Enabling Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles

TASK 1: STATE OF THE INDUSTRY REPORT

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Executive Summary

This State of the Industry report is the first milestone in the University of Virginia's Enabling Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles Project. The report analyzes and compares the currently available communications technologies using literature reviews, related reports, and expert opinions as inputs for the analysis. In addition, the wireless technologies and applications commonly used by different modes of transportation including light passenger vehicles, transit vehicles, and heavy trucks are examined. Finally, the report compares various communication technologies in different application service scenarios to determine the key functions and requirements.

1 Introduction

1.1 Project Goals

The goal of this project is to accelerate the introduction of aftermarket OBE units to the vehicle fleet. Without a rapid deployment, the safety, mobility, and convenience benefits of the USDOT Connected Vehicle Research Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the penetration required for maximum benefit. Therefore, aftermarket deployment is critical. The combination of aftermarket and new vehicle sales equipped with 5.9 GHz DSRC or other communication technologies will produce instantaneous benefits to the consumer. Furthermore, from the consumer perspective, only a system that provides immediate benefits will offer utility. Without utility, the USDOT Program systems and applications will not be accepted by consumers on its own merits.

In this industry report, various communications technologies under the current USDOT Connected Vehicle Research Program are examined including: 5.9 GHz DSRC, cellular 3G/4G/LTE/WiMAX, satellite, Wi-Fi, FM-RDS and Infrared. In addition, various vehicle types including light passenger vehicles, transit, and trucks, are considered.

1.2 Report Layout

In Chapter 2, the current wireless communications technologies are presented that includes 5.9 GHz DSRC, cellular 3G/4G/LTE/WiMAX, satellite, Wi-Fi, Bluetooth, FM-RDS and Infrared. The capabilities (e.g., latency, operating frequency, range, data rate and coverage) for each technology are briefly described in this chapter. In addition, the capabilities of the various wireless technologies are compared in a matrix analysis table. Furthermore, this chapter provides a comparison of the various wireless technologies for different applications (e.g., safety, efficiency and comfort/entertainment) in a matrix analysis table.

Chapter 3 describes the various communications technologies in different vehicles (e.g., light passenger vehicles, transit vehicle and heavy truck vehicles) applications requirement. Finally, a comprehensive overview of the progression of various pertinent technologies and applications are compared in an analysis table.

Chapter 4 discusses four safety application scenarios by using various wireless communications technologies including: Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW). For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services. This chapter also studies eight vehicular research projects (The USDOT Connected Vehicle Research Program, IVBSS, AASHTO Connected Vehicle, CAMP OTA Interoperability, INTERSAFE-2, CVIS, VICS and Smartway) by using various communication technologies. Finally, a summary of various communication technologies in safety/efficiency/entertainment application service scenarios is presented.

Chapter 5 provides conclusions based upon the literature review and expert judgment.

2 Wireless Communication Technologies

This section discusses the current one-way and two-way wireless communications technologies that are available or planned. The capabilities for each technology are briefly described in this section. In section 2.8, the capabilities of the various wireless technologies are compared in a matrix analysis table. In section 2.9, the various wireless technologies for different applications are compared in a matrix analysis table. Section 2.10 gives conclusions.

2.1 5.9 GHz DSRC

Strength: low latency, high mobility, free communication costs

Weakness: low bandwidth, limited coverage

Dedicated Short-Range Communication (DSRC) is a short to medium range communication technology operating in the 5.9 GHz range. It was established for services involving vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications. The Standards Committee E17.51 endorses a variation of the IEEE 802.11a MAC for the DSRC link. DSRC supports vehicle speeds up to 120mph, nominal transmission range of 300m (up to 1000m), and default data rate of 6Mbps (up to 27Mbps). This will enable operations related to the improvement of traffic flow, highway safety, and other Intelligent Transport System (ITS) applications in a variety of application environments called WAVE/DSRC (Wireless Access in a Vehicular Environment). Furthermore, DSRC has the potential to provide low latency communications, which have been identified as a necessary capability to support the vehicle safety applications. In order to realize this potential, however, the correct technological choices must be made for the FCC (Federal Communications Commission) rules for this spectrum, and for the standards to be used in this band. The band plan being proposed in the United States for the 75 MHz of spectrum in the 5.9 GHz range has been under development for some time. Figure 2.1 shows the 5.9 GHz DSRC channel plan (one control channel and 6 service channels).

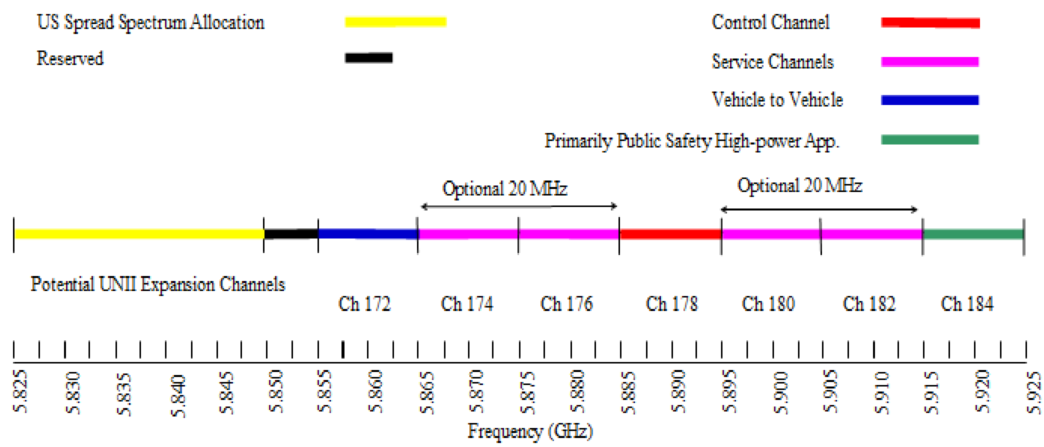

Figure 2.1 5.9 GHz DSRC Channel Plan [1]

2.2 Cellular 3G/4G/LTE/WiMAX

Strength: high bandwidth, wide coverage, high mobility

Weakness: high latency, requires communication costs

3G/4G/LTE/WiMAX generation mobile telecommunications refers to the set of standards for mobile phones and mobile telecommunication services fulfilling the International Mobile Telecommunications-2000 (IMT-2000) specifications by the International Telecommunication Union. Application services include wide-area wireless voice telephone, mobile Internet access, video calls and mobile TV, all in a mobile environment. To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200 kbit/s. The "always on" packet data capabilities of the 3G cellular technologies will virtually eliminate the call set-up delays of data connections over current cellular systems. However, end-to-end latency is likely to remain in the range of at least several seconds, due to the server processing required in the mobile location registers, and the multiple packet forwarding necessary to deliver data to/from dynamically changing cellular sites. As well, data communications over these networks tend to be lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. These latency limitations will likely preclude the use of cellular communications for the majority of the vehicle safety applications.

2.3 Two-way satellite

Strength: wide coverage, provides navigation information for vehicles

Weakness: high latency, requires airtime costs

Satellites are used for a large number of purposes. Common types include military and civilian Earth observation satellites, communications satellites, navigation satellites, weather satellites, and research satellites. There are several application services using satellite technology such as satellite phone, satellite radio, satellite television and satellite navigation. Ubiquitous coverage over the continental US (as well as extended global coverage), provides a strong argument to consider two-way satellite services for wireless connectivity on vehicles. So far, however, the data services that are available and affordable have rather limited data capacity. Even with these data capacity limitations, there are a fairly wide range of telematics-type applications that could be supported using a short message data structure. For example, low bandwidth packet data services over satellite could be used to support vehicle telemetry applications, such as probe vehicle monitoring. Since the two-way satellite services are designed to operate as point-to-point communications channels, their mode of operation is not compatible with the vehicle safety applications. Another serious deficiency of these systems in relation to the vehicle safety applications communications requirements is the large inherent system latency. The expected airtime costs are yet another unresolved issue.

2.4 Wi-Fi

Strength: wide deployment, easy configurations, cost savings

Weakness: limited coverage, high latency, high mobility cause high packet loss rate

The 802.11 series of standards were developed by the IEEE specifically to support wireless LANs. Both 802.11a and 802.11b (depending upon data rates required) could potentially support the inclusion of vehicles in wireless home LANs. Such home systems could provide extensive data downloads to garaged vehicles, as well as allowing the vehicles to download non-time-critical information to wider area networks. At the present time, 802.11b systems are rapidly being deployed for home, office and public area LANs. These developments offer the opportunity for 802.11b-equipped vehicles to upload and download data through these wireless LANs while the vehicles are within range of the “hot spots”. In addition, when a car connects via a WiFi AP, it can potentially transfer data at the same rates as static clients connected to the same network. However, as cars move at high speed rate, their connectivity is both fleeting (caused high packet loss rates), usually lasting only a few seconds at urban speeds, and intermittent, with gaps from dozens of seconds up to several minutes before the next time they obtain connectivity.

2.5 Bluetooth

Strength: low power (consumes less battery), low cost

Weakness: high latency, low speed, limited coverage

Bluetooth is a proprietary open wireless technology standard for exchanging data over short distances (using short wavelength radio transmissions in the ISM band from 2400-2480 MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security. Bluetooth may serve as a vehicle-to/from-infrastructure communications channel for stationary vehicles in close proximity to the desired communications point. Although the operational parameters of Bluetooth in terms of range and latency preclude its ability to support most of the identified vehicle safety applications, it could be used for safety related tasks, for example, updating navigational databases while the vehicle is parked in the garage. The range limitations that prevent the use of Bluetooth to support vehicle safety applications, however, would not prevent it from supporting commercial applications like electronic payments at fast food drive-thrus, or entertainment-related communications between a vehicle and the owner's home infrastructure. In addition, Bluetooth allows transfer speeds of up to 1 Mb/s.

2.6 FM-RDS

Strength: high coverage, low cost

Weakness: high latency, low speed

FM-RDS (Radio Data System) is a one-way communications protocol standard for embedding small amounts of digital information in conventional FM radio broadcasts. This protocol is also used to send traffic data to PND (Personal Navigation Device) types of receivers. In 1992 the US National Radio Systems Committee issued the North American version of the RDS standard, called the Radio Broadcast Data System. The CENELEC (European Committee for Electrotechnical Standardization) standard was updated in 1992 with the addition of Traffic Message Channel and in 1998 with Open Data Applications and in 2000, RDS was published worldwide as IEC (International Electrotechnical Commission) standard 62106. As far as implementation is concerned, most car stereos will support at least AF (Alternative Frequencies), EON (Enhanced Other Network), REG (Regional), PS (Program Service) and TA/TP (Traffic Announcement, Traffic Program). There are a growing number of RDS implementations in portable and navigation devices thanks to lower-priced, small-footprint solutions.

2.7 Infrared

Strength: wide used for military and civilian purposes, low cost

Weakness: limited coverage

Infrared (IR) light is electromagnetic radiation with a wavelength longer than that of visible light, measured from the nominal edge of visible red light at 0.74 micrometers, and extending conventionally to 300 micrometres. These wavelengths correspond to a frequency range of approximately 1 to 400 THz, and include most of the thermal radiation emitted by objects near room temperature. Microscopically, IR light is typically emitted or absorbed by molecules when they change their rotational-vibrational movements. Infrared imaging is used extensively for military and civilian purposes. Military applications include target acquisition, surveillance, night vision, homing and tracking. Non-military uses include thermal efficiency analysis, remote temperature sensing, short-ranged wireless communication, spectroscopy, and weather forecasting. Infrared astronomy uses sensor-equipped telescopes to penetrate dusty regions of space, such as molecular clouds; detect objects such as planets, and to view highly red-shifted objects from the early days of the universe. In vehicular applications, Japan use infrared beacons and FM multiplex broadcasting in their VICS (Vehicle Information and Communication System) and Smartway systems. In their VICS system, infrared beacon can provide information about expressways and ordinary roads as far as 30 km ahead, and 1 km behind from the car. FM multiplex broadcasting can provide information about the prefectures you are in, neighboring area and regional borders.

2.8 Matrix Analysis by the Various Communication Technologies in Different Capabilities

In this section, the capabilities of the various wireless technologies are compared and summarized in Table 2.1.

