Current Trends in Vehicular Ad Hoc Networks

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Abstract

Vehicular Networks are receiving a lot of attention due to the wide variety of services they can provide. Their applications range from safety and crash avoidance to Internet access and multimedia. A lot of work and research around the globe is being conducted to define the standards for vehicular communications. These include frequency allocation, standards for physical and link layers, routing algorithms, as well as security issues and new applications. In this paper we review the standardization work and researches related to vehicular networks and discuss the challenges facing future vehicular networks.

***Index Terms*— DSRC, IEEE 802.11, MAC, Routing, Security, UTRA-TDD, Vehicular communications, WAVE.**

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Vehicular Networks are receiving a lot of attention due to the wide variety of services they can provide. Their applications range from safety and crash avoidance to Internet access and multimedia. A lot of work and research around the globe is being conducted to define the standards for vehicular communications. These include frequency allocation, standards for physical and link layers, routing algorithms, as well as security issues and new applications. In this paper we review the standardization work and researches related to vehicular networks and discuss the challenges facing future vehicular networks.

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1. Introduction

Millions of people around the world die every year because of car accidents and many more are injured. Implementations of safety information such as speed limits and road conditions are used in most parts of the world but still much more work is required. Vehicular Ad Hoc Networks (VANET) should, upon implementation, collect and distribute safety information to massively reduce the number of accidents by warning drivers about the danger before they actually face it. Such networks comprise of sensors and On Board Units (OBU) installed in the car as well as Road Side Units (RSU). The data collected from the sensors on the vehicles can be displayed to the driver, sent to the RSU or even broadcasted to other vehicles depending on its nature and importance. The RSU distributes this data, along with data from road sensors, weather centres, traffic control centres, etc to the vehicles and also provides commercial services such as parking space booking, Internet access and gas payment. The network makes extensive use of wireless communications to achieve its goals but although wireless communications reached a level of maturity, a lot more is required to implement such a complex system. Most available wireless systems rely on a basestation for synchronization and other services; however using this approach means covering all roads with such infrastructure which is impractically too expensive. Ad hoc networks have been studied for some time but VANET will form the biggest ad hoc network ever implemented, therefore issues of stability, reliability and scalability are of concern. VANET therefore is not an architectural network and not an ad hoc network but a combination of both; this unique characteristic combined with high speed nodes complicates the design of the network.

In this paper we provide an overview of the technologies and ongoing research related to VANET. The history and the first generation VANET systems around the world are reviewed in the next section. Current frequency allocation and physical layer standards are presented in section three. In section four the WAVE and IEEE 802.11p standards for vehicular communications are discussed. The fifth part presents link layer, routing and broadcasting algorithms designed and studied in the European project FleetNet. An overview of VANET applications is provided in section six along with some current prototypes of these applications. A discussion about security issues followed by open research problems are presented in sections seven and eight, and then finally the paper is concluded.

2. Background of Vehicular Communications

The original motives behind vehicular communications were safety on the road, many lives were lost and much more injuries occurred due to car crashes. A driver realising the brake lights of the car in front of him has only a few seconds to respond, and even if he responded in time cars behind him could crash since they are unaware of what is going at the front. This motivated one of the first applications for vehicular communications, namely cooperative collision warning which uses vehicle to vehicle communication [1]. Other safety applications soon emerged as well as applications for more efficient use of the transportation network, less congestion and faster and safer routes for drivers. These applications cannot function efficiently using only vehicle to vehicle communications therefore an infrastructure is needed in the form of RSU. Although safety applications are important for governments to allocate frequencies for vehicular communications, non-safety applications are as important for Intelligent Transportation Systems (ITS) for three reasons [2]:

1) ITS systems rely on essential equipments which should be installed in every car and are widely available to the users. However, it

is unlikely that individuals can afford such expensive equipment.

2) Safety applications generally require limited bandwidth for short intervals of time. Since bandwidth efficiency is an important factor, non-safety applications are important to increase bandwidth efficiency.
3) The availability of RSU provides an infrastructure which can be used to provide a lot of services with only a little increase in cost.

