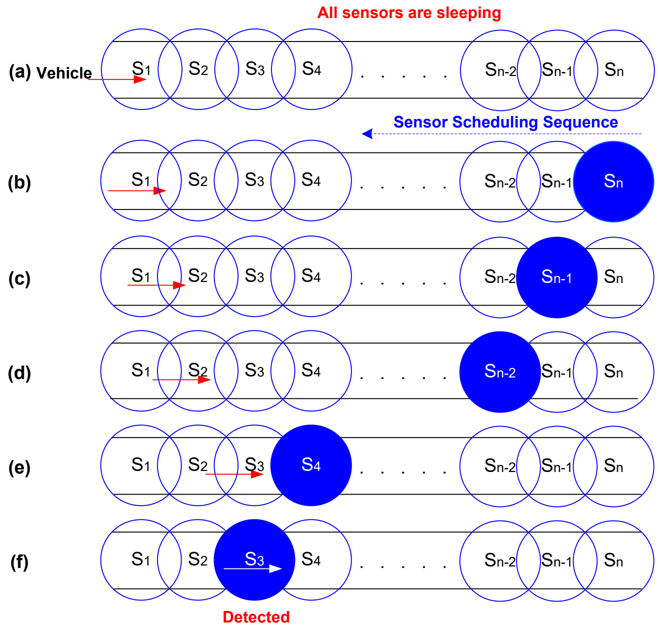

Figure 1. Basic operation of VISA illustrated for a road segment of length d with entrance point on the left and protection point on the right [16, 17].

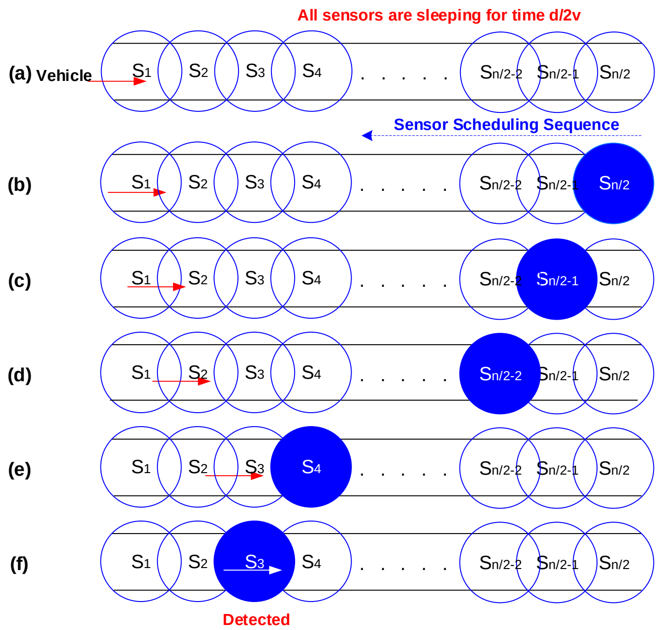

Figure 2. Basic operation of Dual Sensing Scheduling illustrated for a road segment of length $d/2$ and the midpoint at sensor $S_{n/2}$ for vehicles entering from left side of the road.

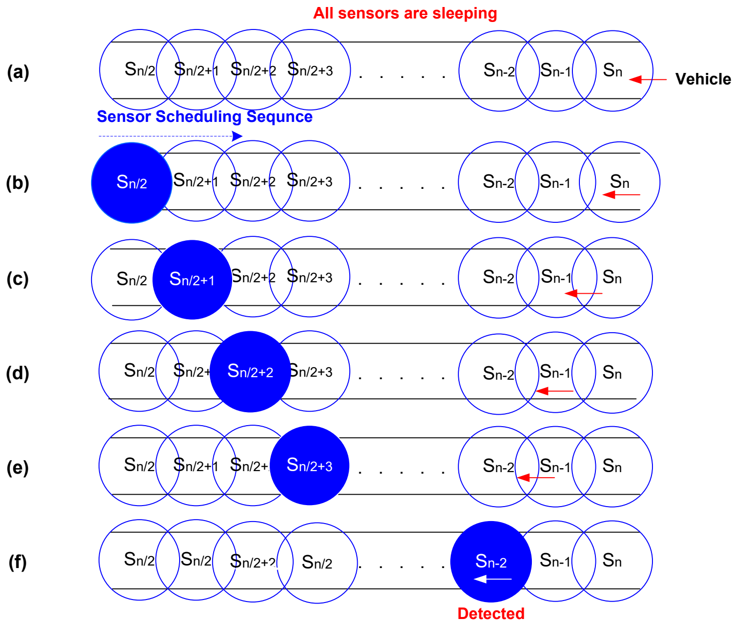

Figure 3. Basic operation of Dual Sensing Scheduling illustrated for a road segment of length $d/2$ and the midpoint at sensor $S_{n/2}$ for vehicles entering from right side of the road.

