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Wireless Access Technologies for Smart Highway: Requirements and Preliminary Results

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요 약 차량통신은 통신기술과 도로/자동차기술을 융합함으로써 응용분야를 확장해왔으며, 여러 응용분야 중 중요한 한 가지가 스마트하이웨이 프로젝트이다. 스마트하이웨이는 현재의 고속도로 시스템에서 정시성, 안전성 및 편의성을 향상시킨 진보된 차세대 고속도로이다. 본 논문에서는 차량통신을 위한 무선전송기술을 스마트하이웨이에 중점을 두고 소개한다. 먼저 전제적인 통신시스템의 구조 및 기본적인 서비스/통신 요구사항에 대해 소개한 후 L2레벨 핸드오버 및 무선전송기술에 대해 논의한다. 마지막으로 WAVE시스템을 이용한 기본시험결과에 대해서도 소개한다.

Abstract Vehicular communications extend their application areas by combining communication technologies with roads/vehicles, and one of major applications is Smart Highway project. Smart Highway is a new advanced highway system which enhances the current highway system in Korea by improving reliability, safety and convenience. In this paper, we introduce wireless access technologies for vehicular communications especially focusing on Smart Highway. We first introduce the overall communication system architecture and the basic service and communication requirements for Smart Highway. Then, we discuss wireless access technologies including L2-level hand-over scheme. In addition, the results of experimental measurements of Wireless Access in Vehicular Environments (WAVE) system are introduced.

Key Words : Vehicular communications, Wireless access technology, Smart Highway, WAVE, Experimental measurement

Ⅰ. Introduction

Recently, wireless communication technologies have been merged with vehicles and roads, which create a new paradigm of intelligent transport systems (ITS) areas[1]. To provide various services in the road, communication aspects as well as construction aspects have to be considered. Therefore, information and communication technologies (ICT) play important role in ITS, and wireless access technologies are one of the key factor for implementations. The convergence of ICT with vehicles and roads have been applied in various ITS related projects via vehicle-to-vehicle (V2V) and vehicle-to-Infrastructure (V2I) communications. Cooperative Vehicle Infrastructure Systems (CVIS)[2] is the most successful project in Europe, where CVIS builds the open platform by adopting several communication equipments, i.e., one Dedicated

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Short Range Communications (DSRC), one cellular system (3G), and two Communications Access for Land Mobiles (CALM) M5. In the United States, IntelliDrive[3] has been carried out to maximize safety and mobility as well as support green environment by using seamless Vehicle-to-Xmedia (V2X) communications. To elaborate the current highway system, Smart Highway project has been launched in Korea. This project is a long-term, i.e., 10 years, national project, and may be considered as a future ITS. Smart Highway aims to provide safety, reliable travel time, sustainability and eco-environment. To accomplish these objectives, wireless communication technology is one of main factors in Smart Highway. In this paper, we will discuss wireless access technology in Smart Highway. The rest of this paper is organized as follows. Overall Smart Highway system is introduced in Section II, which includes system architecture, service/communication requirements. In section III, various wireless access technologies are discussed. Experimental measurements of WAVE system are presented in Section IV, and conclusions are given in Section V.

Ⅱ. Smart Highway System

In this section we will consider the overall system architecture and service/communication requirements for Smart Highway.

1. System Architecture

Smart Highway has physical and logical infrastructure. Physical infrastructure consists of physical roads, communication networks, and vehicles which equipped with communication devices. Logical infrastructure means software which includes communication protocols and application software. We focus on the communication system of physical infrastructure in Smart Highway. Fig. 1 represents communication system architecture for Smart Highway. The communication system consists of smart terminal (ST), road side equipment (RSE) and control center. ST provides service platform and wireless access capability with hand-over. RSE supports wireless access and backbone network connection, and it may have a local server which informs the road status. Control center provides IPv6 based platform and applications through the IPv6 networks.