Table 2.1 Comparison of Wireless Technologies in Different Capabilities

Technologies / Capabilities	5.9 GHz DSRC	Cellular 3G	Two-way Satellite	Wi-Fi	Bluetooth	FM-RDS	Infrared
Latency	200 micro sec [2]	1.5~3.5 sec [2]	60+ sec [2]	3~5 sec [2]	3~4 sec [2]	NA	NA
Operating frequency	5.9 GHz	Depending on its system	Depending on its type	2.4 GHz for 802.11b/ 5 GHz for 802.11a	2.4 GHz	87.5~108 MHz	1 to 400 THz

Range	1000 m [2]	~20-30 km	NA	1000 m [2]	10 m [2]	NA	0.74~300 micrometers
Data rate	Up to 27Mbps	Up to 240Kbps	Uplink: 60~1024Kbps Downlink: 256~2048kbps	802.11b: up to 11Mbps 802.11a: up to 54Mbps	Up to 1Mbps	1.1875 kbit/s	IrPHY: 2.4 kbit/s to 1 Gbit/s
Coverage	Nominal	High	High	Nominal	Low	High	Low
Two-way communication	O	O	O	O	O	X	X
Point-to-point/ Point-to-multipoint communication	O	O	O	O	O	O	O

2.9 Comparison of Wireless Technologies for Different Applications

Intelligent Transport Systems (ITS) are a promising solution to some problems (e.g., traffic accidents, congestion, environmental impacts and energy consumption) and active research is now taking place around the world to advance this technology. ITS is defined as using information and communication technology to form systems that address vehicles, roads and users as a triune entity in order to improve safety, transportation efficiency and comfort while protecting the environment, as shown in Fig. 2.2. ITS aims at establishing a sustainable mobility that balances comfort with safety, security and reduced environmental impacts. **There are three ITS major categories that are under research and implementation as listed below [3],**

- **Safety Applications: Safety applications are time-critical. They include assistance for safe driving (e.g. warning systems), airbags, impact and rollover sensors, adaptive cruise control, and distance control systems, etc.**
- **Efficiency Applications: Efficiency applications are intended for advances in navigation systems, establishment of electronic toll collection, optimization of traffic management and increasing efficiency in road management by building an integrated system of people, roads and vehicles utilizing advanced data communication technologies.**
- **Comfort/Entertainment Applications: Comfortable/Entertainment applications require a large bandwidth for the exchange of data within the car or with external devices. This domain is becoming very important due to the relevance of telematics in modern life: hands-free telephony, car navigation systems, CD, DVD, rear-seat entertainment, and remote diagnostics, etc.**

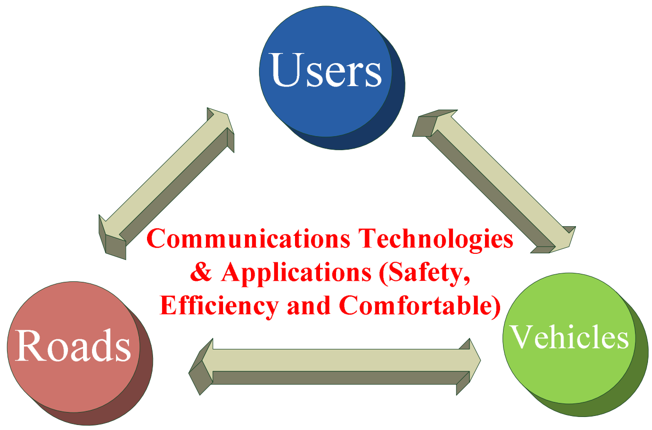

Figure 2.2 ITS Conceptual Model [4]

The various wireless technologies for different applications are explained as follows.

The 5.9GHz DSRC latency is three orders of magnitude lower than other existing wireless technologies. It appears to uniquely meet the basic communications requirements for most of the vehicle safety applications. The 5.9 GHz DSRC also support a wide range of roadside-to-vehicle and vehicle-to-vehicle communications, for which most of the efficiency applications (such as electronic toll collection) can be developed today (e.g., Kapsch has deployed 5.9 GHz DSRC for ETC).

Data communications over cellular 3G networks tend to be lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. The latency (at least several seconds) limitations will likely preclude the use of cellular communications for the majority of the time-critical vehicle safety applications. Internet connectivity via cellular 3G services can also support entertainment application (such as interactive online games).

Since the two-way satellite services are designed to operate as point-to-point communications channels, their mode of operation is not compatible with the vehicle safety applications. The two-way satellite communication is suitable for low bandwidth packet data services over satellite and could be used to support vehicle telemetry applications, such as probe vehicle monitoring.

The Wi-Fi systems could provide extensive data downloads to garaged vehicles, as well as allowing the vehicles to download non-time-critical information (such as video entertainment applications) to wider area networks.

Bluetooth is a low-power, low-cost, short-range (10m) wireless communication system. The coverage range and latency limitations that prevent the use of Bluetooth to support vehicle safety applications, however, would not prevent it from supporting commercial applications like electronic payments at fast food drive-thrus, for example, or entertainment-related communications between a vehicle and the owner’s home infrastructure.

The comparison of various wireless technologies for different applications is shown in Table 2.2. 5.9 GHz DSRC is very suitable for time-critical applications (e.g., assistance for safe driving). Wi-Fi or Bluetooth is suitable for in-vehicle applications (e.g., maps download for Wi-Fi communication and hands-free calling with mobile phones for Bluetooth communication). However, Cellular 3G or Satellite is very suitable for comfort applications (e.g., multimedia download for cellular communication and satellite television/satellite navigation for satellite communication).

Table 2.2 Comparison of Wireless Technologies for Different Applications

Technologies / Applications	5.9GHz DSRC	Cellular 3G	Two-way Satellite	Wi-Fi	Bluetooth
Safety	A	C	C	C	C
Efficiency	B	B	B	B	B
Comfortable/Entertainment	C	A	A	A	A

A: Very suitable; B: Suitable; C: Inappropriate

2.10 Summary

The vehicular application choice of which wireless technology to use will always involve making trade-offs among multiple factors – cost, coverage range, data rate, reliability, power consumption, technology life, scalability, and others. For example, 5.9GHz DSRC (suitable for time-critical safety vehicular applications) is meant to be a complement to cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and ranges up to 1 km are important. 5.9GHz DSRC is also suitable for non-safety applications (such as electronic toll collection or payment applications). 5.9 GHz DSRC will work for ETC, but the majority of ETC in US today uses 915 MHz DSRC. Bluetooth allows transfer speeds of up to 1 Mb/s, which is suitable for entertainment applications (e.g., music sharing), but the effective range is too short for DSRC applications. Primarily because of its low latency and reasonable range, 5.9 GHz DSRC has become the wireless technology of choice for safety applications

In 2005, the USDOT VSC (Vehicle Safety Communications) project developed a comprehensive list of communications-based vehicle safety and non-safety application scenarios [2]. More than 75 application scenarios were identified and analyzed resulting in 34 safety and 11 non-safety application scenario descriptions. Each safety application scenario was further defined to include an initial estimate of potential safety benefits, and eight high potential benefit safety application scenarios were selected for further study: traffic signal violation warning, curve speed warning, emergency electronic brake lights, pre-crash warning, cooperative forward collision warning, left turn assistant, lane change warning and stop sign movement assistance [2]. Currently, the U.S. DOT's Connected Vehicles program is leading the activities on cooperative vehicular systems in the US [5].

In addition, with the rapid progress of semiconductor technology, mechanical components are gradually being replaced by electronics. Consumer demand for safety, comfort and energy efficiency is leading the auto electronics industry toward positive growth. Industry output is likely to reach US$155 billion in 2009 and increase to US$170 billion in 2010. As demand increases for safety, comfort and energy efficiency, the market for auto electronics such as security and telematics systems is expected to soar. It has been forecasted that the market share for auto security will increase from 13% to 16% between 2004 and 2009 [6].

3 Comparison of Various Communications Technologies and Applications in Different Type of Vehicles

Each type of vehicle has its own associated communication technologies and applications. Three types of vehicles are discussed including light passenger, transit, and heavy truck vehicles. This section will make comparisons of various communications technologies for different modes of transportation including light passenger, transit, and heavy truck vehicles.

3.1 Light Passenger Vehicles

Using technologies: 5.9 GHz DSRC, Satellite, Cellular, sensors

Applications: OnStar System, IVBSS

According to U.S. Department of Transportation's definition, a passenger vehicle means a car or truck, used for passengers, excluding buses and trains. Passenger vehicles are cars and light trucks up to 14,000 pounds Gross Vehicle Weight Rating (GVWR). Table 3.1 shows International Organization of Motor Vehicle Manufacturers statistics for two types (passenger/commercial) of vehicles. (http://oica.net/category/production-statistics)

Table 3.1 Production statistics for two types of vehicles in United States

Production Statistics	2006	2007	2008	2009	2010
Passenger Vehicle	4,366,220	3,929,368	3,776,641	2,195,588	2,731,105
Commercial Vehicle	6,897,766	6.856.461	4,916,900	3,535,809	5,030,338
Total (unit)	11,263,986	10,780729	8,693,541	5,731,397	7,761,443

3.1.1 OnStar System

The first application of light passenger vehicles was OnStar system [7], which is a subsidiary of General Motors that provides subscription-based communications, in-vehicle security, hands free calling, turn-by-turn navigation, and remote diagnostics systems throughout the United States, Canada and China. OnStar services are only available currently on vehicles manufactured by General Motors and Saab Automobile. The service is available for all vehicles that have the factory-installed OnStar hardware. A similar service is known as ChevyStar in Latin American markets. The service currently has more than five million customers. In addition, a new retail rear-view mirror with a built-in OnStar module, branded as OnStar FMV, became available to the public on July 24th, 2011. It provides some of the features an OEM system has, such as Automatic Crash Response, Stolen Vehicle Tracking, Turn-by-Turn Navigation, and Roadside Assistance.

The OnStar service relies on CDMA mobile phone voice and data communication, primarily via Verizon Wireless in the United States and Bell Mobility in Canada, as well as location information using GPS technology. Drivers and passengers can use its audio interface to contact OnStar representatives for emergency services, vehicle diagnostics and directions. OnStar equipped vehicles with an active subscription will also contact representatives based in Warren, Michigan; Charlotte, North Carolina; Makati, Philippines; and Oshawa, Ontario in the event of a collision in which the airbags are deployed. Newer models (on vehicles from approximately 2006 and later) will contact OnStar in any type of collision regardless of airbag deployment. This new service is called Advanced Automatic Crash Response (AACR) and is designed to assist emergency response efforts. When a driver presses the Red OnStar Emergency button or Blue OnStar button, current vehicle data and the user's GPS location are immediately gathered. This information is then sent to OnStar. OnStar Emergency calls are routed to the OnStar Center with highest priority. Three centers exist to receive emergency calls: Warren, Michigan; Charlotte, North Carolina and Ontario, Canada, and all centers are open 24 hours a day.

All OnStar equipped vehicles have Stolen Vehicle Tracking, which can provide the police with the vehicle's exact location, speed and direction of movement. Starting 2009, General Motors began equipping some new vehicles with Stolen Vehicle Slowdown. This feature allows OnStar to remotely slow down the stolen vehicle. The service is also expected to help reduce the risk of property damage, serious injuries or fatalities resulting from high-speed pursuits of stolen vehicles. Customers may opt out of that function. The first successful use of this service occurred in October 2009 when a stolen Chevrolet Tahoe was recovered and its suspected thief was apprehended. Also in 2009, General Motors began equipping some new vehicles with Remote Ignition Block, allowing OnStar to remotely deactivate the ignition so when the stolen vehicle is shut off, it cannot be restarted. All Stolen Vehicle Assistance services (Stolen Vehicle Tracking, Stolen Vehicle Slowdown and Remote Ignition Block) can be requested by the OnStar subscriber, but OnStar will not activate them until confirming with the police that the vehicle has been reported as stolen. OnStar subscribers may be eligible for anti-theft and low mileage insurance discounts. Since OnStar can help with the recovery of a stolen vehicle, some insurance companies recognize this and offer a discount. Also, with certain insurance companies (for example, GMAC Insurance) and with subscriber permission, OnStar will send the insurance company the vehicle's odometer reading every month. If the subscriber qualifies as a low-mileage driver, they may be eligible for an insurance discount.

Even if the vehicle is OnStar equipped, no OnStar services are available until the system is activated. Vehicle owners can choose between two plans:

- Safe & Sound: $18.95/mth ($24.95 in Canada), which includes Automatic Crash Response, Stolen Vehicle Assistance, Roadside Assistance, Remote Door Unlock, Remote Horn and Light Flashing, Red Button Emergency Services and OnStar Remote Vehicle Diagnostics
- Directions & Connections: $28.90/mth ($39.90 in Canada), includes all services in the Safe & Sound plan, plus turn-by-turn navigation

3.1.2 IVBSS

The second application of light passenger vehicles was IVBSS (Integrated Vehicle-Based Safety Systems), which includes Forward Collision Warning, Lane Change Merge, and Curve Speed Warning as safety sub-system for passenger car. The detailed description will discuss as follows:

- FCW Sub-system

Forward Collision Warning (FCW) system warns the driver when his/her vehicle is in danger of colliding with another vehicle that exists in its lane. The objective of this system is to warn the driver early enough so he/she can avoid the collision. FCW system design attempts to address different forward collision scenarios such as:

1) Host vehicle (vehicle equipped with the system) is moving in straight or curved road, and there is a slower/stopped/decelerating lead vehicle in the host vehicle current lane (straight or curved).
2) Host vehicle is moving in straight or curved road following a lead vehicle. The lead vehicle changes lane and new slower/stopped/decelerating lead vehicle appears in the host vehicle current lane (straight or curved).
3) Host vehicle is moving in straight or curved road following a lead vehicle. The host vehicle changes lane toward a new slower/stopped/decelerating lead vehicle.

In all of these scenarios the FCW is expected to warn the driver. The timing of the warning will depend on the design tradeoff that is needed to minimize the number of false alarms.

