A Study on Efficient Infrastructure Architecture for Intersection Collision Avoidance Associated with Sensor Networks

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ABSTRACT

The intersection collision avoidance service among various telematics application services is regarded as one of the most critical services with regard to safety. In such safety applications, real-time, correct transmission of service is required. In this paper, we study on efficient infrastructure architecture for intersection collision avoidance using a cooperative mechanism between vehicles and wireless infrastructure. In particular, we propose an infrastructure, called CISN (Cooperative Infrastructure associated with Sensor Networks), in which proper numbers of sensor nodes are deployed on each road, surrounding the intersection. In the proposed architecture, overall service performance is influenced by various parameters consisting of the infrastructure, such as the number of deployed sensor nodes, radio range and broadcast interval of base station, and so on. In order to test the feasibility of the CISN model in advance, and to evaluate the correctness and real-time transmission ability, an intersection sensor deployment simulator is developed. Through various simulations on several environments, we identify optimal points of some critical parameters to build the most desirable CISN.

Key Words : Intersection Collision Avoidance, Simulator, Sensor Node Deployment, Telematics, and Wireless Sensor Networks

Ⅰ. Introduction

In recent decades, advances in MEMS, microprocessors and wireless communication technologies have enabled the development of various applications through the deployment of sensor networks, composed of hundreds or thousands of tiny, low cost nodes. In these various sensor applications, intelligent transportation systems (ITS) and telematics applications associated with various sensors, in particular, are positioned as challenging applications, dealing with transportation-related problems.

In this paper, we concentrate on intersection collision problems with regard to safety. Intersection collisions make up approximately 26% of all crashes, according US statistics[1]. Moreover, approximately one fourth of all fatal crashes occur at or near an intersection[2,3]. There is considerable federal and government level [4-9] interest in the design and implementation of intelligent, real-time systems that can interpret knowledge of current traffic conditions at an intersection, and the vicinity, to predict potential collisions or near-misses, and issue suitable countermeasures.

There has been substantial research relating to the design and implementation of intersection collision avoidance systems[10-16]. This research can be divided into two categories. The first is achieving collision avoidance using a vehicle-based system[10-12,16]. The second is using infrastructure-based or cooperative methods between infrastructure and vehicles[13-15].

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* 본 연구는 2008년도 시립인천전문대학 교내연구비 지원에 의하여 수행되었음
논문번호 : KICS2007-06-281, 접수일자 : 2007년 6월 22일, 최종논문접수일자 : 2008년 4월 31일

In this paper, an infrastructure for intersection collision avoidance, which operates using a cooperative mechanism between vehicles and wireless infrastructure, is proposed. In particular, an infrastructure associated with wireless sensor networks is exploited, in which a proper number of sensor nodes are deployed on each road surrounding the intersection. The proposed CISN is distinguished from previous work in several points. The first is that since the proposed system follows a cooperative system approach, vehicles do not require line-of-sight as in [3], and the CISN is not affected by vehicle topology changes, in contrast to [10,11]. The second is that unlike the other cooperative approaches[13-15], the CISN is only composed of wireless components, involving a base station, sensor nodes, and vehicles. Such a wireless infrastructure has several advantages, such as flexibility in installment and maintenance, and the availability of gathering distributed sensing information when operating under large scale conditions.

The subsequent sections of this paper are organized as follows. Section Ⅱ presents the proposed intersection collision avoidance service architecture. Section Ⅲ introduces the developed ICAS deployment simulator. In section Ⅳ, the performance of collision avoidance service in the CISN model is evaluated. In section Ⅴ, the model architecture for safe collision avoidance service consisting of optimized parameters is presented on the basis of the evaluation results performed in section Ⅵ. Section Ⅶ presents the conclusion.

Ⅱ. Architecture of CISN (Cooperative Infrastructure associated with Sensor Networks)

2.1 Intersection collision risks

In contrast to longitudinal and lateral collisions that occur in a single direction of traffic flow, most intersection collisions involve vehicles in different crossing path directions. Fig. 1 presents various collision risks, which occur between a subject vehicle (SV) and different crossing path direction vehicles, in an intersection. SV1 may proceed to one direction of 2, 3, and 4. At this moment, SV has collision risks with vehicles in different crossing path directions (a, b, and c), as presented in Fig. 1. In addition, the right of Fig. 1 illustrates a hazard in the case where line-of-sight of SV is obstructed. In such situations, line-of sight is not guaranteed, making vehicles more likely to conflict with each other.

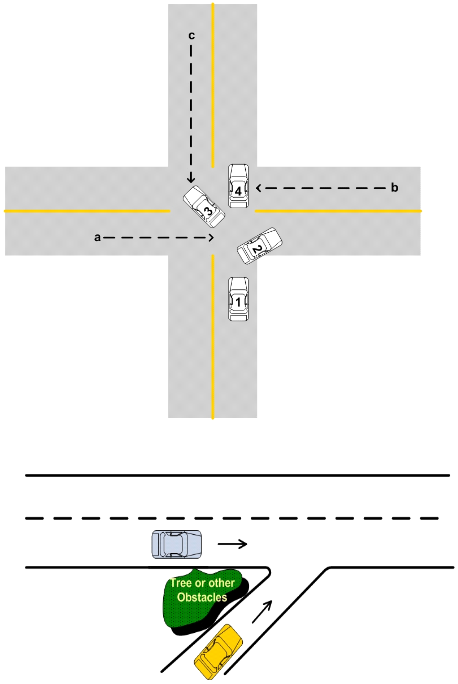


Fig. 1. Various collision risks at an intersection or junction

2.2 The intersection collision avoidance service of CISN

Collisions in intersections can occur from a driver's incorrect judgment, even in the case where a traffic light exists. In addition, due to rain or snow, it is likely that a pool of water or freezing zone arise sin and around an intersection. These kinds of accidents cannot be solved by simply using a traffic light.

