Wireless Vehicular Networks

Keyshav Mor

Matrikulation Nummer : 396743

Fakulität IV : Fachgebiet Elektrotechnik & Informatik

Technische Universität Berlin

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***Abstract*—This document presents a summary of a seminar and discussion on the prevalent and future trends in Wireless Vehicular Networks. This document introduces the 802.11 wireless standard and its evolution to the Wave 802.11p standard. The technical aspects of 802.11p are explained briefly including its frequency spectrum, modulation techniques, services architectures and data frame structure. A study by Qualcomm Inc. to compare CV2X with 802.11p is also briefly reviewed in the concluding sections.**

Keywords--Vehicular Networks, Wireless, WLAN, 802.11p, WAVE, CV2X, CALM, C2C, COMesafety, DRSC, OFDM, CSMA-CA, EDCA etc.

I. Introduction

The Wireless Vehicular Networks are the future of Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2X) communication. As self-driving vehicle and electric mobility research advances, the need for Wireless V2V and V2X communication protocols cannot be ignored. With the death of 1.3 million people each year in road accidents and more than 20 million people ending up injured due to such road crashes, it is a matter of immediate importance to introduce networks which help cars and drivers communicate better , to save precious human lives and economic losses up to $518 Billion each year. These conditions gave rise to standardization of the WLAN 802.11 standard for Wireless Vehicular communication which would be discussed in detail in the document.

II. THE 802.11 WLAN STANDARD

A. V2X Communication

V2X communication refers to the exchange of messages between the vehicles driving on the road, the traffic infrastructure and in special cases, the communication of the vehicle and the passenger with Internet.

The V2X communication protocols largely focus on safety applications with hard real time deadlines and also on applications with soft real time applications.

The range of communication is expected to be from 50-500 metres with periodic messaging capability of data length up to 500 bytes. Maximum latency allowed is only 100 milliseconds and sometimes as small as 20 milliseconds.

The main focus of the V2X communication protocols is to ensure Vehicle & Traffic Safety, Traffic Efficiency and Infotainment applications.

B. The WLAN Standard

The generic WLAN standard 802.11 laid the foundation of the V2X communication protocols, particularly the 802.11p WAVE standard.

The 802.11 standard was defined by the 802 working group of IEEE. The standard is designed for wireless communications. It operates in 900 MHz, 2.4, 3.6, 5 and 60 GHz frequency bands.

The range of communication varies from 20 metres in Indoor settings up to 5000 metres in outdoor settings. The data transfer rates vary from 1 Mbit/sec to 3466.8 Mbit/sec.

The modulation techniques used are usually Direct Sequence Spread Spectrum (DSSS) and Orthogonal Frequency Division Multiplexing (OFDM).

C. Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum involves the modulation of the message signal over a carrier signal which is convoluted with a random PN sequence to generate a phase shifted signal which is then transmitted over the air.

On the receiver side, the same phase shifted signal is demodulated using the same PN sequence from the transmitter side.

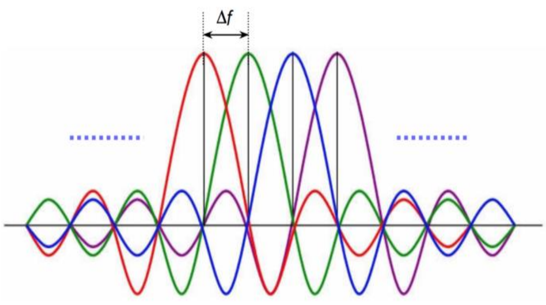
The phase shift keying could be either Binary, Quadrature, 16, 64 phase shift keying. While Binary PSK has low error rates, it also has low data carrying capacity. Whereas as 64 PSK is more prone to error but has high data carrying capacity.

D. Othrogonal Frequency Divisional Multiplexing

In Orthogonal Frequency Division Multiplexing, multiple channels are spread out over the frequency spectrum. These channels are of 20 MHz width and overlap in frequency domain.

