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# Virtual Scanning Algorithm Based on Additional-area in Road Surveillance

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**Abstract:** The road surveillance based on wireless sensor network nowadays has received great attention and its application has been extensively used in practice. In this application, when the invasion target moves from road entrance to system protection points in road network, the nodes in wireless sensor network could detect the target timely and give an alarm before the target reaches the protection points.There are three main types of algorithms for nodes awake in road surveillance application presently, namely AAU(Always Awake-Up) algorithm, DC(Duty-Cycling) algorithm and Virtual Scanning Algorithm (VISA). VISA, which tailored and optimized for road network surveillance, has better performance than the others.This paper puts forward Virtual Scanning Algorithm based on Additional-area(VISAA), which introduces the more sleep time of the nodes based on the Additional Communication Area, to ensure the surveillance more reliability and effectively.The simulation results show that our algorithm has positive significance to improve the performance of road surveillance.

**Keywords:** Road surveillance, wireless sensor network, virtual scanning algorithm.



## 1. INTRODUCTION

Surveillance for critical infrastructure and areas is regarded as one of the most practical applications of wireless sensor network [1]. The basic idea is discovering the monitoring information by the nodes in a wireless sensor network in road area, to aware the vehicles or the persons, after the process of awareness, acquisition, processing, then sends the information to the observer as soon as possible [2], to ensure the safety of the certain area. It greatly utilizes in intelligent transportation systems as well as open battlefields [3]。It's significantly different that surveillance in road network has the moving targets (e.g., vehicles) which confined within road segments, while the road network maps are normally known. We argue that traditional solutions used in other network but not for the road network surveillance couldn't satisfied the required performance. The new straightforward solution for road network surveillance is duty cycling, in which nodes wake up simultaneously for w seconds (the minimum working time before reliable detection could be reported) and then the whole network remains silent for T seconds, thus improve the life-time of the whole network. The design of the time w is important for the algorithm's performance. The existing algorithms are not well utilizing the character of the low duty cycle sensor nodes in the wireless sensor network as well as the advantages of that the nodes could be densely deployed in the network, therefor bring out the problems such as the average detection time is too long and other issues. Thus, there still need new algorithm, which improves further energy efficiency as well as dependability of surveillance in road network. Our intellectual contributions are as follows:

1. Reduces working time based on the additional communication area of the neighbor nodes, thus improving the network lifetime;
2. Improves the reliability of surveillance by index-based increasing of sleeping time as well as dynamically adjusts the node's work slot according to the nodes' remaining energy.

The rest of this paper is organized as follows: First of all, we summarize related work for Road Network Surveillance in Section 2. In Section 3, we then formulate the model of Virtual Scanning Algorithm. Section 4 explains our Virtual Scanning Algorithm based on Additional-area. Section 5 evaluates our design. We finally conclude this paper along with future work in Section 6.

## 2. RELATED WORK

Current algorithms for road network surveillance are divided into three categories. The Always Awake-Up algorithm, the Duty Cycle of the algorithm, and the Virtual Scanning Algorithm. In Always Awake-up algorithm [4], all nodes works all the time, its advantages is the average detection time is the least, as long as the target entering the certain area, it will be discovered by the nodes in the network immediately. However, The high energy consumption made that it could not use in practical for the limitation of the wirelss sensor network. But this type of algorithm could detect all the target, it could be a theoretical standard to compare with other algorithms, just like Flooding algorithm. In fact, for the recent work, there have algorithms for low duty cycle wireless sensor network utilizing the Flooding algorithm in its unique way, could not only reduces energy consumption, but also improves the transmission reliability, to achieve better performance during the delivery process [5]. The Duty Cycle algorithm [6] based on low duty cycle network. All the nodes in the network simultaneously work for $T_{work}$, then sleep for $T_{sleep}$. DC algorithm greatly enhance the network lifetime, but its performance of average detection time and reliability declines. It is difficult to directly applys in practical. For improving the performance of the detection, C. Gui and P. Mohapatra propose the virtual patrol [7], in which a virtual patrol moves along the predefined path in 2-dimensional space and triggers sensors adjacent to the virtual patrol's path for detection.But the 2-dimensional solutions couldn't use directly in road network for the unique character of the road network. The Virtual Scanning Algorithm [8] takes into the idea of virtual scanning. It could extend n times (when the network has n nodes) of the network lifetime with the reliable detection at the certain required detection time. Of course, it increases n-1 nodes more than Duty Cycle algorithm. But the cost of an ordinary node already extremely low, while increases the performance greatly. Thus VISA improves the reliability as well as the lifetime of the network to a large extent. But VISA didn't utilize the relativity between the neighbor nodes.This paper utilizes the deployment of the nodes in the road network, to increase the sleep time in each node, thus improves the network lifetime with the high reliability and nearly the same detection time.