FCW system will not warn for vehicles that are not moving in the travel direction of the host vehicle. FCW system will not warn for vehicles that are moving or stopped outside the host vehicle lane.

- LCM Sub-system

The Lane Change Merge (LCM) sub-system addresses side collision scenarios involving intentional lane-change maneuvering of the host vehicle. Side looking radar is used to identify potential hazards in an adjacent zone extending from just in front of, to substantially rearward of the host vehicle. Vision is a stretch objective for LCM for the light vehicle IVBSS and will be used to augment the radar data. A warning is generated when a vehicle collision hazard exists in the adjacent zone, due to the lateral motion of the host vehicle. Supplemental information is provided via a mirror icon that is lit when a same-direction moving vehicle is detected in the blind-spot zone, or when a vehicle will be in the blind-spot zone.

Three basic functions comprise the LCM subsystem: to warn of side-collision hazards due to lane-change and merge situations; to inform of occupied blind-spot zone; and to calculate lateral available maneuvering room (AMR) for use by other subsystems. The detailed description was as follows. In addition, three side-looking radar sensors positioned on either side of the host vehicle provide obstacle data to the subsystem: rear-facing; rear side; and front side.

- To warn of side-collision hazards due to lane-change and merge situations:

  The data provided by the radar is used to create an understanding of obstacles in the adjacent proximity zone that extends from 0.5 to 3 meters laterally from the side of the host vehicle, and runs from approximately 3 meters forward of the front bumper of the host vehicle, to 18 meters rearward of the back bumper.

- To inform of occupied blind-spot zone:

  The blind-spot zone is a subset of the adjacent proximity zone that represents the area of the adjacent lane that is difficult for the driver to see, both directly by turning his/her head, and indirectly via the side mirror. The blind-spot zone extends from 0.5 to 3 meters laterally from the side of the host vehicle and runs from approximately the B pillar to 3 meters rearward of the back bumper of the host vehicle.

- To calculate lateral available maneuvering room (AMR) for use by other subsystems:

  The Available Maneuvering Room function delivers a pair of outputs that quantify the available lateral distance from the subject vehicle to detected objects in the adjacent path or the adjacent lane. The goal of this function is to optimize IVBSS warnings and improve on the performance that stand-alone IVBSS features can provide. The AMR function will enable IVBSS systems to respond to environment factors beyond the detection capabilities of any single system.

- CSW Sub-system

The CSW (Curve Speed Warning) sub-system warns the driver when the vehicle is traveling too fast for an upcoming curve. The objective of this system is to warn the driver early enough so he/she can avoid possible road departure at some point of the curve. In addition, CSW system design attempts to address curves that exist in:

1) Single road geometry.
2) Branching road geometry.

In all of these road scenarios, the CSW will warn the driver if he/she is driving at a speed more than the desired designed (by system) speed for this curve.

The Basic IVBSS CSW sub-system is a navigation-based system. CSW uses the navigation system to place the vehicle position on the map, and then, the CSW algorithm looks ahead on the map, extracts all possible driving path candidates, determines the intended driving path, performs a curvature calculation on the geometric data of this path, and finally performs a threat assessment based on the vehicle speed and road curvature ahead.

The light passenger vehicle IVBSS system will use a combination of GPS, digital maps, cameras, short-range radar and long-range radar.

Table3.2 is the IVBSS Sub-System Requirements in Passenger Vehicles Applications.

Table 3.2 IVBSS Sub-System Requirements in Passenger Vehicles Applications

IVBSS Sub system	Communication Type	Transmode	Min. frequency (Hz)	Latency (msec)	Max. Req'd comm. Range(m)
Cooperative Forward Collision Warning	Infra. To Vehicle (I2V) One Way Point to Multipoint	Periodic	~10	~100	~150
Lane Change Warning	Vehicle To Vehicle (V2V) One Way Point to Multipoint	Periodic	~10	~100	~150
Curve Speed Warning	Infra. To Vehicle(I2V) One Way Point to Multipoint	Periodic	~1	~1000	~200

3.2 Transit Vehicles

Using technologies: 5.9 GHz DSRC, Satellite (DGPS), Cellular, sensors (LIDAR)

Applications: BRT, Bus Station Tracking System

According to U.S. Department of Transportation's definition, a transit vehicle means a bus or light rail vehicle. According to 2006 data, there about 70,000 transit buses in the United States. There are also over 400,000 school buses. Transit buses account for about 2.2 billion vehicle miles per year, and according to the Federal Transit Administration (FTA) have a useful life of about 12 years. Transit vehicles are typically highly-customized with a variety of electronic equipment selected by transit operators to improve the monitoring of bus operations or better reporting of passenger usage data. All bus transit vehicles will fall under the same Connected Vehicle standards.

Transit vehicles represent a good target for early adoption of Connected Vehicle systems, as long as they can be shown to provide value to the operator. The cost of the equipment is relatively modest in comparison with other electronic systems typically deployed, so deployment of such equipment will generally depend on proving some level of operational benefits. There are two popular systems for transit vehicles.

3.2.1 BRT

Bus rapid transit (BRT) is a term applied to a variety of public transportation systems using buses to provide faster, more efficient service than an ordinary bus line. Often this is achieved by making improvements to existing infrastructure, vehicles and scheduling. The goal of these systems is to approach the service quality of rail transit while still enjoying the cost savings and flexibility of bus transit. The expression BRT is mainly used in North America; in Europe and Australia, it is often called a busway, while elsewhere, it may be called a quality bus.

The FTA has identified the concept of Bus Rapid Transit as a means to increase the efficiency of transit operations while maintaining transit's proven safety record. BRT also combines the quality of rail transit and the flexibility of buses. It can operate on exclusive transitways, HOV lanes, expressways, or ordinary streets. A BRT system combines intelligent transportation systems technology, priority for transit, cleaner and quieter vehicles, rapid and convenient fare collection, and integration with land use policy. Because of the limited right-of-way available to build new (and possibly dedicated) lanes for BRT operations, the FTA has identified lane assist as an emerging technology which will enable deployment of BRT systems. The premise behind lane assist technology is to increase the safety of BRT vehicles as they operate in the more unique environments, such as narrow lanes. Lane assist technology will allow BRT vehicles to operate at the desired higher operating speeds while maintaining the safety of the passengers, BRT vehicle and the motoring public.

In 2005, two Bus Rapid Transit technologies [8] are proposed from University of Minnesota. (1) Assisting Drivers Operating Buses on Road Shoulders; (2) A Virtual Mirror for Eliminating Vehicle Blind Zones

- Assisting Drivers Operating Buses on Road Shoulders

In bad weather, drivers have a difficult time determining the right boundary of the bus only shoulder, and are therefore reluctant to use the shoulder because they fear dropping a wheel off of the pavement, and getting a bus stuck in the soft dirt adjacent to the shoulder. This is further complicated in snow events and in winter in general, where snow removal operations have left some shoulders snow covered and the right edge of the shoulder even more obscure.

In order to solve the above problems, the driver assistive systems were developed. The driver assistive systems use DGPS and high accuracy geospatial databases as the core technologies upon which all system functionalities are built. (These core technologies can be augmented with other guidance methods in situations where DGPS service is either impractical or unavailable.) DGPS uses fixed GPS base stations and a means to use wireless broadcast capabilities to sent appropriate corrections to a roving GPS receiver in real time.

The driver assistive system also supports three modalities to provide lane assist feedback to the driver. Visual information is presented to the driver via a Head Up Display (HUD) and a Virtual Mirror Display. The visual information presented to the driver via the HUD includes simple system status information, lane boundary position information, and forward target information. To improve visibility on the sides of the bus, a LIDAR (LIght Detection and Ranging) based Virtual Mirror is used. The Virtual Mirror is comprised of three components: a sensor, a processor, and a graphical display.

- A Virtual Mirror for Eliminating Vehicle Blind Zones

While mirrors offer the driver greater visibility of the current surroundings, there are limitations to their use. Planar mirrors provide a relatively small field of view that creates blind zones, areas around the vehicle in which the driver cannot see when using the mirror. These blind zones create the need for the driver to check the mirrors often to determine if a vehicle has entered a blind zone or to turn their head to directly view these areas while driving, increasing the potential for accidents. Non-planar mirrors offer a larger field of view to the driver, but the image is smaller and often distorted, which can lead to the overestimation of distance even when the driver has experience using non-planar mirrors.

In order to solve the above problems, the Virtual Mirror technique was developed. This technique is for side collision warning and avoidance for transit applications. The virtual mirror technique can be "virtually" moved and re-oriented to view areas that would be impractical for a real mirror. If the driver wishes to eliminate the blind zone along the side of the vehicle, the virtual mirror could be "moved" so that it would be near the front corner of the car. The virtual mirror technique has been implemented using existing geospatial database tools and DGPS as a range sensing device; however, for practical applications, LIDAR or similar ranging sensors will have to be used. There are three basic types of LIDAR: DIfferential Absorption Lidar (DIAL), Doppler LIDAR, and range finders.

3.2.2 Bus Station Tracking System

The Bus Station Tracking System gives user the flexibility of enabling the in-bus terminal device to send real-time tracking data and receive it at the server. This system also emphasizes on tracking, monitoring the buses and their status on standard GIS maps such as proprietary map server or any map service providers like Goggle maps, Bing, Mapinfo etc. From table 3.1 [9], bus station tracking system take the bus to track the location, DSRC and GPS are main technologies, showing the bus station in what location, estimated time of arrival at the station, passenger car and the road to traffic congestion status of the case.

Table 3.3 Bus Station Tracking System

	Tradition Bus Stop System	Bus Station Tracking System
Transmission	GPRS	DSRC
Transmission Speed	Max 11Mbps	Max 25Mbps
Transmission Fee	Package	Free
Signal Scope	Long distance	Short Distance
Working Mode	Two Way	One Way /Two Way
On Time	Middle	High

3.3 Heavy Truck Vehicles

Using technologies: 5.9 GHz DSRC, Satellite, Cellular, sensors

Applications: IVBSS

According to U.S. Department of Transportation's definition, a Heavy Truck Vehicles means up to 26000 pounds Gross Vehicle Weight Rating (GVWR). There are approximately nine million medium and heavy vehicles on the road today (FHWA 2006), and each year about 260,000 new heavy vehicles are manufactured (the production rates for 2009 were substantially below normal levels due to economic factors). In general, the population of medium and heavy vehicles is expected to rise at a rate of about 2% per year. More than 700,000 of the heavy vehicles are private buses and motor coaches. The IVBSS system is developed for heavy truck vehicles.

3.3.1 IVBSS

The application of Heavy Truck Vehicles was IVBSS (Integrated Vehicle-Based Safety Systems), which includes Lane Departure Warning, Forward Collision Warning, and Lane Change Merge as safety sub-system for passenger car. The detailed description will discuss as follows:

- LDW Sub-system

The LDW (Lane Departure Warning) subsystem in IVBSS will be integrated into the vehicle and will share the same driver vehicle interface that the other subsystems use. In the IVBSS program, the LDW subsystem will be further integrated with the other subsystems to both improve the performance of the LDW functionality and to improve the performance of the functionality of the other.

The core sensor of the LDW subsystem is the forward-looking camera. The image from the camera is processed and painted lane markers or other non-painted visual features that delineate the lane are detected. From this information, an assessment is made as to whether the host vehicle is within the lane boundaries or departing the lane boundaries. If the host vehicle appears to be unintentionally drifting out of the lane, a warning request is generated to focus the driver's attention on the roadway.

- FCW Sub-system

The FCW (Forward Collision Warning) capability will provide imminent and cautionary alerts to assist drivers in avoiding striking other vehicles from behind (rear-end collisions) or reducing the severity of a collision.

The primary sensors of the FCW subsystem are a pair of TRW AC20 radar units [12]. The AC20 radar unit has onboard processing hardware that will estimate target track data assigned to specific vehicles and objects. A set of evolving parameters is associated to each track that includes: track identification number, relative (radial) distance, relative rate (radial velocity), estimated relative (radial) acceleration, angular position, and track confidence level. The set of tracks will be managed according to the birth and death of vehicle tracks (i.e. entry and exit from the radar FOV). Each AC20 can track up to 8 vehicles simultaneously at a data rate of 40 ms.

- LCM Warning Sub-system

The LCM (Lane Change Merge) warning function advises or warns the driver of an impending crash with another vehicle occupying a proximity zone in the adjacent lane, on either side of the host vehicle, when changing lanes, turning, or passing a vehicle in front. The primary sensor information for the LCM subsystem is provided by four short-range side-looking radar sensors and a pair of rear-looking radar sensors. A pair of rear-looking cameras will also augment the LCM subsystem functionality.

The heavy vehicle IVBSS system will use a combination of Forward Radar, Rear-Looking Radar, Side-Looking Radar, Forward-Looking Camera, Rear-Facing Camera, Yaw Rate Sensor, Tri-axial Accelerometer and GPS Sensor.

