Dual Sensing Scheduling Algorithm for Wireless Sensor Network Based Road Segment Surveillance

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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.

Keywords: Sensing scheduling · Virtual Scanning · Duty Cycling

1 Introduction

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 [1].

Traditional methods have mostly focused on full coverage, Always-Awake based techniques [2–5]. 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 T seconds [6–9].

One of the earliest and state-of-the-art work which utilized scan waves for detection of intruding vehicles was proposed by Jeong et al. and is known as *Virtual Scanning Algorithm* (VISA) [15, 16]. 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

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network and sends waves of scan to detect vehicles as shown in Fig. 1. In Fig. 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 Figs. 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.

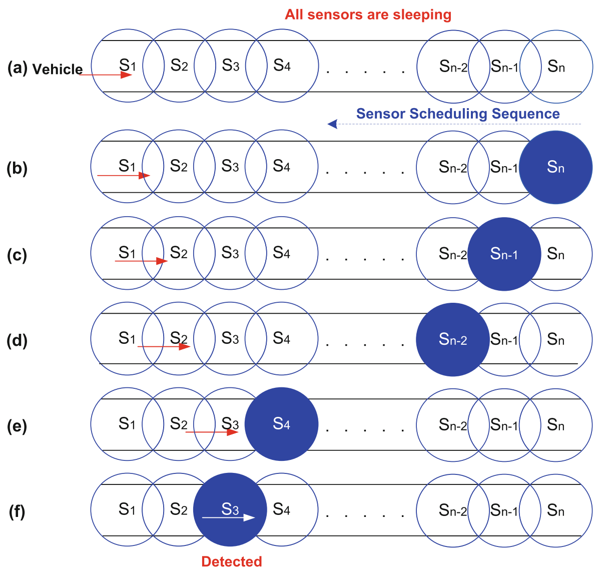

Fig. 1. Basic operation of VISA illustrated for a road segment of length *d* with entrance point on the left and protection point on the right [15, 16].

The rest of the paper is organized as follows: Sect. 2 briefly discusses related work followed by problem formulation in Sect. 3. In Sect. 4, comparison of analytical network lifetime and average detection time is described, and the paper is concluded in Sect. 5.

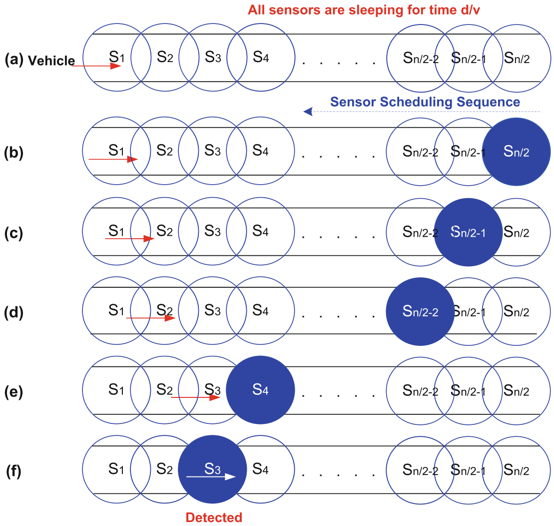

Fig. 2. Basic operation of Dual Sensing Scheduling illustrated for a road segment of length *d/2* and the midpoint at sensor $S_{n/2}$ for vehicles entering from left side of the road.

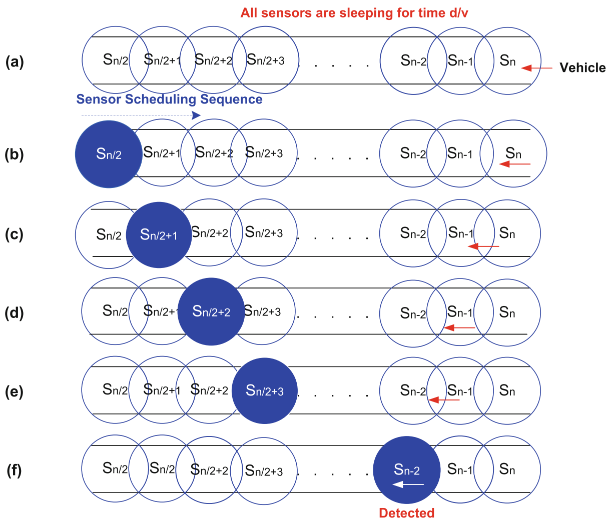

Fig. 3. Basic operation of Dual Sensing Scheduling illustrated for a road segment of length *d/2* and the midpoint at sensor $S_{n/2}$ for vehicles entering from right side of the road.

2 Related Work

WSN based surveillance algorithms for infrastructure monitoring have mostly paid attention to full-coverage in two-dimensional open spaces [2–5]. In [3], 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 [10], 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 [11], 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 [12], Yao et al. presented a localization algorithm based on the observation that signals from different nodes arrive at the target at different times. In [13], 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 [14], 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 [15, 16], 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 is that the movement of target vehicles is confined within road segments, the second is that the road network maps are normally known in advance. They proposed Virtual Scanning Algorithm (VISA) which has already been discussed in the previous section. They also proposed a hole-handling mechanism within the same work. In [1], 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.

3 Problem Formulation

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

4 Dual Sensing Scheduling Algorithm for Road Segment Surveillance

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 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 Fig. 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 [15, 16] as shown in Fig. 1.

