A DESIGN OF INTERSECTION COLLISION AVOIDANCE SYSTEM BASED ON UBIQUITOUS SENSOR NETWORKS

Minsoo Kim, Eunkyu Lee, and Byung Tae Jang

Telematics·USN Research Division, ETRI
161, Kajeong-dong, Yuseong-gu, Daejeon, Republic of Korea
{minsoo, ekyulee, jbt}@etri.re.kr

ABSTRACT:

In this paper, we introduce an Intersection Collision Avoidance (ICA) system as a convergence example of Telematics and USN technology and show several requirements for the ICA system. Also, we propose a system design that satisfies the requirements of *reliable vehicular data acquisition*, *real-time data transmission*, and *effective intersection collision prediction*. The ICA system consists of vehicles, sensor nodes and a base station that can provide drivers with a reliable ICA service. Then, we propose several technological solutions needed when implementing the ICA system. Those are about sensor nodes deployment, vehicular information transmission, vehicular location data acquisition, and intersection collision prediction methods. We expect this system will be a good case study applied to real Telematics application based on USN technology.

KEY WORDS: Telematics, USN, Sensor Network, Ubiquitous, Collision Avoidance, Intersection Collision

1. INTRODUCTION

Over the past few years, lots of attention in network communities has been directed towards applying Ubiquitous Sensor Networks (USN) technologies to real world applications[1]. USN is differentiated from common wireless network environment in that all autonomous sensor nodes of USN can dynamically and continuously create new information and those nodes have considerable features of limited computation ability, limited wireless communication bandwidth, and limited battery power capacity. There have been many research results that focus on efficient data transmission among nodes with minimizing power consumption of each node and minimizing data loss ratio of wireless communication [2,3]. Recently, USN is getting more and more important by applying the USN technologies to current services such as Telematics, LBS, GIS, SIIS, and so on[1,4].

In this paper, we are concerned with Telematics services based on USN technology and especially focus on *Intersection Collision Avoidance* (ICA) issues. First, we define indispensable requirements for the ICA service, and then we propose a detailed system design that can make real-time and reliable services feasible in a real world application. The ICA system consists of a base station, sensor nodes, and vehicles. A base station located at a centre of crossroad gathers vehicular information from sensor nodes and transmits gathered information to vehicles which are approaching to crossroad. Sensor nodes installed at the road surface acquire vehicular information from all cars adjacent to the nodes and transmit the information to a base station. Each vehicle that is approaching to crossroad predicts a traffic accident at crossroad and avoids the predicted accident.

The next section shows recent USN research trends and related works for the ICA. The third section proposes system requirements, detailed system design, and implementation issues for the ICA. The last section shows our conclusion and future works.

2. RELATED WORKS

Many researchers have ever studied various fields of USN such as hardware platform, operating system, wireless communication, middle software and application software[5]. In terms of hardware, most researches have mainly focused on a development of optimized sensor node that has special features of small size, low power consumption, wide communication bandwidth, and broad sensing range[6,7]. In terms of software, active research issues are to develop energy efficient and secure MAC and network protocol and develop energy efficient In-network and stream data management system[8]. Besides the issues, there have been various researches as to a development of middleware and application software in order to apply USN technologies to real world.

The *Cooperative Intersection Collision Avoidance Systems* (CICAS)[9] that is executed as a subproject of 'Intelligent Vehicle Initiative' funded by US DOT aims at an intersection collision avoidance using cooperative communication between vehicular and roadside sensors and processors. The *INTERSAFE* [10]that is executed as a subproject of 'Preventive safety applications (PReVENT)' funded by EC challenges a development of algorithms for vehicle localization, a detection and classification of obstacles, an integration of traffic signal status, and a development of effective warning strategies. For solutions of the challenges, the INTERSAFE uses vehicular video and laser scanner sensors. Besides these projects, there have been various kinds of researches, for example, *ITS Architecture for Canada* [11] that has main point of vehicle-based collision avoidance, infrastructure-based collision avoidance, sensor-based driving safety enhancement, and *Intersection Safety Camera* [12] that allows the photographs to be taken of the rear of the vehicle that is violating the red light, and so on. This paper proposes more advanced intersection collision avoidance method in order to predict an intersection collision more accurately.

3. ICA SYSTEM BASED ON USN

3.1 Requirements for ICA System

Here, we present important requirements and considerations needed when designing our ICA system.

Reliable Vehicular Data Acquisition: In the ICA service, most critical requirement is to acquire a reliable vehicular location, velocity and time information. If we could not acquire the reliable information, it is impossible for the ICA service to provide drivers with an exact prediction for an intersection collision. However, the existing GPS cannot satisfy an acceptable error range in location determination (it is expected within 2*m* in our system). For this requirement, we propose new location determination method using sensor node that is equipped with sensing, computing, communication and power unit.

