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Wireless Sensor Networks For Urban Traffic Monitoring

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Abstract

With the constant increasing of vehicular traffic around the world, especially in urban areas, existing trafficmanagement solutions become inefficient. This can be clearly seen in our life through persistent traffic jam and risingnumber of accidents. Wireless sensor networks (WSN) based intelligent transportation systems (ITS) have emergedas a cost effective technology that bear a pivotal potential to overcome these difficulties. This technology enables anew broad range of smart city applications around urban sensing including traffic safety, traffic congestion control,road state monitoring, vehicular warning services, and parking management.

Keywords

WSN,ITS, traffic management, traffic monitoring, traffic safety, parking management.

Introduction

Nowadays, traffic jam and high number of accidents in urban and metropolitan areas become more andmore stressful and lead to dramatic consequences on economy, human health, and environment.

Intelligent Transportation Systems (ITS) are important systems for both military scenarios andcivil engineering scenarios. For the military scenarios, since the road networks are used formain maneuver of military troops in cities or urban areas, they need to be protected for militaryoperations. For the civil engineering scenarios, the Intelligent Transportation Systems havebeen developed and been evolving to support the driving safety and transportation efficiencythrough the information computing and communications among transportation infrastructuresand vehicles [1].

Nowadays, roads are equipped with electronic tollgates and variable messagesigns for driving and also vehicles with GPS-based navigation systems and emergency notification systems. With this trend, Wireless Sensor Networks (WSN) can be deployed into road networks in order to enhance the driving safety and mobility further.

Figure 1.1: Intelligent Transportation Systems

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In this figure, the wireless sensor networks can beintegrated into ITS to monitor the road condition for driving safety (e.g., road construction sitesor obstacles) and to announce such road condition to vehicles through vehicle-to-vehicle orinfrastructure-to-vehicle communications.

This paper observes thefollowing four characteristics of the road networks, as shown in Figure 1.2:

(i) PredictableVehicle Mobility,
(ii) Road Network Layout,
(iii) Vehicular Traffic Statistics and
(iv) VehicleTrajectory.

The first characteristic is the predictable vehicle mobility, as shown in Figure 1.2(a). Vehiclesmove along the roadways in the road networks with bounded speeds (i.e., speed limits).

The second is the road network layout, as shown in Figure 1.2(b). The layouts of the road networks are available as road maps and these road maps can be represented as road networkgraphs where the vertices are intersections and the edges are road segments.

The third is thevehicular traffic statistics, as shown in Figure 1.2(c). The vehicular traffic statistics (e.g., vehicleinter-arrival time) can be collected for the road segments or intersections due to the mobilitywithin the road network layouts. The fourth is the vehicle trajectory, as shown in Figure 1.2(d).

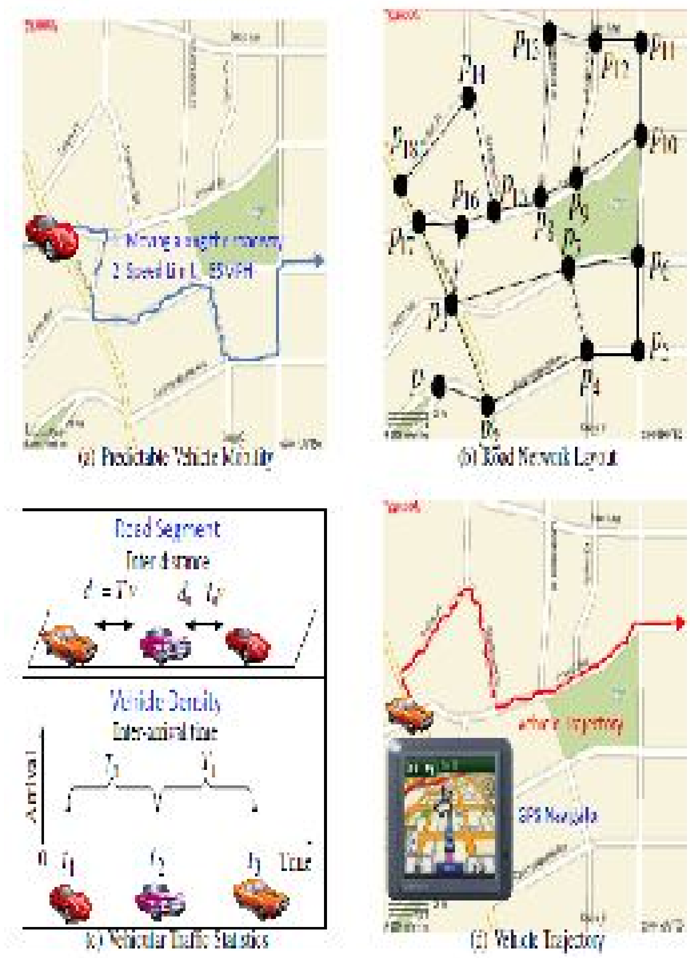

Figure 1.2 Road Network Characteristics

Vehicles tend to follow their vehicle trajectories representing the travel paths along the roadways,guided by the GPS navigation systems for the efficient travel. These four characteristicsopen a door of new research on wireless sensor networks. Therefore, this paper designswireless sensor networking technologies for road networks on the basis of these four characteristicsof road networks.