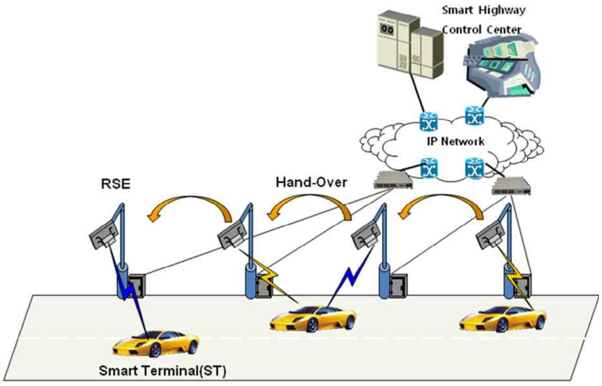

그림 1. 스마트 고속도로를 위한 통신 시스템 구조
Fig. 1. Communication system architecture for Smart Highway

In addition to the communication architecture, it is important that the total amount of information capacity has to be evaluated to design the communication system. The capacity is roughly estimated 60~70 Mbps if we assume that 400 users are uniformly distributed in 4 lanes with 1km communication range, and users mainly send short packet message and transmit video streaming in partial.

2. Service Requirements

Service requirements can be defined by understanding the system operator and users' needs. For both sides, we will derive the basic requirements. System operator requires seamless information environments, which enables to monitor and control the vehicles and road status. This implies that the vehicles are always connected to Smart Highway. Seamless information environments also provide the same benefits to the users via bidirectional information exchanging with operator. With various services supporting, Call & Response (C&R) service has to be provided to the operator.

Users also need various services such as safety, traffic information, and multimedia download including C&R service. It is worth stressing that users require terminal compatibility which provides inter-operability with existing systems such as urban traffic information system (UTIS) and DSRC system. Then, the basic service requirements can be defined in the Table 1.

표 1. 서비스 요구사항
Table 1. Service Requirements

System operator	Users
· Call & Response (C&R) · Multimedia download · Safety messaging · Traffic information	
· Multi-lane Tolling · Vehicle/ Road status monitoring · Location information	· DSRC internetworking · UTIS internetworking

3. Communication Requirements

In addition to the service requirements, we have to define the requirements of communication to provide reliable communication links. To support multi-lane tolling in the spot area, high mobility and high speed packet transmission are required. For C&R services, L2-level hand-over and large communication range are required. For safety messaging, both V2V and V2I communications are needed with very short latency. By summarizing, the communication requirements are presented in the Table 2.

표 2. 통신 요구사항
Table 2. Communication Requirements

Items	Specification
Communication type	V2V, V2I/I2V
Vehicle speed	Maximum 200km/h
Communication range	Up to 1km
Data rate	Maximum 10Mbps
Latency	Less than 100msec
Packet Error Rate (PER)	Less than 10%
Hand-over	L2-level hand-over

III. Wireless Access Technologies

In this section, we overview and compare wireless access technologies for Smart Highway. Five wireless access technologies, i.e., Wireless Local Area Network (WLAN), Wireless Access in Vehicular Environments (WAVE), Wireless Broadband (WiBro), Long Term Evolution (LTE) and DSRC are considered to establish seamless communication environments. First, we briefly overview the physical layer properties of suggested wireless communication technologies. Then, we address the comparison of wireless access technologies in terms of supporting vehicle speed, data rate, latency, communication scheme and cost of operation.

DSRC/WAVE and WiBro use 5GHz and 2GHz frequency band, respectively. Whereas, WLAN use both 2GHz and 5GHz band and LTE may use various frequency bands such as 700MHz, 2GHz or other frequencies. WAVE/WiBro/DSRC and WLAN occupy 10MHz and 20MHz bandwidth, respectively. WiBro has various signal bandwidths depending on services.

WLAN is designed to support low mobility, i.e., approximately 20km/h, and WiBro can support medium velocity. High mobility (up to 200km/h) can be supported by WAVE, DSRC and LTE. Let us consider the data rate. LTE can support very high data rate with high mobility. WLAN provides higher data rate than WAVE and DSRC. However, low mobility makes it difficult to apply in high speed environment. WiBro and WAVE can support approximately 12Mbps. DSRC is mainly used for Electric Toll Collection (ETC) service, it requires low throughput compared with other technologies. In the viewpoint of latency, WAVE and DSRC have very short latency, i.e., less than 100msec, which can be applicable for the safety applications. LTE has approximately 100msec of latency. Whereas, WiBro and WLAN have relatively long latency since their main application mainly aims to internet service. For the communication scheme, WAVE can support V2I/I2V as well as V2V communication. However, other four technologies only adopt V2I or I2V communication. Finally, let us consider the cost of operation. WAVE and DSRC have low cost of operation since these two technologies are operated by the government or other public institutions. WLAN requires medium cost of operation to cover wide areas. Whereas, WiBro and LTE need very high cost of operation since the service company has to buy the assigned frequency band from the government and to make benefits from the customers.