2. Related work

WSN based surveillance algorithms for infrastructure monitoring have mostly paid attention to full-coverage in two-dimensional open spaces [3–6]. In [4], Cardei et al. proposed a method to extend the sensor network life time by organizing the sensors into a maximal number of set covers that are activated successively. Only the sensors from the current active set are responsible for monitoring all targets and for transmitting the collected data, while all other nodes are in a low-energy sleep mode. They modeled the solution as the maximum set covers problem and designed two heuristics that efficiently compute the sets, using linear programming and greedy approach to monitor a set of static targets at known locations. In [11], Rabbat and Nowak presented an approach to source localization and tracking using received signal strength measurements. Based on incremental gradient descent-like optimization methods, their algorithm required small amounts of data to be communicated over short distances. In [12], Chen et al. proposed a fully decentralized, light-weight, dynamic clustering algorithm for target tracking. Instead of assuming the same role for all the sensors, they envisioned a hierarchical sensor network that is composed of two main items: a static backbone of sparsely placed high-capability sensors which will assume the role of a cluster head upon triggered by certain signal events; and low-end sensors whose function is to provide sensor information to cluster heads upon request. A cluster is formed, and a cluster head becomes active, when the acoustic signal strength detected by the cluster head exceeds a pre-determined threshold. The active cluster head then broadcasts an information solicitation packet, asking sensors in its vicinity to join the cluster and provide their sensing information. In [13], Yao et al. presented a localization algorithm based on the observation that signals from different nodes arrive at the target at different times. In [14], Gui et al. proposed a patrolling surveillance algorithm that allows a virtual patrol to move along a predefined path waking up sensors adjacent to the patrol's path according to a schedule in order to track the target.

In [15], He et al. proposed a target detection system that allows a group of cooperating sensor devices to detect and track the positions of moving vehicles in an energy-efficient and stealthy manner. They traded off energy-awareness and surveillance performance by adaptively adjusting the sensitivity of the system. In [16, 17], Jeong et al. noted that as compared to two-dimensional open space surveillance, the road network surveillance is different due to two reasons:

- the first reason is that the movement of target vehicles is confined within road segments,
- the second reason is that the location maps for the road network are normally known in advance which facilitates the location identification. In case if such a location map is not present, then a prior localization step is needed to find the locations of all road side sensors. The localization methods presented in [20] can be readily employed for this purpose.

Jeong et al. proposed Virtual Scanning Algorithm (VISA) which has already been discussed in the previous section. Jeong et al. also proposed a hole-handling mechanism within the same work. In [2], Chen et al. proposed a twice deployment node balance (TDNB) algorithm which provides better performance than VISA in terms of network lifetime by dividing the deployment of the sensor nodes into two phases instead of deploying all the sensor nodes at one time.

As mentioned in [1], wireless sensor networks are comprised of thousands of nodes with limited energy budget. As time passes, these sensor nodes start draining their energy and become dead. In a highly dense network deployment, a large number of such dead nodes in a polygonal shape area are considered as a communication void or a sensing hole. These communication voids are extremely dangerous for greedy geographical routing algorithms as the next hop forwarding process can get stuck at the boundaries of sensing holes. Identification of these holes is crucial for many services in a sensor network. In [18], Fang et al. discuss two hole identification algorithms based on the concept of Delaunay Triangulation. Another very interesting work related to hole detection/identification is reported in [19] where Funke et al. have discussed the use of connectivity and hop-distance information extracted from communication/connectivity graphs of the sensor nodes. This information is exploited in order to reveal the boundaries of holes. In contrast, [17] discusses hole handling approach called MST-based labeling which handles the case of sensing holes after the holes have already been identified either using hole detection algorithms or by analyzing the reported status information collected at a central scheduler node. MST-based labeling algorithm uses concepts of hole labeling, clustering, and minimum spanning trees (MST) to label and assign each endpoint set of a sensing hole to either a protection point or entrance point cluster based on its proximity.

The hole handling algorithm proposed in this paper uses simple concept of labeling the nodes using a special numbering scheme and based on their reported status, carry out a modification in the sleeping and working schedule of the remaining active sensor nodes in every road segment. The simplicity of the proposed algorithm makes it straightforward for every road segment to modify the sensing/sleeping schedule.

3. Problem formulation

Following are separate statements for problem formulation of both problems although in simulation both the techniques are being studied together.

3.1. *Dual sensing scheduling*

The problem is to ensure that all intruding targets from both sides of the road on a two-way road segment are detected before they reach midpoint of the road segment keeping in mind to achieve a suitable lifetime for the sensor network.

3.2. *Hole handling*

The goal of hole handling problem is to mark the boundaries of each communication void (also referred to as a sensing hole) created in the road segment by either absence of placement at startup or draining of energy budget of sensor nodes and to update the sleeping/working schedule accordingly while keeping the optimization of network lifetime in consideration.

The next section describes the dual sensing scheduling algorithm along with analytical performance comparison with other techniques.

