An Performance Measurements of Inter-vehicle Communication System over Wireless WANs

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Abstract

This paper presents performance measurements of implemented inter-vehicle communication system over various wireless WAN interfaces such as WCDMA, HSDPA and WiBro networks respectively. To show the applicability of inter-vehicle communication, a simplified V2I2V-based vehicle communication system is implemented to evaluate major performance metrics by road test. In addition, results of road test for traffic information service are investigated in view of RTT, latency and server processing time. The experimental result indicates that V2I2V-based vehicle communication system sufficiently can provide time-tolerant traffic information to moving vehicles.

Keywords: *Car Communications, Inter-vehicle Communication, Wireless WAN*

1. Introduction

Recently, advanced wireless WAN such as WCDMA, HSDPA and WiBro based on 3G+ of cellular networks increasingly are adopted to provide high speed data rate to subscriber in the world. Also, as demand of mobile device with 3G-capability is increasing, and revenue of carriers is rising compared to that of 2G cellular networks. In view of a variety of service, these advanced wireless WAN can provide more sophisticated services including U-healthcare, telematics and infotainment services by accessing advanced wireless Internet due to faster data rates than that of 2G+ cellular networks such as GPRS, CDMA etc.

Recently, the communications society intensified its focus on vehicular communication architectures and protocols. This includes scenarios such as safety applications, but at the same time, these mechanisms are also intended for use in general purpose Traffic Information Systems (TISs), e.g. for optimized route planning. Basically, two approaches are competing in this field: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication architectures. Presently, mainly WLAN according to the IEEE 802.11p standard is used in this domain. However, for general purpose TISs these V2I applications require massive investments into a new infrastructure, e.g. along highways. V2V communication solutions address this problem by using the moving vehicles as a dynamic infrastructure established by Vehicular Ad Hoc Networks (VANETs). An example is the approach taken by the Self-Organizing Traffic Information System (SOTIS).

This paper presents design and implementation of inter-vehicle communications system that provides Internet access over wireless wide area networks anywhere by offering wireless connectivity to subscribers in restricted area such as car and train. When a moving vehicle encounters car accident on the road, driver can inform a safety-related information to another vehicles via location management system to prevent an additional accidents behind reported car accident point.

The goals of this paper are provisions of a prototype of inter-vehicle communication system, and investigation the availability of inter-vehicle application over a variety of wireless wide area networks by experimental performance evaluation.

The remainder of this paper is organized as follows: next section surveys related work, and mentions the motivation to develop inter-vehicle communication system over cellular networks. Section 3 provides design and implementation details of inter-vehicle communication system. The effectiveness and performance are discussed in Section 4. Finally, Section 5 draws some conclusions.

2. Related Works and Motivation

2.1 ITS/Telematics Standards

DSRC(Dedicated short-range communications) are one-way or two-way short- to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards. In October 1999, the United States Federal Communications Commission (FCC) allocated in the USA 75MHz of spectrum in the 5.9GHz band for DSRC to be used by Intelligent Transportation Systems ITS. Also, in Europe in August 2008 the European Telecommunications Standards Institute (ETSI) has allocated 30 MHz of spectrum in the 5.9GHz band for ITS. The decision to use the spectrum in the 5GHz range is due to its spectral environment and propagation characteristics, which are suited for vehicular environments - waves propagating in this spectrum can offer high data rate communications for long distances (up to 1000 meters) with low weather dependence. Currently its main use in Europe and Japan is in electronic toll collection. DSRC systems in Europe, Japan and U.S. are not, at present, compatible.

IEEE 802.11p is an approved amendment to the IEEE 802.11 standard to add WAVE(Wireless Access in Vehicular Environments). It defines enhancements to 802.11 required to support Intelligent Transportation Systems (ITS) applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). IEEE 1609 is a higher layer standard on which IEEE 802.11p is based. 802.11p will be used as the groundwork for Dedicated Short Range Communications (DSRC), a U.S. Department of Transportation project based on the ISO Communications, Air-interface, Long and Medium range (CALM) architecture standard looking at vehicle-based communication networks, particularly for applications such as toll collection, vehicle safety services, and commerce transactions via cars. The ultimate vision is a nationwide network that enables communications between vehicles and roadside access points or other vehicles. This work builds on its predecessor ASTM E2213-03.

CALM(Communications access for land mobiles) is an initiative by the ISO TC 204/Working Group 16 to define a set of wireless communication protocols and air interfaces for a variety of communication scenarios spanning multiple modes of communications and multiple methods of transmissions in Intelligent Transportation System (ITS). The CALM architecture is based on a IPv6 convergence layer that decouples applications from the communication infrastructure. A standardized set of air interface protocols is provided for the best use of resources available for short, medium and long-range, safety critical communications, using one or more of several media, with multipoint (mesh) transfer. Since

2007 CALM stands for Communication Access for Land Mobile, before that year, CALM stood for Communications, Air-interface, Long and Medium range.

