IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments

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ABSTRACT

Vehicular environments impose a set of new requirements on today's wireless communication systems. Vehicular safety communications applications cannot tolerate long connection establishment delays before being enabled to communicate with other vehicles encountered on the road. Similarly, non-safety applications also demand efficient connection setup with roadside stations providing services (e.g. digital map update) because of the limited time it takes for a car to drive through the coverage area. Additionally, the rapidly moving vehicles and complex roadway environment present challenges at the PHY level.

The IEEE 802.11 standard body is currently working on a new amendment, IEEE 802.11p, to address these concerns. This document is named Wireless Access in Vehicular Environment, also known as WAVE. As of writing, the draft document for IEEE 802.11p is making progress and moving closer towards acceptance by the general IEEE 802.11 working group. It is projected to pass letter ballot in the first half of 2008.

This paper provides an overview of the latest draft proposed for IEEE 802.11p. It is intended to provide an insight into the reasoning and approaches behind the document.

Keywords

IEEE 802.11, DSRC, WAVE

1. INTRODUCTION

The IEEE 802.11p WAVE standardization process originates from the allocation of the Dedicated Short Range Communications (DSRC) spectrum band in the United States and the effort to define the technology for usage in the DSRC band.

This section first provides a brief overview of the DSRC spectrum. The context and history of WAVE standardization is then described.

1.1 DSRC Spectrum Allocation

In 1999, the U.S. Federal Communication Commission allocated 75MHz of Dedicated Short Range Communications (DSRC) spectrum at 5.9 GHz to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle communications.

The primary goal is to enable public safety applications that can save lives and improve traffic flow. Two such application scenarios are shown in Figure 1. Private services are also permitted in order to spread the deployment costs and to encourage the quick development and adoption of DSRC technologies and applications.

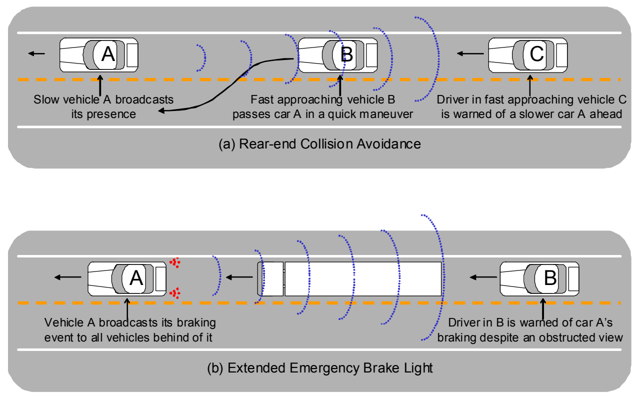

Figure 1, Vehicle safety communication examples

As shown in Figure 2, the DSRC spectrum is structured into seven 10 MHz wide channels. Channel 178 is the control channel (CCH), which is restricted to safety communications only [1]. The two channels at the ends of the spectrum band are reserved for special uses [2]. The rest are service channels (SCH) available for both safety and non-safety usage.

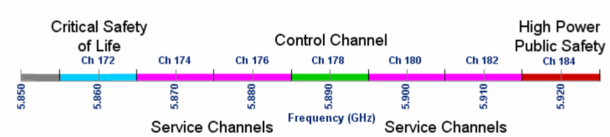

Figure 2, DSRC spectrum band and channels in the U.S.

The DSRC band is a free but licensed spectrum. It is free because the FCC does not charge a fee for the spectrum usage. Yet it should not be confused with the unlicensed bands in 900 MHz, 2.4 GHz and 5 GHz that are also free in usage. These unlicensed bands, which are increasingly populated with WiFi, Bluetooth and other devices, place no restrictions on the technologies other than some emission and co-existence rules. The DSRC band, on the other hand, is more restricted in terms of the usages and technologies. FCC rulings regulate usage within certain channels and limit all radios to be compliant to a standard. In other words, one cannot develop a different radio technology (e.g. that uses all 75 MHz of spectrum) for usage in the DSRC band even if it is limited in transmission power as related to the unlicensed band. These DSRC usage rules are referred as "license by rule".