Besides road safety, new applications were proposed for vehicular networks, among these were Electronic Toll Collection (ETC), car to home communications, travel and tourism information distribution, multimedia and game applications just to name a few. However these applications need reliable communication equipments which are capable of achieving high data rates and stable connectivity between the transmitter and the receiver under high mobility conditions and different surroundings.

Different frequencies for VANET were allocated in different parts of the world. In North America the Dedicated Short Range Communications (DSRC) band 902-928 MHz was allocated. It provided short range communications (<30m) and low data rates (500 kbps). It is still used for some types of electronic toll collection systems but its performance is too limited to satisfy the demanding requirements of ITS applications.

In Japan the bands 5835-5840 and 5845-5850 MHz were allocated for uplink and 5790-5795 and 5800-5805 MHz for downlink for the Association of Radio Industries and Businesses standard ARIB STD-T55. The system relies on road architecture, as with DSRC, and provides ETC service. The standard uses ASK modulation for a data rate of 1Mbps with 8 slot- TDMA/FDD to provide service for a maximum of 8 cars within a range of 30m. Currently a new standard (ARIB STD-T75) is being developed [3].

These systems can be regarded as the first generation for vehicular communications. The different standards and frequencies have hindered the implementation of ITS systems since each country has its own specifications and operating system. Moreover the low data rates and short distances were only suitable for a limited number of applications.

3. Physical Layer

In 1999 the Federal Communications Commission (FCC) allocated a new 75 MHz band DSRC at the 5.9 GHz frequency for ITS applications in North America. The band is divided into 7 channels as shown in Fig. (1) [4].

A physical layer standard is being developed by the American Society for Testing and Material (ASTM) known as the ASTM E2213 standard. It uses Orthogonal Frequency Division Multiplexing (OFDM) as its modulation scheme and covers a range up to 1 km [5].

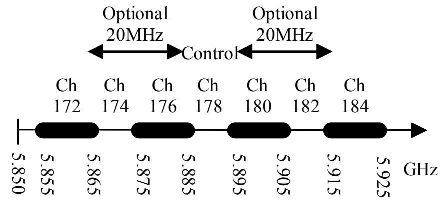

Fig (1): DSRC bands in North America.

OFDM is a multi-carrier modulation scheme. Data is split into multiple lower rate streams and each stream is used to modulate one of the subcarriers. Since the data rate is reduced, lower bandwidth is required for each carrier. The carriers are spaced at intervals of $1/T$, where T is the symbol duration; therefore they are orthogonal to each other. Although high data rates can be achieved using OFDM, the performance of OFDM can degrade rapidly if careful considerations for synchronization and channel variations are not taken. OFDM is sensitive to frequency and phase errors [6, 7]. Because the subcarriers are very close to each other, any drift in the frequency causes Inter Carrier Interference (ICI). In VANET the high relative speeds between vehicles on opposite sides or between the vehicle and the RSU cause an increase in the received frequency as the vehicles move towards each other and a decrease as vehicles move away due to the Doppler effect. This must be taken into account during the design of the receiver as it destroys the orthogonality of the carriers and increases ICI [8].

IEEE 802.11a standard uses 64 carriers, 48 are dedicated for data, 4 are pilot carriers and the other carriers are not used to reduce interference to other bands. Training sequences are used at the beginning of the packet for training and the pilot carriers channel response is extrapolated to estimate the channel response for the other carriers [9]. This scheme performed well with WLAN since the terminals had limited mobility, however with VANET the terminals can move in speeds of 100 km/hr or more. To illustrate this consider two cars moving in opposite directions each with speed of 150 km/hr. At 5.9 GHz this results in a Doppler Shift of 2 kHz, yielding a channel coherence time of 250 μs. The maximum length of an IEEE 802.11 packet is 18768 bits and at 54 Mbps this takes 348 μs to be transmitted. Note that 54 Mbps is the maximum data rate, if the nodes are using a lower data rate (e.g. 6 Mbps) this will take much longer. Therefore the training sequence at the start of the frame will lose its significance by the end of the packet and whether the 4 pilot carriers are sufficient to estimate the channel or not is a matter of concern.

