

Current and Future ITS

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SUMMARY Intelligent Transport System (ITS), aiming to provide innovative services related to traffic management, road safety and convenience, has drawn much attention in academic and industrial worlds in recent years. Japan has been considered as an advanced country in ITS development. This paper first gives an overview of the current ITS operated in Japan including Vehicle Information and Communication System (VICS), Electronic Toll Collection System (ETC), and ITS-spot system. Then this paper introduces the trends and the directions of future ITS including the development of driver-assistant type of road safety system in Japan and USA, and the potential use of white space to meet the additional ITS needs in the future.

key words: ITS, VICS, ETC, ITS-spot, DSRC, 700 MHz band ITS

1. Introduction

Intelligent transport system (ITS), which increases efficiency of transportation and comfort, has been expected to utilize information technology (IT), and last for a long time. For utilizing IT, it is very important that how to design the whole system, especially wireless system because the wireless communications between a vehicle and a roadside infrastructure and between vehicles are necessary

In Japan, Vehicle Information and Communication System (VICS) was launched in 1996 for offering real-time road-traffic information, such as congestion data, traffic restrictions, by using FM multiplex broadcasting, infrared beacon, and radio wave beacon [1]. In 2001 Electronic Toll Collection System (ETC), which avoids traffic congestion around tollbooths, was launched as a commercial service [2], [3]. ITS-spot system has been commercially introduced for the provision of traffic congestion data, road information such as safety related warnings and sightseeing information since 2011 [4]. Most of the current ITS systems are utilized for non-mission critical uses except for few warning applications such as notification of falling object. Next-generation ITS systems using wireless communication between vehicles and between a vehicle and a road infrastructure have been investigated and developed for realizing safety support to reduce traffic accidents in earnest. 700 MHz band has been officially allocated for ITS safety applications in 2011 and practical implementation is ex-

pected [5].

In the US, ITS was investigated to enhance safety, efficiency and security and to reduce fuel consumption and environment impact of grand transportation system under A Ten-Year Vision planned in 2002. Safety initiatives preventing crashes with cooperation between vehicles and the road infrastructure using Dedicated Short Range Communication (DSRC) technology were carried out under Safe, Accountable, Flexible and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) passed in 2005. Newly research plan which core concept is “IntelliDrive” has been introduced by USDOT/RITA (U.S. Department of Transportation/Research and Innovative Technology Administration) since 2010 [6]. Safe, interoperable wireless connectivity among vehicles, infrastructure and passengers’ devices to support safety, mobility, and environmental enhancements has been focused in the plan. A regulatory decision on safety system with communication between vehicles will be issued in 2013.

When the communication between a vehicle and a roadside infrastructure and between vehicles will become more active, shortage of frequency resource will be more serious. If the dynamic spectrum access (DSA) where unlicensed devices temporarily borrow licensed but spatially and/or temporally unused spectrum (a.k.a. white space) is approved, the frequency resource shortage is expected to be relaxed. In the US, white spaces which are unused bands of spectrum after TV signals went digital were approved to be used, and the first commercial white space network has been launched since 2012. On the other hand, in Japan policy for white space utilization has been discussed since 2008, and some opening to unlicensed users will be expected. However in case of white space utilization by vehicles, spectrum-congestion prevention mechanism should be reinforced due to varying use of spectrum caused by the dynamic movement of the vehicles. In academic worlds, lots of standardization and research activities have been carried out recently, including the radio device implement technologies called cognitive radio [7]–[11].

This paper reviews current ITS as well as future prospects, especially focusing on wireless systems. The paper is organized as follows. Section 2 explains the current ITS in Japan including VICS, ETS and ITS-spot service. Section 3 describes the future ITS in Japan. In addition, the future ITS in the US and the future wireless system using white space for ITS are also shown in the section. Finally, Sect. 4 summarizes the paper.

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2. Current ITS

2.1 VICS

Figure 1 shows the information flow of the VICS. The Japan Road Traffic Information Center collects road and traffic information from road administrators and police agencies, and then provides the information to the VICS center. The VICS center, as a central administrative office, processes and edits the information, provides them to vehicle navigation system through the three types of communication media, which are radio wave beacons, FM multiplex broadcasting, and infrared beacons. For the vehicles on expressways, the VICS center uses radio wave beacons and FM multiplex broadcasting, and for the vehicles on the ordinary roads, the VICS center uses infrared beacons and FM multiplex broadcasting to deliver the information to drivers through vehicle navigation system.