The channels can be represented by a sinc function. All these sinc function signals overlap in orthogonal manner i.e the amplitude of all the other signals is zero when amplitude of one of the signals is at its peak.

Thus DSSS and OFDM allows the 802.11a and 802.11p amendments of 802.11 standard to have high data carrying capacity with low inter channel interference despite the fact that the channels are tightly packed across the frequency spectrum, closely overlapping with each other.



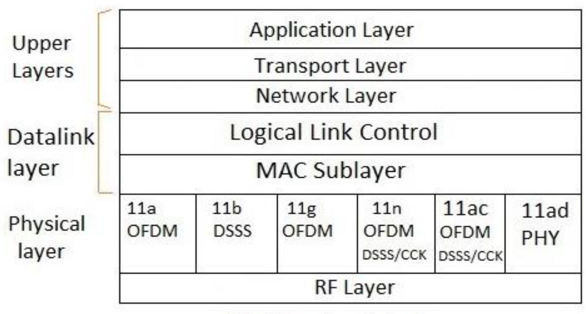
OFDM Spectrum

III. THE WLAN PROTOCOL STACK

The 802.11 standard introduced many amendments like the 802.11a/b/g/n to improve the basic 802.11 standard. These form the PHY layer of the WLAN Stack.

On the top of this comes the 802.11 standard MAC frame which is common for all the 802.11 amendments.

Above this comes the logic link control layer, the networking layer, the transport layer and the application layer.



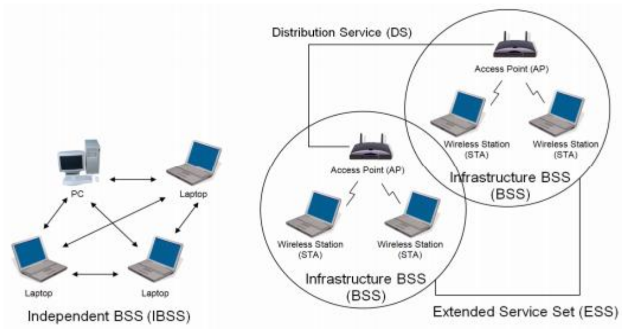
WLAN protocol stack

IV. BASIC 802.11 OPERATIONS

An Infrastructure Basic Service Set (IBSS/BSS) is formed when 802.11 stations share the same access point (AP). Each station listens to beacon signal from the AP before joining the IBSS or BSS after authentication and authorization.

802.11 has a Distribution Service (DS) which logically allows interconnected BSS into one Extended Service Set (ESS).

Each BSS has a Service Set ID (SSID) to identify itself in public or private locations. It is 0 to 32 bytes long. It is different from the BSSID which is a 48-bit long field like a MAC Address which is common to all stations in a service set. It is the MAC Address of the Access Point (AP).



V. THE IEEE 802.11 DATA FRAME FORMAT

The IEEE 802.11 standard data frame format is common to all 802.11 amendments.

The frames include up to 4 address fields to carry Source Address (SA), Destination Address (DA), Transmitting Station Address (TA) and Receiving Station Address (RA).

There is a QoS control field which decides the Quality of Service being provided. The data frame field is of variable length.

To DS	From DS	Address 1	Address 2	Address 3	Address 4
0	0	RA = DA	TA = SA	BSSID	N/A
0	1	RA = DA	TA = BSSID	SA	N/A
1	0	RA = BSSID	TA = SA	DA	N/A
1	1	RA	TA	DA	SA

Figure 6, IEEE 802.11 data frame address field contents

VI. NEED FOR SEPARATE VEHICULAR WIRELESS STANDARD

Authentication and Authorization to join a BSS needs a lot of time in regular WLAN Standards. This violates the latency requirements of V2X communication which could cause vehicle safety hazards.

Ii is impossible to implement a common BSSID for a WLAN network, in case of moving vehicles without modifying the protocol.