## 3. THE MODEL OF VIRTUAL SCANNING

VISA assumes each node in the network wakes up and scans in order from a Protection point to the Entrance, after all nodes scanning, all the nodes sleep for a while (the time that the target move from the Entrance to the Protection), then works again. When the target moves from Entrance to Protection points entering into the detection range of a scanning node, this node could discover the target and the surveillance is achieved, as shown in Fig. (**1**). The work process is similar to a virtual scanning wave from Protection point to Entrance.

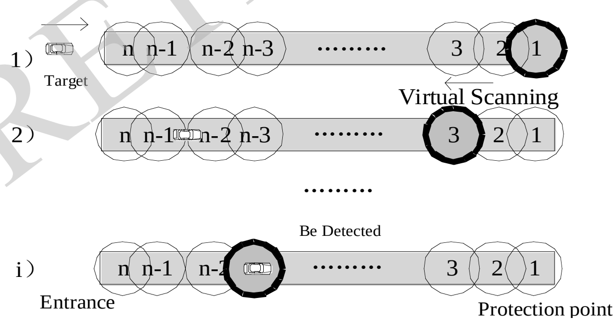


**Fig. (1).** The mode of virtual scanning.

The average detection time of VISA is divided into two cases, that the network is in the situation of work or sleep when the target enters the network. For the two cases, the detection time is the time the target moves from the Entrance to the scanning node which detects the target, assumes that the length of the road is $l$ with $n$ nodes in the road, the average density of the sensor node is $l/n$, each single node work for $T_{work}$ in a cyle, the whole scanning wave works the time of $nT_{work}$, the average speed of the target is $v$, the average detection time is:

$$T_{detection} = l / 2v \tag{1}$$

we could know that the detection time depends on the speed of the target. The network may be in sleep (sleep time should less than $l/v$, to ensure that the target to be detected before achieving the Protection point), set $T_{life}$ as the lifetime of a single node, the network lifetime is:

$$T_{net} = \frac{T_{life}}{T_{work}}(nT_{work} + l / v) \tag{2}$$

It's obviously that with the increase of the value $n$, the sleep time increase too, thus extend the lifetime of the whole network. Our design utilizes the additional communication area of the neighbor nodes to increase the sleep time in each node, so as to enhance the network lifetime.

## 4. VIRTUAL SCANNING ALGORITHM BASED ON ADDITIONAL-AREA

VISA provides a new direction in road surveillance, but in a road surveillance system, the lifetime of each node is not the same, some nodes may exhausted in practical, therefore need new algorithm to adapted to dynamic network. In general, the sensor nodes are used to have the surveillance radius of 15 meters, that means, it is usually detects the range of 30 meters. If effective combination the scanning radius of each node, increasing the sleep time when node deployed densely, or else decreasing the sleep time, then the network performance will be greatly improved. Meanwhile, during the communication between the neighbor nodes, they exchange the remaining energy as well as other information [9], and then the node which has more remaining energy works more time in the next cycle, to achieve uniform energy consumption of the nodes in the network, thus extending the lifetime of the whole network.

To effective combination the scanning radius of each node, VISAA introducing Additional Communication Area [10], that means the increasing scanning range of the neighbor nodes i and i + 1, as shown in Fig. (**2**).

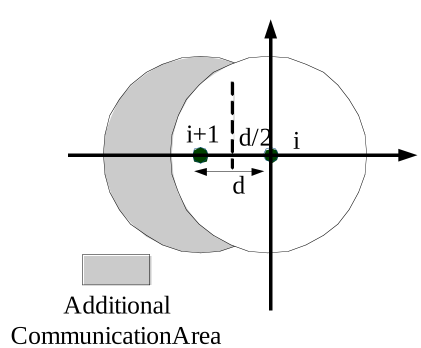


**Fig. (2).** Additional communication area.

The surveillance nodes randomly densely deployed in the road densely, the distance between the two neighbor nodes is $d$. Node i + 1 received scanning wave from node i, assumes that the scanning radius of each node is 1, then the Additional Communication Area of node i + 1 is:

$$ACA = 2\left(\int_{-1-d}^{-\frac{d}{2}} \sqrt{1-(x+1)^2}\, dx - \int_{-1}^{-\frac{d}{2}} \sqrt{1-x^2}\, dx\right) = 2\arcsin\left(\frac{d}{2}\right) + \frac{d}{2}\sqrt{4-d^2} \tag{3}$$