3.4 Summary

Different type of vehicles should use several communication technologies in their application. For example, the light passenger vehicle should use a combination of GPS, digital maps, cameras (e.g., Forward-Looking camera), short-range sensor and long-range sensor (e.g., Forward Looking senor, Rear-looking sensor, Side-Looking sensor, Yaw Rate sensor and GPS sensor). The Transit vehicle should use GPS, cameras (e.g., Forward-Looking camera), short-range sensor in Bus Tracking system. The heavy vehicle should use Forward-Looking Camera and several types of sensors (e.g., Forward sensor, Rear-Looking sensor, Side-Looking sensor, GPS sensor and Yaw Rate sensor). Table 3.2 provides a summary of various communication technologies and applications in different type of vehicles.

Table 3.4 The comparison of technologies and applications in different type of vehicles

Type of vehicles	Technologies	Applications
Light Passenger Vehicles	5.9 GHz DSRC, Satellite, Cellular, sensors	OnStar System, IVBSS
Transit Vehicles	5.9 GHz DSRC, Satellite (DGPS), Cellular, sensors (LIDAR)	BRT, Bus Station Tracking System
Heavy Truck Vehicles	5.9 GHz DSRC, Satellite, Cellular, sensors	IVBSS

The communication requirements for communications-based vehicle safety applications are considering the type of communications, transmission mode, update rate, allowable latency, maximum required range of communication, these descriptions are summarized as following:

Type of Communications: consider (1) source - destination of the transmission (infrastructure-to-vehicle, vehicle-to-infrastructure, vehicle-to-vehicle communica -tions), (2) direction of the transmission (one-way, or two-way), (3) source-reception of the communication (point-to-point or point–to-multipoint).

Transmission Mode: Describe whether the transmission is triggered by an event (event-driven) or (sent automatically at regular intervals (periodic).

Update Rate: Define the minimum at which a transmission should be repeated (e.g., 1Hz).

Allowable Latency: Define maximum duration of time allowable between when information is available for transmission and when it is received (e.g., 100msec).

Maximum Required Range of Communication: Defines the communication distance between two units that is required to effectively support a particular application (e.g., 100m).

The general, the 100 millisecond latency requirement and the broadcast nature of the communications determines the required technology. In addition, the data packets to support most vehicle to vehicle communications are determined to be less than 100 bytes.

In general the **light passenger vehicle** industry is also exceedingly cost conscious. Each vehicle platform is based on a production cost budget, and any extra cost either increases the price or reduces the profitability of the vehicle. As a result, vehicle manufacturers weigh the cost of every part against the need for that part, or the estimated value to be perceived by a prospective buyer. Vehicle executives are highly wary of adding cost without proof that the added value provided by that cost will pay off. The result of this situation is that it is challenging to add new equipment to a vehicle. Typically the demand for the equipment must be obvious in the marketplace before such equipment will be embedded in the design. Many examples of this exist in the history of the motor vehicle. The first car radios appeared in about 1928, eight years after they were available for home use. In 1962 Philips invented the compact audio cassette medium for audio storage, introducing it in Europe in August 1963, and then in the United States in November 1964. However, it was not until about 1974 that cassette players were available for cars, and sometime after that before the cassette player was standard equipment.

As a result, deploying Connected Vehicle related equipment in vehicles requires that the system provides clear value to the vehicle user (such that a vehicle manufacturer can be sure that the added feature will provide value to the customer commensurate with the cost of the equipment). This value must be realizable by customers in a time frame that is relevant to their ownership of the vehicles (that is, they must realize its value while they own the car, and preferably when they are considering their vehicle purchase). These considerations are generally in conflict with the dynamics of the market. The time required to achieve sufficient penetration in the fleet, such that some benefits (value) are obvious to the owner, is longer than that which would motivate the installation (and cost) of the equipment.

Transit vehicles are typically highly customized with a variety of electronic equipment selected by transit operators to improve the monitoring of bus operations or better reporting of passenger usage data.

Heavy trucks generally use multiplex networks for gauges and other electronics, and generally they are configured to support a variety of aftermarket installed electronic equipment. The typical large truck also includes physical provisions for such equipment. As a result, it is much easier to add equipment to a truck, either as original equipment or as aftermarket equipment than it is to add such equipment to a passenger vehicle.

While comprising less than four percent of the overall vehicle population, the heavy vehicle industry is highly aware of the benefits and costs of technology, consequently they are much more proactive in making changes. The industry tends to support retrofit configuration much more easily than the passenger vehicle market, so it is a strong candidate for supporting early adoption of Connected Vehicle systems. Commercial vehicle operators have also demonstrated a willingness to participate in government-sponsored technology initiatives where it this will enhance their efficiency or productivity. Today, for example, about 400,000 trucks use PrePass and NORPASS tags for electronic pre-clearance at weight stations and ports-of-entry.

4 Comparison of Various Communications Technologies in Different Application Service Scenarios

This section discusses a variety of application scenarios by using various wireless communications technologies. Four safety applications, Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW) are described from section 4.1 to section 4.4. For efficiency applications, VICS and Smartway cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. The more detailed will be described from section 4.5 to section 4.6. For comfort/entertainment applications, Visteon's Connected Car application will present in section 4.7. In section 4.8, a Vehicle Group Communication System (VGCS) was developed on the basis of ITRI's experience in the deployment of IEEE 1609/802.11(p) On-Board Units (OBUs). In section 4.9, we discuss eight related research projects (including US, Europe and Japan) by using various communication technologies. In section 4.10, the various communications technologies for different application scenarios are compared in a matrix analysis table.

4.1 Forward Collision Warning (FCW)

Using technologies: sensors, satellite, 3G/4G, Wi-Fi, 5.9 GHz DSRC

The Forward Collision Warning (FCW) application is designed to aid the driver in avoiding or mitigating collisions with the rear end of vehicles in the forward path of travel through driver notification or warning of the impending collision. The application does not attempt to control the host vehicle in order to avoid an impending collision. This FCW application uses information communicated from neighboring vehicles via V2V (Vehicle to Vehicle) 5.9 GHz DSRC. The host vehicle receives BSM (Basic Safety Message) from other vehicles. Using information from BSM regarding other vehicles' position, velocity, heading, yaw rate, and acceleration along with its own position, dynamics and roadway information (map data), the host vehicle determines whether a rear-end collision with the lead vehicle is likely. In addition, the host vehicle transmits position, velocity, acceleration, heading, and yaw rate to other vehicles.

Figure 4.1 is a demonstration of a Forward Collision Warning application scenario. The host vehicle is assumed to have a cooperative Forward Collision Warning system that implies, among other things, that the host vehicle is able to transmit and receive standardized 5.9 GHz DSRC messages designed for V2V safety applications. However it is assumed that not all target vehicles will be equipped with 5.9 GHz DSRC on-board units. In the figure three targets are shown corresponding to three vehicles. Target 2 is shown to have a 5.9 GHz DSRC on-board unit and transmits standardized 5.9 GHz DSRC messages designed for V2V safety applications periodically, while targets 1 and 3 do not have 5.9 GHz DSRC on-board units. The communication range for the 5.9 GHz DSRC message sets should be chosen to take into account the requirements of a Forward Collision Warning system. The Forward Collision Warning system in the host vehicle will process all the targets and classify them as in-path or out-of-path targets. The system will then select the closest-in-path target and process the target's dynamics information and provide a warning to the driver if the threat assessment algorithm indicates a threat.

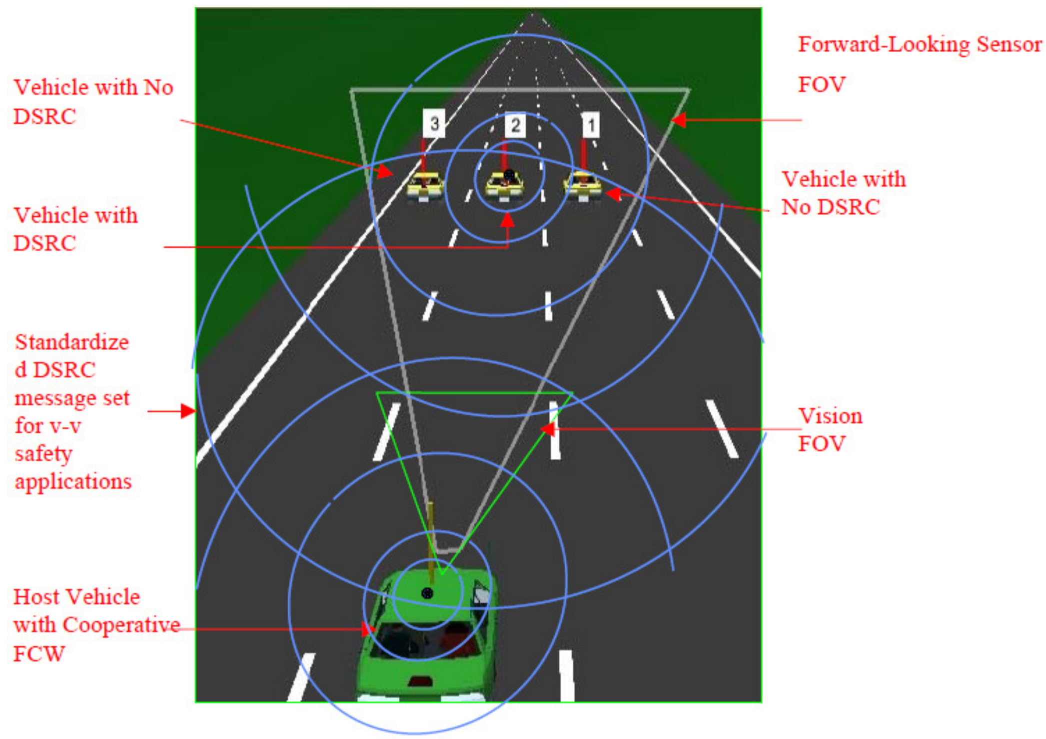

Figure 4.1 Forward Collision Warning scenario [2]

A Forward Collision Warning system will typically use a **forward-looking sensor** [12] mounted at the front of the host vehicle that detects targets (other vehicles or objects) ahead of the host vehicle and in its field of view. An accurate prediction of the forward lane geometry ahead of the host vehicle (up to 200 meters) is necessary in order to properly classify the targets as in-path or out-of-path, and thereby identify potential threats of rear-end collision. For FCW, incorrect classification of in-path and out-of-path targets leads to false alarms and missed detections in the system, which may limit deployment and user acceptance. To predict the forward road geometry ahead of the host vehicle, the system may also use a **GPS** receiver for vehicle position measurement, a map database, a vision system that detects lane markers, a **vehicle speed sensor** [12], and a **yaw-rate sensor** [12]. However, each of these approaches has limitations. Yaw-rate sensors do not possess the capability to determine the forward road geometry up to 150 m since the prediction is based on extrapolation of curvature of the road at the current host vehicle position. The limitations of using yaw-rate to determine forward road geometry are easily demonstrated as a host vehicle travels on a straight section of road into a curve. Lane markings tracker based on a vision system can also be used to provide a forward road geometry estimate but they have been unable to do so at distances required by FCW.

Table 4.1 summarizes various communication technologies for FCW application. The **forward-looking sensor** [12] mounted in front of the vehicles to estimate range, range rate, acceleration, and azimuth of multiple objects ahead of the host vehicle at a maximum detection range of at least 200 m and an azimuth field of view of 16 degrees. The unit should provide dedicated on-board processing capabilities for multiple target identification, tracking and scenario identification. The **yaw-rate sensor** [12] should provide the yaw angle and rate relative to the longitudinal travel of the host vehicle. The **GPS sensor** [12] should be utilized to determine the position of the host vehicle. Positional information will be used in conjunction with a dynamically created digital map (map download through **3G/4G/Wi-Fi** technologies) to provide information related to false alarms, roadside objects, and roadway geometry. The FCW application uses information communicated from neighboring vehicles via V2V **5.9 GHz DSRC**. It is expected that the **5.9 GHz DSRC** equipped vehicles would periodically broadcast the standard message set to neighboring vehicles within a certain desired range. Current automotive radars used in FCW systems are capable of track updates at an update rate of 100 ms and have a range of coverage 150 m. Hence, the update rate for V2V communication is expected to be at least 100 ms, and the communication range is expected to be at least 150 m.

Table 4.1 FCW application by using various communication technologies

Communication technologies	Function description
Sensors	● Forward-looking sensor ● Vehicle speed sensor ● Yaw-rate sensor ● GPS sensor
Satellite	Combine a GPS receiver for vehicle position measurement
3G/4G/Wi-Fi	Download digital map
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication (use the On-Board Unit of 5.9 GHz DSRC to share that information with other vehicles)

4.2 Emergency Electronic Brake Lights (EEBL)

Using technologies: 5.9 GHz DSRC, satellite, 3G/4G, Wi-Fi

When a vehicle brakes hard, the Emergency Electronic Brake Light (EEBL) application conveys this information to surrounding vehicles. The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to other vehicles following behind. Upon receiving such event information, the following vehicle (with a safety device capable of detecting a braking event) determines the relevance of the event and provides a warning to the driver if appropriate. This application would only function during interactions between vehicles with safety systems that will transmit or detect a braking event. This application will help the driver of following vehicles by giving an early notification of lead vehicle braking hard even when the driver's visibility is limited (e.g. a large truck blocks the driver's view, heavy fog, rain). This information could be integrated into an adaptive cruise control system.