The range and security of the network is critical in case of vehicular networks. The security, management and networking aspects had to be added in the form of the IEEE 1609 standard.

As the 2.4 GHz and 5 GHz frequency bands are free and unlicensed, there is a lot of interference from the adjacent channels which could cause security issues and data corruption and collision.
As the 802.11p standard is only a minor modification of the 802.11a standard, there was no need for a new wireless networking protocol and it allowed use of existing hardware, which helped the automotive industry to keep their costs low while implementing the standard in vehicles.

VII. THE WAVE OR 802.11P AMENDMENT

The 802.11p or the WAVE standard is the official amendment of the generic 802.11 standard which stands for Wireless Access in Vehicular Environments.

Parameters	IEEE 802.11a	IEEE 802.11p	Changes
Bit rate (Mb/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27	Half
Modulation mode	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	No change
Code rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4	No change
Number of subcarriers	52	52	No change
Symbol duration	$4\mu s$	$8\mu s$	Double
Guard time	$0.8\mu s$	$1.6\mu s$	Double
FFT period	$3.2\mu s$	$6.4\mu s$	Double
Preamble duration	$16\mu s$	$32\mu s$	Double
Subcarrier spacing	0.3125 MHz	0.15625 MHz	Half

A. *MAC Amendments*

A station in WAVE mode can send and receive data frames with a Wildcard BSSID with “To DS” and “From DS” fields in MAC Data Frame set to 0. Wildcard BSSID contains all 1’s in its frame.

WBSS is WAVE Basic Service Set established when radio in WAVE Mode sends out beacon signal containing all necessary information for a Station to join the WBSS.

A station ceases to be a member when it stops sending and receiving frames that use the BSSID of the WBSS. A station in WAVE mode and a part of the WBSS can still receive frame from others outside the WBSS with the same wildcard BSSID.

A station is WAVE mode is allowed to transmit and receive messages with the Wildcard BSSID without priority, meaning that two vehicle can communication with each other without additional overhead.

A station cannot be a member of multiple WBSS and it should not join IBSS. It should also never use MAC authentication and authorization process. A WBSS ceases to exist when it has no members.

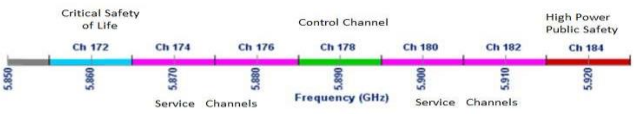
B. *PHY Amendments*

A Dedicated Short Range Communication (DSRC) frequency spectrum was allocated for WAVE in the United States with 75 MHz band in the 5.9 GHz frequency range.

Channels are 10 MHz wide where channel 178 is control channel, Channel 172 and 184 are Safety Channels and other channels are all service channels. Total there are 7 channels with a spacing of 0.66 MHz.

These amendments result in the 802.11p standard having half the bit-rate and half subcarrier spacing of 802.11a but double guard time and symbol duration than that of 802.11a.

In Europe and Japan, the 5.8 GHz band is allocated with a bandwidth of 80 MHz and 20 MHz respectively.



802.11p WAVE frequency spectrum

C. *Distribution Service*

The WAVE standard also allows implementation of the distribution service. It involves setting the “To DS” and “From DS” fields in the MAC Frame to be set to 1.

Such communication would be blocked with the Wildcard BSSID is both the “To DS” and “From DS” fields are set to 0. In any case, the stations in the WBSS would be only able to access DS if they are using a known BSSID in order to send data frames.

D. *IEEE 1609 Standard*

- The IEEE 1609 standard defines the services provided through the 802.11p standard.
- The 1609.3 standard covers the WAVE Connection setup and management.
- The 1609.2 standard defines the security of the WAVE standard.
- The 1609.4 standard defines the multi-channel operation which is important for the WAVE operation.
- The 1609.1 standard defines the resource management among various channels and over different datagram protocols which are possible to be implemented over the WAVE stack.