4. DSSA: dual sensing scheduling algorithm

The assumption is that n sensors are placed on a road segment of length d. Each sensor has a sensing radius of r which is sufficient to scan the width of the road. Let w be the minimum working time needed by a sensor in order that the sensor can reliably detect a target. Let v be the maximum target speed. The targets can enter from both sides of the road segment. The traditional full coverage algorithms where sensors remain turned on all the time are called Always-Awake. A better design can be built based on the observation that it takes at least d/v seconds for a target to pass a road segment of length d at a maximum speed v. Therefore, all sensors in the road segment can sleep together for d/v seconds, which is defined as the silent time of the road network. After this silent time, all nodes wake up simultaneously for detection. This technique is called Duty Cycling. The VISA technique is shown in Figure 1. After all sensors sleep for d/v seconds, sensors are waked up one by one for working time w from the rightmost sensor S_n toward the leftmost sensor S_1. This scan-wave of sensing activities guarantees the detection [16, 17] as shown in Figure 1. The dual sensing scheduling algorithm as shown in Figure 2 and Figure 3 initiates two parallel scan-waves from the midpoint of the road segment d approximately designated by sensor position $S_{n/2}$ after all the sensors on the road segment have slept for a time $d/2v$. The objective of dual sensing algorithm is to ensure detection of vehicles entering from both sides of the road segment. This feature of dual sensing algorithm provides detection of target vehicle in half of the time as compared to VISA. This is discussed in the next two subsections.

4.1. *Analytical network lifetime comparison*

In order to compare the sensor network lifetime, the parameters used by Jeong et al. in [17] are being used as it is. These parameters are shown in Table 1. In Table 2, overall analytical results for all the four techniques are presented. Figure 4 shows the comparison of lifetime among the four techniques. The road segment considered in this figure is $390m$ in length with 195 sensors deployed on the road side for detecting vehicles coming from both directions. The assumed vehicle speed is $64km/hr(40miles/hr)$. For example, for $w = 1s$, VISA has a lifetime of $30.3713hr$, Dual Sensing $15.1856hr$, Duty Cycling $3.2113hr$ and Always-Awake $0.14hr$ which is equal to total lifetime of one roadside sensor i.e., D_{life}.

Table 1. Parameters for analysis [17].

Parameter	Definition
D_{life}	Lifetime that a sensor can work continuously corresponding to its energy budget
D_{net}	Sensor network lifetime
D_{work}	Working time that a sensor needs to work for reliable detection. Normally $D_{work} = w$
D_{sleep}	Sleeping time of each sensor
D_{scan}	Scan time that a virtual scan wave moves along the road segment. $D_{scan} = nw$ for VISA and $D_{scan} = \frac{n}{2}w$ for DSSA
D_{silent}	Silent time that the whole sensor network remains silent; that is, time that a target passes through the road segment of length d. $D_{silent} = \frac{d}{v}$ for VISA and $D_{silent} = \frac{d}{2v}$ for DSSA
D_{period}	Schedule period of the sensor network. $D_{period} = D_{scan} + D_{silent}$

Table 2. Performance analysis of four techniques.

Technique	Sleeping Time (D_{sleep})	Working Time (D_{work})	Network Lifetime (D_{net})	Average Detection Time
Always-Awake	0	D_{life}	D_{life}	0
Duty Cycling	$\frac{d}{v}$	w	$(\frac{D_{life}}{w})(w + \frac{d}{v})$	$\frac{d^2}{2v(wv+d)}$
VISA	$(n-1)w + \frac{d}{v}$	w	$(\frac{D_{life}}{w})(nw + \frac{d}{v})$	$\frac{d}{2v}$
Dual Sensing	$(\frac{n}{2} - 1)w + \frac{d}{2v}$	w	$(\frac{D_{life}}{w})(\frac{n}{2}w + \frac{d}{2v})$	$\frac{d}{4v}$

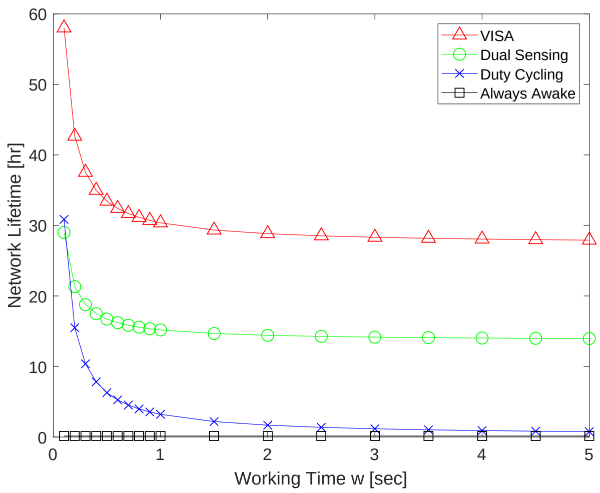

Figure 4. Comparison of network lifetime according to working time w.

4.2. Analytical average detection time comparison

Figure 5 compares the average detection time after a target enters a road segment among the four techniques. VISA detects with a constant delay $d/2v$ and Dual Sensing with a constant delay of $d/4v$ regardless of the working time w as proved in Appendix A. For example, for $w = 1s$, VISA detects target within 10.9688s, Dual Sensing does within 5.4844s, Duty Cycling does within 10.2668s and Always-Awake does without any delay. Therefore, Dual Sensing outperforms Duty Cycling as well as VISA in terms of average detection time.