2.2 Cellular Networks-based Technologies

3G telecommunication networks including UMTS are a relatively new player in this field [1, 2, 3] and offer a couple of benefits for TIS applications. Owing to their system design, in conjunction with much larger data rates compared to 2G networks, TIS operation based on 3G networks becomes economically feasible. In addition, unlike Vehicle-to-Infrastructure (V2I) solutions using WLAN or WiMAX, UMTS-based solutions can rely on readily-available infrastructure.

Compared to WLAN-based TIS solutions, however, the perceived strengths and weaknesses of UMTS networks are quite different. While, for example, the security of Vehicle-to-Vehicle (V2V) networks cannot easily be guaranteed [4], there already are strong security measures in place to guarantee 3G networks' integrity, which can be reused for V2I communication. As a second example, the distance between a message's sender and its intended receivers is almost a non-issue in 3G networks: its impact on the end-to-end delay is negligible. On the other hand, even for short distance messages the end-to-end delay is already quite high compared to that of direct radio links.

A key question to be asked about an infrastructure-based V2I communication system is therefore whether end-to-end delays will still be acceptable not only for common TIS applications, but also for the transmission of safety warnings. Another important question is whether such a system will scale better [5] than more traditional WLAN-based V2V solutions to accommodate high penetration rates, given that in this V2I solution all network traffic has to be routed through the available infrastructure. Together with obvious business reasons, both questions are at the core of the problems which hindered adoption of some of the early 2G-based approaches [6] to V2V and V2I communications via a cellular network proposed in the 1990s. Development of V2I solutions is now picking up again, with new approaches based on 3G networks or advanced wireless WAN.

Experimental approaches have accomplished post-hoc analysis of implemented testbeds using state of the art technology. In these setups, either detailed studies have been conducted [2] or complex extensible testbed architectures have been developed [7]. However, only the currently deployed UMTS versions could be tested and the size of the experiments was limited. Moreover, an evaluation of the environmental impact of TISs based on real world experiments is infeasible, and even simulative studies on this topic are rare [8].

3. Design and Implementation of Inter-vehicle Communication System

3.1 Major Components

In this paper, the first experimentation results for a typical highway and urban scenarios are shown, based on real-world wireless wide area networks such as WCDMA, HSDPA and WiBro. The results clearly outline the capabilities of testbed and experimental evaluation results are consistent with all expectations. Figure. 1 depicts an overview of testbed of implemented inter-vehicle communication system, along with the various software modules that have been integrated to form the testbed that we will use for performance evaluation.

Based on the testbed, this paper describes modules of the testbed which is composed of and details how the modules interact with each other.

Implemented inter-vehicle communication system consists of two parts that are client and Location Management System. Each component performs its own functionalities as followings. Client periodically receives reliable location and time information from Global Positioning System (GPS) through GPS receiver that is attached to UMPC or mobile device. So, client has a library for parsing the GPS data format of NMEA standard to extract necessary information including current location, speed of vehicle and current time etc. In our implementation, client software is embedded in UMPC, provides the functionalities such as delivery of traffic information, displaying of safety-related information on satellite map provided by Google or Daum. Also, client provides running information of current moving vehicle to drivers based on GPS data. LMS is responsible to register safety-related traffic information such as car accident, traffic congestion and a trouble of car on the road. LMS selects some interested vehicles to avoid accident by delivery of safety-alarm to the vehicles as well as storing properties of each vehicle to database periodically.

3.2 Design and implementation of client and LMS

Application Layer Protocol. As explained in Section 3.1, major components of client and LMS communicates with each other as shown in Figure. 1 which depicts overall protocol stacks of inter-vehicle communication system. Client and LMS exchange predefined application messages which indicate a variety of traffic information including registration of traffic congestion, car accident etc., and delivery of safety-alarm to some interested vehicles at application layer. Client software embedded in a variety of mobile devices has GPS device driver provided by manufacturer as well as legacy Internet protocol suites. GPS data acquired by GPS receiver are transmitted on USB interface or Blutooth wireless link to mobile device. Serial communication emulator pushes GPS data up client's application layer at interval of about one second. A link between client and LMS can be established through wireless WAN link in the vehicle. LMS & database server communicate with its peer correspondent layer of client by using application protocol.

Figure. 2 shows message format at application layer between client and LMS. A message is a variable-length message consisting of two parts : header and data. The size of header depends on the size of each field in header and contains information essential to authentication and operation. All fields are filled with ASCII code to ease parsing of received message at LMS application layer.