In Europe a spectrum aligned with the DSRC spectrum in North America is being considered as shown in Fig (2) [10]. The band 5.885 to 5.905 GHz in the form of two 10 MHz channels is expected to be allocated first followed by the rest of the spectrum [11]. The adaptation of UTRA-TDD for VANET communications was studied in the FleetNet project but this is still an open area and some projects adapt IEEE 802.11 for their studies. UTRA-TDD standard, however, can provide a maximum data rate of 2 Mbps for still nodes and 384kbps for mobile nodes [3].

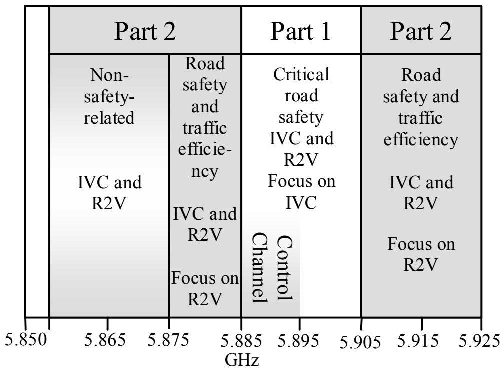

Fig (2): Frequency Proposal in Europe.

In Japan the new ARIB STD-T75 standard uses 14, 4.4 MHz channels, 7 for downlink and 7 for uplink as shown in Fig (3). The standard uses ASK to provide a data rate of 1Mbps and QPSK to provide 1 or 4 Mbps. It also makes use of 8 slots TDMA/FDD to provide service to a maximum of 56 cars within a range of 30m. The system provides ETC service as well as information shower [3]. For Inter-Vehicle Communication (IVC) cars need to communicate in an ad hoc manner. Since no infrastructure is present, cars in the road form a temporary group in order to use the standard to exchange information.

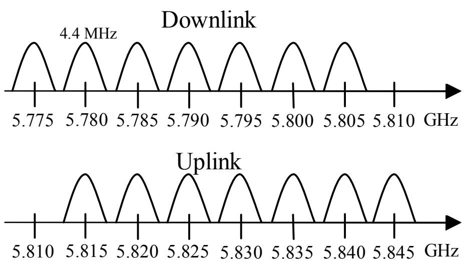

Fig (3): ARIB STD-T75 frequencies.

4. IEEE Standards

While standard ASTM E2213 is being developed, the IEEE standards IEEE P1609.1, P1609.2, P1609.2 and P1609.4 were being prepared for vehicular networks. P 1609.3 is still under further development but the other three were recently released for trial use. P1609.1 is the standard for Wireless Access for Vehicular Environment (WAVE) Resource Manager. It defines the services and interfaces of the WAVE resource manager application as well as the message and data formats. It provides access for applications to the other architecture. P1609.2 defines security, secure message formatting, processing, and message exchange. P1609.3 defines routing and transport services. It provides an alternative for IPv6 and also defines the management information base for the protocol stack. P1609.4 covers mainly how the multiple channels specified in the DSRC standard should be used. The WAVE stack uses a modified version of IEEE 802.11a for its Medium Access Control (MAC) known as IEEE 802.11p [12, 13]. The protocol architecture defined by IEEE is shown in Fig (4) and the WAVE standards in Fig (5) [13].