The characteristics of the above three types of communication media are summarized in Table 1.

First, the radio wave beacons use 2.5 GHz band, and provide 64 Kbps as transmission rate. The transmission range is up to 70 m. These beacons are installed mainly on expressways, delivering the road traffic information in a range of approximately 200 km ahead of the current position.

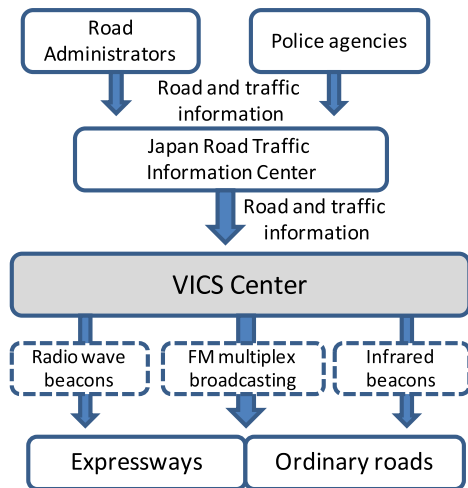


Fig. 1 The information flow of the VICS.

Table 1 The characteristics of three communication media.

	Radio wave beacon	FM multiplex broadcasting	Infrared beacon
Radio Frequency	2.5GHz	76-90MHz	-
Transmission rate	64Kbps	16Kbps	1Mbps
Transmission range	70m	10-50km	3.5m
The number of stations (as of 2009 April)	3,032	518	32,496

Second, the FM multiplex broadcasting uses NHK FM band, and provides 16 Kbps as transmission rate. The transmission range is up to 50 km. The FM multiplex broadcasting is co-located with the local NHK FM broadcasting stations, providing road traffic information about the prefecture where the vehicle is, and the information about neighboring area and regional borders.

Finally, the infrared beacons are mainly installed on main ordinary roads, which provide 1 Mbps as transmission rate. The transmission range is 3.5 m. These beacons deliver road traffic information as far as 30 km ahead of, and 1 km behind the location of the vehicle.

According to the VICS center, there are 3,032 radio wave beacons, 518 FM multiplex broadcasting stations, and 32,496 infrared beacons currently being operated as of 2009. The cumulated number of the in-vehicle VICS unit shipment is 25,181,266 as of 2009. It is clear that the VICS is being utilized successfully as a system for improving road safety and traffic flow, making roads more driver-friendly.

The VICS has been operated for more than 15 years. The performances of transmission rate and transmission range are not exciting today. It is time to consider the system upgrades. Since more and more users are getting the real-time traffic information through the mobile devices, like smartphones, there is one possible direction for next-generation VICS to cooperate with the mobile networks and smartphones.

2.2 ETC

ETC consists of a card with credit function and an in-vehicle device. Figure 2 shows the ways how to use them [2]. All specifications relating to communication and toll collections are standardized. Therefore, there are many flexible ways to utilize the ETC system. For example, one card holder can use his card on any vehicles as long as it is equipped with an ETC in-vehicle device. In addition, multiple ETC cards can be used in one vehicle as long as the same card was used at the entrance and the exit gates.

Figure 3 shows the system architecture of the ETC system. Each tollbooth is equipped with an ETC roadside unit, which is connected to the processing center through wired network. When vehicle approaches the ETC entrance gate of a toll road, the roadside unit receives the vehicle ID and ETC card information from the in-vehicle ETC device through the wireless communication, and then forwards this information to the processing center together with tollbooth information. When the same vehicle approaches the ETC

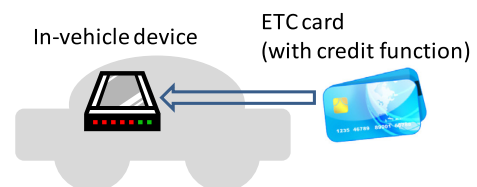


Fig. 2 ETC card and in-vehicle device.

