Inter/Intra-Vehicle Wireless Communication

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Abstract:

This paper surveys the current state-of-the-art in wireless communication technology within vehicles, as well as between vehicles. Different concepts associated with radio frequency bands and wave propagation simulations as they apply to inter-vehicle communication are analyzed. The Medium Access Control (MAC) layer protocols used in inter-vehicle communication are addressed, as are routing protocols. Security issues associated with inter-vehicle communication are reviewed. The intra-vehicle uses of wireless communication, and vehicle-to-roadside communication, are also researched. Lastly, a real-life implementation of vehicle-to-infrastructure and vehicle-to-vehicle technology, and the Institute of Electrical and Electronic Engineers (IEEE) standards that support it, are analyzed.

Keywords:

Inter-Vehicle Communication (IVC), radio frequency bands, wave propagation simulation, Medium Access Control, Directional MAC, Adaptive Space Division Multiplexing, timeslot/code allocation, multi-hopping transmission, IVC routing, security in IVC, Intra-Vehicle Communication, Continuous Air interface for Long and Medium distance, Bluetooth, dedicated short range communication, ultra-wideband, ray optics, signal to noise ratio, omni-directional, cooperative collision avoidance, platoon, public key infrastructure, certification authority, Zigbee, controller area network, vehicle-to-roadside, electronic toll collection, Wireless Access in the Vehicular Environment, IEEE 802.11p and P1609.

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Introduction

Road and traffic safety can be improved if drivers have the ability to see further down the road and know if a collision has occurred, or if they are approaching a traffic jam. This can become possible if drivers and vehicles communicate with each other and with roadside base stations. If traffic information was provided to drivers, police, and other authorities, the roads would be safer and traveling on them would become more efficient.

It is possible to build a multihop network among several vehicles that have communication devices. These vehicles would form a mobile ad hoc network, and could pass along information about road conditions, accidents, and congestion. A driver could be made aware of the emergency braking of a preceding vehicle, or the presence of an obstacle in the roadway. Such a network could also help platooning vehicles (strings of vehicles that communicate with each other so they can maintain a tight inter-vehicle spacing) utilize the roadways efficiently. It can also help vehicles negotiate critical points like blind crossings (intersections without traffic lights) and entries to highways.

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2. Radio Bands Used in Inter-Vehicle Communication

This section discusses the different frequency bands that can be used in IVC. Bluetooth and Ultra-Wideband (UWB) technologies are explored in some detail.

It is possible for communicating vehicles to use both infrared and radio waves. VHF and microwaves are a type of broadcast communication while infrared and millimeter waves are a type of directional communication. Microwaves are used most often, as cited in [Hubaux04]. For instance, 75 MHz is allotted in the 5.9 GHz band for dedicated short range communication (DSRC). It is possible to use Bluetooth, which operates in the 2.4 GHz industry, science, and medicine (ISM) band, to set up the communication between two vehicles. It is reliable up to a speed of 80 km/h and range of 80 m. However, it can take up to 3 seconds to establish the communication. Also, since Bluetooth requires a master and slave setup, the master could potentially refuse a communication request. In addition, the master may already be communicating with another slave, which would lower the possible communication rate.

An alternative to Bluetooth is a new radio frequency technique called UWB. Because of the wideband nature of the signal, UWB has been used in radar applications. The Federal Communication Commission (FCC) refers to UWB technology as having high values of fractional bandwidth (> 0.25). The main advantages of UWB technology are its high data rate, low cost, and immunity to interference. On the other hand, it could possibly interfere with other existing radio services, for instance, the Global Positioning System (GPS). Because of a lower bit error rate (BER), the coded Gaussian pulses waveform is thought to be superior to monocycle pulses. For details see [Elbahhar05]. The system is not believed to be too sensitive to multipath or jitter effects. The fact that UWB could potentially interfere with communication sources is a technical problem that must be solved before it could be used in IVC systems. Also, there is a concern that UWB's radio coverage could extend to uninvolved vehicles, which could generate false or irrelevant information.

This section reviewed the use of different frequency bands in IVC, specifically looking at Bluetooth and UWB technologies. The next section addresses the use of wave propagation simulations in IVC.

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3. Wave Propagation Simulations in Inter-Vehicle Communication

This section analyzes different predictive techniques and models that can be utilized in IVC. Direct and reflected waves are described, as well as ray tracing and multi-path components.

There is interest in the use of the 60 GHz band for inter-vehicle communication. Since a vehicle can communicate with other vehicles both in front and behind it, the line-of-sight (LOS) condition is used to obtain the propagation path. To predict the amount of power received in the LOS case, a 2-wave model can be used. The model contains a direct wave and a wave reflected from the surface of the road. It determines the propagation path loss. The distance between the sending and receiving antennas, as well as the height of the antennas, are variables in the model, but the undulation of the road is not considered. These undulations cause variations in the amplitude and phase shift of the wave reflected from the road. This wave can be calculated by using a reflection coefficient determined from the complex refractive index of asphalt at 60 GHz (n=2-j0.05).

Measured [Yamamoto05] and calculated data show some discrepancies. For instance, the height of the receiving antenna at which the received power is null is affected by the difference in the phases of the 2 waves. Variations in the value of the null are affected by the difference in the amplitudes of the 2 waves. These discrepancies are believed to be caused by undulations in the road. When utilizing a ray-tracing method, the lengths of the reflection areas between the transmitting and receiving antennas can be determined. The distance is larger when the road is concave. This suggests that the power of the road-reflected wave can be changed by the curvature of the road. This effect is increased when the vehicles in communication are moving. The variation in the received power appears to follow a Gaussian distribution. This is believed to be due to the undulation in the road.