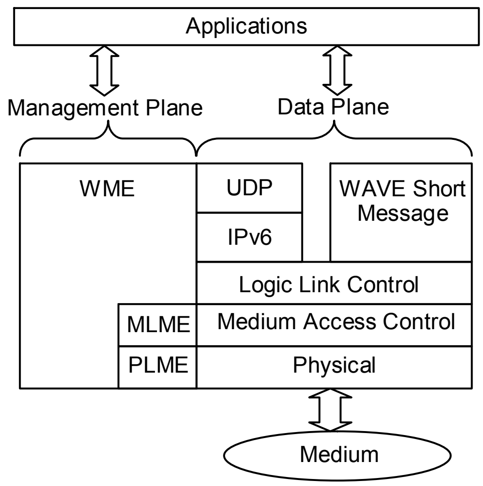

Fig (4): IEEE architecture

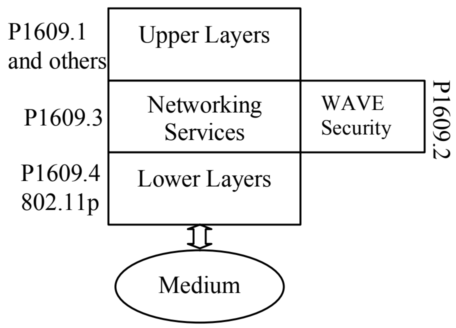

Fig (5): WAVE standards

IEEE 802.11p is still under development. The draft specifies data rates from 3 to 27 Mbps for 10 MHz channels and 6 to 54 Mbps for 20 MHz channels. Nodes communicate with each other in an ad hoc fashion known as Wireless Access for Vehicular Environment (WAVE) mode. RSUs form Basic Service Sets with the vehicles, known as WAVE BSS (WBSS) in order to communicate. An RSU sends WBSS announcement frames and vehicles can optionally join the WBSS. Authentication and association routines are not performed in WBSS and the Point Coordination Function (PCF) will not be used in this standard. Data priorities are handled using Enhanced Distributed Channel Access (EDCA) as defined in the IEEE 802.11e standard. The protocol can operate in the European and Japanese frequencies [12, 14].

The use of Request To Send/Clear To Send (RTS/CTS) packets and windows in IEEE 802.11p does not solve the hidden/exposed terminals in the ad-hoc Vehicle-to-Vehicle (V2V) communications mode due to the high mobility of the terminals. A packet between two stationary, or slowly moving, vehicles passing all the Distributed Coordination Function (DCF) constraints can still collide with another packet sent from a fast moving (or in the opposite lane) vehicle unaware of the RTS/CTS handshake. This scenario can occur rapidly in V2V networks causing very low throughput.

5. FleetNet Project

In Europe the FleetNet project studied the extension of the UTRA-TDD standard for decentralised vehicular networks. An ad-hoc mode of UTRA-TDD known as Opportunity Driven Multiple Access (ODMA) can provide access to approximately five nodes within coverage range but relies on a basestation for synchronization. Since a basestation is not always available to provide synchronization, a new ad-hoc proposal based on UTRA-TDD was introduced [15]. The new modified UTRA-TDD achieves synchronization in two steps, first using GPS to achieve coarse synchronization between nodes, then using a midample to achieve fine synchronization [16, 17]. The standard uses TDMA slots with 16 CDMA codes for every slot. Reserve slots are used by the nodes to reserve a slot prior to communication while high priority data are transmitted via separate dedicated slots [18]. Simulations showed that the modified UTRA-TDD outperformed the IEEE 802.11b [19]. The proposed access mode was extended afterwards to work with several frequencies [20].

Broadcasting and routing algorithms for VANET were also studied in FleetNet project. Their focus was on using the positioning information provided by GPS for routing and broadcasting. Three routing protocols were considered, Position Based Forwarding (PBF), Contention Based Forwarding (CBF) and Ad hoc On-demand Distance Vector (AODV). All these protocols are reactive protocols. Reactive protocols discover the route to a destination only when a message is to be delivered counter to proactive protocols which tend to store routing tables for every destination and update these routing tables continuously. As the topology of VANET changes frequently, the signalling messages of proactive protocols can result in a large overhead load. PBF and CBF use location service algorithms to find the position of the destination, based on this position PBF selects one of the surrounding nodes to forward the message. This process is repeated till the message reaches it destination. In CBF the source transmits the message with the position of the destination; every node receiving the message sets a timer inversely proportional to the difference between its position and the destination. If the timer expires and no other node has broadcasted the message, the node forwards the message to the destination. In AODV the source floods the network with a route request for the destination. Nodes receiving the request calculate a distance vector and forward the message, this process is repeated till the destination is reached which sends a route reply. Once the reply is received the route is ready for sending the data. To reduce the flooding effects maximum hop count and Time To Live (TTL) fields are used in route messages. Simulations show that CBF performs better than the other algorithms and it adapts to changes in the topology which interrupt routes in the other two protocols. CBF, however, requires the assistance of maps in cities when multiple roads intersect and run in parallel, its performance in congested areas also requires more investigation since several cars may have the same distance to the destination which can cause collisions [21, 22].