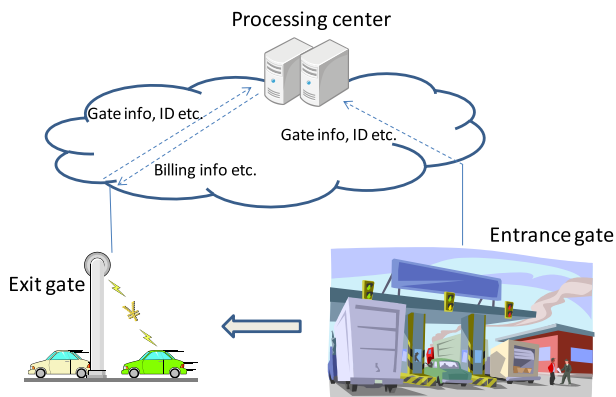


Fig. 3 The system architecture of the ETC system.

Table 2 Transmission parameters of ETC system.

Item	Parameters
Radio access type	TDMA-FDD
Multiplexed number of TDMA	Less than 8 (2, 4 or 8, variable)
Carrier frequency difference between transmission and reception	40 MHz
Modulation method	ASK
Bit rate	1024 kbps
Medium access control method	Adaptive slotted ALOHA
Maximum transmission power	Roadside unit: 300mW In-vehicle device: 10mW

exit gate, the roadside unit receives the vehicle ID and ETC card information from the in-vehicle device and forwards it to the processing center. The processing center calculates the billing information based on the same vehicle ID information, and then sends back the billing information to the roadside unit at the exit gate.

The communication specification of ETC system is defined in ARIB (Association of Radio Industries and Businesses) STD-T55 [12]. ETC system uses 5.8 GHz radio frequency band for wireless communication. The original carrier frequency spacing was 10 MHz, which has been upgraded to 5 MHz since 2004. There are two communication channels assigned to ETC system to avoid the intra-system interference between the adjacent lanes at the same tollbooth.

Table 2 shows the transmission parameters of it. It uses TDMA-FDD (Time Division Multiple Access – Frequency Division Duplex) as radio access type. The maximum multiplexed number of TDMA is 8, which means one roadside unit can communicate with up to 8 in-vehicle devices at the same time. The modulation method is ASK and the bit rate is 1024 kbps. The maximum transmission power of an in-vehicle device is 10 mW. In Japan, the in-vehicle device is considered as unlicensed radio device.

According to the ORSE (Organization for Road System Enhancement), as of the end of March 2011, the ETC system is available on expressways and at main toll ways throughout Japan. The number of ETC tollbooth is 1,503,

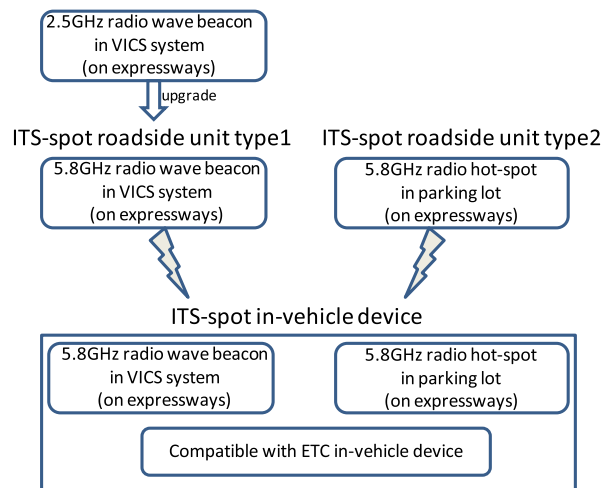


Fig. 4 The variety of the ITS-spot system.

Table 3 The characteristics of 2.5 GHz and 5.8 GHz beacons.

	2.5GHz Radio wave beacon	5.8GHz Radio wave beacon
Transmission rate	64Kbps	4Mbps
Transmission range	70m	20m
The number of road side units	3,032 (as of 2009 April)	1610 (Type1: 1557, Type2: 53, as of 2011 July)

out of 1,508, the total number of tollbooth in Japan. The cumulated number of the ETC in-vehicle device shipment is 38 million as of May 1st 2012. On the metropolitan expressways almost 90% of all vehicles use ETC.