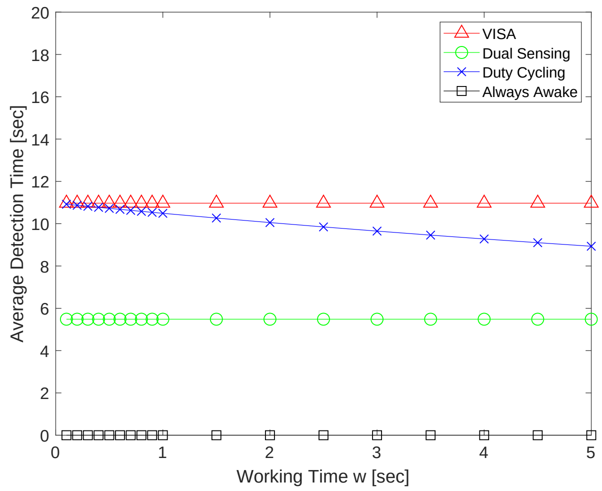

Figure 5. Comparison of average detection time according to working time w.

5. LHHA: labeling-based hole handling algorithm

Holes might be created in the wireless sensor network due to several reasons. Two of these reasons are:

- Holes due to imperfections in the sensor placement process
- Holes due to draining of energy budget of sensor nodes

The hole handling method proposed in this work is based on the concept of labeling of all the entrance points, protection points, and other road side sensors with a numbering scheme. The proposed method assumes the presence of a DSSA Scheduling Access Point (AP) with the responsibility of periodically receiving status messages from all the sensor nodes, creating an ordered status list, and then examining the ordered status list in order to detect any missing status entry/entries which pinpoint the presence of hole(s). This examination process for sensing holes will result in identification of all holes belonging to the following two types:

- Simple hole: It is created due to one malfunctioning sensor.
- Compound hole: It is created due to malfunctioning of contiguous sensors.

5.1. Node labeling scheme

In order to carry out the desired hole type identification, the hole handling mechanism uses a node labeling scheme to assign a unique label to every sensor node formed of three numbers $i.j.k$ where i and j represent the left entrance point and right entrance point of the road segment in consideration, k represents the individual sensor node, and k has the range from 1 to $(n-2)$. The left entrance point is assigned the label $i.j.0$ and the right entrance point is assigned the label $i.j.(n-1)$ where n is the number of sensor nodes in one road segment. For the first road segment shown in Figure 6, the labeling scheme is shown in Figure 7.

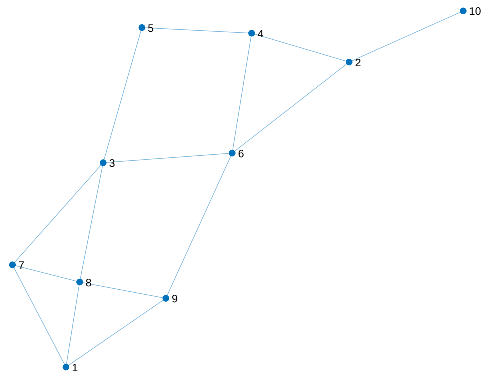

Figure 6. Undirected graph for a sample road network with all entrance points marked with vertex IDs.

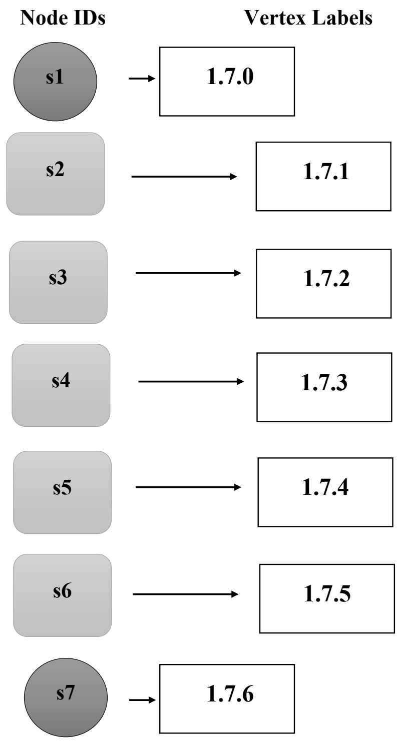

Figure 7. Labeling of all vertices in a road segment with endpoints 1 and 7.

5.2. Identifying simple and compound holes

Using the proposed labeling scheme, the left and right boundary nodes of a simple hole are identified as shown in Figure 8. The left and right boundary nodes mark the region where the sensing coverage has been weakened and these markings act as a barrier around that hole and these markings can also be used for any further action to either rectify the problem or just to simply avoid any forwarding along those regions which have developed communication voids. This information can be extremely useful for any data forwarding algorithm also.

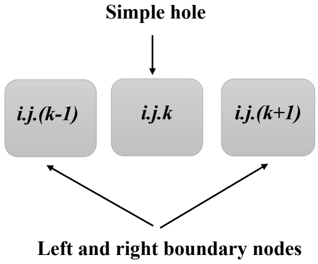

Figure 8. Boundary nodes for a simple hole.

The left and right boundary nodes of a compound hole are identified as shown in Figure 9. The size of the compound hole can be determined by using the formula $k_{right-boundary-node} - k_{left-boundary-node} - 1$.