A broadcasting algorithm based on CBF has also been suggested for safety applications. A car encountering an accident broadcasts a safety message with its current position. Other cars receiving this message set a retransmission timer inversely proportional to their distance from the source and re-broadcast the message if no other node broadcasts first and keeps re-broadcasting till it receives a message from another node or the message is no longer relevant [23].

6. Applications of VANET

A large number of applications have been specified by governments for DSRC applications, we cover here a few of them. Traffic control is a major factor for efficient use of the transportation network. Currently traffic lights organize the flow of traffic at junctions. With DSRC traffic lights become adaptive to the traffic and can provide priority to emergency vehicles as well as safety to pedestrians and cyclists. Moreover information about the status of the road can be distributed to cars to warn them of problems ahead such as ice or maintenance work on the road. This system will also be very efficient in the case of accidents, automatically notifying the nearest ambulance and other emergency vehicles to approach the accident, if needed, and even provide telemedicine services if the patient requires immediate attention especially when there are no nearby hospitals. Crash prevention is the main motive behind ITS, therefore a number of applications have been specified. Crash prevention applications that rely on an infrastructure include road geometry warning to help drivers at steep or curved roads and warn overweight or overheight vehicles, highway-rail crossing and intersection collision systems to help drivers cross safely, pedestrian, cyclist and animal warning systems to inform drivers of possible collisions, these systems become of vital importance at night or under low visibility conditions [1].

Safety applications which do not rely on an infrastructure include an emergency brake announcement which is the most important application for crash prevention. The first two cars might not benefit from the emergency brake system but farther cars can avoid the crash. Lane change assistance, road obstacle detection, road departure warning as well as forward and rear collision warning are all examples of safety V2V applications. Vehicles can also automatically send help requests in case of an accidents which can be vital when no other cars are around [1]. An ongoing European project, eCall, aims at providing this automatic call service by 2009 using existing cellular infrastructure [24]. The OBU system can also help the driver in other different ways such as vision enhancement via image processing techniques, lane keeping assistance and monitoring of onboard systems as well as any cargo or trailers connected to the vehicle. Such systems are generalised as Advanced Driver Assistance Systems (ADAS) [24].

The commercial applications of the system cover a wide range of innovative ideas aiding individuals and tourists such as booking a parking area, downloading tourism information and maps for restaurants and gas stations, navigation and route guidance, payment at toll plazas, Internet access and connection to home computers. Other devices within the vehicle can also be connected to the On Board Units (OBU) to access any services provided by the network or through the Internet. These applications are not required by the government but they encourage people to install the system.

A Japanese project called P-DRGS (Dynamic Route Guidance System) is one possible implementation of the navigation and route service. This project is currently developing a system know as PRONAVI currently consists of a server accessible through the Internet. Users enter their start position, destination and time to start their journey and the server responds with the best two routes. The routes are compiled from a 9 months survey as well as simulations. In its final version the system should be able to collect data from the sensors installed in cars and provide the routes to the OBU [25].

The Vehicle Information and Communication System (VICS) is another Japanese implementation of roadside to vehicle communications. Subscribers to the system get an onboard navigation system that receives weather, road conditions, traffic information and any other related data from road side units and displays them to the user [26].

In Europe the eSafety initiative was launched in April 2002. Currently it has 14 workgroups working in the areas of accident causation analysis, communications, digital maps, Emergency Call (eCall), heavy duty vehicles, Human-Machine Interaction (HMI), information and communication technologies for clean mobility, implementation road map, international cooperation, Real-time Traffic and Travel Information (RTTI), research and development, security, service-oriented architectures and user outreach. The eSafety forum aims to accelerate the development, deployment and use of eSafety systems to obviate 50% of the number of fatalities in Europe by 2010 [24].

7. Security issues

The ongoing Network On Wheels (NOW) project addresses a number of issues in vehicular networks with a focus on security. The project adopts an IEEE 802.11 standard for wireless access and aims at implementing a reference system. The project addresses a number of security threats for VANET [27]. VANET security should satisfy four goals, it should ensure that the information received is correct (information authenticity), the source is who he claims to be (message integrity and source authentication), the node sending the message cannot be identified and tracked (privacy) and the system is robust. Several attacks can be identified and these can be generalized depending on the layer the attacker uses. At the physical and link layers the attacker can either disturb the system by jamming or overloading the channel with messages. Injecting false messages or re-broadcasting an old message is also a possible attack. The attacker can also steal or tamper with a car system or destroy a RSU. At the network layer the attacker can inject false routing messages or overload the system with routing messages. The attacker can also compromise the privacy of drivers by revealing and tracking the positions of the nodes. The same attacks can also be achieved using the application layer [28].