2.3 ITS-Spot

ITS-spot system is another nation-wide ITS system started in 2011 for improving the road safety and convenience. It uses 5.8 GHz radio frequency band for wireless communication, the same as the ETC system. It has very close relationship with the VICS system and the ETC system. Figure 4 shows the relationship and the variety of it. There are two types of ITS-spot road side units, named type1 and type2 in this paper.

The type1 ITS-spot road side units are installed on expressways as the upgraded communication media to the 2.5 GHz radio wave beacon in the VICS system. Table 3 shows the characteristics of the 2.5 GHz and 5.8 GHz beacons. The 5.8 GHz beacon can realize more than 60 times higher transmission rate than 2.5 GHz beacon. In addition to the road traffic information provided by 2.5 GHz beacons, the 5.8 GHz beacons also provide the information related to safe driving, such as rear-end collision avoidance information, sharp curve warning, and falling object warning by combining the sensor information on the roads. Since the 2.5 GHz beacons are decrepit, the Ministry of Land, Infrastructure, Transport and Tourism has decided not to newly in-

install the 2.5 GHz beacons since 2011, and replace the existing 2.5 GHz beacons with the 5.8 GHz beacons in a step-by-step manner. There are 1,557 type1 ITS-spot roadside units, the 5.8 GHz beacons already installed as of 2011 July [4].

The type2 ITS-spot road side units are installed in the parking lot on expressways to provide the local information and the internet access services. There are 53 type2 ITS-spot road side units installed as of July 2011 [4].

The communication specification of the ITS-spot system is defined in ARIB STD-T75 [13], which is backward compatible with the ETC's ARIB STD-T55. ITS-spot system also shares some radio channels with the ETC system. Figure 5 shows the channel assignment on 5.8 GHz in Japan. There are seven pairs of channels on 5.8 GHz band. The ETC system uses two pairs, the D1, U1 and the D2, U2. The ITS-spot system uses all of them. Since the ETC tollbooths are away from the ITS-spot roadside units, the ETC system and the ITS-spot system can share the same radio channels.

There are other services which can be provided by the ITS-spot system. For example, the ITS-spot system may provide payment service at a parking lot or a drive-through store as long as the ITS-spot roadside unit is installed. The ITS-spot system also can be utilized for road traffic information gathering. So far the VICS system relies on sensors and cameras on the road to obtain the road traffic information at a particular location. Since the ITS-spot roadside units can exchange information with each individual vehicles using wireless communication, the travel time between two ITS-spot roadside units for each vehicle can be calculated very precisely. If the privacy of each individual vehicle can be protected, the ITS-spot system can be a very good system to gather real-time road traffic information.

Since the ITS-spot system has very close relationship with the VICS system and the ETC system, it is possible to create a combo radio system to combine ITS-spot, VICS and ETC together to reduce the cost. The shipment of this type of new in-vehicle device will start shortly. But it may take

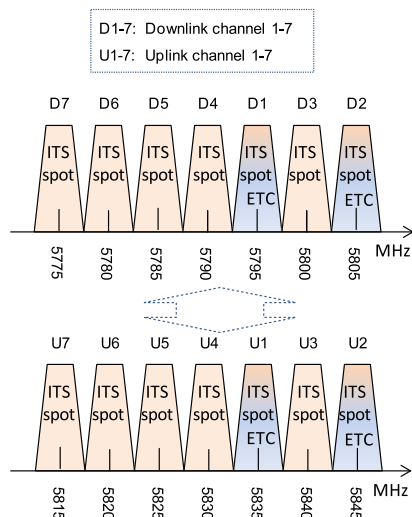


Fig. 5 The channel assignment of the ITS-spot and the ETC.

time for current users to replace the old in-vehicle device for new one.