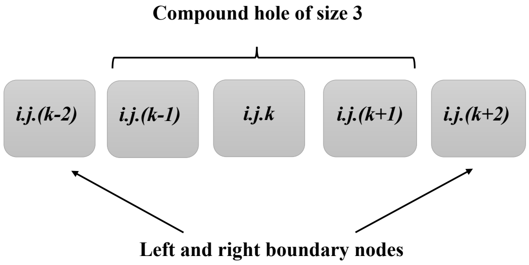

Figure 9. Boundary nodes for a compound hole.

After identifying the size of the hole, the DSSA scheduler sends updated sleeping schedule (in accordance with the formulas shown in Table 2 for D_{sleep}) to the remaining functioning nodes in that particular segment so that the surveillance quality of that particular road segment is not compromised. This has the effect of reducing the sleep times of the remaining nodes and as will be observed in the simulation results, it will reduce the network lifetime also. A future extension of this work might be to remove the DSSA Scheduler altogether and compute all the sensing schedules in a distributed way through entrance and protection points in the road network.

6. Performance analysis

In this section, performance results of DSSA approach are being reported after comparing with three other schemes for road network surveillance. The performance metrics chosen for study are exactly like the ones chosen for the analytical case i.e., network lifetime and average detection time. Since the most popular work in the road network surveillance for military scenarios is the VISA approach, therefore, DSSA is compared with VISA and additionally with Duty Cycling and Always-Awake approaches. In the performance comparison, the effect of the working time (D_{work}) on network lifetime and average detection time has been studied. In addition, the effect of simple sensing holes on the network performance has also been studied. The simulation has been performed in C++ language. 18 different values of working times have been used to study the effects. Hole handling has only been compared with MST-based labeling method which is reported in [16] as part of VISA approach.

First of all, the simulation-based overall system trend for network lifetime was studied with a fixed energy budget of 60 kilojoules. It was found that the VISA scheduler can sustain for $27.77hr$, DSSA for $13.88hr$, Duty Cycling for $1.94hr$, and Always-Awake for $0.1041hr$. For the network lifetime comparison in all of the following subsections, the same fixed energy budget was used but for average detection time comparison, a full day energy budget was used for accurate results. A small section of an actual road network was used for two-way road endpoints, entrance, and protection points.

6.1. Effect of working time on network lifetime

Figure 10 shows the comparison of network lifetime among the four techniques reported in seconds. For the analytical comparison, it was shown in hours, therefore the values on Y-axis are different from the analytical case. In general, for a fixed energy budget of 60 kilojoules, and for $w = 1s$, DSSA provides a lifetime which is 6.25 times greater than Duty Cycling and 133.5 times greater than the Always Awake approaches.

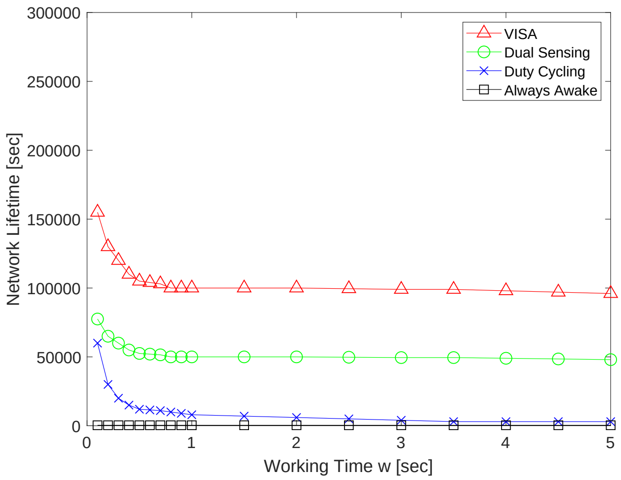

Figure 10. Effect of working time w on network lifetime.

6.2. Effect of working time on average detection time

Figure 11 shows the comparison of average detection time in seconds for the four techniques. The general observation is that almost for all the considered working times, DSSA provides an average detection time which is on average two times better (smaller) than the VISA approach.

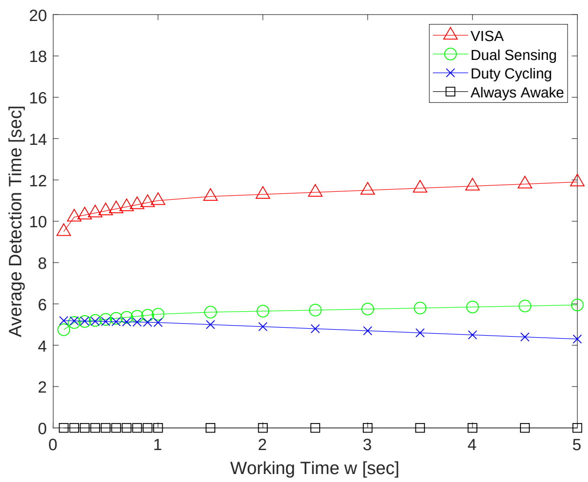

Figure 11. Effect of working time w on average detection time.