In the IEEE WAVE standard vehicles can change their IP addresses and use random MAC addresses to achieve security [12]. Vehicles also keep the message exchange to a minimum at the start of the journey for some time so that the messages can not be tied to the vehicle.

A number of security algorithms have been developed in France Telecom R&D department. The security proposal provides security at the link layer for vehicle safety and commercial applications, higher layer security protocols can also be used to further enhance the security or provide end to end security in a multihop link.

The proposal makes use of four types of certificates, two long term and two short term. One long term and one short term certificates are used for ITS services while the others are for non-ITS applications. Long term certificates are used for authentication while short term certificates are used for data transmission using public/private key cryptography.

Safety messages are not encrypted as they are intended for broadcasting, but their validity must be checked; therefore a source signs and sends a message without encryption along with its certificate. Other nodes receiving the message validate it using the certificate and signature and may forward it without modification if it is a valid message. Non-ITS data can rely on higher layer protocols to provide end-to-end security especially over a multihop link [29].

8. Open Research Areas

Vehicular networks introduce a new challenging environment for communication engineers. The communication channel can vary from a simple point to point microwave link for cars in open areas, to rich Rayleigh fading within the cities. Moreover the channel varies considerably every few seconds and line of sight blockage occurs frequently. Therefore the physical layer generally operates under various channel conditions and is expected to provide high data rates and transfer large amounts data even though the communication time can be limited to a few seconds. Adaptive and efficient channel estimation algorithms are needed, diversity techniques to overcome fading effects should be examined and Doppler effects should be carefully considered especially when using OFDM signalling.

The link layer should provide various delay and QoS classes to satisfy the different requirements of the applications. It should also organize the access to the medium and resolve collisions under high mobility conditions. The RTS/CTS mechanism of IEEE 802.11 will perform poorly in V2V communications because the nodes move very fast. UTRA-TDD provides a number of elegant solutions but how will it perform under different load conditions remains a matter that requires further investigation. The maximum data rate for UTRA-TDD is 2 Mbps which is lower than the minimum data rate specified for IEEE 802.11p.

Efficient broadcasting algorithms are essential for delivery of safety and routing messages. Routing protocols that rely on GPS were introduced in section 5. However these protocols still require further investigations to test their stability and capabilities to work when few cars are on the road as well as in congested areas are of concern.

IP version 6 has been proposed for use in vehicular networks. Cars should be able to change their IP addresses so that they are not traceable, however it is not clear how this will be achieved. Moreover this can cause inefficiency in address usage since when a new address is assigned the old address cannot be reused immediately. Delayed packets will be dropped when the car changes its IP address which causes unnecessary retransmissions.

Vehicular networks rely on distributed untrustworthy nodes which should cooperate with each other and with RSUs. Issues of security are a major concern for safety applications as well as for commercial applications. Any developed security solution should meet the diverse needs of the applications while taking into consideration the processing capabilities of the OBU. The network should also work with minimum human interaction since otherwise it will divert the driver's attention from the road.

Other related research areas of great importance include sensor design, antenna design, OBU specifications, driver-OBU interface, RSU design, RSU to RSU communication network specifications and VANET servers' requirements and software platforms just to name a few. These systems should cooperate in an efficient manner to reach the ultimate goal of faster, safer and information rich journeys on the road.

9. Conclusion

In this paper we provided an overview of the development of the communication standards and ongoing research for vehicular networks. Frequencies have already been allocated in North America and Japan and are expected soon in Europe. The IEEE 802.11p and WAVE suite were recently released for trial use. Routing protocols, broadcasting algorithms and security algorithms are being developed for vehicular networks as well as safety and commercial applications. Vehicular networks will not only provide safety and life saving applications, but they will become a powerful communication tool for their users.

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