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The Strip Clustering Scheme for data collection in large-scale Wireless Sensing Network of the road

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Abstract

For intelligent traffic and road structural health monitoring, Wireless Sensing Network has been applied widely in transportation, and large quantity of sensor nodes have been embedded in roadways. Now the service lives of sensors are limited mainly because of their battery power storage. So the life cycle of the whole network can be extended if the service life of each sensor in the network is prolonged. In this paper, the Strip Clustering Scheme (SCS) is proposed to replace the Conventional Scheme (CS). This method includes region division, cluster head node selection, link construction, data fusion and transmission. Adopting SCS can reduce a lot of redundant data and the total energy consumption of the network by data fusion. In addition, adopting SCS can also extend the monitoring area without increasing the communication range of the Access Point (AP), and facilitate further expansion of the network as a result. Based on the numerically simulated results, CS method can be used for the WSN within 75 m, and SCS method is more suitable when the monitoring range is larger than 75 m. To achieve the optimal network costs and the network life cycle by using SCS, the range of *d* (the longitudinal spacing of adjacent nodes), is suggested as 10–12.5 m and the energy of cluster head nodes is 60% higher than the energy of non-head nodes with fixed *w* (the transverse distance of adjacent nodes). And the extra energy of head nodes can be obtained by adding the number of battery within the head nodes or using renewable energy technologies.

Keywords: WSN; Road; Energy consumption; Conventional Scheme; Strip Clustering Scheme

Introduction

The application of Wireless Sensing Network (WSN) in transportation infrastructure has been a research hotspot for road health assessment and traffic monitoring [1–3]. Although there have been remarkable progress in the pavement performance evaluation using macro-scale simulation [4,5] and micro-scale simulation [6], to achieve intelligent traffic and road structural health monitoring, many sensors need to be embedded in the road to form a WSN. Different types of sensors and multi-sensors were used in WSN of road according to their objectives [7]. For traffic-monitoring purposes, the most popular sensors include: magnetic sensor [7–10], strain gauges [2,3], load cells [2,3], acceleration sensors [9–11], dual-loop detectors [12].

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For infrastructure monitoring purposes, various intrusive pavement sensors including acceleration sensors [13,14], magnetic sensor [13], temperature sensors [13,15], moisture sensor [15] and strain sensor [15], were used to collect the responses of pavements (e.g. stress, strain, temperature, vibration).

In some previous projects, the sensor nodes collected pavement responses and transmitted the data directly to the Access Point (AP) by wireless transmission module [10–13]. The AP sent data to the local server by certain communication technology such as GPRS/CDMA/IP. Then after processing the data, the local server sent the processed results to mobile terminals or traffic management center. In this way, the WSN manager can query information about traffic flow and structural health in real time, and the users can browse the relevant information on the website [7]. Since the AP is exposed to the air, it is easy to replace the batteries or use cable to supply power. But it is difficult to supply power to the sensor nodes, which are embedded and driven by internal batteries. The sensors will fail eventually because of the limited battery storage, and early failure of some nodes will reduce lifecycle of WSN [9,13]. The radio plays a critical role in the sensor node lifetime, as most of the energy is consumed in radio communication [8]. Therefore, the energy consumption of WSN can be optimized by adjusting its data collection scheme.

The Conventional Scheme (CS) for data collection is to make all the sensor nodes transmit data to the AP directly. The energy consumption of a node will be affected by the distance significantly. The sensor node, which is farther away from the AP, consumes more energy and is more likely to fail, which will reduces the efficiency of the WSN [8,16]. Energy is wasted because adjacent sensors send their signals to the AP in similar routes redundantly [2,3,13,17]. Channels might be congested and network speed might be decreased because all the nodes transmit their data at the same time to the AP following a TDMA schedule [1,7]. In addition, the packet dropping probability boosts when the number of nodes increases, and energy could also be wasted due to the re-transmission of packets lost in collisions [13,18].

In this paper, the Strip Clustering Scheme (SCS) is proposed to compare with the CS (Conventional Scheme) based on the formal radio model and characteristics of sensor nodes' deployment for the road. The procedures of SCS will be introduced, which includes region division, cluster head node selection, link construction, data fusion and transmission. SCS can reduce a lot of redundant data and the total energy consumption of the network by data fusion.

Related work

Deployment of sensor nodes in the road

Common deployments of sensor nodes include mesh topology (e.g., parking lot), string topology (e.g., overtaking assistance), star topology (e.g., speed detection), barrier topology (e.g., traffic load estimation) [1]. In a practical application, the deployment of sensor nodes depends on the monitoring object and algorithm.

In some previous research projects [7,8], two sensor nodes were embedded on the centerline of each lane to calculate the speed of vehicles, and the distance between sensors depended on the range of expected speeds to be measured. In the research conducted at Virginia Tech [2,3], three types of sensor nodes were embedded in transverse and longitudinal direction, and the sensor matrix was used to achieve traffic monitoring and pavement distress monitoring. In the research conducted at Sensys Networks, Inc [13,19], four arrays of vibration sensors were installed 15 ft apart along the traffic direction for weigh-in-motion and pavement performance monitoring. Note that though there have been many researches in the pavement area [20–22], very few are on the sensor layout.

This sensor layout was designed to minimize lane-to-lane interference and maximize the in-lane signal-to-noise ratio. In the research conducted by Wenteng Ma's group [10], 3 arrays of magnetic sensors were installed 4 ft apart in the middle of the lane to classify traffic, with three sensors installed 3 ft apart in each array.

According the previous relevant research, some assumptions are adopted in this research: the sensor nodes deployed with a spatial density and laid linearly along the road; the instrumentation section is L meters long and W meters wide; the longitudinal spacing between the sensor nodes is d meters and the transverse spacing is w meters, as shown in Fig. 1.

Radio model

Sensor node mainly consists of four parts: sensors, micro-processor, a radio (transceiver) and a battery power source. The radio plays a critical role in the sensor node lifetime, as the overall power consumption is mainly affected by the energy required by radio communication [8,13]. And the WSN lifetime directly depends on the sensors' power source.

In this paper, we use the formal radio model and this model took into account of energy consumption of data transmitter, data receiver and data fusion [16,23]. The

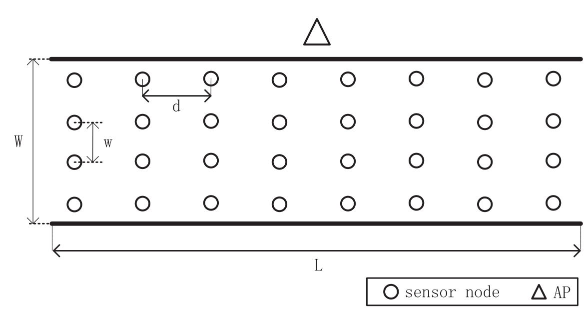

Fig. 1. Deployment of sensor nodes for the road.

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