Command field indicates the type of operation delivered from client. Operations include LOGIN, LOGOUT, GPS_Log, Alert etc. *Sequenc*e field means the sequence number of messages that are exchanged between client and LMS in a session. Although TCP is used to assure a reliable transmission at transport layer, additional sequence number is added for LMS to acknowledge successfully received message from client. Because of unreliable transmission of UDP, this sequence number can effectively be used to analyze frequencies of error occurrence, out-of-order delivery of message if the system adopts UDP instead of TCP as a transport protocol. LMS authenticates each driver by *Userid* field when driver access and try login to LMS. So, each driver has his or her own unique identifier. *Sessid* means session identifier between client and LMS, which is generated by combination connection establishment time and user identifier. The exact time that client sends routine message to LMS is stored at *Ctime* field in message. This field is needed to calculate round-trip-time

(RTT) and latency between client and LMS. To assure the accuracy of calculation of time, all clients and LMS are synchronized to a specific time server periodically. *Data* filed contains supplementary data of *Command* field. If *Command* field contains a code of *GPS_Log*, this field conveys NMEA protocol data received from GPS satellite through GPS receiver. If *Command* field has a code of ALERT, *Data* field indicates one among predefined types of events such as car accident, construction, traffic congestion and out of order of vehicle. In all cases, *Data* field also provides vehicle's location information such as longitude and latitude.

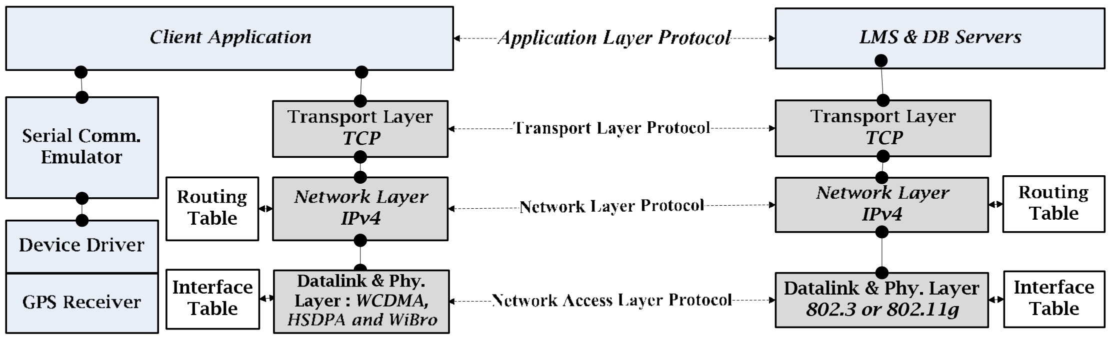


Figure. 1. Protocol Stacks of Inter-vehicle Communication System over Wireless WAN

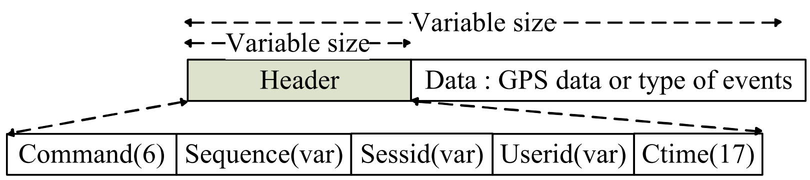


Figure. 2. Message format of application protocol

Software Architecture. Client software implemented in UMPC is composed of several modules according to its functionality. A class of software module and relations among them are depicted in Figure. 3. *GPS_Display* shows values of major fields of received GPS data on UMPC screen for providing driving information to driver periodically. *WebBrowser_Display* shows current location of moving vehicle on Google map or Daum map with satellite image at interval of one second as well as a driving course. *Log_Diplay* and *Log_Managing* store some data field into client's local database, then, process periodical GPS messages to measure performance metrics, collect statistics of performance metrics by combination with LMS's statistics at post-processing stage. *Connection_Managing* maintains current session with LMS by reconnecting to it automatically in case connection lost due to poor quality of signal over wireless WAN. If vehicle enters into tunnel etc. which prevents to receive a good quality of signal, the connection at datalink and physical layer can be lost due to poor signal quality. *Connection_Managing* try to reconnect to LMS and maintains the session continually. *NMEA Parser* analyzes incoming NMEA sentences and granting GPS data in data structures, also generates NMEA sentences. This module supports various types of sentences such as GPGGA, GPGSA, GPGSV, GPRMC and GPVTG.