When d = 1 achieve the maximum value of ACA:

$$ACA_{.\max} = \left(\frac{\pi}{3} + \frac{\sqrt{3}}{2}\right) \approx 1.91 \tag{4}$$

Node i + 1 need nott work immediately when it has partially overlapped area with node i, in other word, the more of the ACA, the less additional delay(sleep time) $T_{add}$ for the node i + 1, that means, node i+1 sleep $T_{add}$ more than it's schedule, then starts scanning, thus saving energy. Theoretically with the distance $d_{i,i+1}$, the $T_{add}$ could achieves the value of $T = d_{i,i+1}/v$, $v$ is the speed of the target, but for the scanning reliability, our algorithm utilizes the index-based increasing of sleep time $T_{add}$ according to ACA $\in$ [0, 1.91]. Assumes that the maximum sleep time of node i + 1 is $T$, the $T_{add}$ for node i+1 is:

$$\mathrm{T}_{\mathrm{add}} = T.\sqrt{\frac{e - e^{(\frac{ACA}{1.91})}}{e-1}} \tag{5}$$

With Equation 5, the scanning wave reaches node i, node i wake up at time of $T_{awake}(i)$ and scans for $T_{work}$, then go to sleep. The next node i + 1 continue sleeps the time of $T_{add}(i+1)$ , and then wake up to work with the time of $T_{work}$ - $T_{add}$, the awake time of node i+1 is:

$$T_{awake}(i+1) = T_{awake}(i) + T_{work}(i) + T_{add}(i+1) \tag{6}$$

Then the wave continues pass down to the next hop. For example, when the node i + 1 is far away from node i, there's maximum ACA, node i + 1 works according to the original cycle; while the node i + 1 has little ACA, the two nodes has nearly the same position, node i + 1 is not necessarily to scan, in order to avoid node energy consumption in this case, we could set a threshold RT, ensure that the next hop doesn't scan when the ACA is more than a certain value, to extend the network lifetime.

Then the node in VISAA has the network sleep time of $T_{silent}$, and also has the new sleep time of $T_{add}$ in each node. Compared with VISA, the number of the $T_{add}$ in VISAA is n-1.VISAA works like a discontinuous scanning wave from Protection points to Entrance. Node i first sleeps the time of $T_{slient}$, then continue sleeps the time of $T_{add}$, then wakes up to scan the time of $T_{work}$ -$T_{add}$, complete it's work cycle. To ensure the target from Entrance to Protection points could be detected, the sleep time $T_{silent} \leq l/v_{max}$, for maximum saving of the energy, $T_{silent=}l/v_{max}$. Since the n-1 nodes has their $T_{add}$, n-1 nodes increases total sleep time of T,the value of T is:

$$T = \sum_{i=1}^{n} T_{add}(i) \tag{7}$$

Therefore the entire network lifetime $T_{net}$ is increased to :

$$T_{net} = \frac{T_{life}}{T_{work}}(nT_{work} + T + l / v) \tag{8}$$

Since the scanning wave works along the road as VISA, the average detection time of VISAA is still *as* Equation 1.

With the more sleeping time as well as the exchange of the remaining energy between the neighbor nodes,our algorithm works as follows:

1) The nodes random deployed densely, assumes that the next node is i + 1, while the current node is i , they know the position information of each other, thereby have the value of ACA, node i sends a message directed to the next node i+1, to tell node i +1 the information of the awake time $T_{awake}(i)$, as well as the work time $T_{work}(i)$;
2) Node i + 1 calculates the awake time of itself according to Equation 6, until the last node get it's awake time;
3) After all the nodes in the the network have their awake time and the work time in a cycle, the first node begin to scan, in order to ensure the scanning wave works uninterrupted, node i + 1 exchanges the remaining energy with node i during the process it receives scanning wave at $T_{awake}(i+1)$, when the remaining energy of node i + 1 is higher than node i, in the next work cycle node i could sleep for $T_{sleep}(i)$ which less than $T_{work}(i)$, that is, node i + 1 awakes at $T_{awake}(i+1)= T_{awake}(i)+ T_{work}(i)+ T_{add}(i+1)- T_{sleep}(i)$, and works for $T_{work}(i+1)+T_{sleep}(i)$, thus ensuring that the nodes in the network could have uniformly energy consumption while keep the same success ratio of detection, to extend the network lifetime;
4) After the completion of a scan cycle, the whole network node sleeps for $T_{silent}$, then restarts the scan.