Therefore, in order to avoid such kinds of accidents and collisions, a collision avoidance system, which can make vehicles stop or pass slowly, by predicting various hazards beforehand, is required.

CISN basically consists of vehicles, base stations, and sensor nodes, which are deployed to sense physical environments in and around the target intersection.

Vehicle: The ultimate function is to exchange information with sensor nodes or base stations. The vehicle consists of two independent wireless interfaces: the first is to communicate with a sensor node and the second is for the base station. Each vehicle transmits a beacon periodically through a wireless module equipped in the vehicle. The beacon includes the driving information, such as current speed, location (using GPS),and time information. If a sensor node hears a beacon message, the message is delivered to the BS through multi-hop routing in real-time. In addition, each vehicle can communicate with BS through another wireless device. Thereby, a vehicle can predict a collision risk and avoid collisions.

Base station: The base station (or Service station) plays an important role in gathering vehicles' real-time information relayed from sensor nodes, and broadcasting collision warning information to vehicles approaching the intersection. This base station (BS), which is located at the center or vicinity of an intersection, is a computing device composed of high performance sensor nodes.

Sensor node: The sensor node is a tiny, smart embedded system, capable of sensing, computation, and wireless communication. These nodes are almost uniformly deployed on the ground of each traffic lane from the intersection center, using a specific required number. The sensor nodes are responsible for transmitting the vehicle's beacon, coupled with its sensing information, to the BS via multi-hop communication. In order to reduce unnecessary power consumption, and to minimize collision and co-interference, short range wireless communication is used.

Fig. 2 illustrates collision avoidance service of CISN model.

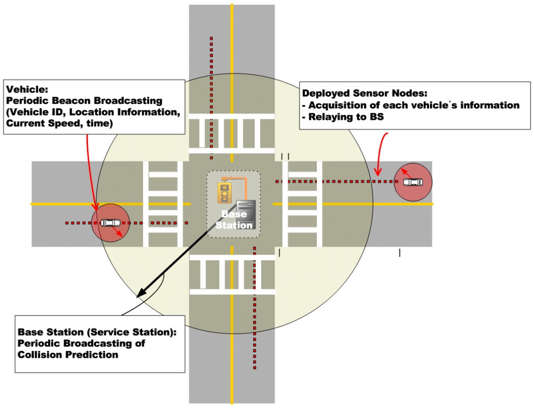


Fig. 2. CISN architecture

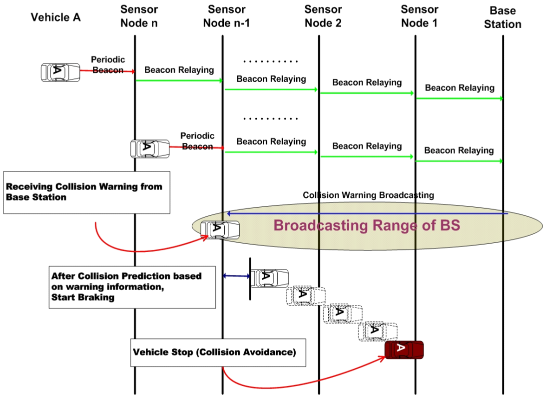


Fig. 3. Collision avoidance mechanism associated with deployed sensor nodes

Collision avoidance mechanism of CISN is achieved using a cooperative real-time information exchange between components, as presented in Fig. 3. A vehicle approaches an intersection with a periodic beacon. As a vehicle gets near to the intersection, sensor nodes deployed around the intersection receives the beacon message and forwards the message combined with additional sensing information, to the BS, via multi-hop communication. The BS gathers vehicles' information from sensors on each road within its period, and broadcasts collision warning to its perimeter. All vehicles within radio range of the BS can simultaneously receive the broadcasting message. Then, a collision prediction algorithm is performed, based on current information and collision warning information received from the BS. Then, the vehicle starts to brake. If collision avoidance service normally operates, the vehicle can stop completely, before entering the intersection. Then, the vehicles can pass through the intersection safely, or stop by identifying potential collision problems.

2.3 Requirements for collision avoidance service of CISN

In order to efficiently perform intersection collision avoidance service, the following several requirements must be considered.

Real-time: Collision occurs when two or more vehicles exist in the same time and space. Accordingly, all information relating to vehicle detection (by beacon message) and multi-hop beacon communications, should maintain freshness of information. In addition, BS information gathered from sensor nodes should be updated using the freshest information.

Correctness: Services for safety should first be designed on the basis of correctness. For correct information transmission, sensor nodes should be able to detect vehicles correctly, and this information should be reliably forwarded to the BS. In addition, based on this information, collision warning broadcasting should be correctly achieved.

Limitation of Transmission range: In the CISN, collision avoidance is achieved by receiving collision warning broadcasts. Intuitively, the longer the radio range of the BS, the greater is collision avoidance coverage. However, excessive radio range can increase the possibility of co-interference between neighboring intersections, as well as greater energy consumption with respect to increasing transmission power. Therefore, a minimum range within the transmission range of the BS, which can correctly avoid collision, is required.