Table 3. summarizes the comparison of five technologies. It also shows the main service for each technology. The table indicates that WAVE and DSRC can provide very low latency with high mobility where the former has medium data rate and the later have low data rate. LTE also support low latency with high mobility and very high data rate, but it requires very high cost of operation. By using WLAN and WiBro, high data rate can be achieved, but they have long latency which prohibits safety applications from vehicular communications. Only WAVE support both V2V and V2I/I2V communications. Based on the properties of wireless access technologies, WAVE is a good candidate of communication system for Smart highway since it can be applied safety related applications as well as internet service. However, it may be efficient to utilize all available technologies for adapting various scenarios depending on service request.

In addition to wireless access technologies, it is important to support L2-level hand-over for seamless communication environments in Smart Highway. To reduce the overall hand-over time, several hand-over schemes have been proposed in the literatures[4][5][6]. We suggest a new hand-over scheme which is suitable for high mobility. In highway environments, RSEs are aligned along the road. It means that the wireless channel may be predictable since the location of RSE is fixed and predetermined. This is distinct from the other wireless environments. This special environment enables us to predict the location and channel information of neighbor RSE. Therefore, the hand-over

표 3. 무선통신 기술 비교
Table 3. Comparison of Wireless Access Technologies

Category	WLAN	WAVE	WiBro	LTE	DSRC
Frequency band	2GHz, 5GHz	5GHz	2GHz	700MHz/2GHz	5GHz
Channel bandwidth	20MHz	10MHz	10MHz	1.25~20MHz	5MHz
Vehicle speed	20km/h	200km/h	60km/h	350km/h	200km/h
Data rate	Max 54Mbps	Max 27Mbps	Max 30Mbps	Max 300Mbps	1Mbps
Latency	~ 1sec	100msec<<	~1sec	~100msec	~100msec
Communication scheme	V2I	V2V/V2I	V2I	V2I	V2I
Cost of operation	Medium	Low	High	High	Low
Main service	Internet	ETC, Safety	Internet	Multimedia	ETC

algorithm for Smart Highway has following properties

- Time slot based beaconing and channel switching
- Fast scanning based on the predetermined location information of RSE
- Beacon frame which contains neighbor RSE information
- Flexible beacon management based on neighbor RSE information

Based on above properties, we can apply fast L2-level hand-over by dramatically reducing the scanning time where this hand-over scheme supports individual C&R service.

IV. Performance Measurement of WAVE

In the previous section, we have shown that WAVE is a good communication technology for Smart Highway due to its supporting of high mobility, very low latency, high data rate and V2I/V2V communications. In this section, we present preliminary test results of WAVE system.

1. WAVE system configuration

We build WAVE system using FPGA in both vehicles and infrastructure. The system is compatible to IEEE 802.11p standard[7] and has following features:

- RF frequency range: 5.835~5.925GHz
- Channel bandwidth: 10MHz
- Modulation: OFDM (BPSK, QPSK, 16QAM)
- MAC protocol: CSMA/CA, EDCA

2. Test Results

The properties of 5.8~5.9GHz channel and channel models are introduced in [8][9]. We measured the system performance in highway environments with 5.85 GHz center frequency, and QPSK signaling. With 20dBm of EIRP, we first measure communication range. Then, latency, throughput, and PER are measured under various packet lengths (512, 1024 and 1518 bytes) and vehicle speeds (20km/h, 60km/h, 100km/h, 120km/h, 160km/h and 180km/h).

(1) Communication range

- Measurement setup: The vehicle is located 2km away from the RSE. The RSE continuously transmits packet, and the vehicle moves towards the RSE. On receiving packets at the vehicle, the vehicle stops at that point. The RSE stops sending packets and retransmits 1000 packets, and the vehicle check PER. If the PER is less than 10%, that distance between the RSE and vehicle is regarded as communication range. Otherwise, we move the vehicle 100m from the initially receiving point and repeat the above procedure.
- Results: The vehicle receives packets with less than 10% PER approximately 1.5km distance from the RSE.