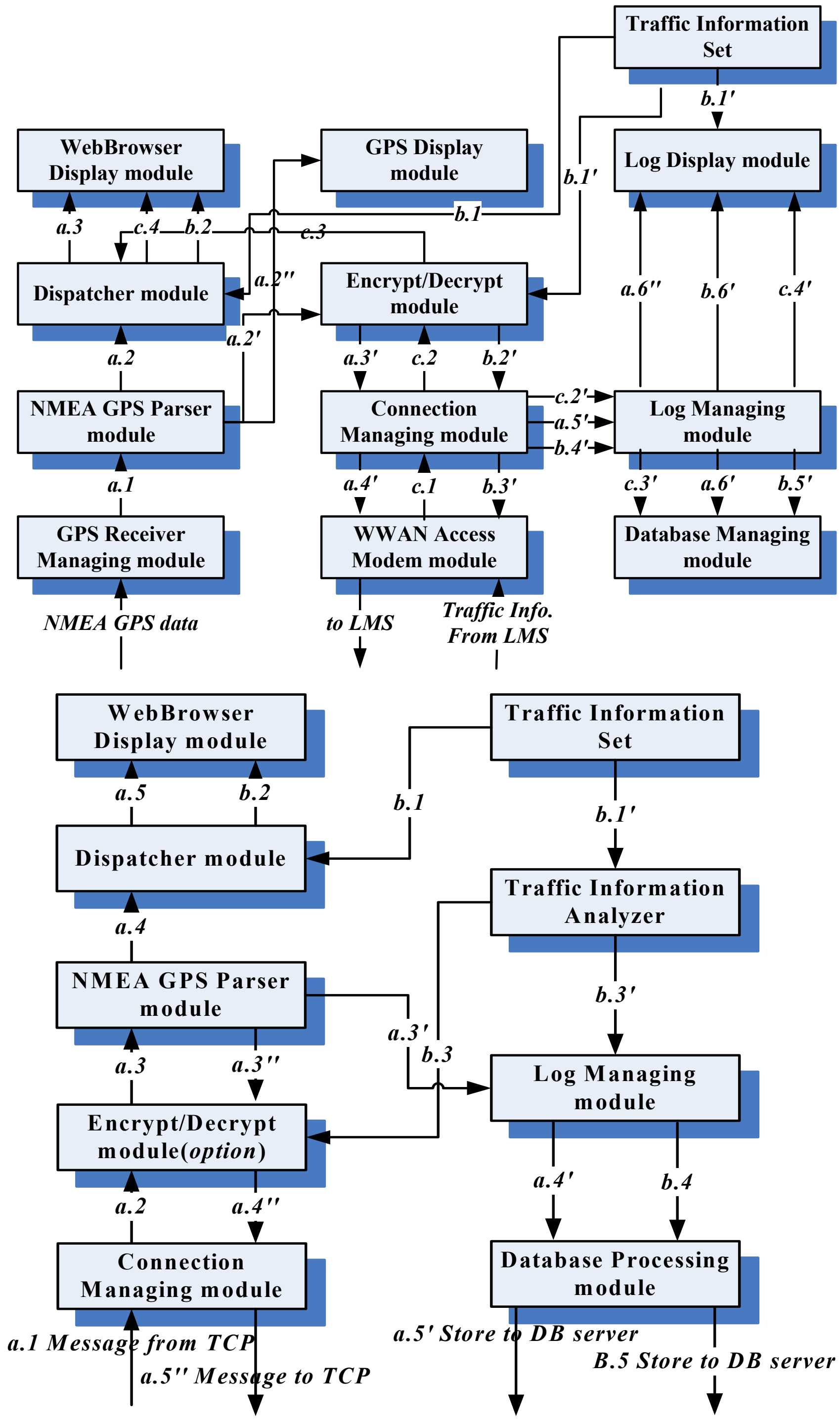


Figure. 3. Software architecture. The upper and bottom Figureures respectively show the major modules both client and LMS, as well as data flows among major modules. Here, a step-by-step data flowing are designated by a.1, a.2 and a.3 etc., and different data sources are identified by different prefix such as a.1, b.1 and c.1

Operational Procedure. Operational procedures of application protocol between client and LMS are shown in Figure. 4. Also, state transition diagrams of client and LMS are shown in Figure. 5 respectively. To ease understanding of each state transition diagram, you can refer operational procedures among components in Figure. 3 and Figure.4.