The dual sensing scheduling algorithm as shown in Figs. 2 and 3 initiates two parallel scan-waves from the midpoint of the road segment *d* approximately designated by sensor position $S_{n/2}$. 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 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 [15, 16] 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 a 1000 m in length with 300 sensors deployed on the road side for detecting vehicles coming from both direction. The assumed vehicle speed is 64 km/h (40 miles/h). For example, for $w = 5$ s, VISA has a lifetime of 43.57 h, Dual Sensing 11.28 h, Duty Cycling 1.71 h and Always-Awake 0.14 h.

Table 1. Parameters for analysis [15, 16].

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

Table 2. Performance analysis of four techniques.

Technique	Sleeping (T_{sleep})	Working (T_{work})	Network lifetime (T_{net})	Avg. detection time
Always-Awake	0	T_{life}	T_{life}	0
Duty Cycling	d/v	w	$(T_{life}/w)\ (w + d/v)$	$d^2/(2v(wv + d))$
VISA	$(n - 1)w + d/v$	w	$(T_{life}/w)\ (nw + d/v)$	$d/2v$
Dual Sensing	$((n/2) - 1)w + d/v$	w	$(T_{life}/2w)\ ((n/2)w + d/v)$	$d/4v$

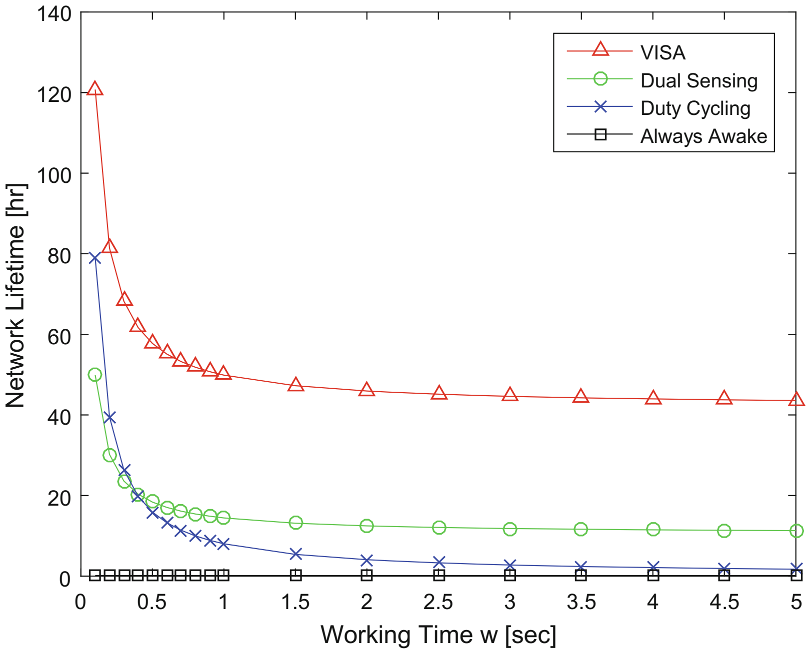

Fig. 4. Comparison of network lifetime according to working time *w*.

4.2 Analytical 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* as proved in Appendix A of [16] and Dual Sensing with a constant delay of *d/4v* regardless of the working time *w*. For example, for *w* = 5 s, VISA detects target within 28.12 s, Dual Sensing does within 14.06 s, Duty Cycling does within 25.82 s and Always-Awake does without any delay. Therefore, Dual Sensing outperforms Duty Cycling as well as VISA in terms of average detection time.

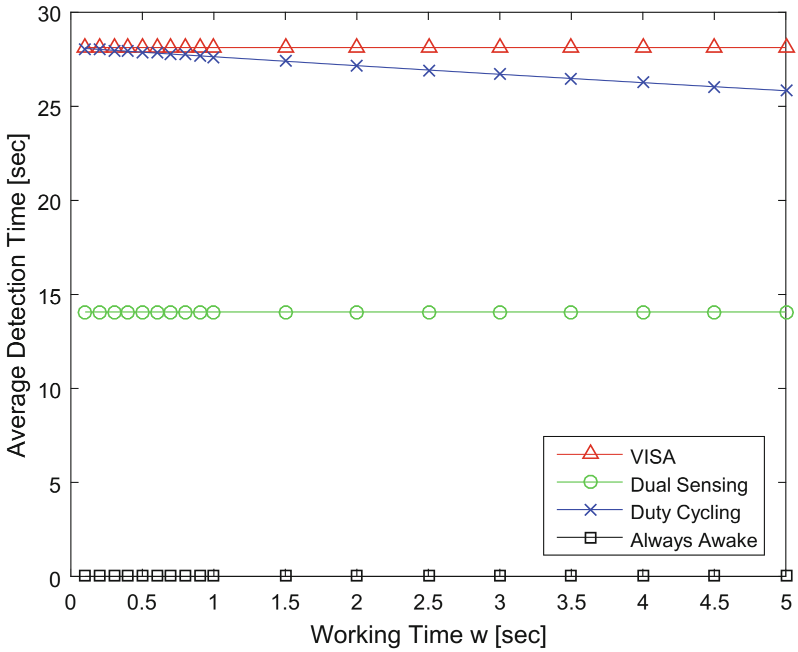

Fig. 5. Comparison of average detection time according to working time *w*.

5 Conclusion

This work has presented a Dual Sensing Scheduling algorithm which is a modified version of state-of-the-art 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 will be studied in a future work.

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