Costs: The sensor nodes are deployed along roads surrounding the intersection. However, the excessive deployment of nodes increases installing and maintenance costs. Therefore, the deployment of sensor nodes should be strategically achieved within the correct vehicle detection range.

Ⅲ. ICAS Deployment Simulator

In order to fully satisfy the requirements presented in the previous section, the optimized tuning of various parameters consisting of the CISN is required.

Prior to field testing of the CISN, a simulator, ICAS Deployment simulator, is developed. The main objective of simulator development is to test the feasibility of the CISN model in advance, and to retrieve the optimized value of parameters satisfying the requirements in various environments. The ICAS simulator is distinguished from traditional simulators[14,16,17], for traffic and intersection monitoring in that the ICAS deployment simulator is designed to accommodate the CISN architecture, which has different properties and deployment over the previous system.

The ICAS simulator has an extensive input structure, which involves wireless communication configurations between sensors and vehicles, and between vehicles and the BS. Through this simulator, detailed information regarding success or failure of collision avoidance with respect to deployment strategy, in addition to traffic environment information, is obtained. Figure 4 shows an internal architecture of the CISN simulator. The simulator is composed of three major components: Common simulation parameter module, Output management module, and Simulator engine module. Common simulator parameter module is in charge of configuring various input parameter including traffic environment, sensor node entity, base station entity. Simulator engine module is a heart of the simulator. The module performs a simulation by executing tasks registered in the scheduler based on each objects, including vehicle object, sensor node object, and BS object. Each object is reconfigured by user. For example, as a default protocol for sensor nodes, dedicated routing is used in the sensor node object. However, by replacing it to different protocol, other sensor

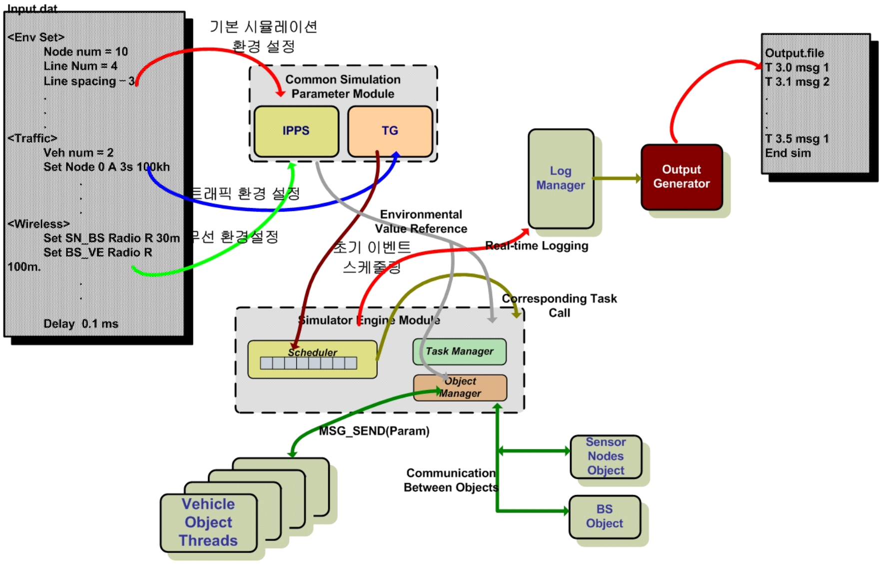
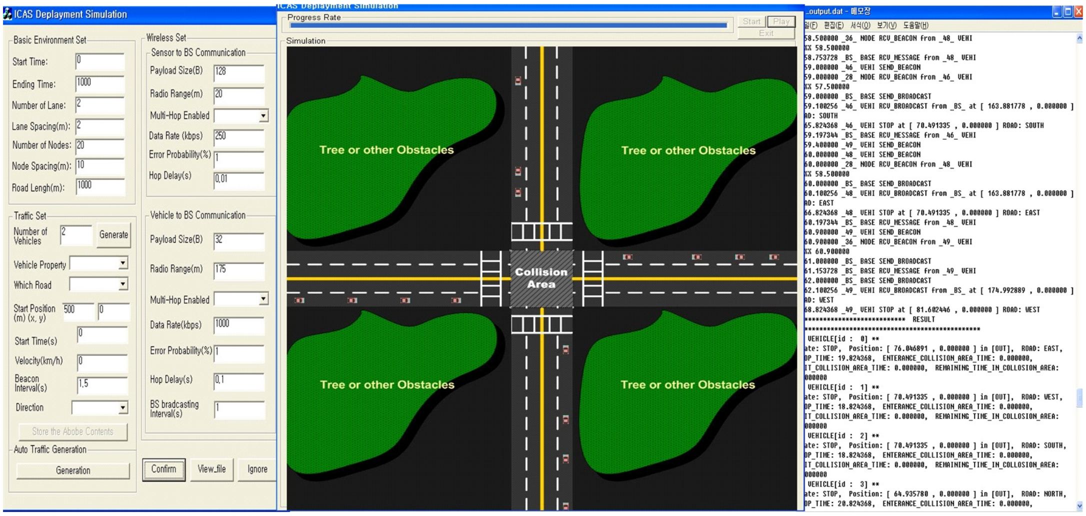


Fig. 4. Internal Architecture of ICAS Deployment Simulator



Basic Environment Set
Start Time: 0
Ending Time: 1000
Number of Lane: 2
Lane Spacing(m): 2
Number of Nodes: 20
Node Spacing(m): 10
Road Lengh(m): 1000