An IVC channel model has been proposed [Maurer04] that also uses a ray-tracing technique to describe the multi-path components. In order to design and optimize IVC systems, a detailed understanding of the transmission channel is needed. Impulse Responses (IRs) of the physical radio channel between automobiles are measured and compared to model results. The IVC system is based on the IEEE 802.11a wireless LAN standard, operating at a center frequency of 5.2 GHz. Real-time measurements of the complex channel transfer function were obtained from two vehicles (vans) equipped with a transmitter and receiver unit. Quarter-wavelength mono-pole antennas are used and mounted 20 cm above the rooftop of each vehicle. Both vehicles are maneuvered through traffic as the measurements are taken. The measured statistical channel parameters are compared to a simulation of a common motorway scenario.

A ray-optical wave propagation model is used in this scenario. The model takes into account dynamic road traffic, the environment adjacent to the road, and the multi-path wave propagation effects between the transmit and receive vehicle. The model generates realistic time-series of IRs. Doppler-shift and Doppler-spread behavior of the IVC-channel is modeled. These parameters are effected by the movement of the transmit and receive vehicles and adjacent automobiles. Two different traffic models exist, macroscopic and microscopic. They differ in their level of resolution. Macroscopic models describe road traffic as a flow of liquid or gas. But single molecules (single vehicles) are not distinguishable. Because only groups of vehicles are considered, the microscopic traffic model was chosen. Here the individual motion of every single vehicle is modeled. Snapshots of the instantaneous positions and velocities of vehicles are generated, as well as their interactions (braking and overtaking) with each other. The model used in the simulation also included the positioning of objects (buildings, parked vehicles, etc.) adjacent to the road.

The wave propagation model (ray optics) assumes a small wavelength (high frequency) compared to the dimensions of the objects used in the simulation scenario. If this is true, the reflection and diffraction effects of multi-path can be seen. Each multi-path can be thought of as a ray. Diffractions are calculated using the uniform geometrical theory of diffraction (UTD), and Fresnel reflection coefficients are used to account for reflections off of rough surfaces. The slow fading component of the measured signal is associated with the path loss of the channel. [Maurer04] compares this to the simulation results, and they match very closely.

This section presented several different models that can be used in IVC simulations. The effect of road undulation was also analyzed. The next section addresses the technical details associated with different MAC protocols used in IVC.

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4. Medium Access Control (MAC) in Inter-Vehicle Communication

This section summarizes MAC protocol specifics as they apply within IVC. Performance measurements are reviewed, and several new concepts are presented.

An ad-hoc network between vehicles is better suited for vehicle communications than centralized service. The centralized architecture is not very efficient since information has to go from one vehicle to a central base station and then back to another vehicle. Wireless connectivity between moving vehicles can be provided by existing 802.11 compliant devices. Data rates of up to 54 Mbps can be achieved with 802.11a hardware. This type of communication can be made affordable if the unlicensed ISM bands are used. Compared to indoor Wireless Local Area Network (WLAN) uses, vehicular traffic scenarios have greater challenges. These are caused by the varying driving speeds, traffic patterns, and driving environments.

Performance measurements by an 802.11b-based WLAN in vehicular scenarios have been made [Singh02]]. Two vehicles with ORiNOCO IEEE 802.11b WLAN cards, and laptops running Linux were used for the tests. Omni- directional antennae were mounted on the top of the cars to increase the range of connectivity. The cars also had GPS devices to allow their location and velocity to be tracked. One of the laptops is set up as the sender of streaming User Datagram Protocol (UDP) packets, while the other is set up as the receiver. Each of the wireless cards are set up to operate in broadcast ad-hoc mode. This mode disables MAC retransmissions. The sender generates random bits in the UDP packets. Every second the GPS devices provide latitude, longitude, speed, and bearing.

Signal quality information is logged at the receiver via the wireless MAC software utilities. The bit reception rate at the receiver, or throughput, is determined by the number of packets received every second. The number of lost packets and signal to noise ratio (SNR), or link quality, are also noted at the receiver. These performance parameters are measured while the separation and relative velocity between the two vehicles is varied. To measure the connectivity of the vehicles, tests were performed with the vehicles following and crossing each other.

The 802.11b WLAN performance worsened with difficult communication scenarios. For instance, the link quality (or SNR) degraded with increasing distance. A sub- urban environment, with 40 mph speed limits and containing a few building structures and roadside tree groups, showed the best link quality. The vehicles stopped at traffic lights in this environment, but not frequently. Urban environments had speed limits up to 25 mph and contained roadside building constructions. The traffic scenario was a rush hour traffic jam. The vehicles stopped often at traffic lights and in jams. These were the worst conditions for inter-vehicle communication. The link quality of the freeway environment (open area with little roadside vegetation and speed limits of 65 mph) lies in between the sub-urban and urban. The freeway-crossing test, surprisingly, showed an increase in link quality until the vehicles were separated by 500 meters, and then it began to decrease.

The throughput also decreased as the distance increased. In the freeway-crossing case, however, the throughput initially increased with distance before starting to fall. In the sub-urban case, the throughput fell as the velocities of the vehicles increased. Increasing the packet size from 256 to 1024 bytes appeared to increase the throughput for urban scenarios. It also helped in the freeway-crossing case, when the vehicles were separated by smaller distances. At larger separations a smaller packet size was better. The connectivity was maintained while the vehicles were separated by up to 1000 meters. The connectivity appeared to be better with a smaller packet size.

4.1 Directional MAC (DMAC) Protocol

For IVC, a robust MAC scheme is needed so that the channel is shared efficiently between mobile nodes. There are several MAC protocols based on the IEEE 802.11 standard that have been adapted for wireless ad-hoc networks. But most of these require the use of omni-directional antennas. Directional antennas can also be used, and they can improve the network performance by improving the spatial re-use of the channel. To accomplish this, the MAC protocols need to use the physical layer's directional transmission capabilities. The Directional MAC protocol (DMAC) uses only directional transmissions. For details see [Sadashivaiah05]. It has a way to tell neighbors to delay their transmission if it is going to harm the pending transmission. This will help avoid the "hidden terminal" and "deafness" problems. It also has a simple and efficient way to obtain a neighbor's location, and use it in the directional transmissions.