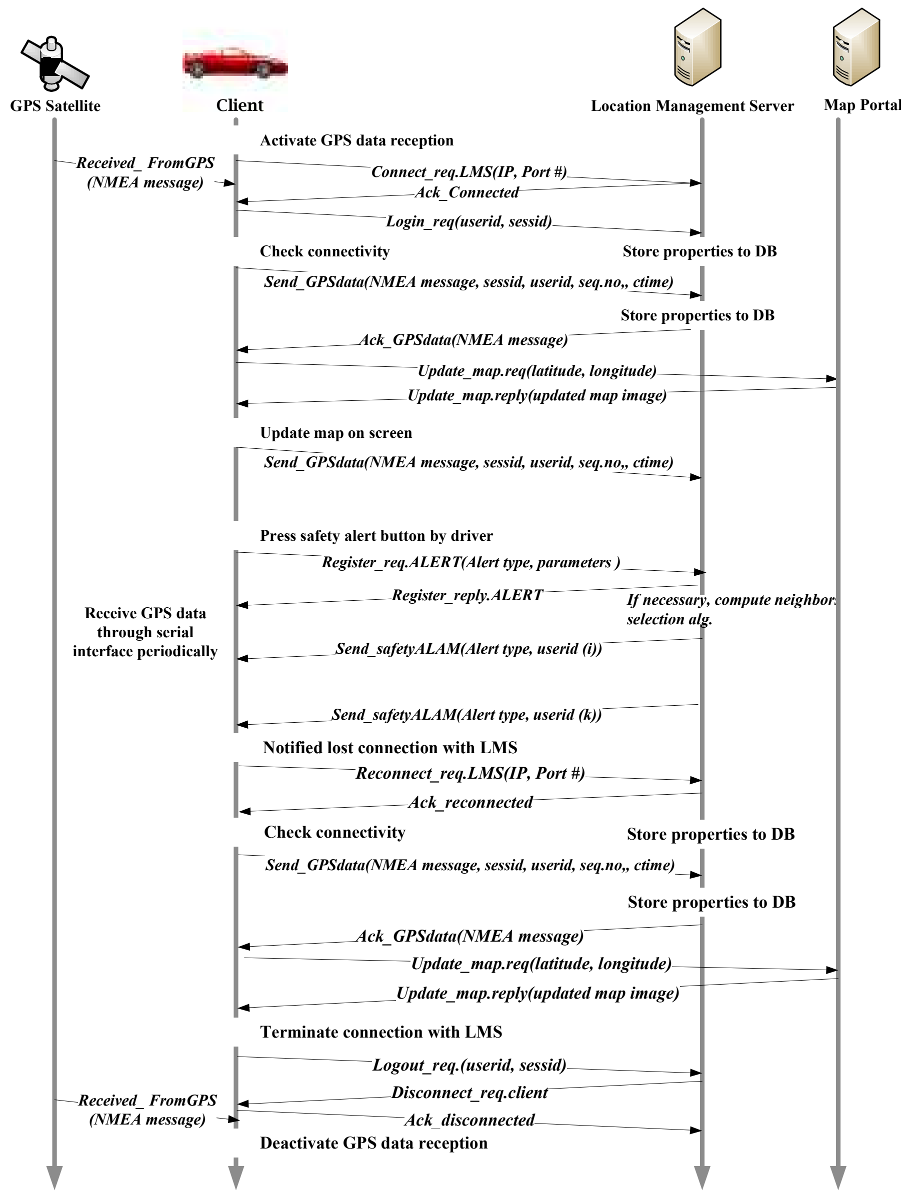


Figure. 4. Operational procedure among components of inter-vehicle communication system : The Figureure illustrates procedures for connection establishment, data transfer, delivery of safety information and connection termination among components.

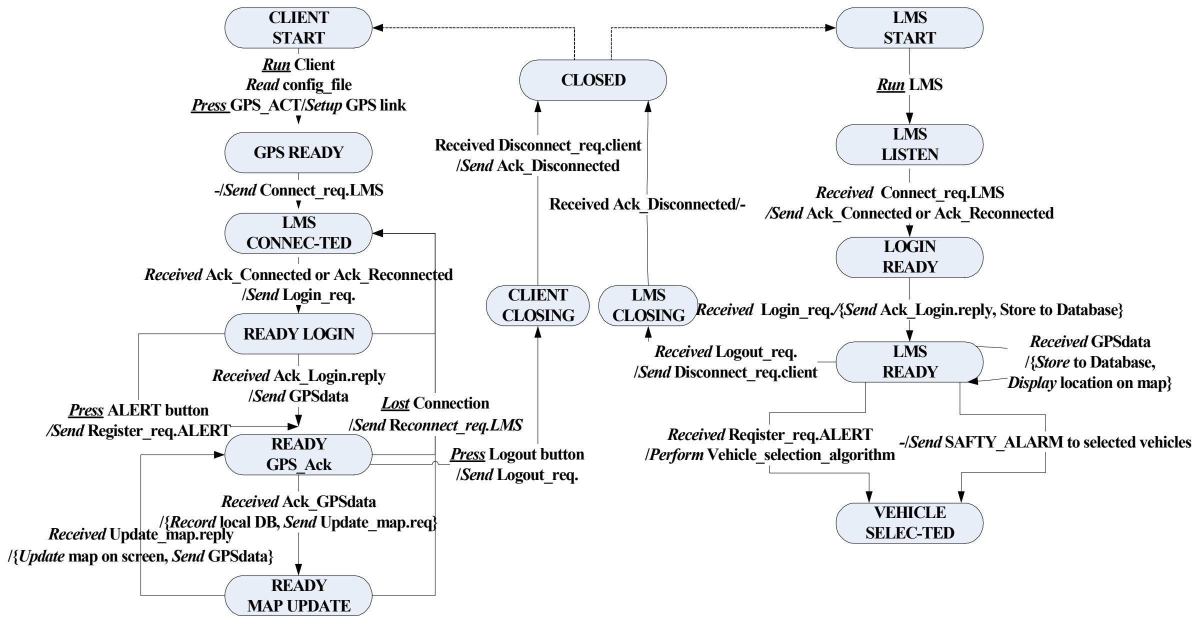


Figure. 5. State transition diagrams of both client and LMS

Implemented graphic user interfaces are shown in Figure. 6, and driver by the GUI of client application can register various events such as car accident, congestion and construction on road by touching screen with touch panel, then these events are delivered to LMS which have a role of registration and delivery of safety-related events t to interested vehicles.