VISAA saves energy of each node by utilizing the Additional Communication Area of neighboring nodes, and the index-based approximation can optimize the reliability as well as the efficiency of our algorithm,to make the algorithm has more adaptability in the dynamic network.

## 5. PERFORMANCE SIMULATION

In this section, we analyze the performance of our algorithm, comparing with VISA for road network surveillance. Our platform used has the road with the length of 800 meters, the nodes randomly deployment on the road densely. The target moves from Entrance to Protection points with speed v. The parameters are shown in Table **1**.

Since the sensor working time w is the minimum working time before reliable detection can be reported, this evaluation reveals how different hardware response speeds affect the VISA and VISAA. As shown in Fig. (**3**), VISAA provides significantly longer network lifetime than VISA, especially when the working time is small, when w is 1 second, VISAA extends network lifetime nearly 50% more than VISA.With the increase of w, the network lifetime decrease rapidly and turns to steady after the value of 3 seconds. It suggests that the value of w should be as small as possible with the precondition of successful detection.

As shown in Fig. (**4**), with the the number of sensor nodes increases, the network lifetime $T_{net}$ increases too. The two algorithms have nearly the same $T_{net}$ when the number of nodes is 20, for the additional communication area is nearly the maximum. When the number is 200, VISAA algorithm

**Table 1. Simulation configuration.**

| Parameter | Description |
|---|---|
| The length of the road l | 800 meters |
| The number of the Nodes n | (20,40,60,80,100,120,140,160,180,200), The default is 60 |
| Sensing range R | R= 2r= 30meters where r is sensing radius. |
| Sensor working time w | Nine points in [0.1,0.9] with step time 0.1 sec and nine points in [1,9] with step time 1 sec. The default w is 1 sec. |
| Node Energy E | The default is 50000 |
| Node working Energye | The default is 10 |
| Target Speed v | $V \sim N(\mu_v, \sigma_v)$,The default $(\mu_v, \sigma_v)$ is (20,5) m/s |

increases about 10 times compares with the number of 20,while the network lifetime is relatively 200% more than VISA.

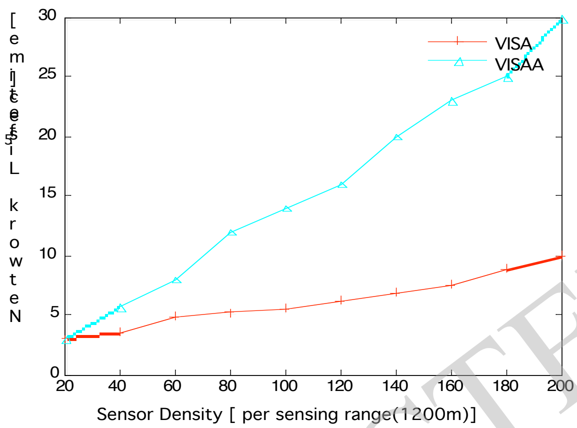


**Fig. (4).** The impact of network lifetime in different sensor density.

In Fig. (**5**), the average detection time of VISAA has a little more than *VISA*, that because VISAA sleep more than VISA, then the speed of virtual scan wave is a little slower than VISA. The results show that VISAA can provide several times lifetime of VISA at the expense of a little longer average detection time.

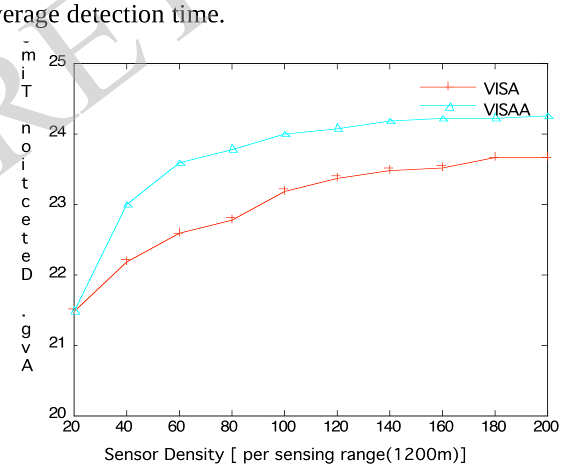


**Fig. (5).** The impact of average detection time in different sensor density.

## CONCLUSION

This work introduces VISAA based on the concept of virtual scanning. We analytically demonstrate and testify the feasibility of our design. It achieves much longer network lifetime and a little longer detection time simultaneously compares with VISA. In practical applications, the invasion target appears with some probability distributions, if combines with these distributions as well as the nodes' efficiency, the algorithm would achieve greater performance.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

## ACKNOWLEDGEMENTS

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