6.3. Effect of number of sensors on network lifetime

In order to observe the effect of increasing the number of sensors within a sensor range of $2r$ where r is the transmission radius, number of sensors in $2r$ range were varied from 2 to 20 with increments of 2. The increase in the number of sensors lengthens the network lifetime for both DSSA and VISA approaches as shown in Figure 12. This is due to the fact that an increase in the number of sensor nodes in a particular region leads to shortening of scan time D_{scan}, permitting all the sensor nodes to sleep longer. Similarly, if the number of sensor nodes in a given sensor range $2r$ are decreased, it has a drastic effect on network lifetime as fewer nodes leads to smaller sleeping time which drains the sensor nodes much faster. This trend can also be observed in the same Figure 12 for case of 2 nodes. However, the high sensor density does not contribute much to the network lifetime to Duty Cycling and Always-Awake, since their sleeping time is independent of the number of sensors. It should be noted that DSSA is using two parallel scans at the same time, hence its network lifetime will always be smaller than VISA approach.

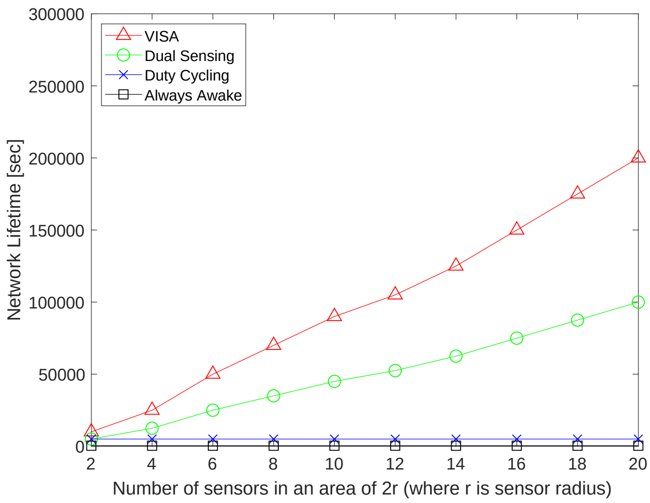

Figure 12. Effect of number of sensors on network lifetime.

6.4. Effect of number of sensors on average detection time

Figure 13 shows the effect of increasing number of sensors on the average detection time. Initially, when the number of sensors is less than 10, the lower number of sensors near endpoints makes the possibility of detection higher resulting in shorter detection time. But, as more and more sensors are added along the same sensing segments, the average detection time smoothes out after 10 sensors per sensing range. This is due to the failure probabilities of sensors as more sensors are deployed, they fail often, leading to depriving the average detection time of getting any considerable advantage of the presence of increased number of sensors.

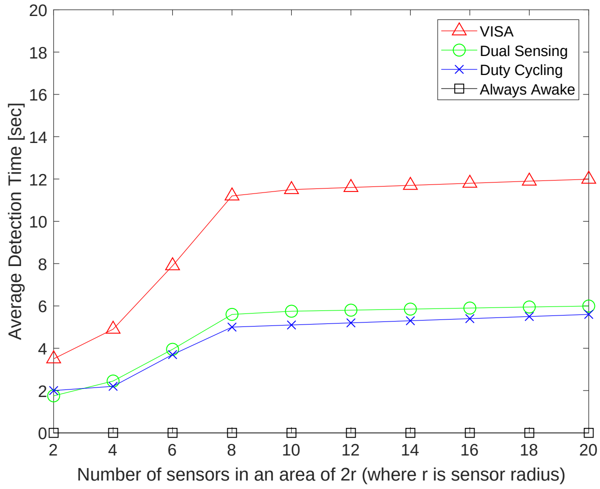

Figure 13. Effect of number of sensors on average detection time.

6.5. Effect of hole handling on network lifetime

Figure 14 shows the comparison of network lifetime between MST-based labeling and LHHA reported in seconds and hours. As shown in Figure 14, MST-based labeling gives longer lifetime than LHHA becuase it is using VISA scan. Although the network lifetime will be shorter in the presence of holes, the general trend remains the same with MST outperforming LHHA in terms of network lifetime.

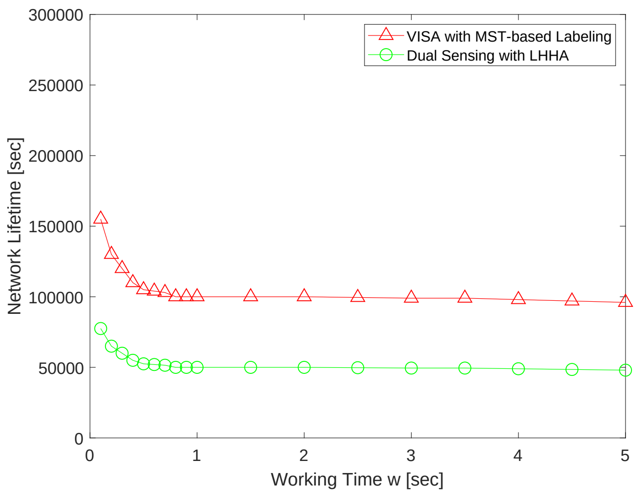

Figure 14. Effect of hole handling on network lifetime.

6.6. Effect of hole handling on average detection time

Figure 15 shows the comparison of average detection time between MST-based labeling and LHHA reported in seconds. As shown in Figure 15, LHHA provides faster detection than MST-based labeling because it is using DSSA scan. The general trend remains the same with LHHA outperforming MST in terms of average detection time.