Figure. 6. GUI(Graphic User Interface) of client application. The left Figureure shows the current path of running vehicle on map image that provided by Daum Ltd. of portal site in Korea. The right Figureure shows the overlaid map image over satellite image.

4. Performance Evaluation

4.1 Test Environment

For performance measurement, road test in real environment is performed for investigating major performance metrics such as round-trip-time, latency, standard deviation of latencies etc. as followings :

Performance Measurement. Figure. 7 illustrates the network architecture and road test environment, and the leftmost picture shows equipments including client and GPS receiver in vehicle. Road tests are performed under two different environments of urban and rural areas over WCDMA, HSDPA and WiBro networks. In urban area, vehicles move at a speed of range from 0 Km/h to 60 Km/h around the Daegu Metropolitan City, Rep. of Korea. The Daegu city is densely populated city in the Korea, so, there are many pedestrian crossings, crossroads, buildings and another obstacles. Meanwhile, vehicles move at a speed of range from 0 Km/h to 130 Km/h on the expressway outside the Daegu boundary as a rural area. The measured performances are summarized in from Table 2 to Table 5. As vehicles move faster, as the RTT and latency are gradually increase in both rural and urban areas. On the other hands, LMS processing time is nearly constant to about 40 ms which is practically devoted to processing Database operation. Generally, measured values in the urban are superior to that on expressway in rural area in view of RTT and latency etc.