Real-time and Reliable Data Transmission: Another important requirement in the ICA service is to reliably transmit real-time information acquired by sensor nodes to all vehicles. For the requirement, we adopt a 'Collect-and-Broadcast' method that collects data from all sensor nodes and then broadcasts them to all vehicles approaching at an intersection. The method can reduce a cost caused by mutual communication between all vehicles and sensor nodes. For the method, we have to develop an optimal nodes deployment method on roadway and real-time network routing protocol among the nodes.

Effective Intersection Collision Prediction: The last important requirement in the ICA service is to assure an effectiveness of an intersection collision prediction. Here, our goal is to develop real-time algorithm to improve accuracy for a collision prediction and to notify a collision prediction before entering an intersection (at least 2 seconds beforehand). In this paper, we predict an intersection collision using circular 'danger zone', which is located at a centre of crossroad. For example, if there are two or more vehicles in the 'danger zone' at the same time, we predict that there will be an intersection collision.

3.2 ICA System Design

The three requirements for the ICA service should be considered in a system design process. Figure 1 shows our system design that is composed of three main parts: Vehicles, Sensor Nodes, and a Base Station.

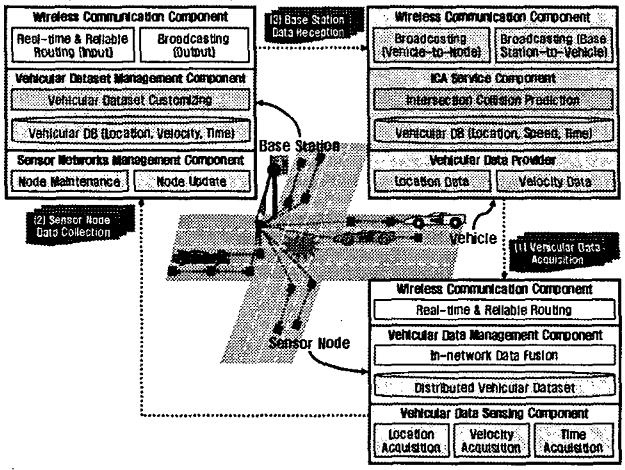

Figure 1. A System Design for the ICA Service.

In Figure 1, a primary role of vehicle is to predict an intersection collision and notify drivers that an accident will happen in the intersection. The ICA service component executes the primary role, where all other vehicular data for the component are given from a base station through broadcasting. In addition, the vehicle contains a vehicular data provider component that can provide sensor node with its data such as location and velocity data.

A main role of sensor node is to acquire vehicular data of location, velocity, and time and transmits them to a base station using real-time and reliable routing protocol. The vehicular data sensing component and the vehicular data management component executes the main role for our ICA system. However, it is not easy to acquire exact location information within an error bound of 2*m* from lots of high speedy vehicles. In the implementation issues of the subsection 3.3, we show how USN technology could be used in order to sense the exact location information.

A base station should be able to gather all vehicular information as soon as possible from sensor nodes, customize the information as an effective message format, and broadcast the message to all vehicles approaching at an intersection of crossroad. These main roles are executed at the vehicular dataset management component. The effective message format will be explained in detail in the subsection 3.3.

Lastly, a basic working scenario for the ICA service can be shown at Figure 2.

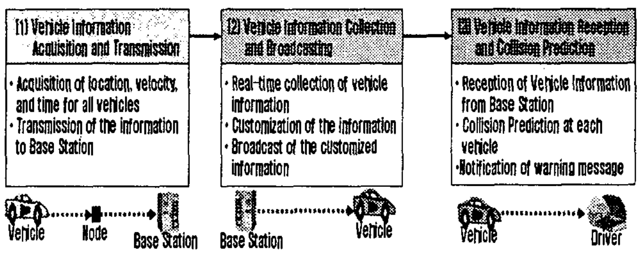

Figure 2. A Working Scenario for the ICA Service

3.3 Implementation Issues of ICA System

This subsection shows several implementation issues of the ICA system: (1) Sensor Nodes Deployment, (2) Vehicular Information Transmission, (3) Vehicular Location Data Acquisition, and (4) Intersection Collision Prediction.

3.3.1 Sensor Nodes Deployment

Our ICA system basically needs sensor networks infrastructure in order to acquire real-time vehicular information. The sensor networks infrastructure means a base station installed at the intersection of crossroad and lots of sensor nodes installed on roadways. Here, a goal of sensor nodes deployment is to install a base station and sensor nodes cost-effectively. It is desirable for us to install sensor nodes at the smallest number as much as possible. At the smallest number of nodes, we have to consider a wireless network connection among nodes, a minimization of information loss rate, and a fault-tolerant nodes deployment. Therefore, the above considerations and the smallest number of nodes are trade-off. In our system, we design sensor nodes deployment considering environmental settings, traffic conditions, and wireless communication settings. Environmental settings include number of nodes, distance between nodes, number of traffic lanes, and distance between traffic lanes. Traffic conditions include number of vehicles, direction of vehicles, and velocity of vehicles. Lastly, wireless communication settings include radio range, antenna type, bandwidth, data rate, delay, and packet error rate. Figure 3 shows several possibilities of sensor nodes deployment for our ICA system. We are currently verifying a feasibility of the possibilities using a simulation system.