3. Future ITS

3.1 Future ITS in Japan

Automakers developed lots of stand-alone vehicle safety system, e.g. ABS (Anti Lock Brake System), VSC (Vehicle Stability Control) to reduce the traffic accidents. However stand-alone safety systems are not sufficient all the time. Recently, R2V (roadside-to-vehicle) and V2V (vehicle-to-vehicle) communications have drawn much attention for being possibly achieving better safety assistance to drivers by exchanging safety related messages between neighboring vehicles or between vehicle and roadside infrastructure to extend driver's view. Figure 6 shows the typical applications for R2V and V2V communications. The typical application for vehicle-to-vehicle safety communication is blind intersection collision avoidance, especially under NLOS (Non-line-of-sight) situation. Each vehicle broadcasts its location, speed, heading and acceleration information periodically (e.g. 100 ms) to inform neighboring vehicles about its presence. On the other hand, traffic signal violation warning is a very good example for roadside-to-vehicle communication. In this case, the roadside unit periodically broadcasts traffic signal information to the vehicles around an intersection. There are also lots of other applications being discussed based on the same concept.

In order to realize the R2V and V2V communications, similar activities, such as radio frequency assignment, demonstration experiment and radio system development, have been carried out in the USA, Europe and Japan.

In Japan, the 10 MHz band from 715 MHz and 725 MHz was assigned for ITS in Telecommunications Council Report in July 2007. Later in 2011, the ITS band

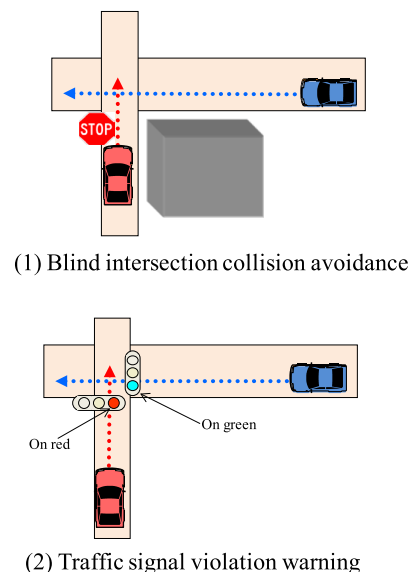


Fig. 6 The typical applications for R2V and V2V communications.

Table 4 The characteristics of 700 MHz band ITS.

Item	Parameters
Center frequency	760 MHz
Modulation method	BPSK/OFDM, QPSK/OFDM, 16QAM/OFDM
Error correction	Convolution FEC R=1/2, 3/4
Bit rate	3Mbps – 18Mbps
Medium access control method	CSMA/CA
Maximum transmission power	10mW/MHz

was changed to 755-765 MHz due to the change of radio frequency assignment plan in 700 MHz-band and 900 MHz-band. In Aug 2011, the Information and Communications Council approved ITS system as a new radio system on 700 MHz band in Japan. In Dec 2011, the Radio Regulatory Council also approved the use of 700 MHz band for ITS. Based on these approvals, ARIB developed the radio communication standard for it, and published the standard as ARIB STD-T109 in Feb 2012, which title is 700 MHz band intelligent transport systems [14]. Some characteristics defined in ARIB STD-109 are shown in Table 4. The 700 MHz band ITS uses OFDM as modulation method and CSMA/CA as medium access control method, the same as IEEE 802.11.

In 2008, large-scale vehicle-to-vehicle communication experiments were planned at the office of the Prime Minister [15], and carried out by Ministry of Internal Affairs and Communications, National Police Agency, Ministry of Land, Infrastructure, Transport and Tourism, and automakers. The results of the experiments showed that vehicle-to-vehicle communication prototype systems accomplished the application requirement (95% reachability in 5 m) even under a congested environment with hands of vehicles communicating with each other [16]. Other testing results in urban area, e.g. the experiments in Ginza, Tokyo were also reported in recent years showing the communication performance is good enough for system implementation [17].

The 700 MHz band ITS are moving toward realization. The large-scale proof-of-concept demonstration will be carried out in 2013 followed by the show case in ITS world congress in Tokyo. The commence operations will start in 2014.

3.2 Future ITS in US and EU

In the US, DSRC is emerging as a critical vehicular communication technology. Based on the popular IEEE (Institute of Electrical and Electronics Engineers) 802.11 (WiFi) protocol, DSRC uses licensed spectrum in the 5.9 GHz band to enable vehicles to communicate with other vehicles (V2V) and with roadside infrastructure devices (V2I) over distances of a few hundred meters. This communication supports a wide variety of applications, often broadly categorized as safety, mobility, environment, and entertainment.