Similar efforts are occurring in other parts of the world to set spectrum aside for vehicular usage. Europe, for example, is getting close to allocating 30 MHz of spectrum band in the 5 GHz range for the express purpose of supporting vehicular communications for safety and mobility applications.

1.2 WAVE Standardization History

In the U.S., the initial effort at standardizing DSRC radio technology took place in the ASTM 2313 working group [5]. In particular, the FCC rule and order specifically referenced this document for DSRC spectrum usage rules.

In 2004, this effort migrated to the IEEE 802.11 standard group as DSRC radio technology is essentially IEEE 802.11a adjusted for low overhead operations in the DSRC spectrum. Within IEEE 802.11, DSRC is known as IEEE 802.11p WAVE, which stands for Wireless Access in Vehicular Environments [4]. IEEE 802.11p is not a standalone standard. It is intended to amend the overall IEEE 802.11 standard [3].

One particular implication of moving the DSRC radio technology standard into the IEEE 802.11 space is that now WAVE is fully intended to serve as an international standard applicable in other parts of the world as well as in the U.S.

The IEEE 802.11p standard is meant to:

- Describe the functions and services required by WAVE-conformant stations to operate in a rapidly varying environment and exchange messages without having to join a Basic Service Set (BSS), as in the traditional IEEE 802.11 use case.
- Define the WAVE signaling technique and interface functions that are controlled by the IEEE 802.11 MAC.

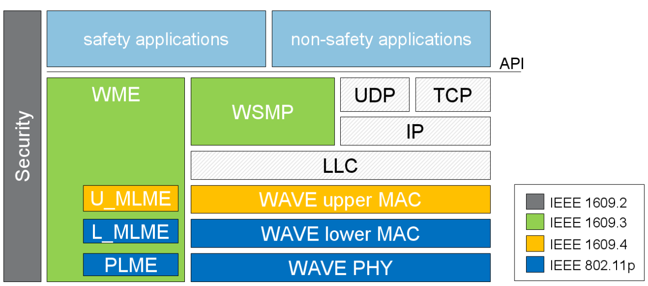

Figure 3, DSRC standards and communication stack

As shown in Figure 3, IEEE 802.11p WAVE is only a part of a group of standards related to all layers of protocols for DSRC-based operations. The IEEE 802.11p standard is limited by the scope of IEEE 802.11, which is strictly a MAC and PHY level standard that is meant to work within a single logical channel. All knowledge and complexities related to the DSRC channel plan and operational concept are taken care of by the upper layer IEEE 1609 standards. In particular, the IEEE 1609.3 standard covers the WAVE connection setup and management [6]. The IEEE 1609.4 standard sits right on top of the IEEE 802.11p and enables operation of upper layers across multiple channels, without requiring knowledge of PHY parameters [7].

At the time of writing, the IEEE 802.11p draft version 3.0 had already gone through its third letter ballot in the IEEE 802.11 working group. It failed to reach the critical approval rate of 75% by just 2 votes. The task group is currently resolving the comments received through the letter ballot and updating the draft standard document accordingly. This paper provides an overview of the general direction and technical approach in this draft standard but its content should not be viewed as binding or final.

2. MAC AMENDMENT DETAILS

In an overly simplified manner, the IEEE 802.11 MAC is about how to arrange for a set of radios in order to establish and maintain a cooperating group. Radios can freely communicate among themselves within the group but all transmissions from outside are filtered out. Such a group is a Basic Service Set (BSS) and there are many protocol mechanisms designed to provide secure and robust communications within a BSS.

The key purpose of the IEEE 802.11p amendment at the MAC level is to enable very efficient communication group setup without much of the overhead typically needed in the current IEEE 802.11 MAC. In other words, the focus is on simplifying the BSS operations in a truly ad hoc manner for vehicular usage.

In this section, we first provide an overview of the core mechanism in setting up the IEEE 802.11 connectivity. Then the approach introduced by the IEEE 802.11p amendment is described.