The designs proposed in this paperare different fromthe legacy designs for wireless sensor networking based on the two-dimensional space.

In this paper, the following four important technologies are addressed forthe security and communications in military applications and civil engineering applications,respectively:

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(i) Localization for sensor location,
(ii) Road Surveillance for vehicle monitoring,
(iii) Data Forwarding for road sensing data delivery and
(iv) Reverse Data Forwarding forroad condition information sharing.

First, for the wireless sensor localization, this paperintroduces an Autonomous Passive Localization (APL), tailored for road networks. This sensorlocalization is the prerequisite function for wireless sensor networking. It is assumed thatsensors are deployed sparsely (hundreds of meters apart) to save costs in road networks. Thismakes the existing localization solutions based on the ranging ineffective. To address this issue,our work is inspired by the fact that vehicles move along routes with a known map, whichmeans the characteristics of the predictable vehicle mobility and the road network layout. Usingbinary vehicle-detection timestamps, distance estimates are obtained for any pair of sensors onroadways to construct a virtual graph composed of sensor identifications (i.e., vertices) and distanceestimates (i.e., edges). This virtual graph (i.e., sensor network topology) is then matched with the topology of road map (i.e., road network topology), in order to identify where sensors are located in road networks.

Second, for the road network surveillance, this paper proposes a Virtual ScanningAlgorithm (VISA), tailored and optimized for road network surveillance. This road networksurveillance is very important to the battles in urban areas or cities. The proposed designuniquely leverages upon the facts that

(i) the movement of targets (e.g., vehicles) is confinedwithin roadways and
(ii) the road network maps are normally known, which are the predictablevehicle mobility and the road network layout, respectively.

The detection of moving targets isguaranteed before the mobile targets reach designated protection points (such as temporary basecamps), while maximizing the lifetime of the sensor network. The main idea in the proposedsurveillance algorithm is to use virtual scan - waves of sensing activities scheduled for roadnetwork protection. Importantly, to the best of our knowledge, this is the first attempt to studyhow to guarantee target detection while sensor network deteriorates, using a novel sensing holehandling technique.

Third, for the data forwarding of sensing data, this paper proposes a Trajectory-BasedData Forwarding (TBD), tailored for the data forwarding in light-traffic vehicular ad-hoc networks.This data forwarding is very important in the delivery of the road sensing data towardsthe infrastructure nodes, such as Internet access point or roadside unit. This is because theseinfrastructure nodes can play the role of hub for sharing the road condition information for thedriving safety. State-of-the-art schemes have demonstrated the effectiveness of their data forwardingstrategies by exploiting known vehicular traffic statistics (e.g., densities and speeds)in these vehicular networks. Even though these results are encouraging, further improvementscan be made by taking advantage of GPS-based navigation systems with the growing popularity.

This paper presents the first attempt to investigate how to effectively utilize vehicles' trajectory information in a privacy-preserving manner. In the proposed design, the trajectoryinformation (i.e., vehicle trajectory) is combined with the vehicular traffic statistics to improvethe performance of data forwarding in road networks.

Fourth, for the reverse data forwarding for sharing road condition information, this paper proposes a data forwarding scheme called Trajectory-based Statistical Forwarding (TSF),tailored for the infrastructure-to-vehicle data delivery in vehicular networks. This reverse forwardingis very important to deliver such road condition information from infrastructure nodesto moving vehicles for the driving safety.

TSF forwards packets to a multihop-away target pointwhere the vehicle is expected to pass by, which is defined as rendezvous point of the packet andthe destination vehicle. Such a target point is optimally selected to minimize the packet deliverydelay while satisfying the required packet delivery probability. The optimality is analyticallyachieved by utilizing both distributions of the packet delay and the destination vehicle delay,which are obtained from the vehicular traffic density and the vehicle trajectory.

Conclusions

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This paper introduces the four important technologies in Wireless Sensor Networks (WSN) for Intelligent Transportation Systems (ITS) in both military scenarios and civil engineering scenarios. These technologies are based on the key characteristics on the road networks thatcan be used for the system designs as follows:

(i) The predictable vehicle mobility within the roadways;

(ii) The abstract representation of road network layouts into road maps;

(iii) The vehicular traffic statistics representing the vehicle density on road networks;

(iv) The vehicletrajectory representing the vehicle mobility along the roadways.

The designed proposed in this paper are the first attempts to investigate the new settings of road networks and utilizethe four characteristics of the road networks above. Therefore, these designs are more efficientin road network settings than the legacy wireless sensor networking schemes based on the twodimensionalspace.

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