A "Request To Send" (RTS) transmission is sent directionally, in a circular way, when a node is ready to transmit data. This is done through all of the directional antennas until the area around the source node is scanned. This circular RTS (CRTS) consists of RTS-CTS-DATA-ACK. As neighbors pick up this information they stop their transmissions - but only towards the direction of the sender. They do this for the amount of time indicated in the CTRS packet.

When a node is in idle mode, it hears omni-directionally, but upon receiving the CTRS signal it uses selection diversity. This means that it uses the antenna that is receiving the maximum power. It then sends directional Clear To Send (CTS) messages via that antenna. Upon receiving the CTS, the source transmits its data packet. In this way the source and destination nodes don't need to know each other's location. This type of communication allows more simultaneous communication links.

Because of this increased spatial re-use, DMAC should have better performance in IVC applications. However, because of the mobility of the vehicles, this may not occur. Also, the end-to-end delay needs to be better studied. This is important since safety-related data needs to be delivered quickly.

4.2 Adaptive Space Division Multiplexing (ASDM)

When wireless communication occurs directly between vehicles, security and scalability issues arise. For instance, Denial of Service (DoS) threats are present in the wireless medium and can disable communications in a network. Against jamming attacks, spread spectrum techniques offer protection. However, this requires more bandwidth, which points out the need for protocols to scale well as the available bandwidth shrinks. As IVC grows and becomes a large mobile ad-hoc network, the protocols must be capable of scaling to a large network size with a high density of nodes (vehicles). The performance of the system is especially important when this happens, since reaction times get shorter when following distances become shorter in a dense environment. The protocols must also be able to quickly adapt to a changing topology. This happens when relative velocities of vehicles increase.

A new link layer protocol, Adaptive Space Division Multiplexing (ASDM) [Blum05] addresses these issues. It is an extension of Space Division Multiple Access (SDMA) which assigns time slots based on where a vehicle is located on the roadway. ASDM breaks the roadway up into cells and contains a mapping function that maps the cells to time slots. It also has assignment rules that determine which of the time slots a vehicle can use. This protocol allows a vehicle to ensure a certain Quality of Service (QoS) by maintaining an adequate following distance. The distance is related to the number of timeslots the vehicle is allowed. Thus, a vehicle can keep its frequency of transmissions constant by maintaining a certain following distance. It also is more efficient with respect to bandwidth usage by utilizing timeslots that have been assigned to empty cells in the roadway. When vehicles approach areas that are highly congested, the link layer must deal with more vehicles within radio range of each other. But, since their speed decreases, their periodic transmission rate may also decrease. So they can shorten their following distance but still maintain an allowable QoS.

4.3 Timeslot/Code Allocation and Multi-Hopping Transmission

In IVC, each vehicle must sense media information and send its own vehicle information to surrounding vehicles. However, the sensing can take a long time, and if the vehicles are densely packed together, it becomes difficult for a vehicle to allocate a time slot or code to use in sending its data. [Dobashi05] discusses a new concept where sensing distance and frame transmission distance vary based on the density of the vehicles. Multi-hop communication is also used to transmit a vehicle's own information.

In IVC, when one vehicle is communicating with many other vehicles, the following observations can be made. First, because of the high mobility involved, the transmitting cycle is very short, generally 50 msec. So a vehicle is moving 1.39 m in 100 km/hr. Also, the transmission frame size is small, usually no more than several tens of bytes. Lastly, crisis information, such as obstacles in the roadway, need to be obtained within a certain distance, so the vehicle can be controlled safely. Another characteristic is that all of the vehicles periodically send frames frequently. For example, if a vehicle transmits 100 bits every 20 msec, and if the system requires a distance of 100 m, there will be 100 vehicles in that distance. This results in a traffic rate of 500 kbps.

[Dobashi05] conducted an experiment where each vehicle broadcasts its own vehicle information in the following parameters: Protocol = 802.11b (RTS/CTS with ACK), Packet size = 64 [bytes], Number of nodes = 12, Density of vehicles = 0.48, 0.20, 0.15, 0.10 [vehicles/m](2 lanes), Transmission interval = 10-1000 [msec]. For example, 0.48 [vehicles/m] means the distance between two vehicles is 5 meters. The results are shown in Figure 1.