E. *Medium Access Control*

The 802.11p standard implements a Distributed Control Function (DCF) as Point Control Function (PCF) are not applicable for V2X communication.

The DCF follows a principle of Collision Sense Multiple Access – Collision Avoidance (CSMA-CA) where the channel is only accessed if the physical layer senses no ongoing activity

The medium is indicated busy if the received power level is higher than a particular threshold. It should be indicated busy even in absence of transmission if received power is higher than a higher threshold.

Import to consider here is the Inter Frame Spacing which indicates how long the medium should be idle before a new transmission begins. Important messages have a shorter IFS (SIFS) and periodic messages have a distributed IFS (DIFS). Whenever the station senses that the medium is busy, the station selects a random number of back off slots, which decrement after the medium is sensed idle. The countdown stops whenever the medium is busy. As the slot count reduces to zero, the frame is transmitted.

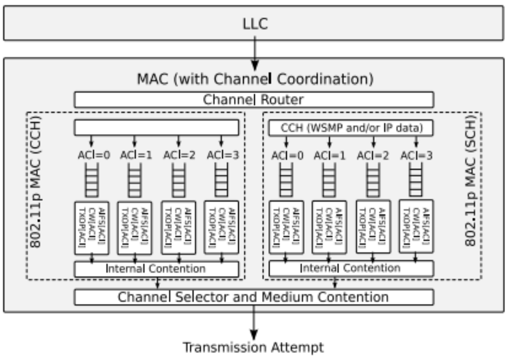
F. *Enhanced Distributed Channel Access*

To prioritize the important safety and time critical messages over regular periodic service messages, 802.11p standard implements the Enhanced Distributed Channel Access (EDCA). This helps create a Quality of Service support with 4 defined Access Categories.

Each frame is assigned one category depending on the application generating the message, the importance and the urgency of the message. The Arbitration Inter Frame Space Number (AIFSN) replaces the DIFS.

Frames with Access Category Index (ACI) 3 have a smaller AIFSN and thus lower barrier to access the medium than the frames with ACI 0, 1 & 2.

ACI 2 and 3 are reserved for critical safety messages. ACI 0 is for regular access and ACI 1 is foreseen for non-prior background messages.



EDCA

VIII. Architectures of Wireless Vehicular Networks

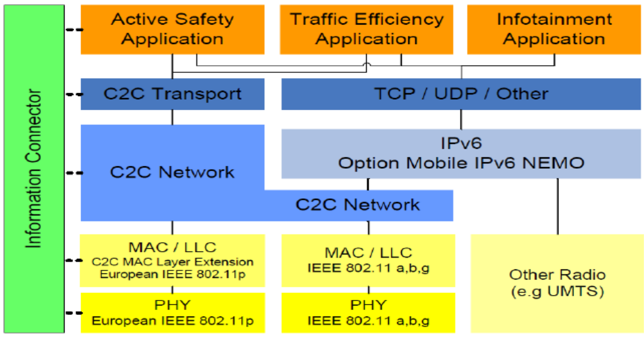
The WAVE Architecture implements the WAVE standard. The WAVE Architecture is a culmination of a few legacy V2V and V2X architectures like C2C, COMeSafety and CALM Architectures.

A. *C2C*

C2C stands for Car to Car Communication developed in Europe.

The top layer is the application layer. The safety and critical applications are implemented over the C2C Transport and Networking Layer with the MAC/LLC and PHY Layer implemented over 802.11p and 802.11a/b/g respectively.

Safety applications are implemented over 802.11p, Traffic Efficiency Applications over 802.11 a/b/g and infotainment services over IPv6 etc.