Figure 4.2 demonstrates an Emergency Electronic Brake Lights scenario on a 3-lane highway. In the figure, vehicle E brakes hard and broadcasts the message. Vehicles with 5.9 GHz DSRC radio unit will listen to the message sent by vehicle E and check to evaluate if the message is relevant (e.g., for vehicle C, a "hard brake" message from D might not be relevant). If the "hard brake" message is relevant to the application host vehicle, the driver is warned (e.g., driver of vehicle B and C).

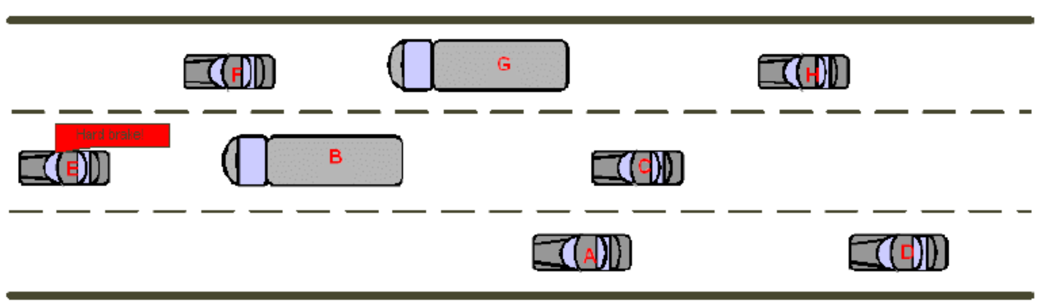

Figure 4.2 Emergency Electronic Brake Lights scenario [2]

Table 4.2 summarizes various communication technologies for EEBL application. For this application scenario, it is assumed that the vehicle in an emergency braking situation would be equipped with a **5.9 GHz DSRC** unit. It is also assumed that the message from the vehicle would be sent to the following vehicles, including the ones that are behind a much larger vehicle (e.g., a big truck). The message sender needs to have an algorithm to decide if an "emergency braking" message delivery is necessary (e.g., deceleration greater than 0.6g). If a vehicle determines that it is braking hard then it could use the On-Board Unit of 5.9 GHz DSRC to share that information with others. In order to determine if an "emergency braking" message is relevant to the listening vehicle, the listening vehicle needs to know the relative location from which the message originated (e.g., front, rear, left, right). This can be done based on its **GPS** information and the **GPS** information of the braking vehicle. A map database (map download through **3G/4G/Wi-Fi** technologies) would help to provide information such as which lane the vehicle is traveling. In addition, the road curvature can be taken into account when an application host vehicle evaluates “emergency braking message” to see if a warning to the driver is necessary.

Table 4.2 EEBL application by using various communication technologies

Communication technologies	Function description
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication (use the On-Board Unit of 5.9 GHz DSRC to share that information with other vehicles)
Satellite	Get GPS position information
3G/4G/Wi-Fi	Download digital map

4.3 Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)

Using technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi

The Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) [13][14] safety application is designed to assist drivers in avoiding crashes in the intersection by warning the driver of an impending violation of a traffic signal or a stop sign. Cooperative means that the system involves both infrastructure and in-vehicle elements working together. A CICAS-V equipped vehicle approaching a CICAS-V equipped intersection receives messages about the intersection geometry, GPS differential corrections, and status of the traffic signal. The driver is issued a warning if the equipment in the vehicle determines that, given current operating conditions, the driver is predicted to violate the signal in a manner which is likely to result in the vehicle entering the intersection. This application requires the device to receive Signal Phase and Timing (SPaT) messages transmitted by the roadside equipment (RSE) at CICAS-V equipped intersections.

The basic concept of CICAS-V is illustrated at a high level in figure 4.3 for a signalized intersection. In the figure, a CICAS-V equipped vehicle approaching a CICAS-V equipped intersection receives messages about the intersection geometry and status of the traffic signal. The driver is issued a warning if the equipment in the vehicle determines that, given current operating conditions, the driver is predicted to violate the signal in a manner which is likely to result in the vehicle entering the intersection. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of traffic control device violations will decrease, and result in a decrease in the number and severity of crashes at controlled intersections.

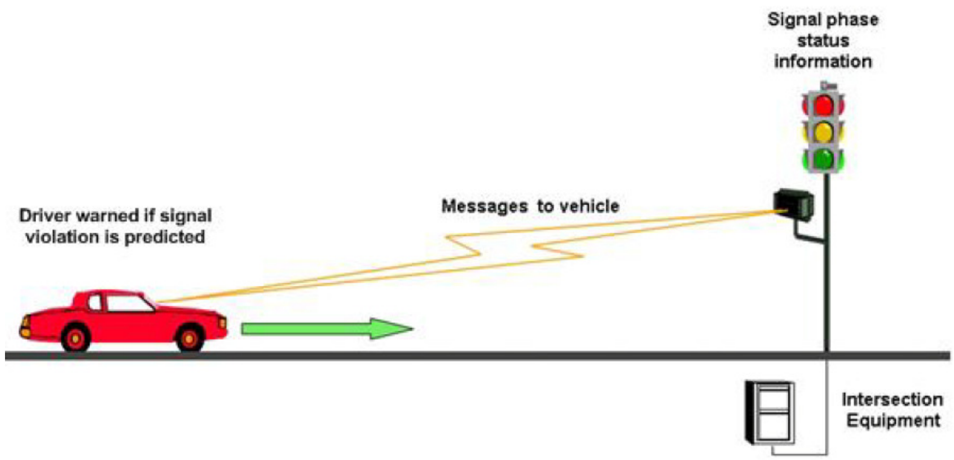

Figure 4.3 Cooperative Intersection Collision Avoidance System – Violations scenario [13]

Table 4.3 summarizes various communication technologies for CICAS-V application. In this application, each vehicle contained a computing platform, **5.9 GHz DSRC** radio (using the existing WAVE radio), **DGPS** (Differential GPS) system, and other hardware software components that were integrated with the vehicle bus to obtain **vehicle-sensor** data. The computing platform performed the data processing, warning algorithms, DVI (Digital Visual Interface), and other software functions required by the application. The equipped vehicles were used for the evaluation of the elements of the concepts of operation (e.g., map broadcast, message set, and timing) and the functional evaluation of the in-vehicle and the intersection application. The CICAS-V system requires an intersection map (map download through **3G/4G/Wi-Fi** technologies) of sufficient accuracy to enable matching the vehicle to the road or even to the lane in intersections with dedicated turn lanes.

The application design is dependent on the availability of RSE at CICAS-V signalized intersections that have a local GPS base station receiver. The GPS base station receiver is configured to compute correction factors for the **GPS Satellite** signals that are needed to make the position result from GPS position estimation algorithms match the base station's known fixed location. In addition to the 5.9 GHz DSRC and GPS antennas, the RSE is also connected to a **Wi-Fi** antenna that allows local software updates and system maintenance.

Table 4.3 CICAS-V application by using various communication technologies

Communication technologies	Function description
Sensor	GPS sensor
Satellite	DGPS (obtain GPS position information)

5.9 GHz DSRC	V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	● Download digital map ● V2R (Vehicle to Roadside) communication
Wi-Fi for RSE	Local software updates and system maintenance

4.4 Curve Speed Warning (CSW)

Using technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi

Curve Speed Warning (CSW) aids the driver in negotiating curves at appropriate speeds. This safety application will use information communicated from roadside beacons located ahead of approaching curves. The communicated information from roadside beacons would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the roadside equipment.

Figure 4.4 demonstrates a Curve Speed Warning (CSW) scenario on a mountain road. The vehicle enters the communication range of a roadside beacon. The beacon continuously transmits curve geometry for the upcoming series of turns. In addition to standard curve parameters, broadcast messages note the minimal shoulder due to a cliff at the hairpin and, if equipped with surface condition sensors, the presence and location of ice on the road. Given sensor and beacon constraints, additional beacons may provide supplemental coverage at various points along the road. The vehicle computes a safe curve speed based on broadcast message content, which contains the posted speed limit, current road geometry, shoulder characteristics, weather conditions, and, if equipped, road surface conditions, as well as the vehicle’s inherent handling characteristics and any applicable vehicle sensor data. The CSW application must be provided to the driver early enough to allow a controlled deceleration and safe negotiation of the curve.

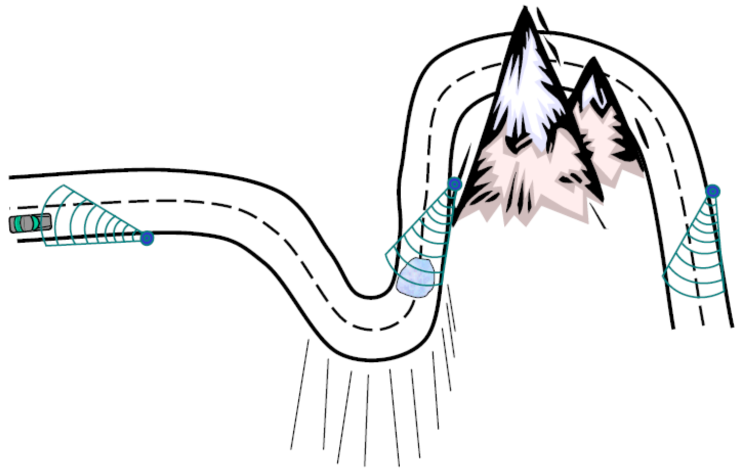

Figure 4.4 Curve Speed Warning scenario [2]

Table 4.4 summarizes various communication technologies for CSW application. The in-vehicle system combines information from the roadside beacon (through **5.9 GHz DSRC/3G/4G/Wi-Fi** communication) with vehicle parameters and on-board **sensor** data to determine if the driver should be warned to reduce speed in order to safely negotiate the curve. In this application, a warning could be derived using a digital map database (map download through **3G/4G/Wi-Fi** communication), **GPS** position (through **satellite** communication), vehicle speed, on-board **sensor** information, and vehicle handling characteristics, such as maximum allowable lateral acceleration and stability control parameters. The curve speed warning becomes much more reliable and accurate when up-to-date curve layout and actual road surface conditions are communicated from a roadside beacon to the approaching vehicle. The roadside beacon will provide road geometry parameters, which especially benefits vehicles that do not have onboard digital maps, current map updates, or GPS positioning. Changes to the curve's geometry may be available via the beacon (possibly updated by a road maintenance crew or by digital map updates), which may be derived from probe vehicle reports. If properly equipped, an enhanced beacon may provide local **sensor** data to determine the actual road surface condition.

Table 4.4 CSW application by using various communication technologies

Communication technologies	Function description
Sensors for roadside	● Weather condition sensors (e.g., rain, heavy fog) ● Surface condition sensors (e.g., the presence and location of ice on the road) ● GPS sensor
Sensor for vehicle	GPS sensor
Satellite	Get GPS position

5.9 GHz DSRC	V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	● Download digital map ● V2R (Vehicle to Roadside) communication

4.5 VICS Applications

Using technologies: sensors, satellite, Radio wave, Infrared, FM

VICS (Vehicle Information and Communication System, since 1990)[15] is an innovative information and communication system, enables user to receive real-time road traffic information about congestion and regulation. This information is edited and processed by Vehicle Information and Communication System Center, and shown on the navigation screen by text or graphical form.

The VICS Center provides VICS information 24 hours a day, 365 days a year to the entire country using the three types of media shown below. There are two types of "Beacon", one is "Radio wave beacon" on expressways, and the other is "Infrared beacon" on major ordinary roads. "FM multiplex broadcasting" provides wide area information, and "Beacons" send necessary and detailed information about nearest road condition based on the position where the car is moving.

(1) Radio wave beacon

These beacons are installed mainly on expressways as shown in figure 4.5, providing road traffic information in a range of approximately 200km ahead of the car.

- Radio wave beacon can provide information about expressways, a by-path near interchanges, and neighboring ordinary roads, in a range of about 200 km ahead from the car.
- This information tells you the condition of traffic congestion, link-travel-time on expressway, regulations, SA/PA information, interruption, interval-travel-time between interchanges, etc.
- The navigation equipment can receive radio from your running direction within 70 meter radius from each beacon.

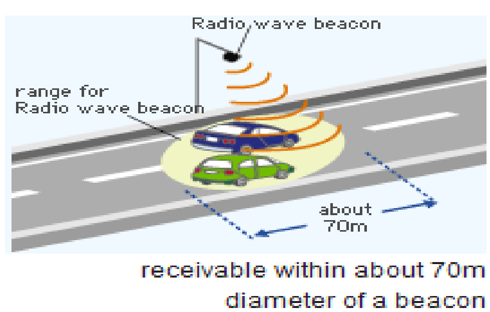

Figure 4.5 Radio wave beacon scenario

(2) Infrared beacon

These beacons are installed on main ordinary roads as shown in figure 4.6, providing road traffic information as far as 30km ahead of, and 1km behind the car.

- Infrared beacon can provide information about expressways and ordinary roads as far as 30 km ahead, and 1 km behind from the car.
- This information tells you the condition on traffic congestion link-travel-time, regulations, parking lot information, interval-travel-time, etc.
- The navigation equipment can receive signal from running direction within 3.5 m from each beacon.