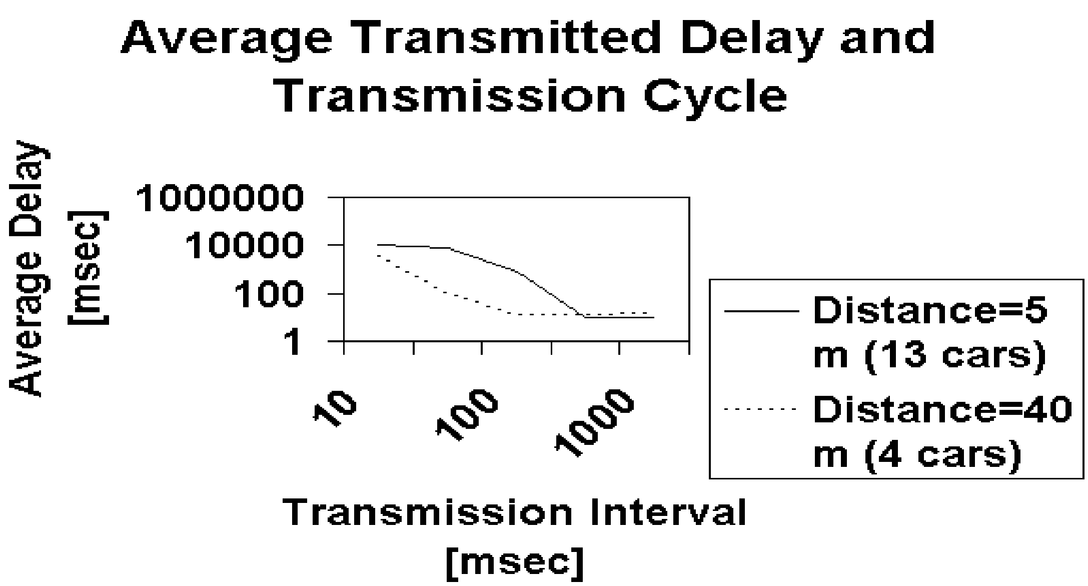

Figure 1. Relationship Between Transmission Interval and Average Delay in terms of Different Vehicle Interval Values [Dobashi05]

In the 0.48 [vehicles/m] density, each vehicle is unable to transmit its own information due to a large delay.

Even at the lower densities the information cannot be transmitted within the necessary time if the transmission interval is less than 50 msec. This is because the 802.11 protocol used the RTS/CTS mode with acknowledgements (to avoid collisions). In IVC, a simpler protocol is needed.

In a reserved type MAC protocol, time slot or code assignment is performed for every vehicle. However, if the vehicles are densely located, there may not be any empty timeslots or codes, even with sensing. If the timeslot or code allocation is not successful, the vehicle cannot send its own information. For instance, even though many codes are vacant, when information is being sent to vehicles within 100 meters, the sensing distance is 200 meters. If the distance between vehicles is 5 meters, the number of available codes is not enough since there are 160 vehicles in 2 lanes for one direction. [Dobashi05] shows in Figure 2 that the allocated code rate is not large enough as the gap increases and the node density rises.

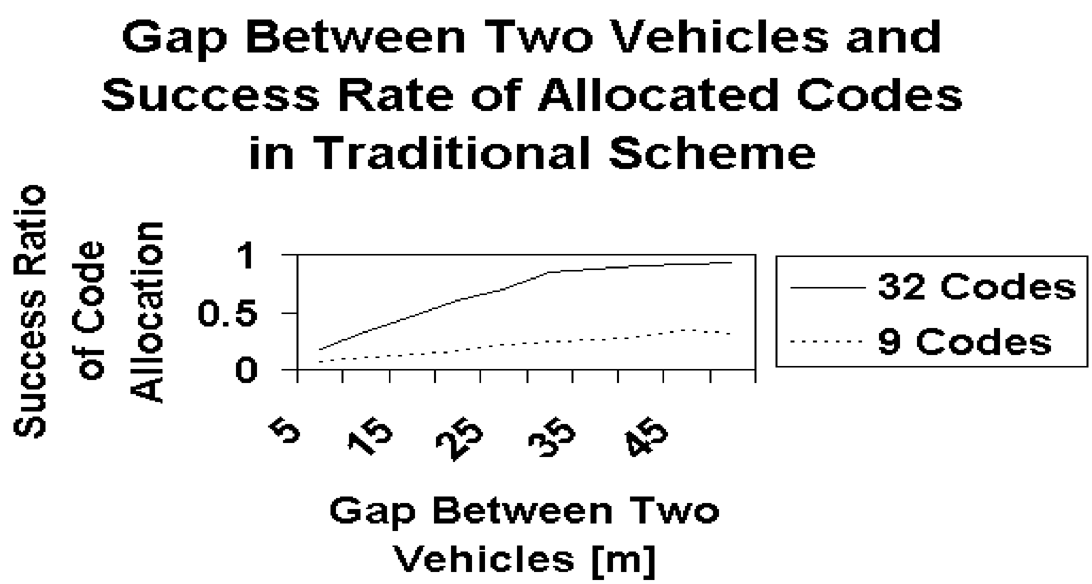

Figure 2. Code Allocated Rate Via Gap Between Two Vehicles by Traditional MCS/CDMA [Dobashi05]

Multi-hop retransmission can be used to better utilize the wireless bandwidth. In the [Dobashi05] simulation, several transmitting distance and multi-hopping environments were evaluated. When the largest transmitting distance is R (the system required distance), the number of hops is 1. For R/2 the number of hops is 2. For n hops the transmitting distance of one node is R/n. A retransmission request for each node is 3-times the vehicle's own traffic since the request is sent to the forward and backward nodes. So if the hop count increases by n, the amount of traffic will increase by (2n-1) times. But since the frame transmission distance for each node is 1/n times shorter than before, the wireless resource is decreased by $(2n-1)/n^2$. Or, as shown in Figure 3, the larger the hop count is, the less the wireless network resources consumed.