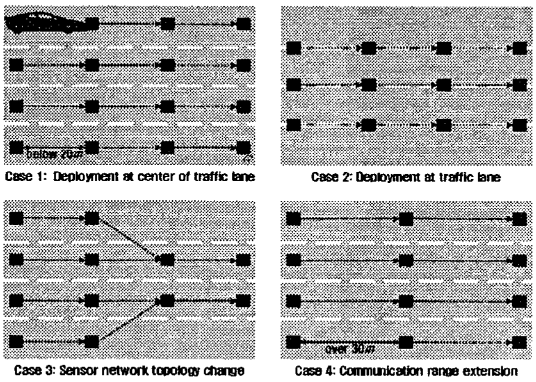

Figure 3. Possibilities of Sensor Nodes Deployment.

3.3.2 Vehicular Information Transmission

After sensor nodes are deployed, we have to implement a fault-tolerant, real-time and reliable routing protocol from nodes to a base station. It is very difficult for us to design such routing protocol, because of the real-time requirement. For example, let's assume that the maximum speed of vehicle is $100km/h$ (it goes $30m$ per one second) and the first sensor node is deployed at a distance of $150m$ from the intersection. So, the ICA system has only 5 seconds in order to perform all intersection collision prediction processes. Therefore, if the ICA system wants to notify a collision prediction before at least 2 seconds, all scenario steps of Figure 2 should be performed in 3 seconds. Our ICA system practically sets a goal that it will take 1 second to perform the step 1, 1 second to perform the step 2, and 1 second to perform the step 3. So, the ICA has to transmit reliable vehicular information from sensor nodes to a base station within 1 second. To solve this problem, we design a fixed routing table based on a feature of fixed sensor nodes. The fixed routing can reduce the necessary time for transmitting vehicular information by leaving out lookup time of next sensor node and avoiding lots of network contentions.

Another important consideration in this section is to minimize a message protocol size that is composed of vehicular information sets. The message contains vehicular direction, speed, location, traffic lane, and traffic sign information. Figure 4 shows the message protocol in detail.

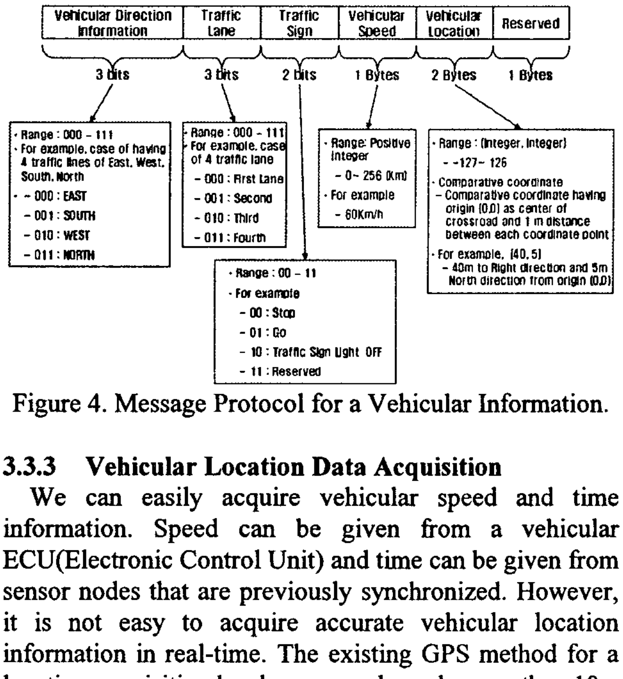

Figure 4. Message Protocol for a Vehicular Information.

3.3.3 Vehicular Location Data Acquisition

We can easily acquire vehicular speed and time information. Speed can be given from a vehicular ECU(Electronic Control Unit) and time can be given from sensor nodes that are previously synchronized. However, it is not easy to acquire accurate vehicular location information in real-time. The existing GPS method for a location acquisition has large error bounds more than $10m$ and has a signal blockage and data distortion area, where the GPS signal cannot go through a hindrance such as tunnels and buildings. It is impossible to use the GPS method as a location acquisition method for predicting an intersection collision. Therefore, we propose a new location acquisition method that is more accurate than GPS method and does not exist a signal blockage and data distortion area. A new location acquisition method uses sensor nodes that are installed at roadway and vehicles. Here, all sensor nodes on roadway aware their exact location information through previous measurement. Communication range between sensor nodes and vehicles is adjusted at a distance of 2 or $3m$. The adjustment of communication range can be made by reducing a power for wireless networking. Main scenario of our method is very simple as shown in Figure 5.