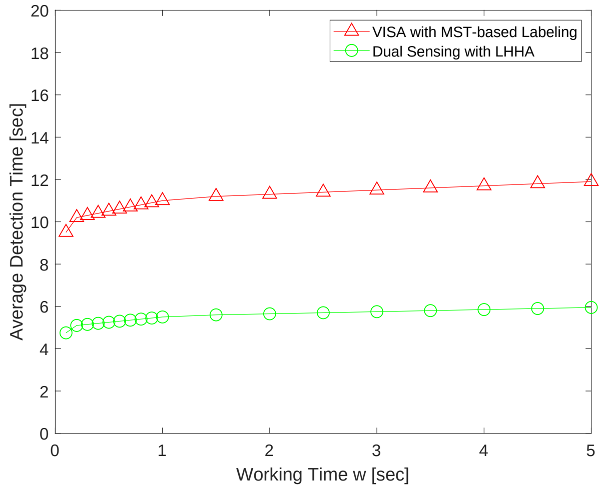

Figure 15. Effect of hole handling on average detection time.

All the obtained simulation results are consistent with the analytical results confirming that the DSSA approach can easily be adopted for two-way roads in civilian scenarios. VISA approach of [16] continues to be the best approach for military scenarios.

7. Discussion

A possible extension of this road network surveillance algorithm may be to look for ways in which energy harvesting techniques as well as fault-tolerance techniques can be combined with the dual sensing scheduling schemes with the outcome that instead of simply marking/labeling faulty sensors or those who have drained their energy budget, there can be either recharging or reconfiguration with spare sensors. A combination of energy harvesting/fault tolerance and scheduling will have the effect of greatly increasing total network lifetime.

Two possibilities for energy harvesting are as follows:

- Solar energy harvesting may be used which involves use of photovoltaic cell array to power sensor nodes on roadside.
- RF energy harvesting may be used by flying an unmanned aerial vehicle (UAV) to enable the wireless charging at short-range. In addition, RF wake-up is also possible at long-range.

Two possibilities for fault-tolerance are as follows:

- A fault-tolerant triple modular redundancy system with a majority voter circuit can be implemented to afford spatial redundancy to the endpoint sensors.
- A fault-avoidance reconfiguration system can be implemented which allows a non-functioning roadside sensor to be substituted by a functioning spare sensor. More than one spare can be provided for critical entry points in the road network.

8. Conclusions

This paper has presented a Dual Sensing Scheduling algorithm which is a modified version of the VISA technique. Using the concepts mainly derived from the VISA technique, the distinct feature of the proposed algorithm is that it provides target detection for two-way road segments with constant delay. Application of Dual Sensing on a larger size road network has also been studied. A hole handling method has also been proposed to label the hole boundaries and update the sleeping schedule.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Khan F, Nguang SK (2018) Dual Sensing Scheduling Algorithm for Wireless Sensor Network based Road Segment Surveillance. *Proceedings of the 3rd EAI International Conference on Smart Grid and Innovative Frontiers in Telecommunications (SMARTGIFT 2018)*, 260–267.
2. Chen L, Li Y, Li Z, et al. (2014) Twice deployment node balance algorithm for road network surveillance. *Int J Distrib Sens N* 10: 1–8.
3. Abrams Z, Goel A, Plotkin S (2004) Set K-cover algorithms for energy efficient monitoring in wireless sensor networks. *Proceedings of IEEE International Conference on Information Processing in Sensor Networks*, 424–432.
4. Cardei M, Thai MT, Li Y, et al. (2005) Energy-efficient target coverage in wireless sensor networks. *Proceedings of the 24th IEEE Annual Joint Conference of IEEE Computer and Communications Societies*, 1976–1984.
5. Kumar S, Lai TH, Balogh J (2004) On K-coverage in a mostly sleeping sensor network. *Proceedings of the 10th ACM Annual International Conference on Mobile Computing and Networking (MOBICOM)*, 144–158.
6. Tian D, Georganas N (2003) A node scheduling scheme for energy conservation in large wireless sensor networks. *Wireless Communications and Mobile Computing Journal* 3: 271–290.
7. Gui C, Mohapatra P (2004) Power conservation and quality of surveillance in target tracking sensor networks. *Proceedings of the 10th ACM Annual International Conference on Mobile Computing and Networking (MobiCom)*, 129–143.
8. Ren S, Li Q, Wang H, et al. (2005) Analyzing object tracking quality under probabilistic coverage in sensor networks. *ACM Mobile Computing and Communications Review* 9: 73–76.
9. Cao Q, Abdelzaher T, He T, et al. (2005) Towards optimal sleep scheduling in sensor networks for rare event detection. *Proceedings of the 4th IEEE/ACM International Symposium on Information Processing in Sensor Networks*, 20–27.