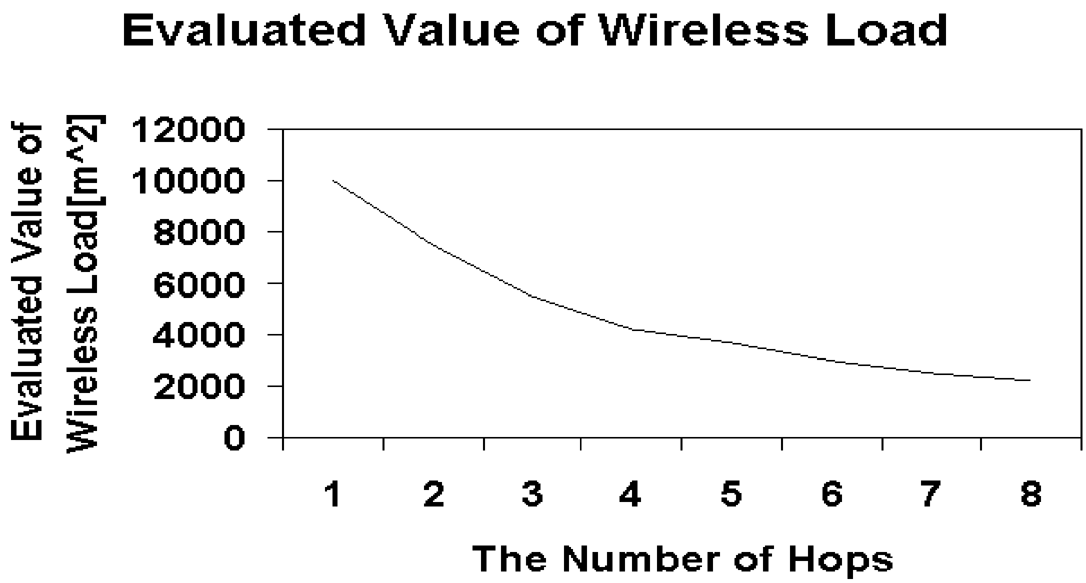

Figure 3. The More Hop Count Is, the Less the Wireless Network Resource Consumption Will Be [Dobashi05]

This section presented the technical details associated with several MAC protocols used in IVC. In particular, DMAC, ASDM, timelsot/code allocation, and multi-hop transmission concepts were analyzed. The next section takes a look at different IVC routing protocols.

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5. Inter-Vehicle Routing Protocols

This section analyzes the impact of naive and intelligent broadcast message forwarding between vehicles. Specific results associated with the use of a collision avoidance scheme on platooning vehicles is presented.

It is possible to design a Cooperative Collision Avoidance (CCA) system that helps prevent chain collisions. A high-speed wireless communication network that delivers warning messages quickly and reliably is needed to accomplish this. When an emergency situation arises, a vehicle that is part of a CCA platoon needs to send a message to all of the cars behind it in the platoon. The vehicle sends a broadcast message and all vehicles that receive it selectively forward it based on the direction it came from. This ensures that all members of the platoon eventually receive the warning.

[Biswas06] discusses different types of forwarding, including a naive broadcast and an intelligent broadcast. During the naive broadcast forwarding, the vehicle sends a broadcast message periodically at regular intervals. Upon receiving this message, a vehicle ignores it if it comes from behind with respect to its direction of movement. But if it comes from the front, it believes there must be an emergency in the front and begins to decelerate and send periodic broadcast messages of its own. In this way all of the platoon vehicles will eventually receive the warning message and decelerate to avoid a collision with vehicles ahead of it.

A limitation of this method is the large amount of forwarded messages. A result of this is that the number of message collisions can increase for 802.11 MAC. MAC collisions can in turn lower the message delivery rate and increase the delivery time. This happens if the message is dropped and forces the event-detecting vehicle to periodically retransmit it.

Biswas06] presents an intelligent broadcast with implicit acknowledgement to counteract this problem. This improves system performance by limiting the number of messages broadcast within the platoon for a given emergency event. If the event-detecting vehicle receives the same message from behind, it assumes that at least one vehicle in the back has received it, and stops broadcasting. The assumption is that the vehicle in the back will be responsible for moving the message along to the rest of the platoon. Note that it is possible for a vehicle to receive a message more than once, forwarded by different vehicles in the front. If this happens, the vehicle only acts on the first message.

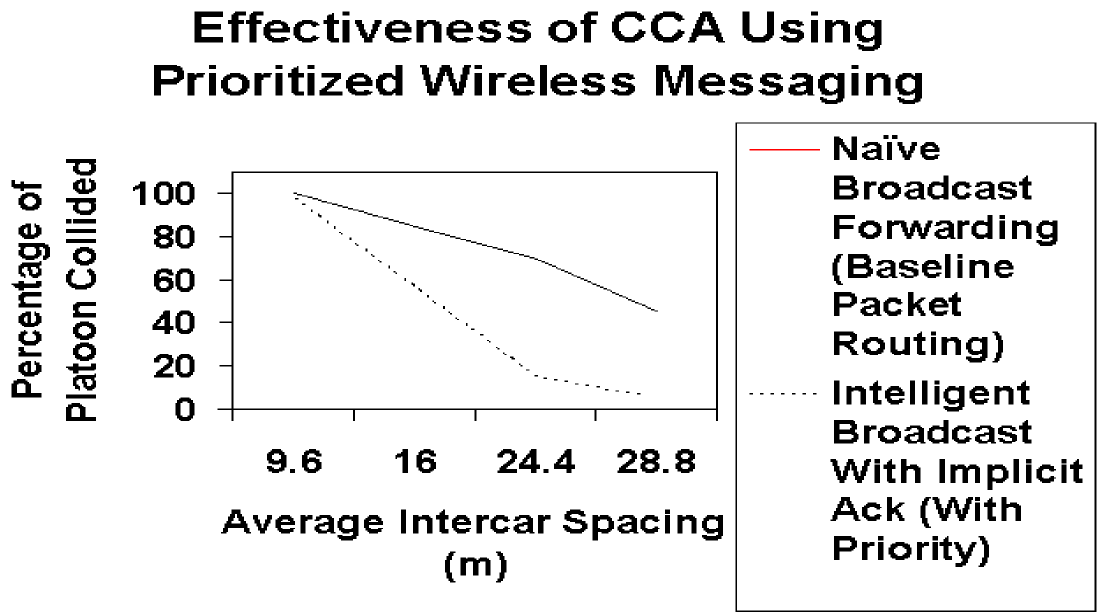

Figure 4. The Number of Vehicles Crashed as a Percentage of the Platoon (of 50 Vehicles) [Biswas06]

In Figure 4, [Biswas06] plots the number of vehicles that crash as a percentage of the platoon (50 vehicles), for intervehicle spacing of 0.3 sec (9.6 m) to 0.9 sec (28.8 m). Without CCA, all cars in the platoon will collide in a chain collision. With just the naive broadcast forwarding, it is possible to reduce this to 48% when the spacing is 1 sec. With intelligent broadcast forwarding, containing a link-layer priority structure that assigns a higher priority to safety-impacting CCA data, this is further reduced to 10%. Also see the effect of a noisy channel on crash performance in Figure 5. With very small vehicle spacing, it doesn't make any difference. Even with larger vehicle spacing, it takes 50% of the messages being corrupted due to channel errors before the crash performance is affected. However, once the packet loss increases beyond 50% it affects the CCA operation, causing more platoon vehicles to collide.