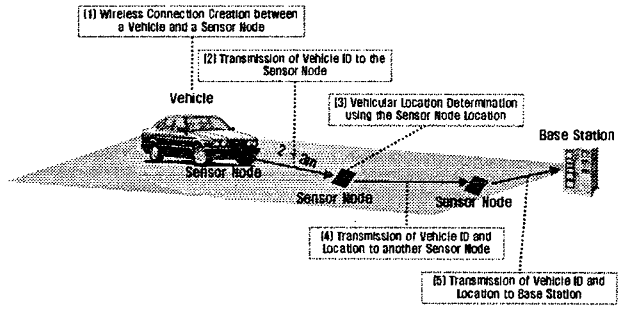

Figure 5. Vehicular Location Acquisition Secnario.

In other words, the new method can acquire real-time and high accurate location information when a wireless communication is established between a vehicle and a node. However, it is very difficult to implement the new method in a real roadway environment. It may cause many difficult problems such that it should acquire a location from a high speedy vehicle of 100*km/h* in maximum speed and satisfy a given error bound within 2 or 3*m*. Besides, there are many problems caused by sensor nodes deployment, antenna setup of sensor node, and so on. Unfortunately, there are no optimal solutions for these problems. In our system, we are performing many test works to find an optimal solution.

3.3.4 Intersection Collision Prediction

Last implementation issue is to compute an intersection collision using vehicular location, velocity, and time information. This computation is performed at each vehicle, because it is nearly impossible to perform the computation continuously at a base station and then notify the results to each vehicle in real-time. Because of the important real-time requirement, we, first, propose very simple algorithm to predict an intersection collision. This algorithm defines a dangerous circle of 5 or 10*m* radius from the intersection centre and computes how many vehicles will be located at the dangerous circle using each vehicular location, velocity, and time information at the same time. If there are 2 or more vehicles will be located at the circle, the vehicles will notify drivers of a warning message. In our system, we are currently focusing on the real-time requirement in solving a prediction problem. Therefore, if the real-time requirement is fully satisfied with our system, the simple algorithm will be changed into more complex method to improve the prediction accuracy.

4. CONCLUSION

In this paper, we introduced the "Intersection Collision Avoidance" service based on USN technology as a killer application of Telematics. For the service, we proposed a ICA system that has following requirements: (1) it can acquire reliable vehicular data of location, velocity, and time; (2) it can transmit vehicular data to a base station and vehicles reliably and in real-time; and (3) it can predict an intersection collision effectively in real-time. The ICA system is composed of vehicles, sensor nodes, and a base station. A main role of vehicles is to predict an intersection collision and notify drivers of warning message. Sensor nodes acquire vehicular data and transmit them to a base station with reliable wireless communication. A base station gathers all vehicular data from sensor nodes, customizes them into an effective message format, and broadcasts it to all vehicles. Also, we proposed several technological issues that should be considered when implementing the ICA system. Those are (1) sensor nodes deployment issue, (2) vehicular information transmission issue, (3) vehicular location data acquisition issue, and (4) intersection collision prediction issue.

Summarizing our work, we newly designed the ICA system and proposed several technological solutions for the ICA system. We think this system will be a good example applied to Telematics application based on USN technology. In future works, we plan to simulate the ICA system for verifying its feasibility and performance. If the verification is successfully performed, we plan to construct a real ICA prototype system.

References

1. A. Mainwaring, J. Polastre, R. Szewczyk, and D. Culler. Wireless Sensor Networks for Habitat Monitoring, ACM, Sensor Networks and Applications, 2002

2. Y. Yao and J. Gehrke, The Cougar Approach to In-network Query Processing in Sensor Networks, SIGMOD, September, 2002

3. J. Gehrke and S.Madden, Query Processing in Sensor Networks, Pervasive Computing'2004

4. C. Sadler, P. Zhang, M. Martonosi, and S. Lyon, Hardware Design Experiences in ZebraNet, ACM Sensys, Nov. 2004.

5. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, A Survey on Sensor Networks, IEEE Communication Magazine, Aug. 2002.

6. Mote system, http://www.xbow.com/

7. Nano-24, http://www.octacomm.co.kr/

8. W.R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, Energy-Efficient Communication Protocol for Wireless Microsensor Networks, Hawaii Intl. Conf. on System Sciences, Jan. 2000.

9. CICAS, http://www.its.dot.gov/cicas/

10. INTERSAFE, http://www.prevent-ip.org/en/prevent_subprojects/intersection_safety

11. ITS Architecture for Canada, http://www.its.-sti.ca/Architecture/english/static/

12. Intersection Safety Camera, http://www.winnipeg.ca/police/safestreets/