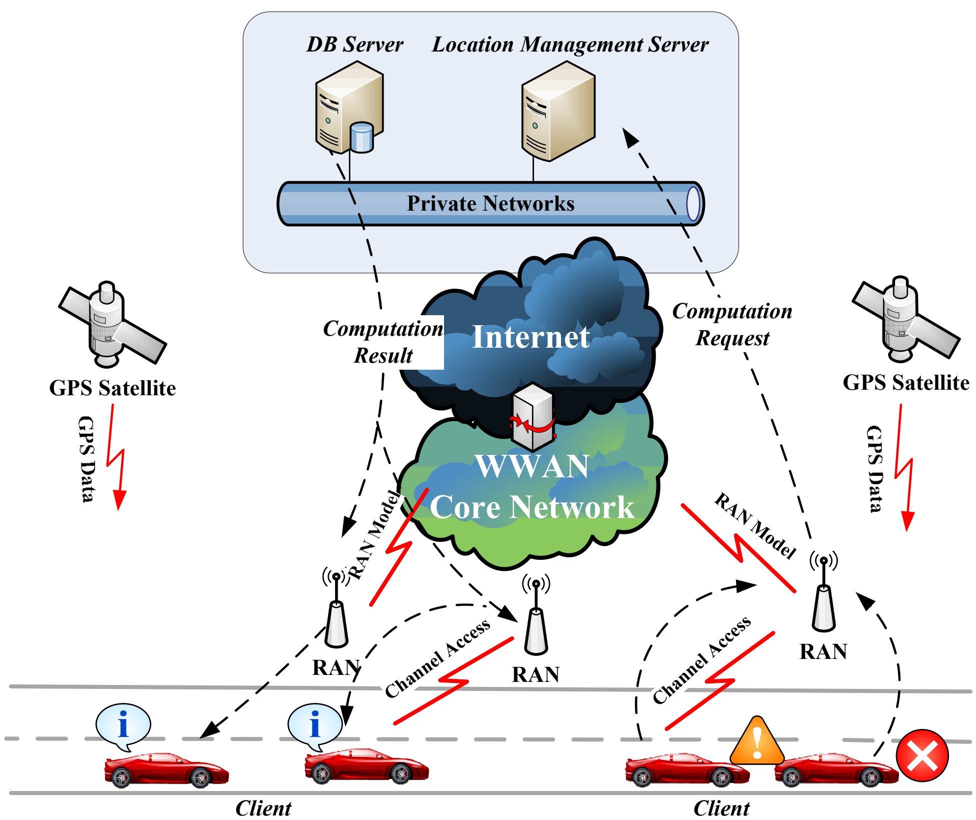


Figure. 7. Network architecture and road test environment

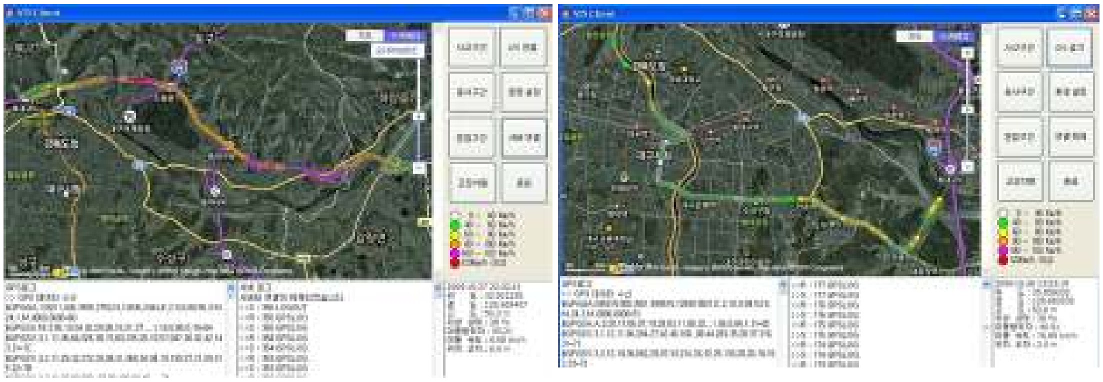
Table 1. Road test environment

Items	Description
LMS and DB Server	● Model : Desktop PC, OS : MS Windows XP professional, ● CPU : Intel Core2duo 2.66GHz, Memory : RAM 1GByte
Client	● Model : Fujitsu U1010(UMPC), OS : MS Windows XP Home Edition, ● CPU : Intel A110 800MHz, Memory : RAM 1GByte, Bluetooth 2.0, 802.11g
WWAN Access Modem	● Model : CBU-450D, WCDMA/HSDPA/WiBro supports
GPS Receiver	● Model : GPS731 manufactured by Assem Ltd., MT3329 chipset-66channel, NMEA0183 v3.0 support, Bluetooth v2.0, USB interface
Types of Wireless WAN	Tested over WCDMA, HSDPA and WiBro networks respectively.
Road test environment	Tested in urban area and on the expressway in rural area about 1 hour respectively

For performance measurement of implemented inter-vehicle communication system, all four vehicles run on two different paths around Daegu Metropolitan City, as shown in Figure. 8, which is the third largest metropolitan area in South Korea, and by city limits, the fourth largest city with over 2.5 million people.

First, two vehicles run along with path 1 which indicates highway express about 35Km in rural area, so there are no obstacles such as buildings, mountains etc. along with the path 1. Second, also two different vehicles run along with path 2 which shows urban area across Daegu city in Figure. 8. Along with the path 2, vehicles frequently encounter many pedestrian crossings, crossroads, buildings and another obstacles.

(a) Two different driving paths



(b) At the left Figureure, sandybrown, pink and red colored sub-paths on path 2 indicates that vehicles move fast over 80 Km/h in rural area. Green and yellow colored sub-paths on path 1 shows that vehicles move below 80 Km/h in urban area.

Figure. 8. Driving paths around Daegu Metropolitan City, Rep. of Korea.

4.2 Performance Evaluation by Road Test

Performance measurements are perforemed over three different wireless infrastructures including WCDMA, HSDPA and WiBro networks, and measurement results are summarized in Table 2 - Table 5. Major performance metrics are end-to-end latency and RTT(round-trip-time) between client process and LMS process as varying speed of vehicles. Especially, RTT includes the processing time in LMS.

Generally, averaged latency and RTT is tend to increase as speed of vehicles increase in both rural area and urban area. Also, averaged latency and RTT in rural area such as highway express are greater than those in urban area due to higher speed of vehicles in rural area.

Additionally, experimental performance measurements show different averaged latency and RTT according to type of wireless infrastructures. Averaged latency in urban area over WCDMA network are about 660 ms, however, averaged latency in urban area over WiBro network are about 500 ms.

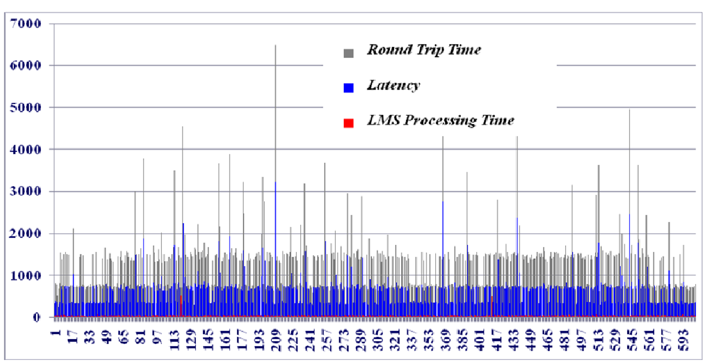


Figure. 9. Performance measurements over HSDPA network : The graph shows round-trip-time, latency between client and LMS, and LMS processing time in both rural and urban areas (unit : ms, message sequence number)

Table 2. Performance measurements over HSDPA network

Items \ Metrics(averaged, ms)	Round-trip-time	Latency	LMS processing time
Highway(rural area)	*1280.9*	*619.1*	*39.7*
Urban area	*923.4*	*440.5*	*40.2*
Minimum on highway	*516.0*	*110.0*	*14.0*
Minimum on urban area	*640.0*	*258.0*	*15.9*
Maximum on highway	*6495.0*	*3224.0*	*514.0*
Maximum on urban area	*5234.0*	*2594.0*	*296.0*
Standard deviation on highway	*629.1*	*315.5*	*28.6*
Standard deviation on urban area	*487.18*	*243.52*	*18.07*