2.1 IEEE 802.11 Operations Overview

2.1.1 Basic Service Set

An Infrastructural Basic Service Set is a group of IEEE 802.11 stations anchored by an Access Point (AP) and configured to communicate with each other over the air-link. It is usually just referred to as a BSS. The BSS mechanism controls access to an AP's resources and services, and also allows for a radio to filter out the transmissions from other unrelated radios nearby. A radio first listens for beacons from an AP and then joins the BSS through a number of interactive steps, including authentication and association.

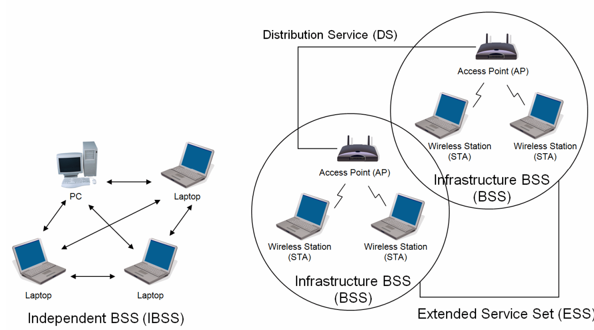

Figure 4, Independent and extended service set concepts

As shown in Figure 4, the IEEE 802.11 standard further allows administrators to logically combine a set of one or more interconnected BSSs into one ESS (Extended Service Set) using DS (Distribution Service). An ESS appears as a single BSS to the LLC (Logical Link Control) layer at any station associated with one of those BSSs.

The ad-hoc operating mode defined for IEEE 802.11 also follows the similar interactive establishment process of a Infrastructure BSS and is called IBSS (Independent BSS). While the name is "ad hoc", IBSS still carries too much complexity and overhead to be suitable for vehicular communications in the DSRC use cases.

A BSS is known to the users through the Service Set Identification (SSID). This corresponds to the names of WiFi hotspots that people can observe and connect to at home or public locations. The SSID information field is between 0 and 32 Bytes.

2.1.2 BSSID and received frame filtering

The SSID should not be confused with the BSSID, which stands for Basic Service Set Identification. In contrast to SSID, BSSID is the name of a BSS known to the radios at the MAC level and is a 48-bit long field just like a MAC address. Each BSS must have a unique BSSID shared by all members. This is ensured simply by using the MAC address of the AP.

For an IBSS, a locally administered IEEE MAC address is used. This is formed by using a random 46-bit number with the individual/group bit set to 0 and the universal/local bit set to 1.

BSSID filtering is the key mechanism to restrict, at the MAC level, all incoming frames to only those received from radios that are members in the same BSS.

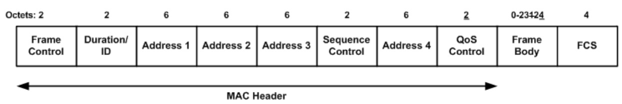

Figure 5, IEEE 802.11 data frame format

As shown in Figure 5, each IEEE 802.11 data frame includes up to 4 address fields. These address fields are used to carry source address (SA), destination address (DA), transmitting STA address (TA), receiving STA address (RA) and BSSID. The use of the four address fields differ according to the "To DS" (Distribution Service) and "From DS" bits in the frame control field, and is illustrated in Figure 6.

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

The MAC level of a station, upon receiving a frame from the PHY, uses the contents of the Address 1 field to perform address matching for receiving decisions. If the Address 1 field contains a group address (e.g., a broadcast address), the BSSID is compared to ensure that the broadcast or multicast originated from a station in the same BSS.

A special case of the BSSID is the wildcard BSSID, which is composed of all "1s". The current IEEE 802.11 standard limits the usage of the wildcard BSSID to only management frames of subtype probe request.

2.2 WAVE Approaches

2.2.1 WAVE mode

IEEE 802.11 MAC operations, as described above, are too time-consuming to be adopted in IEEE 802.11p. Vehicular safety communications use cases demand instantaneous data exchange capabilities and cannot afford scanning channels for the beacon of a BSS and subsequently executing multiple handshakes to establish the communications.

Think, for instance, of a scenario where a vehicle encounters another vehicle on the road coming from the opposite direction: depending on the vehicles dynamics, the time available for the communications may be extremely short.

Therefore, it is essential for all IEEE 802.11p radios to be, by default, in the same channel and configured with the same BSSID to enable safety communications.