10. Kumar S, Lai T, Arora A (2005) Barrier coverage with wireless sensors. *Proceedings of the 11th ACM Annual International Conference on Mobile Computing and Networking (MobiCom)*, 284–298.
11. Rabbat MG, Nowak RD (2004) Decentralized source localization and tracking. *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing*, 921–924.
12. Chen WP, Hou JC, Sha L (2003) Dynamic clustering for acoutic target tracking in wireless sensor networks. *Proceedings of the 11th IEEE International Conference on Network Protocols*, 284–294.
13. Yao K, Hudson RE, Reed CW, et al. (1998) Blind beamforming on a randomly distributed sensor array system. *IEEE Journal of Selected Areas in Communications* 16: 1555–1567.
14. Gui C, Mohapatra P (2005) Virtual patrol: A new power conservative design for surveillance using sensor networks. *Proceedings of the 4th International Symposium on Information Processing in Sensor Networks*, 246–253.
15. He T, Krishnamurthy S, Stankovic JA, et al. (2004) Energy-efficient surveillance system using wireless sensor networks. *Proceedings of the 2nd International Conference on Mobile Systems, Applications and Services*, 270–283.
16. Jeong J, Gu Y, He T, et al. (2009) VISA: Virtual scanning algorithm for dynamic protection of road networks. *Proceedings of the 28th IEEE Conference on Computer Communications (InfoComm)*, 927–935.
17. Jeong J, Gu Y, He T, et al. (2010) Virtual scanning algorithm for road network surveillance. *IEEE T Parall Distr* 21: 1734–1749.
18. Fang Q, Gao J, Guibas LJ (2004) Locating and bypassing routing holes in sensor networks. *Proceedings of the 23rd IEEE Conference on Computer Communications (InfoComm)*, 2458–2468.
19. Funke S, Klein C (2006) Hole detection or: "how much geometry hides in connectivity?" *Proceedings of the 22nd ACM Annual Symposium on Computational Geometry*, 377–385.
20. Khan F (2020) Localization in wireless sensor networks. PhD Thesis, The Univiersity of Auckland, Auckland, New Zealand.

Appendix A: Analytical average detection time for dual sensing scheduling derivation

Average detection time for Dual Sensing Scheduling has been derived with the following assumptions:

- Speed of car remains same.
- Speed of approaching car is denoted by v.
- Each roadside sensor covers a segment of length $\frac{d}{n}$.
- There are n sensors on the whole segment. But the segment is divided into two equal fragments each of length $\frac{d}{2}$.
- Dual sensing performs scanning of road segment with a speed of $\frac{d}{nw}$ where w is working time.
- Relative speed between scan and car is $\frac{d}{nw} + v$.

Keeping the entrance of cars while the scanning is in progress or when all the sensors are sleeping for a fixed sleeping time of $\frac{d}{2v}$, two scenarios are possible:

Scenario 1: Car enters a road segment from an entrance point while a scan is in progress:

If a car enters at time t_A during the scanning phase, the scan operation has already traversed a distance of $\frac{dt_A}{nw}$ and hence it will require only the remaining time $(\frac{d}{2} - \frac{dt_A}{nw})/(\frac{d}{nw} + v)$ time to detect the car. This time after simplification will become $\frac{(nwd-2dt_a)}{2(nwv+d)}$. Integrating this expression for t_A over an interval of $[0, \frac{n}{2}w]$ gives us the average detection time for this scenario:

$$E[D_{scanning}] = \int_0^{\frac{n}{2}w} \frac{(nwd - 2dt_A)}{2(nwv + d)} \frac{2}{nw} dt_A \tag{A-1}$$

$$E[D_{scanning}] = \frac{nwd}{4(nwv + d)} \tag{A-2}$$

Scenario 2: Car enters a road segment from an entrance point while the whole segment is silent due to segment-wide sleeping time:

If a car enters at time t_A after the whole network is in silence phase, the car has already traversed a time $t_B v$ because it entered at a certain time t_B before even the detection was started at time $(\frac{d}{2v})$. Therefore it takes $(\frac{d}{2} - t_B v)/(\frac{d}{nw} + v)$ amount of time before it gets detected where time $t_B = \frac{d}{2v} - t_A$. There is also a need to add the time t_B along with the aforementioned time.

Hence, average detection time for this scenario will be $t_B + (\frac{d}{2} - t_B v)/(\frac{d}{nw} + v)$. After substituting the value of t_B and simplifying, it will become $\frac{(\frac{nwd}{2} - dt_a + \frac{d^2}{2v})}{(nwv+d)}$. Integrating this expression over an interval of $[0, \frac{d}{2v}]$ gives us the average detection time for this scenario:

$$E[D_{sleeping}] = \int_0^{\frac{d}{2v}} \frac{(\frac{nwd}{2} - dt_A + \frac{d^2}{2v})}{(nwv + d)} \frac{2v}{d} dt_A \tag{A-3}$$

$$E[D_{sleeping}] = \frac{2nwd + \frac{d^2}{v}}{4(nwv + d)} \tag{A-4}$$

Combining the two scenarios

The above two scenarios can be combined using the following equation to give the value of average detection time:

$$E[D] = \frac{\frac{n}{2}w}{\frac{n}{2}w + \frac{d}{2v}} E[D_{scanning}] + \frac{\frac{d}{2v}}{\frac{n}{2}w + \frac{d}{2v}} E[D_{sleeping}] \tag{A-5}$$

$$E[D] = \frac{d}{4v} \tag{A-6}$$