The primary focus of DSRC research among automakers, government officials, and other stakeholders is collision avoidance. When a vehicle broadcasts its core mobility state

information, i.e. location, speed, heading, acceleration, etc., neighboring vehicles can use that information to predict potential collision threats, warning the driver or even taking control of the vehicle (e.g. automated braking). The U.S. Department of Transportation (DOT) estimates that V2V collision avoidance can impact 82% of multi-vehicle crashes involving non-impaired drivers [6]. Driving safety can also be improved via V2I applications, e.g. stop light warning, curve speed warning.

The outdoor, high velocity vehicular environment poses unique data communication challenges, including fading, delay spread, and short duration interactions. Automakers have demonstrated the feasibility of DSRC for collision avoidance in a variety of scenarios [18] based on a set of interoperability standards [19]. They are participating in a one year US DOT-sponsored “Model Deployment” in Michigan to measure the effectiveness of the technology, using 3000 DSRC-equipped vehicles. Current research is investigating several issues, including scalability and security. Scalability addresses the efficacy of safety communication in high vehicle density environments; channel congestion control is a particular focus. Security issues include authentication of messages, preservation of driver privacy, and requirements involving communication between vehicles and security infrastructure devices.

European automakers and standards bodies are considering very similar technologies to those being tested in the US. In Japan the technologies for vehicle safety communication have some common features with the US and Europe, but also important differences (e.g. spectrum, upper layer protocols, security).

Extensions of DSRC to non-safety applications will provide additional benefits in the future. V2V applications include platooning and eventually autonomous driving. Potential V2I applications are abundant, though in some cases cellular communication may provide more efficient service delivery.

V2V and V2I communication based on 5.9 GHz DSRC is nearing the end of its pre-deployment phase in the US and in Europe. First generation systems are likely to be just that, the first of several generations, each more capable and more enabling than the last. The future is expected to bring an expanding set of applications, moving beyond collision avoidance. Indeed, many of these applications have been part of the vision for DSRC-based ITS all along [20]. The promise of fewer accidents and fatalities makes DSRC deployment in vehicles possible, and deployment in turn opens the door to a wide variety of additional benefits.

Next generation DSRC applications are often classified in the following (overlapping) categories:

- *Mobility*: helping the driver find a destination and reach it quickly and efficiently. Examples include real-time navigation and emergency vehicle alerts.
- *Environment*: reducing fuel consumption and damaging emissions. Examples include green light speed advisory and platooning.

- *Commerce*: advertising the availability of goods and services and providing a means to complete transactions. Examples include electric charging station availability and drive-thru payments.
- *General*: This includes the important category of “things not yet conceived.” The lesson from smartphones is that new communication tools often lead to unexpected areas of innovation.

Two potential obstacles to widespread deployment of these applications are: a) lack of DSRC roadside equipment offering services and providing backhaul, and b) alternative communication channels, principally cellular. Indeed, when DSRC and cellular systems both satisfy an application’s *technical* requirements (e.g. speed and latency), business, policy, and governance issues may determine the best choice. Proximity between communication endpoints appears to be one important indicator, for example DSRC has a natural advantage when the service can be delivered over one hop.

Technical challenges include: maintaining backward compatibility across generations, updating the capabilities of older vehicles, and integrating communication and sensor technology. The former is largely a standards issue, while the latter two tasks will be addressed by vehicle manufacturers individually.

3.3 Further Future of Vehicular Networks with Diverse Spectral Needs

As the number of vehicles and applications using the dedicated ITS spectrum increase, one can expect substantial growth in the bandwidth and capacity requirements. Eventually, such applications might suffer from spectrum scarcity and overcrowding, as has already been experienced by other mobile wireless communications sectors. This motivates recent efforts to look for spectral resources elsewhere. It is very important for DSA to ensure the rights of the incumbent spectrum license holders are respected. One method of achieving DSA functionality is cognitive radio, which employs autonomous communications techniques. Existing solutions in the cognitive radio domain usually assume no mobility, which is a major challenge to be overcome in vehicular settings. Moreover, all of the existing cognitive radio architectures and standards are centralized around a base station or a variant where a master-slave relationship between the base station and the end-user terminals governs the entire flow of events. This type of architecture is of less interest in a dynamic vehicular environment where most of the communications is expected to occur among vehicles without the intervention of a centralized component.