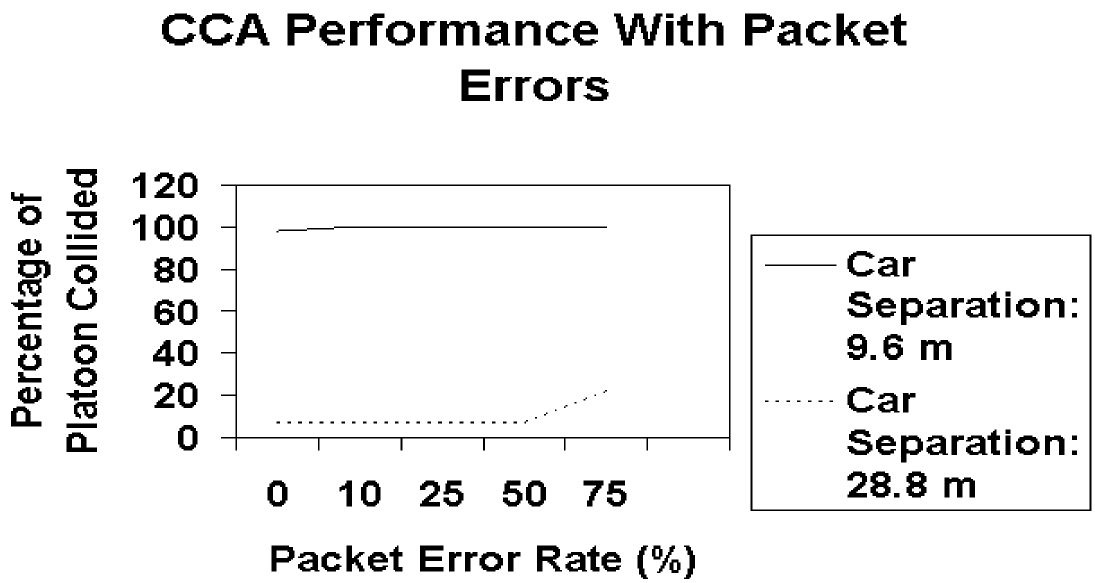

Figure 5. Vehicle Collision Performance [Biswas06]

In position-based routing (see [Hartenstein01]) a unique identifier such as an IP address is used to signify a vehicle, along with its current position (GPS coordinate). This scheme is simpler than others and only requires that a vehicle know its own position and that of its one-hop neighbors. Assuming a packet contains the destination position, the router just forwards the packet to a node closer to the destination than itself. Because of the high relative speeds of the large number of vehicles involved in IVC, this scheme is considered to be adaptive with respect to network topology and is scalable.

This section analyzed the different effects of naive and intelligent broadcast messages. It also addressed CCA in a platoon, as well as position-based routing. The next section enumerates the security issues that are present in IVC.

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6. Security Issues in Inter-Vehicle Communication

This section lists the different security and privacy concepts in IVC. Different types of attackers and attacks are described, as are the techniques used to combat them.

The security of vehicular networks is crucial. It is imperative that life-critical information cannot be inserted or modified by a malicious person. The system must be able to determine the liability of drivers while still maintaining their privacy. These problems are difficult to solve because of the network size, the speed of the vehicles, their relative geographic position, and the randomness of the connectivity between them. An advantage of vehicular networks over the more common ad hoc networks is that they provide ample computational and power resources. For instance, a typical vehicle in such a network could host several tens or even hundreds of microprocessors.

[Raya05] indicates that an attacker can be classified as having three dimensions: "Insider vs. Outsider", "Malicious vs. Rational", and "Active vs. Passive". The types of attacks against messages, can be described as follows: "Bogus Information", "Cheating with Positioning Information", "ID disclosure", "Denial of Service", and "Masquerade". The DoS attack is the nightmare of security experts. These are often executed for no rational reason. They are very difficult to stop in a wireless medium. To limit the success of these attacks, switching between channels or even communication technologies (DSRC, UTRA-TDD, or Bluetooth) is an option.

Since safety messages are presumed to not include any sensitive information, confidentiality is not required. So the exchange of safety messages requires authentication but not encryption. Digital signatures are a good choice because safety messages are normally standalone. Because of the large number of network members and variable connectivity to authentication servers, a Public Key Infrastructure (PKI) is a good way to implement authentication. Under the PKI solution, each vehicle would be given a public/private key pair. Before sending a safety message, it signs it with its private key and includes the Certification Authority (CA) certificate. Because of the use of private keys, a tamper-proof device is needed in each vehicle. This is where the secret information will be stored and the outgoing messages will be signed. To lower the risk of compromise by attackers, the device should have its own battery and clock. The clock should be capable of being resynchronized when passing by a trusted base station on the side of a road.

This section presented the different types of attackers and attacks that are present within IVC. Several techniques used to thwart these attacks were also discussed. The next section presents the use of wireless communications within a vehicle.