Traffic Set
Number of Vehicles: 2
Vehicle Property:
Which Road:
Start Position (m) (x, y): 500 0
Start Time(s): 0
Velocity(km/h): 0
Beacon Interval(s): 1.5
Direction:

Wireless Set
Sensor to BS Communication
Payload Size(B): 128
Radio Range(m): 20
Multi-Hop Enabled:
Data Rate (kbps): 250
Error Probability(%): 1
Hop Delay(s): 0.01

Vehicle to BS Communication
Payload Size(B): 32
Radio Range(m): 175
Multi-Hop Enabled:
Data Rate(kbps): 1000
Error Probability(%): 1
Hop Delay(s): 0.1
BS bradcasting Interval(s): 1

```
58.500000 _36_ NODE RCV_BEACON from _48_ VEHI
XX 58.500000
58.753728 _BS_ BASE RCV_MESSAGE from _48_ VEHI
59.000000 _46_ VEHI SEND_BEACON
59.000000 _28_ NODE RCV_BEACON from _46_ VEHI
XX 57.500000
59.000000 _BS_ BASE SEND_BROADCAST
59.100256 _46_ VEHI RCV_BROADCAST from _BS_ at [ 163.881778 , 0.000000 ]
AD: SOUTH
65.824368 _46_ VEHI STOP at [ 70.491335 , 0.000000 ] ROAD: SOUTH
59.197344 _BS_ BASE RCV_MESSAGE from _46_ VEHI
59.400000 _49_ VEHI SEND_BEACON
60.000000 _48_ VEHI SEND_BEACON
60.000000 _28_ NODE RCV_BEACON from _48_ VEHI
XX 58.500000
60.000000 _BS_ BASE SEND_BROADCAST
60.100256 _48_ VEHI RCV_BROADCAST from _BS_ at [ 163.881778 , 0.000000 ]
AD: EAST
66.824368 _48_ VEHI STOP at [ 70.491335 , 0.000000 ] ROAD: EAST
60.197344 _BS_ BASE RCV_MESSAGE from _48_ VEHI
60.900000 _49_ VEHI SEND_BEACON
60.900000 _36_ NODE RCV_BEACON from _49_ VEHI
XX 60.900000
61.000000 _BS_ BASE SEND_BROADCAST
61.153728 _BS_ BASE RCV_MESSAGE from _49_ VEHI
62.000000 _BS_ BASE SEND_BROADCAST
62.100256 _49_ VEHI RCV_BROADCAST from _BS_ at [ 174.992889 , 0.000000 ]
AD: WEST
68.824368 _49_ VEHI STOP at [ 81.602446 , 0.000000 ] ROAD: WEST
***************************  RESULT
***********************************************
 VEHICLE[id :  0] **
ate: STOP,  Position: [ 76.046891 , 0.000000 ] in [OUT],  ROAD: EAST,
OP_TIME: 19.824368,  ENTERANCE_COLLISION_AREA_TIME: 0.000000,
IT_COLLISION_AREA_TIME: 0.000000,  REMAINING_TIME_IN_COLLOSION_AREA:
000000
 VEHICLE[id :  1] **
ate: STOP,  Position: [ 70.491335 , 0.000000 ] in [OUT],  ROAD: WEST,
OP_TIME: 18.824368,  ENTERANCE_COLLISION_AREA_TIME: 0.000000,
IT_COLLISION_AREA_TIME: 0.000000,  REMAINING_TIME_IN_COLLOSION_AREA:
000000
 VEHICLE[id :  2] **
ate: STOP,  Position: [ 70.491335 , 0.000000 ] in [OUT],  ROAD: SOUTH,
OP_TIME: 18.824368,  ENTERANCE_COLLISION_AREA_TIME: 0.000000,
IT_COLLISION_AREA_TIME: 0.000000,  REMAINING_TIME_IN_COLLOSION_AREA:
000000
 VEHICLE[id :  3] **
ate: STOP,  Position: [ 64.935780 , 0.000000 ] in [OUT],  ROAD: NORTH,
OP_TIME: 20.824368,  ENTERANCE_COLLISION_AREA_TIME: 0.000000,
```

Fig. 5. ICAS Deployment Simulator

network protocol can be evaluated. Lastly, output management module consists of log manager and output parser.

This structure enables optimized system design using feedback. Figure 5 presents a simulation process. The left is a window configuring various simulation environments, the center window is a visualized viewer of simulation operation, and the right is an event log viewer, with respect to the current simulation.

Ⅳ. Performance Evaluation

In this section, the performance of collision avoidance service in the CISN model is evaluated.

The experiments are performed using the ICAS deployment simulator. First, the single traffic environment and complex traffic environment are used in the experiment, depending on the parameters. In addition, the service time is evaluated on the basis of the observed result.