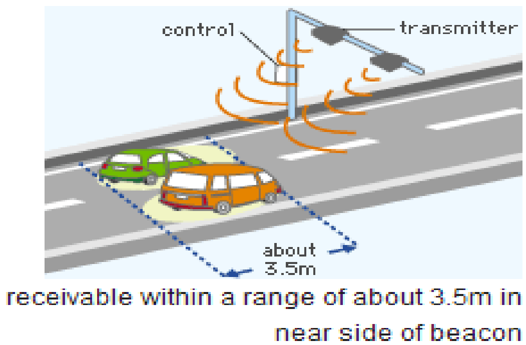

Figure 4.6 Infrared beacon scenario

(3) FM multiplex broadcasting

In figure 4.7, FM multiplex broadcasting provides road traffic information in the relevant prefecture and its surroundings from the local NHK FM broadcasting stations.

- FM multiplex broadcasting can provide information about the prefectures you are in, neighboring area and regional borders.
- Multiplexed with audio broadcasting from NHK FM stations, the information is sent in the same frequency band.
- The information is transmitted twice five minute to ensure reception, with the data of 50,000 characters per 2.5 minutes.

Figure 4.7 FM multiplex broadcasting scenario

VICS provides three kinds of displays in real time depending on the type of car navigation unit:

(1) Map Display (Level 3): This map display overlays VICS information about traffic congestion, etc. onto car navigation system maps. Drivers can see road and traffic information on their current location that allows them to avoid congestion and select the shortest route to their destination.

(2) Simple Graphic Display (Level 2): VICS information is displayed in simple graphic form on the monitor of the car navigation unit. The main feature of this type of display is that information is shown in simple, graphic patterns or text.

(3) Text Display (Level 1): VICS information is displayed in text form on the monitor of the car navigation unit. Information is provided clearly and briefly using short phrases.

The information received will vary according to the car location and the capabilities of the car navigation unit. Table 4.5 summarizes various communication technologies for VICS application.

Table 4.5 VICS application by using various communication technologies

Communication technologies	Function description
Radio wave, Infrared, FM	Transmits processed information to car navigation units.
Sensor for vehicle	GPS sensor
Satellite	Get GPS position

4.6 Smartway Applications

Using technologies: sensors, satellite, 5.8 GHz DSRC, Bluetooth, 3G/4G, Wi-Fi

A Smartway [16] cooperative vehicle-highway system platform facilitates the deployment of services from a core service, such as ETC, to services in conjunction with car navigation systems such as VICS (Vehicle Information and Communication System), one of the Smartway cooperative vehicle-highway system services. A Smartway platform also enables the smooth deployment of a variety of services, including services to support safe-driving such as AHS (Advanced cruise-assist Highway Systems), payment services for parking, etc., along with private sector services. The Smartway cooperative vehicle-highway system platform makes possible a variety of services and can be implemented smoothly, efficiently, and at a low overall cost.

Figure 4.8 shows the concept of the Smartway applications. The cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. Specifically, a variety of services are provided using a platform that consists of elements such as DSRC, ITS onboard units, digital maps, and roadside sensors, with the vehicle, driver, other vehicles, road managers, and service providers serving as the constituent elements of ITS. The private sector is expected to provide diverse services through the open Smartway platforms.

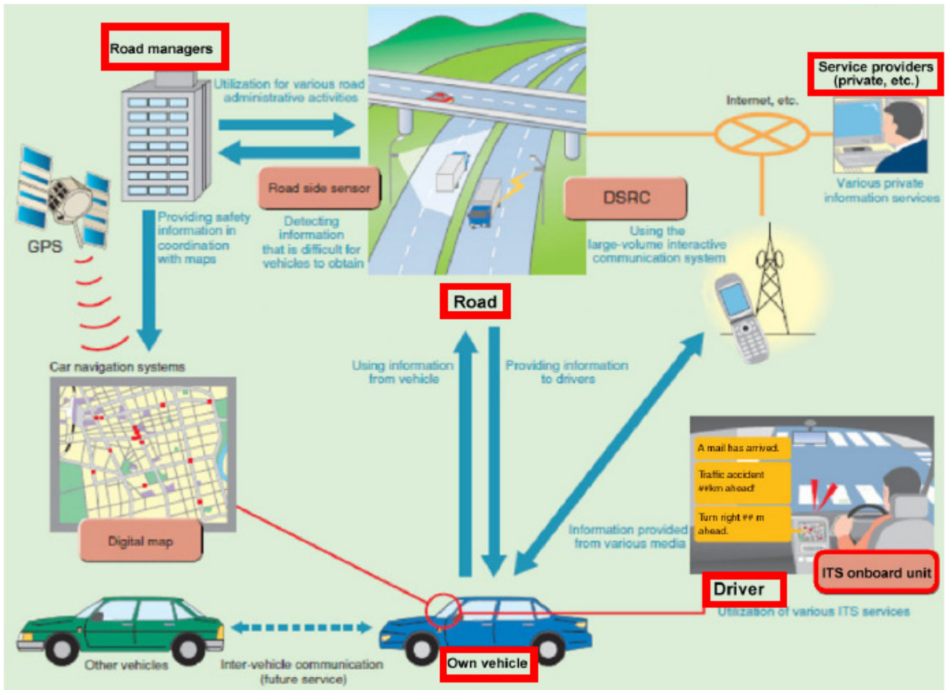

Figure 4.8 Various component elements and applications involved in ITS [16]

Figure 4.9 illustrates the deployment of services on the Smartway cooperative vehicle-highway system platform. A platform can be used to implement a wide variety of applications, including information supply applications, support for safe driving, road management, parking facilities, and disaster prevention measures. Table 4.5 summarizes various communication technologies for Smartway application.

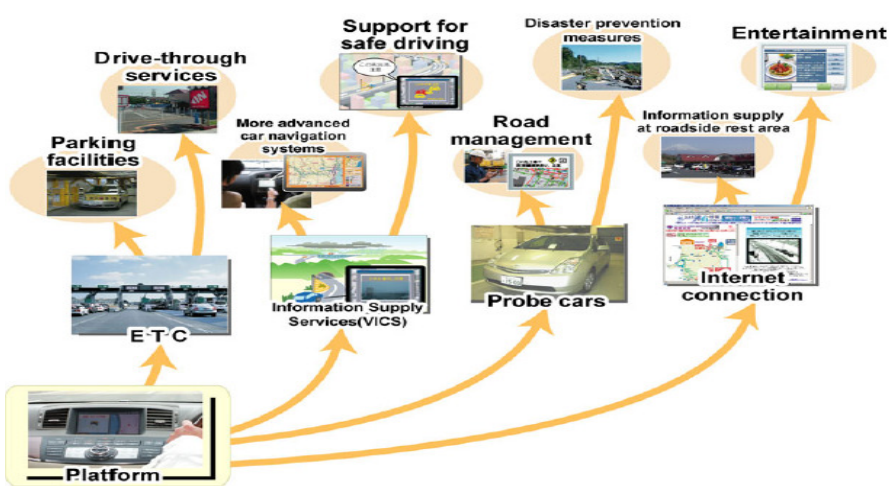

Figure 4.9 Evolution of Smartway applications [16]

Table 4.6 Smartway application by using various communication technologies

Communication technologies	Function description
Sensors for roadside	• Weather condition sensors (e.g., rain, heavy fog) • Surface condition sensors (e.g., the presence and location of ice on the road) • GPS sensor
Sensor for vehicle	GPS sensor
Satellite	Get GPS position
5.8 GHz DSRC	• V2V (Vehicle to Vehicle) communication • V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	• Download digital map • V2R (Vehicle to Roadside) communication

4.7 Connected Car Application

Using technologies: 5.9 GHz DSRC, sensors, 3G/4G, Bluetooth, satellite, WiFi

"Connected Car" application is being considered for roadside inspections, freight tracking, road-condition notifications, parking management and enforcing rules on drivers' working hours. The core enabler of "Connected Car" application is providing effective data communications between vehicles and other sources and users of transportation and related data. The desire to deliver this capability in a focused and consistent manner was the primary driver behind the specification and development of 5.9 GHz DSRC. The communications networks, protocols, security, and messaging formats continue to be fundamental items of discussion and development for "Connected Car" research, development, testing, and demonstration.

The "Connected Car" is Visteon's Internet-connected platform for next generation infotainment services for the automotive market. The car is simply another mobile device, and the ability to fully integrate disparate features, functions and content is a critical aspect of providing a user experience that is optimized for the car. Using a combination of GPS and Wi-Fi, cars can communicate their location data to a central office, but it also enables them to communicate with each other. Visteon's "Connected Car" concept is an ideal platform for showcasing the power of providing seamless access to media while in the car. The prototype vehicle will be able to get online via a variety of methods, and considering that an estimated 62.3 million global consumers will have Internet access in their vehicles by 2016 (compared to just 970,000 at the end of 2009).

Figure 4.10 shows the basic ideas for using various wireless technologies in V2V/V2I communication. In the figure, all current popular communication technologies are used, including sensors, 5.9 GHz DSRC, satellite, WiFi, 3G/4G/WiMAX and Bluetooth.

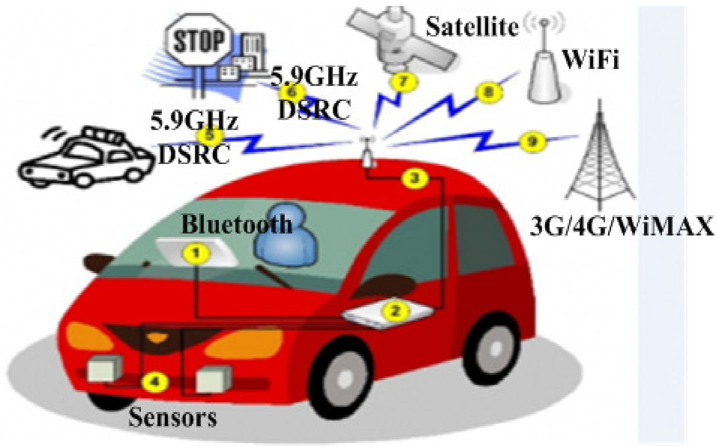

Figure 4.10 Basic concept of the Connected Car system

Table 4.7 summarizes various communication technologies for Connected Car application. In this application, **5.9 GHz DSRC** could be used, for example, to warn nearby cars of sudden braking or an airbag deployment, thereby alerting cars out of visual range and preventing or limiting accidents. It could be used to set up ad hoc networks to pass data between cars in order to, for example, signal icy spots on the road (many cars can detect ice through **sensors** as part of their skid-control systems) or co-ordinate "platoons"—groups of vehicles travelling closely together under automatic control. Other proposed uses include signaling the approach of emergency vehicles and ensuring that traffic lights give priority to buses and emergency vehicles. Besides using the 5.9 GHz DSRC technology, letting users listen to their favorite radio stations through a **3G/4G** or **Bluetooth** connection. The "Connected Car" application is also preparing a whole new in-car infotainment experience based around the Internet. Visteon clearly has put flexibility center stage by designing an open architecture automotive-grade in-vehicle infotainment (IVI) development platform that is capable of connecting to the outside world through various methods, including the use of embedded phones, tethered mobile devices or USB connectivity cards. Much more advanced GPS/video system would be in the car if it had access to the web (through **satellite, WiFi** or **3G/4G** communication).

Table 4.7 Connected Car application by using various communication technologies

Communication technologies	Function description
5.9 GHz DSRC	● V2V (Vehicle to Vehicle) communication ● V2R (Vehicle to Roadside) communication
Sensors	● GPS sensor ● Weather condition sensors (e.g., ice, rain, heavy fog)

Satellite	Combine a GPS receiver for vehicle position measurement
Bluetooth	In-vehicle infotainment (radio, music connection)
3G/4G/Wi-Fi	● In-vehicle infotainment (radio, web access) ● V2R (Vehicle to Roadside) communication

4.8 Vehicle Group Communication Application

Using technologies: sensor, satellite, 5.9 GHz DSRC

Over the comfort/entertainment applications in vehicle networks, group communications are expected to enhance the experience and amusement of driving. Since 2009, ITRI design and implement a Vehicle Group Communication System (VGCS) [17][18] over real-life IEEE 1609/802.11(p) On-Board Units (OBUs). VGCS can track the group members' current locations and broadcast voice/data over a vehicle group, enhancing drivers' and riders' experiences when they cruise together. Using VGCS each group member can broadcast his/her voice to other group members. The communications among group members are logically full-duplex. That is, one can speak and listen at the same time. With this function, a group member can quickly report its own status and observed road/traffic condition to the group leader and other group members, when encountering accidents or raising special needs (e.g., refueling). This way, the group leader can change the movements of the vehicle group to fast respond with the changes of road/traffic conditions and group members' needs (e.g., change the destination/route of the vehicle group or temporarily gather all group members in a certain place). VGCS also provides an integrated GUI interface to show and track the locations of all vehicle group members. Each group member periodically broadcasts its own location information using the 802.11(p) radio. Using this interface, the leader of the vehicle group can track the locations of all his group members, helping him make decision on the movements of the whole vehicle group. Table 4.6 summarizes various communication technologies for VGCS application.