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7. Intra-Vehicle Communication

Wireless communication techniques can also be used to perform automotive functions inside a vehicle. This section addresses how this is done and summarizes possible uses in the future.

There are several wireless standards that can be utilized for intra-vehicle use: "IEEE 802.15.1 - Bluetooth", "IEEE 802.15.3 - UltraWideband (UWB), high data rate", and "IEEE 802.15.4 - ZigBee, low data rate". A comparison of the three standards is shown in Table 1.

	Bluetooth	ZigBee	UWB
Range(Nom)	10 meters	10 meters	< 10 meters
Chip Price	$5	$2	< $1
Data Rate	Medium	Low	High
Throughput	Medium	Low	High
Interference	Good	Good	Excellent
Media	Voice/Data	Data	Video/Radar
SIG	Consortium	Alliance	Forum
Main Layers	5	5	Evolving
Data Payload	2744	104	Evolving
Power Req	Low	Very-Low	Ultra-Low
Tx Power	1 mW	< 1 mW	200 uW
Security	Good	Good	Excellent
Installed Base	Very Large	Small	Small
Tx Penetration	Good	Good	Excellent
Spec Stability	Excellent	Good	Evolving
Mode	FHSS	DSSS	DS, MBOA
Frequency	2.4 GHz	.8, .9, 2.4 GHz	3.1-10.6 GHz
Channels	23 or 79	1, 10, or 16	Evolving
Error Correct	8-bit, 16-bit	16 CRC	Evolving
Topology	Star	Star, Mesh	Peer-to-Peer
No. of Nodes	7, or more	65534	Evolving
Link BW	1 MHz	20-250 KHz	120MHz-1GHz

Table 1. Comparison Between Bluetooth, ZigBee, and UWB [Akingbehin05]

Bluetooth has several advantages which make it the most commonly used standard today. It is a proven technology, and is relatively cheap. It can transmit voice and data, and has a large data frame payload. It also has low power requirements and can penetrate obstacles such as walls. It has a large installed base and a guaranteed latency, as well as a stable specification. Automobile components and modules, normally connected by electrical signal wires, are increasingly being replaced by wireless signals. A reduction of 50% in the amount of signal wires is the goal. Typically, an automobile contains about five miles of wiring, so this would be a lot of wireless signals! A hybrid containing wired clusters of automobile components and wireless inter-cluster connections are becoming more common. An instrument dash panel is an example of a cluster.

There are advantages to the hybrid wireless concept, such as the weight reduction due to the replacement of the signal wires, as well as simpler electrical wiring. The maintenance of the electrical submodules would also be easier. A systems approach to this idea replaced an initial component-level approach. Now international standards and off-the-shelf components are being used whenever possible. The implementation is evolving from desktop PCs, toggle switches, and lamps, to microcontroller cards, LEDs, silicon chips, auto sensors and actuators, as well as auto transducers.

During the late 1980's, a serial communication bus called the Controller Area Network (CAN) was developed. It was used in the automotive industry. Sensors, actuators, devices, switches, and displays can communicate over a CAN bus at speeds up to 1 Mbps. CAN has now been standardized as ISO 11898 by the International Standardization Organization. There are more than 1500 implementations of this standard. The hardware/ software implementation is being restructured so it can function as a physical layer below the CAN bus. This will allow the existing CAN networks to evolve to a wireless communication mode using Bluetooth technology.

Wireless network behavior, under different conditions, is being evaluated by performance and reliability models. Various factors can be observed within these models. For instance, do other networks that are close to the wireless network interfere with it? As network traffic grows, does wireless network performance get worse? Do electromagnetic environmental effects harm the wireless network performance? What is the effect of high speed vehicular traffic on the wireless network? What about the echo and resonance effects of the wireless network being enclosed within a confined steel space (vehicle)? Is it possible that electronic noise from spark plugs and other switching devices will effect the wireless network?

There are other issues associated with the use of wireless networks within automobiles as well. Can the point-to-point communication mode be replaced with broadcast or other appropriate communication modes? Can polling be replaced with interrupt-driven software? Can linear and non-linear signals be supported similarly to on-off signals?

Infotainment, telematics, and mobile commerce are the most prominent application areas for Bluetooth, WiFi, and WiMax. The Original Equipment (OE) market for Bluetooth is expected to grow steadily from 2006 to 2012, while the OE market penetration for WiFi and WiMax should emerge during this time. High-end luxury sedans and SUVs are expected to become the first vehicles to adopt these technologies in North America. The fact that there are many different wireless network technologies in vehicles should stimulate the market's growth as the market matures. Bluetooth, WiFi, WiMax, UWB, ZigBee, and wireless Universal Serial Bus (USB) are some of the new wireless technologies that are offering automakers and their suppliers many possibilities to enhance the potential of their products.

This section surveyed the use of wireless communications within a vehicle, while the following section looks at how vehicles communicate with roadside infrastructure.

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8. Vehicle-to-Roadside Communication

Information is also available from roadside sources. Car to roadside communications use the 63 GHz band. This very high frequency provides a very high bandwidth link with roadside beacons. The beacons are placed every kilometer or less, enabling high data rates to be maintained in heavy traffic. This can provide on-demand or real-time video and high speed Internet access. The vehicle drivers and passengers are thus able to receive traffic information, browse the web while on the move, shop online, and even participate in video-conferences.

Another application that takes advantage of vehicle-to-roadside communication technologies is Electronic Toll Collection (ETC). This is already a fairly mature technology that allows for electronic payment of highway tolls. The communication is traditionally via microwave or infrared techniques, more recently through GPS technology. An electronic monetary transaction occurs between a vehicle passing through a toll station and the toll agency. ETC systems require Onboard Units (OBU), vehicle detection and classification, and enforcement technologies. The ETC equipment substitutes for having a person (or coin machine) manually collect tolls at toll booths. In addition, it allows these transactions to occur while vehicles travel at highway cruising speed.