4.1 Performance evaluation in single collision scenario

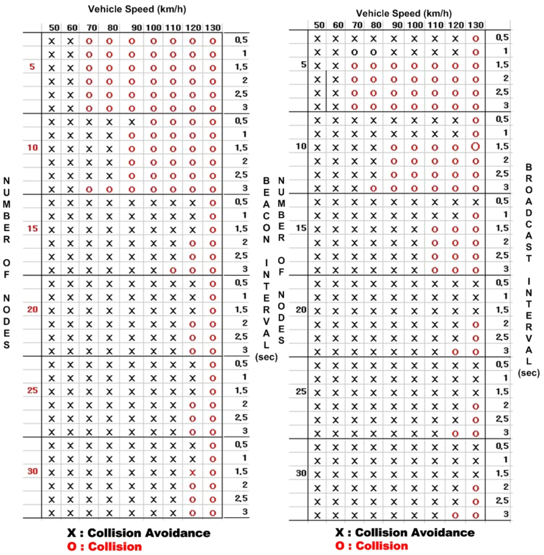
A. Basic simulation configurations: In terms of simulation environment configuration, the ICAS simulator is largely divided into four sections. As presented in Table 1, the basic environment section includes simulation time, the number of sensor nodes, node deployment spacing, and road properties. The traffic set section is the configuration component for traffic generation. In addition, each wireless communication setting can be configured in two sections, Sensor to Vehicle Comm. and Vehicle to BS comm. Table 1 presents the default configuration values for experiments in each section.

B. Service scenario: For this experiment, a situation, in which two vehicles simultaneously start from a particular road, is conducted. This is conducted to observe the intensity at which overall performance is influenced, with respect to variation of individual parameters, such as the number of nodes, vehicle speed, beacon interval, and base station's radio range and broadcast interval. In addition, the optimized value's range for each parameter is found by evaluating the individual experimental result.

Table 1. Basic simulation settings

Basic Environment Set		Sensor to Vehicle Comm	
Start Time(s)	0	Payload Size(B)	128
Ending Time(s)	1000	Radio Range(m)	20
Number of Lane	2	Data Rate(kbps)	250
Lane Spacing(m)	2	Error probability (%)	1
Number of Nodes	20	Hop Delay(s)	0.01
Node Spacing(m)	10	Vehicle to BS Comm.	
Road Length(m)	1000	Payload Size(B)	32
Traffic Set		Radio Range(m)	150
Start Position(m)	1000	Data Rate(kbps)	1000
Start Time(s)	2	Error Probability(%)	1
Velocity(km/h)	VAR	Hop Delay(s)	0.1
Beacon interval(s)	1.5	Broadcast interval(s)	2

C. Variation of vehicle's beacon interval: the left part in Fig. 6 presents the collision distribution results with respect to variations in vehicle's velocity, the number of nodes, and the vehicle's beacon interval. In the experiments, additional parameter values are used by default. From the result, the deterioration of service performance with respect to vehicle's speed is most prominent. In the case of high speed vehicles, even though the vehicles are detected, then, the information is forwarded, and finally the BS broadcasts a collision warning message. However, at the high speed, turn-around time (from vehicle detection time until broadcasting time) is longer than braking time. It is important to note that the phenomenon improves by increasing the number of nodes. As presented in Fig. 6, when deploying nodes greater than 15, collision avoidance is successfully performed up to a speed of 120km/h. From the result, the initial assumption is assumed, "if nodes less than 15 are deployed on each road, service performance will degrade considerably, particularly, in high speed environments."



Vehicle Speed (km/h)

NUMBER OF NODES	50	60	70	80	90	100	110	120	130	BEACON INTERVAL (sec)
	X	X	O	O	O	O	O	O	O	0,5
	X	X	O	O	O	O	O	O	O	1
5	X	X	O	O	O	O	O	O	O	1,5
	X	X	O	O	O	O	O	O	O	2
	X	X	O	O	O	O	O	O	O	2,5
	X	X	O	O	O	O	O	O	O	3
	X	X	X	X	X	O	O	O	O	0,5
	X	X	X	X	O	O	O	O	O	1
10	X	X	X	X	O	O	O	O	O	1,5
	X	X	X	X	O	O	O	O	O	2
	X	X	X	X	O	O	O	O	O	2,5
	X	X	O	O	O	O	O	O	O	3
	X	X	X	X	X	X	X	X	O	0,5
	X	X	X	X	X	X	X	X	O	1
15	X	X	X	X	X	X	X	X	O	1,5
	X	X	X	X	X	X	X	O	O	2
	X	X	X	X	X	X	X	O	O	2,5
	X	X	X	X	X	X	O	O	O	3
	X	X	X	X	X	X	X	X	O	0,5
	X	X	X	X	X	X	X	X	O	1
20	X	X	X	X	X	X	X	X	O	1,5
	X	X	X	X	X	X	X	O	O	2
	X	X	X	X	X	X	X	O	O	2,5
	X	X	X	X	X	X	X	O	O	3
	X	X	X	X	X	X	X	X	O	0,5
	X	X	X	X	X	X	X	X	O	1
25	X	X	X	X	X	X	X	X	O	1,5
	X	X	X	X	X	X	X	O	O	2
	X	X	X	X	X	X	X	O	O	2,5
	X	X	X	X	X	X	X	O	O	3
	X	X	X	X	X	X	X	X	O	0,5
	X	X	X	X	X	X	X	X	O	1
30	X	X	X	X	X	X	X	X	O	1,5
	X	X	X	X	X	X	X	O	O	2
	X	X	X	X	X	X	X	O	O	2,5
	X	X	X	X	X	X	X	O	O	3

X : Collision Avoidance
O : Collision

BEACON INTERVAL (sec)

Vehicle Speed (km/h)