Table 4.8 VGCS application by using various communication technologies

Communication technologies	Function description
Sensor for vehicle	GPS sensor
Satellite	Get GPS position
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication

4.9 Related Research Projects by Using Various Communication Technologies

4.7.1 The USDOT Connected Vehicle Research Program

The implementation dilemmas associated with the original VII (Vehicle-Infrastructure-Integration) approach and the new technologies emerging in the market indicated that it was time to adapt the research program based on new information. But, significantly, the original vision remained the same; it was only the USDOT Connected Vehicle Research Program [19] approach to achieving the vision that needed to be revised to take advantage of new opportunities.

Results of a recent high-level NHTSA analysis of the potential of V2V and/or V2I to address crash types indicate that V2V has the potential to address a large proportion of crashes involving unimpaired drivers. Specifically, up to 82 percent of all crashes by unimpaired drivers could potentially be addressed by V2V technology. If V2V were in place, another 16 percent of crashes could potentially be address by V2I technology. In imminent crash situations, V2V is uniquely capable of addressing forward collisions and lane change/merge collisions. At very high market penetration levels V2V can also address intersection collisions. V2I has the potential to address road departure and intersections crashes at lower market penetration levels. The actual effectiveness of V2V and V2I in addressing these crash types still remains to be tested.

While the potential of V2V technology was recognized in the VII Program, benefits would be delivered only when a sufficient number of equipped vehicles were on roadways to interact. Early in the VII program, it was difficult to envision a feasible way out of this dilemma. But now, a plethora of consumer electronics devices are available in vehicles. The exponential growth of the use of these devices by travelers may open up a new avenue to accelerate DSRC into the vehicle fleet.

The concept is to embed DSRC communications in aftermarket devices, such as navigation systems, so that they emit a simple “Here I Am” message. The “Here I Am” message would be a subset of the full V2V message. Portable navigation systems are prevalent, and many smaller consumer devices also have navigation applications. “Here I Am” messages are continually emitted when these devices are turned on, and do not require any driver interface. Safety could be significantly increased by notifying other vehicles of the location of a vehicle that contains a “Hear I Am” device.

Aftermarket devices have access to power, communication (typically cell) and location via GPS. This basic data, plus a little more, constitutes the “Here I Am” message. The V2V message includes all of this information, plus more robust data that is available directly from vehicle systems. The differences in message content will determine the type of applications that can be supported. "Here I Am" messages will probably have limitations in their capabilities; they will likely not have access to data from internal vehicle electronic systems. On the other hand, there is much that could potentially be accomplished with these simple messages. In addition, the presence of "Here I Am"- equipped devices would provide increased early benefit to fully equipped V2V vehicles, which could sense the location of an emitting device. The V2V research program includes testing and validation of aftermarket DSRC devices and their potential benefit for owners of both vehicles and devices. If the research shows that these devices are effective, the market penetration dilemma may be diminished. If not, then other options need to be pursued. DSRC ASDs (Aftermarket Safety Devices) developed and produced under this solicitation will undergo evaluation and testing by US DOT as described in this solicitation. Those ASDs deemed qualified will be eligible for placement on a Qualified Products List (QPL) for use in the upcoming planned Safety Pilot model deployment. US DOT anticipates that the Government, or designated Contractor, may purchase 300 to 500 ASD units from the various suppliers (e.g., ITRI) on the ASD QPL for use in the model deployment. US DOT anticipates that these purchased units will then be tested and installed in the candidate vehicles, subsequently referred to as aftermarket-equipped vehicles.

4.7.2 IVBSS

The IVBSS (Integrated Vehicle-Based Safety Systems) [20] program is a five-year cooperative research agreement to combine several crash warning subsystems-including forward collision, lane departure, lane change, and curve speed warning--into a single, integrated concept to enhance the safety of both passenger vehicles and heavy trucks.

During the first two years of the IVBSS program (2006-2007), the industry team designed, built, and conducted tests to verify the prototype systems on the passenger cars and heavy trucks. The prototype vehicles underwent a series of closed-course track tests aimed at ensuring that the integrated system met the performance requirements and was safe for use by unescorted volunteer drivers during the field operational test, which was planned for Phase II. Approval to proceed with Phase II was granted on April 8, 2008.

In Phase II (June 2008-October 2010), a fleet of 16 passenger cars and 10 heavy trucks were constructed and prepared for the field test. Ten (10) IVBSS-equipped International ProStar 8600-series trucks owned by Conway Freight, Inc. of Ann Arbor, Michigan were used. The heavy truck field test began in February 2009 and was completed on December 15, 2009. The trucks were driven by 20 volunteer drawn from the pool of Conway's regular pick-up and delivery and line haul drivers and operated over a ten month period, amassing 16,500 hours of driving. Approximately 650,000 miles of driving data was collected with 140,000 miles of baseline data and 510,000 miles with the integrated system enabled.

The light vehicle field test began in April 2009 and was completed on May 1, 2010. Sixteen 2006-07 Honda Accord LX sedans were outfitted with the IVBSS sensor suite and used by 108 volunteer drivers recruited in Southeastern Michigan. Field test participants used the vehicle for a 40-day period. During the first 12-days, the integrated system was disabled, allowing collection of baseline driving data. The integrated warning system became operational at the end of the 12th day, allowing collection of 28 days of driving data per volunteer. Light vehicle drivers were debriefed following completion of their use of the test vehicle and were invited to participate in focus groups along with other drivers. Approximately 220,000 miles of driving data was collected during the field test, with 74,000 miles of baseline driving data and 146,000 miles with the integrated system enabled.

Visteon is responsible for IVBSS system design, development and integration of: FCW with brake pulse; Lane Change Warning (LCW) with BSD; LDW (Lateral Drift Warning); CSW (Curve Speed Warning); radar to radar and radar to vision fusion; driver behavior model and arbitration; HMI (Human Machine Interface) for the multi-feature system; and the fabrication of 6 development vehicles and a 16-vehicle FOT (Field Operational Test) fleet. The FOT involves exposing a fleet of 16 IVBSS-equipped Honda Accord cars to 12 months of naturalistic driving. Laypersons with a valid driver's license were recruited to drive passenger cars equipped with the integrated system and data collection hardware installed on-board. The 108 test participants are lay drivers from southeastern Michigan who drove these cars as their personal vehicles for several weeks. The cars were instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics data. Subjective data on driver acceptance was collected using a post-drive survey, driver debriefing and a series of focus groups.

4.7.3 AASHTO Connected Vehicle

In 2009, AASHTO (American Association of State Highway and Transportation Officials) [21] prepared its Connected Vehicle Strategic Plan. Among the specific actions identified in the plan was the need to perform an analysis of the potential approaches for deploying the infrastructure components of Connected Vehicle systems by state and local transportation agencies. The plan also called for the identification of AASHTO's role in all aspects of Connected Vehicle infrastructure deployment.

This plan approaches Connected Vehicle infrastructure deployment as a set of likely sequential scenarios. It recognizes that technologies and events will continue to impact agency operations even without intentional decisions on the part of those agencies. The focus is on articulating the needs of the agencies and anticipating the context in which agencies will make specific deployment decisions.

The scenarios describe the progressive deployment of Connected Vehicle systems out to a twenty-year horizon. They start with an assessment of the current state, touching on key drivers and activities. Each step in time corresponds to a new deployment goal—a particular emphasis for that phase of development. Anticipated external events and policy decisions are also identified, and the most likely arc of technology developments is projected from the current state.

As a general guiding principle, the scenarios assume that public agencies will be motivated to deploy the field infrastructure for Connected Vehicle systems to achieve near-term benefits from applications that enhance mobility, provide localized safety improvements, or enhance the operational performance of the agency in some manner. Public agencies will deploy DSRC field infrastructure in recognition of its long-term value in Connected Vehicle active safety applications, but will leverage that investment to support a variety of applications in the near-term.

NHTSA (National Highway Traffic Safety Administration) plans to make two decisions relating to DSRC deployment. The first will be for light vehicles in 2013, and the second will be for heavy vehicles in 2014. NHTSA is not calling this a regulatory decision, but rather an "Agency" decision, and has committed to analyzing research results between now and then to determine whether or not subsequent action is merited. Subsequent action could include a rulemaking to require V2V safety equipment in vehicles. However, action could take many forms, with rulemaking being only one option.

For the purposes of IVBSS project, the scenarios assume that NHTSA will, in some fashion, decide to move forward with a requirement to mandate factory-installed DSRC equipment on-board both light and heavy vehicles. Assuming this happens, prior experience would suggest that on-board equipment (OBE) will first appear in newly-manufactured light vehicles for the 2020 model year, rolling out in 2019.

This timing assumption has a major influence on the deployment approach presented in the scenarios. While it can be said that the benefits to drivers of OBE-equipped passenger cars and heavy vehicles will increase as the deployment of RSEs increases, it is also true that there are no benefits to the deployers of RSEs if there are no OBE-equipped vehicles with which to communicate. Therefore, in order to encourage near-term deployment of DSRC roadside infrastructure, the state and local agencies must pursue approaches that do not rely on the presence of a growing population of factory-equipped passenger vehicles before the end of the current decade.

4.7.4 CAMP OTA Interoperability

A team formed by Visteon, PATH, and ITRI is currently participating in this CAMP-OTA (Over-the-air) interoperability study. The project, Interoperability Issues of V2V Based Safety System Project (V2V-Interoperability), is led by CAMP (Crash Avoidance Metrics Partnership, an automaker consortium) and is sponsored by US Department of Transportation (USDOT). The V2V-Interoperability Project addresses part of the NHTSA V2V Safety Application Research Plan. It is a follow-up to the recently completed Vehicle Safety Communications (VSC, 2003-05) and Vehicle Safety Communications – Applications (VSC-A, 2007-09) projects that specifically addresses interoperability challenges that are critical to the deployment and effectiveness of V2V safety systems. The goal of this project is to ensure that all V2V safety applications work across any, and all, equipped vehicles, regardless of make, model, or qualified retrofit equipment.

The V2V Interoperability system that will be developed as part of the project will serve as a test bed by which many technical issues that are currently roadblocks to deployment will be addressed. Issues that directly impact interoperability include message sets, communication standards, congestion control, data authentication, security, and privacy. Test bed and system requirements will be developed and will focus on facilitating the resolution of technical issues only. Any policy related issues or recommendations that arise from researching technical issues will be conveyed to the appropriate participants who are involved in resolving these issues. Resolutions to technical issues will be verified against current standards and anomalies or gaps, if present, will be identified, addressed and brought back to the appropriate standards bodies.

4.7.5 INTERSAFE-2

The INTERSAFE-2 project [22], which is funded by EC under the 7th Framework Program (June ’08 – May ’11), aims to develop and demonstrate a Cooperative Intersection Safety System (CISS) that is able to significantly reduce injury and fatal accidents at intersections.

Today, most so called “black spots” have been eliminated from the road networks. However, intersections can still be regarded as black spots. Depending on the region and country, from 30 to 60% of all injury accidents and up to one third of the fatalities occur at intersections. This is due mainly to the fact that accident scenarios at intersections are among the most complex ones, since different categories of road user interact in these limited areas with crossing trajectories.

The novel CISS combines warning and intervention functions demonstrated on three vehicles: two passenger cars and one heavy goods vehicle. Furthermore, a simulator is used for additional R&D. These functions are based on novel cooperative scenario interpretation and risk assessment algorithms.

The cooperative sensor data fusion is based on:

- state-of-the-art and advanced on-board sensors for object recognition and relative localization,
- a standard navigation map and information supplied over a communication link from
- other road users via V2V if the other vehicle is so equipped
- infrastructure sensors and traffic lights via V2I if the infrastructure is so quipped to observe the complex intersection environment.

As a result, the deployment of the INTERSAFE-2 system could provide a positive safety impact of 80% with respect to injuries and fatal accidents at intersections. Thus a total safety benefit of up to 40% of all injury accidents and up to 20% of all fatalities in Europe is possible.

The utilization of V2X communication for CISS at a small number of equipped intersections would boost the overall market penetration of communication in vehicles, since the benefit for those who buy first could be experienced at every equipped intersection.

4.7.6 CVIS

CVIS (Cooperative Vehicle-Infrastructure Systems) [23] is a major new European research and development project aiming to design, develop and test the technologies needed to allow cars to communicate with each other and with the nearby roadside infrastructure.

Based on such real-time road and traffic information, many novel applications can be produced. The consequence will be increased road safety and efficiency, and reduced environmental impact.

The project's ambition is to begin a revolution in mobility for travelers and goods, completely re-engineering how drivers, their vehicles, the goods they carry and the transport infrastructure interact.

With CVIS, drivers will influence the traffic control system directly, and get guidance to the quickest route to their destination. Information shown on road signs will be available wirelessly and be shown on a display in the vehicle. Such displays can also warn drivers of approaching emergency vehicles, allowing emergency personnel to reach accidents faster with less danger for themselves and for cars along their path. In the same way, hazardous goods shipments can be tracked at all times and have priority along a pre-selected safe route.

Other key innovations include high-precision positioning and local dynamic maps, a secure and open application framework for access to online services and a system for gathering and integrating monitoring data from moving vehicles and from roadside detectors and sensors.