(2) Latency

- Measurement setup: The vehicle moves towards the RSE from 3km away. The vehicle sends a packet to the RSE when the distance between the vehicle and RSE is 500m. Then, the infrastructure returns the acknowledgement signal. When the vehicle receives the acknowledgement signal, the time difference packet sending time and the acknowledgement receiving time is recorded. We record this time difference as latency. Notice that latency is measured between the application layers.
- Results: Our measurement results show that latency is different depending on the packet size, and the vehicle speed does not affect latency. The average latency is approximately 3ms, 5.2ms, and 7.4ms for 512 bytes, 1024 bytes, and 1518 bytes, respectively.

(3) PER

- Measurement setup: The vehicle moves towards the RSE from 3km away. The RSE sends 2000 packets when the distance between the vehicle and the RSE is 500m. Then, the received packets are recorded. We carried out PER measurements for both unicasting and broadcasting. We also measure the PER for V2V communication. However, we omit the test results since there is no big difference between V2I and V2V communication.
- Results: Table 4. represents the results of PER. For unicasting, the worst PER is 0.2%, which corresponds to 1996 reception out of 2000 transmissions regardless of the vehicle speed and packet size. However, this result does not count the retransmission in unicasting. For broadcasting, the PER increases as the packet size and vehicle speed increase in general. It is shown that the worst PER is approximately 5% at 180km/h with 1024 bytes of packet size. The results reveal that the PER keeps less than 10% for any case.

표 4. VoIP 서비스 종류
Table 4. PER depending on various packet sizes and vehicle speeds

		# of Rx packets/ error rate (%)		
		512bytes	1024bytes	1518bytes
30km/h	Unicasting	2000/ 0	2000/0	2000/0
	Broadcasting	2000/ 0	2000/0	2000/0
60km/h	Unicasting	1999/ 0.05	1999/ 0.05	1998/0.1
	Broadcasting	2000/0	1988/0.6	1998/0.1
100km/h	Unicasting	2000/0	1999/0.05	1997/0.15
	Broadcasting	2000/0	1971/1.45	1966/1.7
120km/h	Unicasting	2000/0	1997/0.15	1998/0.1
	Broadcasting	1963/1.85	1946/2.7	1985/0.75
160km/h	Unicasting	1996/0.2	1996/0.2	1998/0.1
	Broadcasting	1960/2	1982/0.9	1956/2.2
180km/h	Unicasting	1998/0.1	1997/0.15	1997/0/15
	Broadcasting	1988/0.6	1900/5	1922/3.9

(4) Throughput

- Measurement Setup: Throughput is measured by using five vehicles where we use two buses and three sedans. One sedan is used to measure throughput which is located behind the buses, and other four vehicles are used for generating background traffic data. Throughput is also measured using the same setup for latency and PER measurements. We measure the throughput for both downlink and uplink.
- Results: For downlink, the average throughput is approximately 4Mbps regardless of the vehicle speed and packet size. For uplink, the average throughput is approximately 1.8Mbps. The decrement in throughput of the uplink is due to the transmission blocking by buses.

3. Implementation Issues

In the previous subsection, we introduced the results of practical measurement. Based on practical measurements, we consider several implementation issues. First of all, non line-of-site (NLOS) problem has to be solved. Since 5.8~5.9GHz frequency band is used for vehicular communications, it is hard to support reliable communication links without LOS. In the vehicular environments, there exist many blocking objects such as big trucks and curve areas. To overcome this problem, we may use a relay node for regenerating or retransmission the received packets. Another issue is the usage of antenna pattern. There is tradeoff between the antenna gain and beam pattern. If the antenna gain is high and two vehicles are located very closely or the distance between the RSE and vehicle is too close, it is observed the reliable communication links are not established due to the narrow vertical beam width of antenna beam pattern. Broad beam pattern can be achieved at the expense of antenna gain which results in the decrement of communication range. To solve this phenomenon, the antenna gain and beam pattern have to be chosen properly. The other practical issue is the location information of vehicles. For various use cases, the location of vehicle will be a critical factor especially in safety related applications such as V2V anti-collision warning, sudden stop warning and road working warning. Nowadays GPS is commonly used for finding the location. However, GPS does not provide accurate information and has several meters of error. To address this issue, the technique for finding location with very high resolution has to be adopted.

V. Conclusion

Smart Highway is a future ITS which has “Smart road” and “Smart vehicle”. We introduced the overall communication system architecture of Smart Highway and analyze the service and communication requirements. From those requirements, we investigated various wireless access technologies depending on several categories. Based on the surveys of wireless access technologies, we introduce the measurement results of WAVE system including some implementation issues.

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