NUMBER OF NODES	50	60	70	80	90	100	110	120	130	BROADCAST INTERVAL (sec)
	X	X	X	X	X	X	X	X	O	0,5
	X	X	O	O	X	X	X	X	O	1
5	X	X	O	O	O	O	O	O	O	1,5
	X	X	O	O	O	O	O	O	O	2
	X	X	O	O	O	O	O	O	O	2,5
	X	X	O	O	O	O	O	O	O	3
	X	X	X	X	X	X	X	X	O	0,5
	X	X	X	X	X	X	X	X	O	1
10	X	X	X	X	O	O	O	O	O	1,5
	X	X	X	X	O	O	O	O	O	2
	X	X	X	X	O	O	O	O	O	2,5
	X	X	X	O	O	O	O	O	O	3
	X	X	X	X	X	X	X	X	X	0,5
	X	X	X	X	X	X	X	X	O	1
15	X	X	X	X	X	X	O	O	O	1,5
	X	X	X	X	X	X	O	O	O	2
	X	X	X	X	X	X	O	O	O	2,5
	X	X	X	X	X	X	O	O	O	3
	X	X	X	X	X	X	X	X	X	0,5
	X	X	X	X	X	X	X	X	X	1
20	X	X	X	X	X	X	X	X	X	1,5
	X	X	X	X	X	X	X	X	O	2
	X	X	X	X	X	X	X	X	O	2,5
	X	X	X	X	X	X	X	O	O	3
	X	X	X	X	X	X	X	X	X	0,5
	X	X	X	X	X	X	X	X	X	1
25	X	X	X	X	X	X	X	X	X	1,5
	X	X	X	X	X	X	X	X	O	2
	X	X	X	X	X	X	X	X	O	2,5
	X	X	X	X	X	X	X	O	O	3
	X	X	X	X	X	X	X	X	X	0,5
	X	X	X	X	X	X	X	X	X	1
30	X	X	X	X	X	X	X	X	X	1,5
	X	X	X	X	X	X	X	X	O	2
	X	X	X	X	X	X	X	X	O	2,5
	X	X	X	X	X	X	X	O	O	3

X : Collision Avoidance
O : Collision

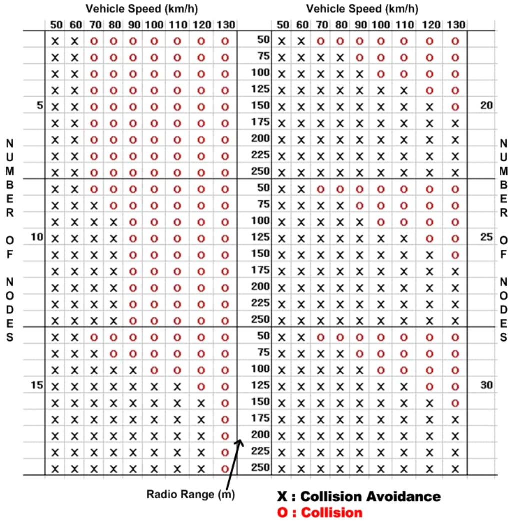
Fig. 6. Collision distribution results with respect to variation of beacon interval of vehicles, broadcast interval of base station, the number of deployed nodes, and vehicle speeds: The same simulation conditions, the left figure, presents the results with respect to variation of beacon interval of vehicles and the right figure presents results with respect to variation of broadcast interval of the base station

In addition to the relationship between service performance and the number of nodes, the figure reveals that the vehicle's beacon interval also influences service performance. In the case of15 nodes and 120km/h, even though the number of nodes is identical, service performance greatly deteriorates relative to increasing the beacon interval value. However, in the beacon interval of 0.5 ~ 1.5 seconds, service performance can improve. In addition, this demonstrates that it is difficult to provide collision avoidance service cases of vehicles traveling at a speed greater than 130km/h.

D. Variation of base station's broadcasting interval: The right figure of Fig. 6 presents the collision distribution results with respect to the variation in broadcast interval. The results also include an impact of service performance with respect to vehicle speed, and the number of nodes.

In the previous experiment, it is demonstrated that the number of nodes considerably influences service performance. In the previous experiment, it is tentatively assumed that the optimal number of nodes is 15. However in this experiment, the result demonstrates that the number of nodes must be greater than 20. In particular, in the case of deployment of more than 20 nodes, even though the vehicle travels at a speed of130km/h, collisions are avoided using a service consuming small broadcast interval (0.5 ~ 1.5)of BS.

E. Variation of base station's radio range: From the two previous experiments, comprehensive results of collisions with various vehicle speeds can be obtained and avoided by collision avoidance service taking the proper value of critical parameters, which includes the number of nodes, vehicle's beacon interval, and broadcasting interval of the BS. In this experiment, collision distribution with respect to the variation of radio range of the BS is observed. In particular, Fig. 7 demonstrates that the radio range parameter has the most direct influence on service performance. It is important to note that, even with the same number of nodes and same speed environment, service performance is much different with respect to variation of radio range of the BS. The distribution results also demonstrate that collisions can be avoided using a radio range of (175 ~ 200m).