This section took a brief look at how vehicles communicate with roadside infrastructure. The next section reviews a real-life implementation of the use of wireless communication technologies in vehicles.

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9. Real-Life Implementations - CALM

Due to the ever increasing needs of road safety and sustainable mobility, a level of communication is needed that in the past did not exist. The result is that new standards in automotive communications have been designed in the last several years. CALM is an acronym for Continuous Air interface for Long and Medium distance. The Wide Area Communications standard, ISO TC204/WG16, has produced a series of draft standards known as CALM. The goal of CALM is to develop a standardized networking terminal that is capable of connecting vehicles and roadside systems continuously and seamlessly. This would be accomplished through the use of a wide range of communication media, such as mobile cellular and wireless local area networks, and short-range microwave (DSRC) or infra-red.

CALM supports user transparent continuous communications. It is the first way to combine General Packet Radio Service (GPRS) with vehicle-optimized WLAN technology. Note that this is not a complicated collection of new, unproven radio technologies. It has the support of Internet services and Intelligent Transportation Systems (ITS) applications, media independent through DSRC L7. It has the cooperation of IEEE 802.11p and P1609 - Wireless Access in the Vehicular Environment (WAVE). CALM defines 5 communication scenarios:

1) Vehicle to Infrastructure (V2I) Non-IPv6 communications

2) V2I/Vehicle to Vehicle (V2V) Local IPv6

3) V2I MIPv6

4) V2I NEMO

5) V2V Non-Ipv6

The following Draft IEEE Standards are critical to CALM's future:

1) IEEE 1609.1 - WAVE Resource Manager (this defines the basic application platform and includes application data read/write protocol between Road Side Units (RSU) and OBU).

2) IEEE 1609.2 - 5.9 GHz ITS Radio Service Security (this defines the 5.9 GHz DSRC Security, formerly IEEE 1556, anonymity, authenticity, and confidentiality).

3) IEEE 1609.3 - WAVE Networking Services (this provides a description and management of the DSRC Protocol Stack, and includes application interfaces, network configuration management, and WAVE Short Message (WSM) transmission and reception).

4) IEEE 1609.4 - WAVE Multi-Channel Operation (this provides DSRC frequency band coordination and management, it manages lower layer usage of the 7 DSRC channels, and integrates tightly with IEEE 802.11p).

5) IEEE 802.11p - Wireless LAN MAC and Physical Layer (PHY) specifications, WAVE (this defines the lower layers of the communications stack, including radio wave forms and wireless medium access procedures).

6) The latest IEEE 1609 draft documents completed in December 2005 (1609.1 completed sponsor ballot, 500+ comments, 1609 part 2-4 launched Mid-January for 30 days sponsor ballot, project approval all parts expected June 2006, IEEE 802.11p is also progressing, latest pre-Hawaii draft is D0.25, possible ballot in March 2006).

In the future, CALM may become the general purpose communication medium and also be used in safety applications. CALM provides universal access through a number of complimentary media and links them with modern Internet protocols, adaptation layers, and management entities. In addition, multi-channel communication units will enable vehicles to talk to other nearby vehicles or to the roadside infrastructure.

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Summary

This paper shows that the design of communication protocols in the framework of IVC is very challenging. This is because there are so many different application requirements, and because of the interaction between an application and its supporting protocols. Most of the existing protocols have to do with MAC and routing. Security and privacy are becoming new concerns.

Wireless in-vehicle network technologies and protocols have the potential to support many new and innovative applications. These applications are based on intra-vehicle, vehicle-to-vehicle, and vehicle-to-roadside networking of in-vehicle systems and devices. These technologies can greatly enhance the infotainment, telematics, safety, comfort, and convenience value of new vehicles. A new era is upon us where vehicles will communicate with the world, the devices within them, and with each other, making the next generation of vehicles into communication hubs.

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Links

- The homepage of the EPFL Vehicular Networks Security Project
- Secure Vehicular Communications Workshop, Feb. 1-2, 2006

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List of Acronyms

ASDM- Adaptive Space Division Multiplexing
BER- Bit Error Rate
CA- Certification Authority
CALM- Continuous Air interface for Long and Medium distance
CAN- Controller Area Network
CCA- Cooperative Collision Avoidance
CRTS- Circular RTS
CTS- Clear To Send
DMAC- Directional MAC
DoS- Denial of Service
DSRC- Dedicated Short Range Communication
ETC- Electronic Toll Collection
FCC- Federal Communication Commission
GPRS- Geberal Packet Radio Service
GPS- Global Positioning System
IEEE- Institute of Electrical and Electronic Engineers
IPv6- Internet Protocol Version 6
IR- Impulse Response
ISM- Industry, Science, and Medicine
ITS- Intelligent Transportation Systems
IVC- Inter-Vehicle Communication
LAN- Local Area Network
LOS- Line-Of-Sight
MAC- Medium Access Control
MIPv6- Mobile IP Version 6
NEMO- Mobile Network
OBU- Onboard Units
OE- Original Equipment
PHY- Physical Layer
PKI- Public Key Infrastructure
QoS- Quality of Service
RSU- Road Side Units
RTS- Request To Send
SDMA- Space Division Multiple Access
SNR- Signal to Noise Ratio
UDP- User Datagram Protocol
USB- Universal Serial Bus
UTD- Uniform Geometrical Theory of Diffraction
UWB- Ultra-WideBand
V2I- Vehicle to Infrastructure
V2V- Vehicle to Vehicle
WAVE- Wireless Access in the Vehicular Environment
WLAN- Wireless LAN
WSM- WAVE Short Message

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Note: This paper is available on-line at http://userfs.cec.wustl.edu/~gsb1/index.html