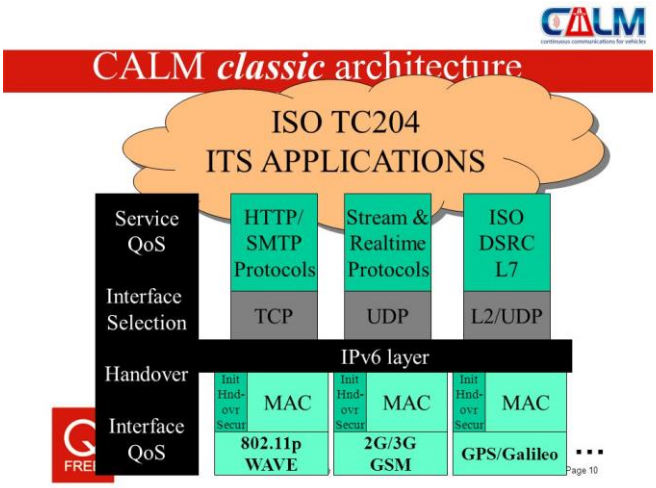


C2C Architecture

B. *CALM Architecture*

CALM stands for Communication Access for Long and Medium Range.

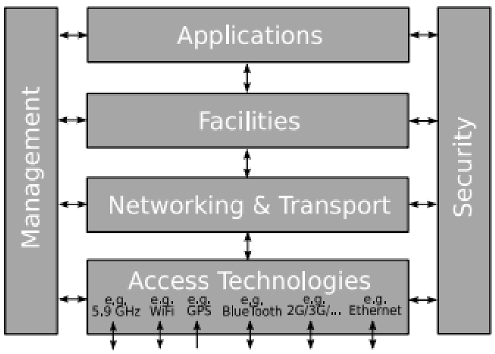
CALM consists of a distributed PHY and MAC Layer of 802.11 amendments, 3G, Bluetooth etc. with a common networking layer of IPv6 which conveys the message to the application layer through different transport layers like TCP, UDP etc.



CALM

C. *COMeSafety Architecture*

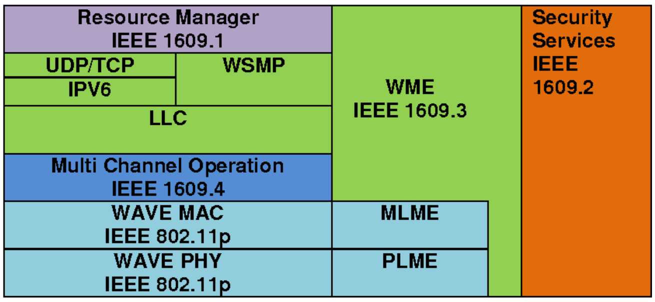
COMeSafety Architecture is an extension of the CALM Architecture with an additional layer for enhancing security of the network.



COMeSafety Architectures

D. WAVE Architecture

The WAVE Architecture takes over from the C2C, CALM and COMeSafety Architecture with a separate channels for critical safety and important messages and other service channels for infotainments and traffic efficiency messages.



WAVE

IX. Comparative Study of CV2X and WAVE

Qualcomm, a vendor of the Car- Vehicle to Everything (CV2X) technology has published empirical evidence that CV2X is better than WAVE as the next generation of V2X communication as the world moves towards 5G.

The study shows that CV2X has better range, data rates, power saving capabilities over WAVE while also being cost effective and SIM less operation.

The study also shows that CV2X is capable of non-network assisted operation even at high vehicular speeds while building up on the existing COMeSafety ITS and WAVE architectures.

X. Application of V2V and V2X Communication

The V2V and V2X Communication infrastructure can be used for various applications like collision warning, hazardous location warning, speed management, alternative route suggestion, advertisement of local services etc.

XI. Conclusion

The document is written as the part of the Networked Embedded Systems course at the Telecommunications Network Department at TU Berlin.

The document is the summary of the lecture on Vehicular Networks and reflects learnings from the lecture. The document is also inclusive of the post lecture discussion between the lecturer and the students, however as there could not be a post lecture discussion due to restriction of time, the document does not include the discussion between the lecturer and the students.

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