NUMBER OF NODES	Radio Range (m)	Vehicle Speed (km/h) 50	60	70	80	90	100	110	120	130
5	50	X	X	O	O	O	O	O	O	O
	75	X	X	O	O	O	O	O	O	O
	100	X	X	O	O	O	O	O	O	O
	125	X	X	O	O	O	O	O	O	O
	150	X	X	O	O	O	O	O	O	O
	175	X	X	O	O	O	O	O	O	O
	200	X	X	O	O	O	O	O	O	O
	225	X	X	O	O	O	O	O	O	O
	250	X	X	O	O	O	O	O	O	O
10	50	X	X	O	O	O	O	O	O	O
	75	X	X	X	O	O	O	O	O	O
	100	X	X	X	X	O	O	O	O	O
	125	X	X	X	X	O	O	O	O	O
	150	X	X	X	X	O	O	O	O	O
	175	X	X	X	X	O	O	O	O	O
	200	X	X	X	X	O	O	O	O	O
	225	X	X	X	X	O	O	O	O	O
	250	X	X	X	X	O	O	O	O	O
15	50	X	X	O	O	O	O	O	O	O
	75	X	X	X	O	O	O	O	O	O
	100	X	X	X	X	X	O	O	O	O
	125	X	X	X	X	X	X	X	O	O
	150	X	X	X	X	X	X	X	X	O
	175	X	X	X	X	X	X	X	X	O
	200	X	X	X	X	X	X	X	X	O
	225	X	X	X	X	X	X	X	X	O
	250	X	X	X	X	X	X	X	X	O
20	50	X	X	O	O	O	O	O	O	O
	75	X	X	X	X	O	O	O	O	O
	100	X	X	X	X	X	O	O	O	O
	125	X	X	X	X	X	X	X	O	O
	150	X	X	X	X	X	X	X	X	O
	175	X	X	X	X	X	X	X	X	X
	200	X	X	X	X	X	X	X	X	X
	225	X	X	X	X	X	X	X	X	X
	250	X	X	X	X	X	X	X	X	X
25	50	X	X	O	O	O	O	O	O	O
	75	X	X	X	X	O	O	O	O	O
	100	X	X	X	X	X	O	O	O	O
	125	X	X	X	X	X	X	X	O	O
	150	X	X	X	X	X	X	X	X	O
	175	X	X	X	X	X	X	X	X	X
	200	X	X	X	X	X	X	X	X	X
	225	X	X	X	X	X	X	X	X	X
	250	X	X	X	X	X	X	X	X	X
30	50	X	X	O	O	O	O	O	O	O
	75	X	X	X	X	O	O	O	O	O
	100	X	X	X	X	X	O	O	O	O
	125	X	X	X	X	X	X	X	O	O
	150	X	X	X	X	X	X	X	X	O
	175	X	X	X	X	X	X	X	X	X
	200	X	X	X	X	X	X	X	X	X
	225	X	X	X	X	X	X	X	X	X
	250	X	X	X	X	X	X	X	X	X

X : Collision Avoidance
O : Collision

Fig. 7. Collision distribution result with respect to variation of radio range of base station, the number of deployed nodes, and vehicle speeds

F. Summary: From the experiments, it is proven that the number of nodes has direct influence collision avoidance service performance. The cost requirement is chosen as 20,the best value for the number of nodes. In addition, the proper range of critical parameters can be determined, without service performance degrading. The beacon interval: 0.5 ~ 1.5 sec, Radio range of BS: 175 ~ 200m, and Broadcasting interval: 0.5 ~ 1.5 sec.

4.2 Performance evaluation in complex traffic scenario

The previous experiments were performed in single traffic scenario. Under such environments, the performance of collision avoidance service is observed and the results are evaluated. This experiment takes more general traffic situations into account. In complex traffic scenario, the performance of collision avoidance service with respect to variation of critical parameters is observed and evaluated. In previous experiments with single traffic, only results regarding whether the two vehicles collide or not was applied. In particular, collision avoidance failure rate is observed. The collision avoidance failure rate denotes a ratio of the number of cars entering a collision area to all vehicles hearing a collision warning broadcast.

Fig.(8 – 10) presents the failure rate of collision avoidance service with respect to variation of the vehicle's beacon interval, radio range of BS, and broadcasting interval, respectively. The variation range of parameters is based on the results in subsection 4.1. It is common that the service failure rate begins to increase from 110km/h as presented in all results. However, such high speed vehicles in dense traffic (average 50 vehicles/min) are hardly practical. Accordingly, the experimental results demonstrate that collision avoidance service of 100 % is guaranteed, up to 100km/h, even in complex traffic environments.

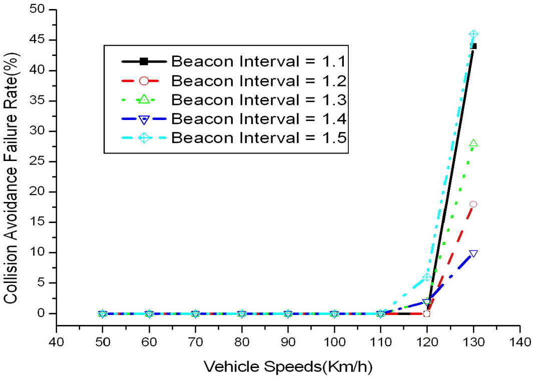


Fig. 8. Collision avoidance failure rate vs. vehicle speeds with respect to variation of beacon interval: multiple traffic environments (50 traffic units on each road)

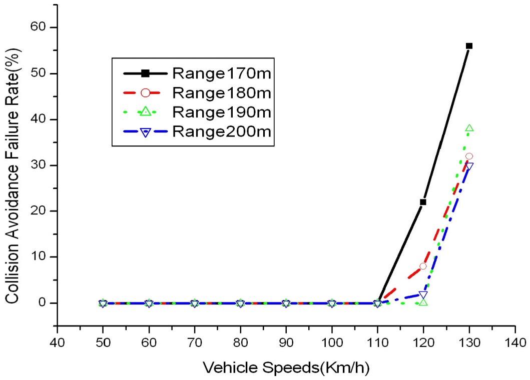


Fig. 9. Collision avoidance failure rate vs. vehicle speeds with respect to variation of radio range of base station: multiple traffic environments (50 traffic units on each road)