Table 3. Performance measurements on the expressway in rural area over WCDMA network

RTT(ms) \ Velocity	< 10Km	< 20Km	< 30Km	< 40Km	< 50Km	< 60Km	< 70Km
Average	*1336*	*1383*	*1381*	*1078*	*1443*	*1495*	*1607*
Std. Dev.	*320*	*290*	*854*	*418*	*154*	*640*	*741*
MAX	*1995*	*1995*	*1619*	*2786*	*1917*	*4860*	*4969*
MIN	*406*	*750*	*1261*	*584*	*1276*	*1245*	*1230*
Latency(ms) \ Velocity	**< 10Km**	**< 20Km**	**< 30Km**	**< 40Km**	**< 50Km**	**< 60Km**	**< 70Km**
Average	*645*	*672*	*669*	*704*	*701*	*727*	*785*
Std. Dev.	*159*	*144*	*45*	*117*	*77*	*321*	*370*
MAX	*967*	*982*	*794*	*1370*	*943*	*2415*	*2462*
MIN	*188*	*359*	*607*	*584*	*623*	*599*	*592*

Table 3. Performance measurements on the expressway in rural area over WCDMA network(continued)

RTT(ms) \ Velocity	< 80Km	< 90Km	< 100Km	< 110Km	< 120Km	< 130Km
Average	*1451*	*1529*	*1476*	*1456*	*1441*	*1529*
Std. Dev.	*215*	*483*	*510*	*355*	*146*	*198*
MAX	*2026*	*3083*	*3630*	*3302*	*1792*	*1761*
MIN	*1292*	*1260*	*1244*	*1229*	*1245*	*1276*
Latency(ms) \ Velocity	**<80Km**	**<90Km**	**<100Km**	**<110Km**	**<120Km**	**<130Km**
Average	*706*	*744*	*718*	*708*	*701*	*745*
Std. Dev.	*106*	*238*	*255*	*179*	*74*	*100*
MAX	*990*	*1519*	*1799*	*1636*	*881*	*866*
MIN	*623*	*607*	*599*	*591*	*599*	*615*

Table 4. Performance measurements in urban area over WCDMA network

RTT(ms) \ Velocity	< 10Km	< 20Km	< 30Km	< 40Km	< 50Km	< 60Km	< 70Km
Average	*1351*	*1269*	*1324*	*1355*	*1434*	*1380*	*1420*
Std. Dev.	*336*	*238*	*213*	*295*	*470*	*216*	*269*
MAX	*4719*	*1699*	*1994*	*2724*	*4563*	*2848*	*2834*

MIN	*391*	*640*	*671*	*672*	*750*	*703*	*1230*
Velocity / Latency(ms)	**< 10Km**	**< 20Km**	**< 30Km**	**< 40Km**	**< 50Km**	**< 60Km**	**< 70Km**
Average	*654*	*613*	*641*	*657*	*696*	*662*	*688*
Std. Dev.	*168*	*119*	*107*	*148*	*235*	*124*	*136*
MAX	*2344*	*827*	*982*	*1339*	*2259*	*1401*	*1402*
MIN	*173*	*298*	*320*	*306*	*360*	*68*	*599*

Table 5. Performance measurements in urban area over WiBro network

Velocity / RTT(ms)	**< 10Km**	**< 20Km**	**< 30Km**	**< 40Km**	**< 50Km**	**< 60Km**
Average	*940*	*864*	*982*	*1073*	*891*	*1208*
Std. Dev.	*355*	*391*	*460*	*395*	*415*	*1093*
MAX	*1947*	*2880*	*3958*	*2042*	*1760*	*5000*
MIN	*484*	*531*	*531*	*532*	*578*	*500*
Velocity / Latency(ms)	**< 10Km**	**< 20Km**	**< 30Km**	**< 40Km**	**< 50Km**	**< 60Km**
Average	*449*	*412*	*471*	*516*	*425*	*584*
Std. Dev.	*178*	*195*	*230*	*208*	*196*	*548*
MAX	*958*	*1417*	*1956*	*1006*	*857*	*2485*
MIN	*219*	*242*	*251*	*244*	*266*	*227*

5. Conclusion

In this paper, we presented experiments to help in the design and evaluation of wireless WAN-based vehicle communication systems. Such wireless WAN approaches might complement recent efforts to establish VANET-based traffic information system - basically because they are already widely deployed and provide capabilities such as inherent security measures and low latency communication independent of the current traffic density. The experimental performance evaluation is not limited by currently implemented wireless WAN infrastructure and thus able to use forthcoming technologies such as LTE and Advanced IMT-2000. We described in detail the each component implemented system were composed of and how these components interacted to form the system. The study demonstrated the availability of vehicle communication system over various wireless WANs. As a conclusion, vehicle communication system equipped with wireless WAN access modems sufficiently supports time-tolerant services such as time-tolerant traffic information and infotainment services in considering the experiment results.

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