All this, however, can only happen if there is full interoperability in the communication between different makes of vehicle and between vehicles and different types of roadside systems. CVIS will therefore develop a mobile router using a wide range of communication media, including mobile cellular and wireless local area networks, short-range microwave (DSRC) or infra-red, to link vehicles continuously with roadside equipment and servers. The project will apply and validate the ISO "CALM (Communications Access for Land Mobiles)" standards for continuous mobile communication, and will provide input to standards development in European and global standardization bodies.

To validate the project's results, all CVIS technologies and applications will be tested at one or more test sites in six European countries: France, Germany, Italy, Netherlands/Belgium, Sweden and the UK.

However, technology is not the only stumbling block on the road to a reality where every car, every traffic light, every road sign and every kilometer of roadway is equipped with CVIS-like technology. A number of non-technical obstacles will also have to be overcome. The CVIS project is therefore creating a toolkit to address key "deployment enablers" such as user acceptance, data privacy and security, system openness and interoperability, risk and liability, public policy needs, cost/benefit and business models, and roll-out plans for implementation.

CVIS Project Key Results

Within the main blocks of Core Technologies, Cooperative Applications, Test Sites and Deployment Enablers, the CVIS project will produce the following key results:

- a multi-channel terminal capable of maintaining a continuous Internet connection over a wide range of carriers, including cellular, mobile Wi-Fi networks, infra-red or short-range microwave channels, ensuring full interoperability in the communication between different makes of vehicle and of traffic management systems;
- an open architecture connecting in-vehicle and traffic management systems and telematics services at the roadside, that can be easily updated and scaled up to allow implementation for various client and back-end server technologies;

- techniques for enhanced vehicle positioning and the creation of local dynamic maps, using satellite positioning, radio triangulation and the latest methods for location referencing;
- extended protocols for vehicle, road and environment monitoring to allow vehicles to share and verify their data with other vehicles or infrastructure nearby, and with a roadside service centre;
- application design and core software development for:
  - cooperative urban network management, cooperative area destination-based control, cooperative acceleration/deceleration and dynamic bus lanes;
  - enhanced driver awareness and cooperative traveler assistance on inter-urban highways;
  - commercial vehicle parking and loading zones booking and management, monitoring and guidance of hazardous goods and vehicle access control to sensitive areas.
- deployment enabling toolkit in the form of models, guidelines and recommendations in the areas of openness and interoperability; safe, secure and fault-tolerant design; utility, usability and user acceptance; costs, benefits and business models; risks and liability; cooperative systems as policy tool; and deployment road-maps.

4.7.7 VICS

In Japan, the VICS (Vehicle Information and Communication System) [15] system aims at improving convenience for drivers by offering following three advantages. First, VICS makes it possible to cut costs by shortening the time required for transportation. Second, VICS improves road safety by providing accurate information. Third, VICS helps to protect the environment by streamlining traffic. The objective of the VICS system is to create a higher standard of living, and contribute to social and economic development by offering these advantages. Eliminating traffic congestion, reducing traffic accidents, and improving road environment are challenges faced by every nation in the modern world. VICS addresses these concerns by enabling drivers to select the shortest, most convenient routes available and ensuring that traffic is dispersed appropriately. VICS is being utilized successfully as a system for improving road safety and traffic flow, making roads more driver-friendly.

4.7.8 Smartway

Smartway [16], Japan's cooperative vehicle-highway systems, consists of roads, vehicles, communication and processing systems. The concept of the Smartway, cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. Specifically, a variety of services are provided using a platform that consists of elements such as DSRC, ITS onboard units, digital maps, and roadside sensors, with the vehicle, driver, other vehicles, road managers, and service providers serving as the constituent elements of ITS. The private sector is expected to provide diverse services through the open Smartway platforms. A Smartway cooperative vehicle-highway system platform facilitates the deployment of services from a core service, such as ETC, to services in conjunction with car navigation systems such as VICS, one of the Smartway cooperative vehicle-highway system services. A Smartway platform also enables the smooth deployment of a variety of services, including services to support safe driving such as AHS, payment services for parking, etc., along with private sector services. The Smartway cooperative vehicle-highway system platform makes possible a variety of services and can be implemented smoothly, efficiently, and at a low overall cost. Various means of communications, such as mobile phone, DSRC, FM multiplex broadcasting etc., are available for connecting road and vehicle. It is important to consider the characteristics of each communication technology when selecting the most suitable communication means.

4.10 Matrix Analysis by the Various Communication Technology in Different Application Service Scenarios

Communications technologies are also changing—and driving change—faster than any other area of technology. The transportation community's needs and opportunities are not unique among private or public industries. The communications products and services on the market are serving an immense range of applications. The diversity of needs has engendered a corresponding diversity of communication solutions, some of which might be applicable to the particular needs of a transportation systems opportunity. **This section provides a summary of communication technologies that have potential for addressing some part of safety, efficiency or comfortable applications.**

In section 2.7, the various wireless technologies for different applications (Safety, Efficiency and Comfort/Entertainment) are compared in a matrix analysis table. In this chapter, Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations

(CICAS-V) and Curve Speed Warning (CSW) safety application scenarios are described. For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services.

Table 4.7 provides a summary of various communication technologies in different application service scenarios. FCW, EEBL and Vehicle Group Communication applications require vehicle-to-vehicle communications, while CICAS-V, CSW, VICS, Connected Car and Smartway applications require infrastructure to vehicle communications.

Table 4.9 Different application scenarios by using various communication technologies

Applications / Technologies	5.9 GHz DSRC	Sensors	Satellite	Bluetooth	3G/4G/ WiMAX	Wi-Fi	Radio	Infrared
Forward Collision Warning (FCW)	○	○	○		○	○		
Emergency Electronic Brake Lights (EEBL)	○		○		○	○		
Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)	○	○	○		○	○		
Curve Speed Warning (CSW)	○	○	○		○	○		
VICS	○ (5.8 GHz)	○	○	○	○	○	○	○
Smartway	○ (5.8 GHz)	○	○		○	○	○	○
Connected Car	○	○	○	○	○	○		
Vehicle Group Communication System	○	○	○		○			

5 Conclusions

A number of comments and remarks can be drawn from this industry report. At the highest level of abstraction, the main conclusion is that 5.9 GHz DSRC is potentially an important enabler of a large number of vehicle safety applications, and other communication technologies offer significant potential application (e.g., efficiency or comfort/entertainment) benefits in the longer term.

- **Comments and Remarks for Wireless Communications Technologies**

The current wireless communications technologies are presented that includes 5.9 GHz DSRC, cellular 3G/4G, satellite, Wi-Fi, Bluetooth, FM-RDS and Infrared. 5.9 GHz DSRC is uniquely suited to mobile vehicular applications needing high bandwidth and low latency in short range communications (on the order of a few hundred meters). Each communication technology has different strengths and weaknesses as shown in Table 5.1.

Table 5.1 Strengths and weaknesses for various communication technologies

Technologies	Strength	Weakness
5.9 GHz DSRC	low latency, high mobility, free communication costs	low bandwidth, limited coverage
Cellular 3G/4G/LTE/WiMAX	high bandwidth, wide coverage, high mobility	high latency, requires communication costs
Satellite	wide coverage, provides navigation information for vehicles	high latency, requires airtime costs
Wi-Fi	wide deployment, easy configurations, cost savings	limited coverage, high latency, high mobility cause high packet loss rate
Bluetooth	low power (consumes less battery), low cost	high latency, low speed, limited coverage
FM-RDS	high coverage, low cost	high latency, low speed
Infrared	wide used for military and civilian purposes, low cost	short coverage

3G/4G cellular communication services are available from a host of providers in the U.S. The technologies underlying those services vary among providers, but all provide similar voice and data services through phone handsets and cellular data modems. Cellular network services are not generally appropriate, however, for real-time localized data exchange. Network latencies and the potential for dropped connections make cellular services inappropriate for real-time V2V and I2V safety applications. Satellite is very suitable for comfortable applications (e.g., satellite television/satellite navigation). Wi-Fi is not specifically designed for vehicular applications, but has been used effectively to communicate between vehicles and fixed stations, such as parking lots and maintenance yards. Wi-Fi connections from vehicles to roadside collectors have been used in probe data collection applications in Michigan. Bluetooth allows transfer speeds of up to 1 Mb/s, which is suitable for in-vehicle entertainment applications (e.g., hands-free calling with mobile phones).

Compared to other wireless communications technologies, however, 5.9 GHz DSRC is still early in its development and application life cycle. Proof-of-concept demonstrations have been deployed in Michigan and California, but there are to date no widespread deployments. Some private demonstrations by a 5.9 GHz DSRC system vendor of tolling applications have been provided to certain agencies. U.S.DOT is currently developing a Safety Pilot Program for a large demonstration of V2V and I2V safety applications in 2011-2013.

- **Comments and Remarks for Different Type of Vehicles**

Different type of vehicles (e.g., light vehicle, transit vehicle and heavy vehicle) should use several communication technologies in their application. Table 3.2 provides a summary of various communication technologies and applications in different type of vehicles. Basic requirements are required that message packet size is small, approximately 200 to 500 bytes, not including the security overhead, which is approximately 200 bytes.

Maximum required range of communications is short, about 50 to 300 meters. Most applications are one-way, point to multipoint broadcasting messages, also have allowable latency of 100 milliseconds. Pre-crash warning has special requirements in two way, point to point messages, and an allowable latency of 20 milliseconds.

- **Comments and Remarks for Different Type of Applications**

Four popular safety applications (Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW)) that are potentially enabled by 5.9 GHz DSRC have been identified just within the scope of this report. Having such a range of potentially enabled safety applications means that the installed cost of 5.9 GHz DSRC (and other required) hardware in vehicles may be able to be balanced by the benefits of the multiple applications, thus substantially reducing the effective cost-per-application. For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services. Chapter 4 also reviews eight research projects (The USDOT Connected Vehicle Research Program, IVBSS, AASHTO Connected Vehicle, CAMP OTA

Interoperability, INTERSAFE-2 and CVIS, VICS and Smartway) by using various communication technologies. Table 5.2 shows that each application uses several types of communication technologies.

Table 5.2 Safety applications by using different communication technologies

Applications	Using Communication Technologies
Forward Collision Warning (FCW)	sensors, satellite, 3G/4G, Wi-Fi, 5.9 GHz DSRC
Emergency Electronic Brake Lights (EEBL)	5.9 GHz DSRC, satellite, 3G/4G, Wi-Fi
Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)	sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi
Curve Speed Warning (CSW)	sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi
VICS	sensors, satellite, Radio wave, Infrared, FM
Smartway	sensors, satellite, 5.8 GHz DSRC, Bluetooth, 3G/4G, Wi-Fi
Connected Car	5.9 GHz DSRC, sensors, 3G/4G, Bluetooth, satellite, WiFi
Vehicle Group Communication System	sensor, satellite, 5.9 GHz DSRC

Furthermore, communications infrastructure presents a variety of challenges, especially since technology is changing so rapidly. Depending on the application, different communications media will be either desirable or necessary. Fiber optic cable, in which many states have invested heavily, and radio systems including 800 MHz were frequently mentioned as either needing expansion or requiring new infrastructure to support backhaul. It was noted that where signalized intersections will be equipped with 5.9 GHz DSRC RSEs for safety applications, technical issues remain, such as line-of-sight, and interference. Any of these could potentially impact a safety system's ability to function properly.

Commercial cellular services have been used in a variety of commercial telematics deployments. The California SafeTrip-21 Connected Traveler Field Test Bed Mobile Millennium project used standard 3G Nokia phones as probe data sources. Cellular connections have been used for backhaul from RSEs in the VII California Test Bed and as one option in the VII POC Test Bed in Michigan. OnStar has used a dedicated on-board cellular connection for many years, and Ford is using a Bluetooth connection to a driver's cell phone handset for its SYNC connection. In addition, although WiMAX has been deployed in the U.S. by Clearwire as a 4G commercial cellular service, it can operate in unlicensed spectrum and can be deployed as a private network. It was used for backhaul purposes as part of the VII POC in the Michigan demonstration test environment.

In recent years, sensors play an important role in safety applications (e.g., FCW, CICAS-V and CSW). Especially, the light vehicle should use a combination of GPS, digital maps, cameras (e.g., Forward-Looking camera), short-range sensor and long-range sensor (e.g., Forward Looking senor, Rear-looking sensor, Side-Looking sensor, Yaw Rate sensor and GPS sensor). The heavy vehicle should use Forward-Looking Camera and several types of sensors (e.g., Forward sensor, Rear-Looking sensor, Side-Looking sensor, GPS sensor and Yaw Rate sensor).

In the future, some safety applications will be broadly useful across the industry, but may not have a large enough market to directly incentivize commercial development. Alternatively, significant investment for research and development relative to the size of the market may create a barrier to entry for any but the largest developers. Interoperability requirements and over-specification of features can constrain innovation and further reduce competitive commercial incentives. In these cases, it may make sense to directly fund development of applications that benefit the industry as a whole. Agency coalitions and pooled funds have successfully used this development model for ITS applications and demonstrated its effectiveness under similar constraints.

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