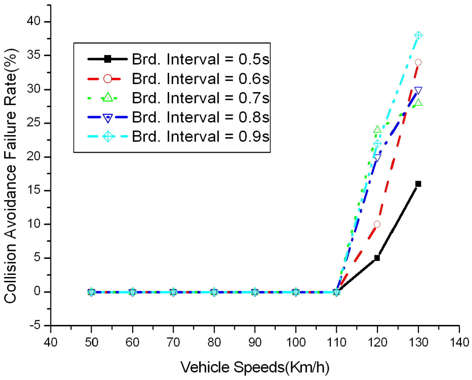


Fig. 10. Collision avoidance failure rate vs. vehicle speeds with respect to variation of broadcast interval of base station: multiple traffic environments (50 traffic units on each road)

4.2 Service time evaluation

In this subsection, the service time in collision avoidance service is evaluated. The variation of average turn around time with respect to increasing vehicles' speeds in different traffic rates, 20, 30, and 40, is observed. The turn around time denotes the total required time from the time when a vehicle is transmitted a beacon message, until the vehicle hears collision warning broadcasting.

As presented in Fig. 11, the turn around time is somewhat influenced by vehicles'speeds. This is because a high speed vehicle may enter a BS broadcast range faster. According to the result, it takes 1.5 ~ 2.5 seconds at the 60 ~ 100km/h speeds. Since the turn around time values are greater than the broadcasting period (1s), service

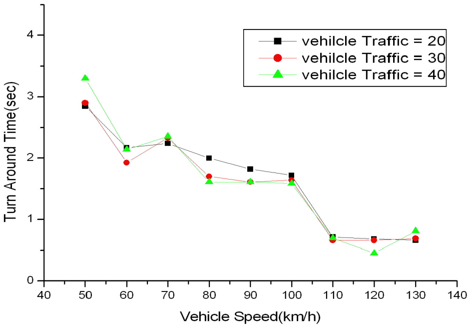


Fig. 11. Turn around time vs. vehicle speed indifferent traffic rates

is successfully achieved up to 100km/h. However, it is important to note that turn around time at a speed greater than 100 km/h is less than 1 second. Therefore, the value cannot satisfy $T_b<s$, which is the time condition for collision avoidance. Accordingly, from this point, of which speed is greater than 100 km/h, service failure rate begins to rapidly increase, as presented in 8, 9, and 10.

Ⅴ. The Desirable CISN Service Model Architecture

In this section, CISN model architecture for safe collision avoidance service, consisting of the optimized parameters, is presented on the basis of the evaluation results performed in the previous section. As demonstrated previously, increasing the number of nodes deployed can increase installation and maintenance costs. According to the experimental results, in the deployment of nodes greater than 20, overall collision avoidance performance is not degraded. Therefore, considering cost requirements, it is desirable that the optimal deployment number of nodes is 20. In addition, in order to reduce the co-interference between BSs of neighboring intersections, the radio range of BS should be minimized in a permissible range where collisions are avoided by the service. Furthermore, in order to avoid unnecessary transmissions, it is desirable that a broadcasting interval of BS and beacon interval of vehicles are chosen at the maximum value permissible for service performance.

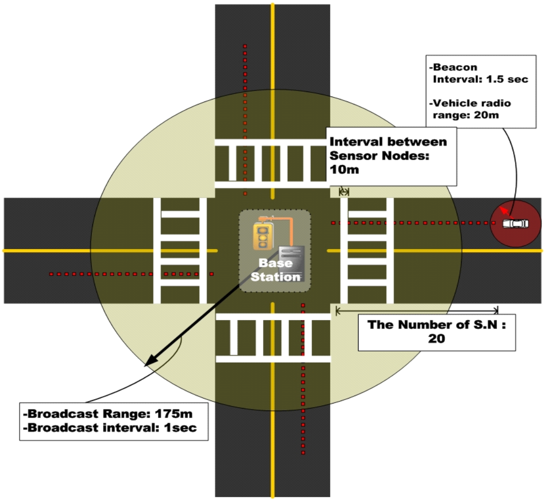


Fig. 12. The deployment model based on a variety of simulation results, satisfying overall requirements for intersection collision avoidance

On the basis of the summarized results, figure 12 illustrates a desirable model for safe collision avoidance service consisting of the optimized parameters.

Ⅵ. Conclusion and Future Work

In this paper, the service architecture for intersection collision avoidance, operating using a cooperative mechanism between vehicles and wireless infrastructure, is introduced. This infrastructure is associated with wireless sensor networks.

In addition, in order to test the feasibility of the CISN architecture in advance and evaluate correctness and real-time transmission ability of intersection collision avoidance service, an intersection sensor deployment simulator is developed.

Through experiments with various deployment environments, critical parameters affecting the performance of collision avoidance service were found. Finally, based on the evaluation results, a desirable example of feasible deployment model with optimum performance for intersection collision avoidance service is presented.

Several interesting results in this paper provide a valuable foundation for future research, which will involve the collision prediction algorithm, real-time network protocols for intersection collision avoidance system, and field tests.

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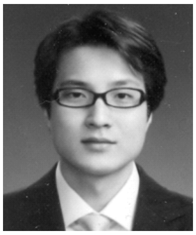

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<관심분야> AD HOC networks, RFID systems, Sensor networks, Ubiquitous networks