In the vehicular environment, application of cognitive radio principles can help to satisfy capacity demand for ITS applications; and to offload time-insensitive applications from the ITS dedicated spectrum. Broadcast television spectrum is one of the possible candidates for dynamic spectrum access in vehicular environments owing to its rel-

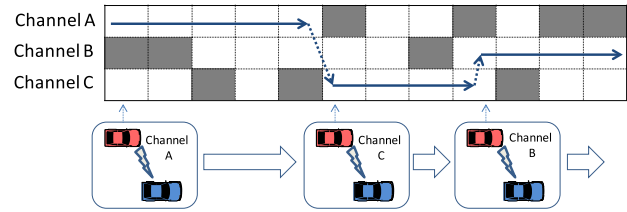


Fig. 7 Cognitive V2V communications concept.

atively static channel utilization by the incumbents. A conceptual overview of V2V communications over white spaces is shown in Fig. 7 where vehicles switch between unused chunks of spectrum.

Before anything, vehicular cognitive network nodes must be aware of the spectrum holes (white space) around them in order to opportunistically utilize the otherwise unused spectrum. Two approaches being considered for spectrum awareness are incumbent user signal sensing and geolocation database lookup. Both approaches pose advantages and drawbacks in vehicular environments. More specifically, neither of these approaches individually can provide sufficient incumbent protection from interference that might be created by vehicular cognitive network nodes [21]. Towards merging spectrum sensing with geolocation database lookup, a representation method of white space vectors customized for high mobility environments is studied in [22]. Once the spectrum holes are detected, the next step is to coordinate and agree with the other vehicle(s) on the channels that are suitable for communications. One of the first studies that looked into the potential of using white spaces for vehicular communications is [10]. In [10], a distributed and autonomous dynamic spectrum coordination method tailored for vehicular environments is proposed. Vehicles coordinate to agree on a control channel, to subsequently setup data channels, and from there to further exchange information on spatial and temporal spectrum variations. Vehicles in this method make use of each other’s temporal and spatial proximity relationships to autonomously agree on control and data channels. [23] reported and demonstrated the world’s first field tests of vehicle-to-vehicle communications over TV white space between two moving vehicles. Furthermore, [11] investigates the spatial dependencies in selecting an appropriate vacant channel for multi-hop vehicle-to-vehicle communications by taking into account several factors, such as the distance between the vehicles, channel bit rate, vehicle velocities, statistical information of channel utilization and propagation range of candidate channels. [24] describes a combination and extension of the work in [23], with the distributed and autonomous control and data channel selection algorithms tailored for a group of vehicles and multi-hop communications.

Moreover, [25] looks into the feasibility of performing vehicular dynamic spectrum access across vacant TV channels. It leverages actual quantitative measurements obtained from a wireless spectrum measurement campaign conducted

along a major interstate highway in Massachusetts. The results show that in most rural and suburban areas, TV white space is a feasible resource for vehicle communications, satisfying performance requirements assuming that the sensing and channel switching functions are performed sufficiently fast. [26] further advances the concept of vehicular dynamic spectrum access by employing artificial intelligence methods such as machine learning, to make a vehicle gradually learn from the past spectral experience and hence quickly converge into the best performing channel depending on the application requirements.

4. Conclusion

This paper has presented an overview of the current and future ITS. Current ITS are spreading year by year. In Japan the penetration rates of VICS and ETC are about 20% and 50% respectively. On the other hand, the penetration of mobile devices and the advance of mobile device technologies have been astonishing. The number of wireless subscriber connections surpasses the total Japanese population. Mobile payment including instantaneous payment has become very popular. Real-time traffic data based on GPS-enabled smartphones monitoring can be shown on mobile devices such as smartphones or tablets. Cooperation with mobile device technologies should be taken into account for the next renewal systems. Decision and penetration of the future ITS will also be affected by costs. However as the future ITS are closely related to safety supports and the numbers of fatalities from traffic accidents totaled in recent years were around 5000 in Japan, rapid penetration will be strongly expected. Considering preparation against aging society, automatic vehicle operation systems are very attractive. To support such systems, beyond-future ITS should also be considered early.

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