A key amendment introduced by the IEEE 802.11p WAVE is the term "WAVE mode". A station in WAVE mode is allowed to transmit and receive data frames with the wildcard BSSID value and without the need to belong to a BSS of any kind a priori. This means, two vehicles can immediately communicate with each other upon encounter without any additional overhead as long as they operate in the same channel using the wildcard BSSID.

2.2.2 WAVE BSS

Even for non-safety communications and services, the overhead of traditional BSS setup may be too expensive. A vehicle approaching a road side station that offers, say digital map download service, can hardly afford the many seconds that are typically needed in a conventional WiFi connection setup because the total time this vehicle would be in the coverage is very short.

The WAVE standard introduces a new BSS type: WBSS (WAVE BSS). A station forms a WBSS by first transmitting a on demand beacon. A WAVE station uses the demand beacon, which uses the well known beacon frame and needs not to be periodically repeated, to advertise a WAVE BSS. Such an advertisement is created and consumed by upper layer mechanisms above the IEEE 802.11. It contains all the needed information for receiver stations to understand the services offered in the WBSS in order to decide whether to join, as well as the information needed to configure itself into a member of the WBSS. In other words, a station can decide to join and complete the joining process of a WBSS by only receiving a WAVE advertisement with no further interactions.

This approach offers extremely low overhead for WBSS setup by discarding all association and authentication processes. It necessitates further mechanisms at upper layers to manage the WBSS group usage as well as providing security. These mechanisms, however, are out of the scope of the IEEE 802.11.

2.2.3 Expanding wildcard BSSID usage

Given the focus of safety as the key usage of WAVE, the use of wildcard BSSID is also supported even for a station already belonging to a WBSS (i.e., configured with a particular BSSID). In other words, a station in WBSS is still in WAVE mode and can still transmit frames with the wildcard BSSID in order to reach all neighboring stations in cases of safety concerns. Similarly, a station already in a WBSS and having configured its BSSID filter accordingly, can still receive frames from others outside the WBSS with the wildcard BSSID.

The ability to send and receive data frames with wildcard BSSID benefits not only safety communications. It is also able to support signaling of future upper layer protocols in this ad hoc environment.

2.2.4 Distribution Service

The DS is still available to WAVE devices. Over the air, this simply means that it is possible for data frames to be transmitted with "To DS" and "From DS" bits set to 1. However, the ability for a radio in a WAVE BSS to send and receive data frames with the wildcard BSSID introduces complications. It is likely that a radio will be restricted to send a data frame with the wildcard BSSID only if the “To DS” and “From DS” bits are set to 0. In other words, radios that are communicating within the context of a WAVE BSS need to send data frames using a known BSSID in order to access DS.

2.2.5 MAC amendment summary

Here is a quick summary of the changes at MAC for WAVE operations:

- A station in WAVE mode can send and receive data frames with the wildcard BSSID with “To DS” and “From DS” fields both set to 0, regardless of whether it is a member of a WAVE BSS.
- A WAVE BSS (WBSS) is a type of BSS consisting of a set of cooperating stations in WAVE mode that communicate using a common BSSID. A WBSS is initialized when a radio in WAVE mode sends a WAVE beacon, which includes all necessary information for a receiver to join.
- A radio joins a WBSS when it is configured to send and receive data frames with the BSSID defined for that WBSS. Conversely, it ceases to belong to a WBSS when its MAC stops sending and receiving frames that use the BSSID of that WBSS.
- A station shall not be a member of more than one WBSS at one time. A station in WAVE mode shall not join an infrastructure BSS or IBSS, and it shall not use active or passive scanning, and lastly it shall not use MAC authentication or association procedures.
- A WBSS ceases to exist when it has no members. The initiating radio is no different from any other member after the establishment of a WBSS. Therefore, a WBSS can continue if the initiating radio ceases to be a member.

3. PHY AMENDMENT DETAILS

At PHY level, the philosophy of IEEE 802.11p design is to make the minimum necessary changes to IEEE 802.11 PHY so that WAVE devices can communicate effectively among fast moving vehicles in the roadway environment. This approach is feasible because IEEE 802.11a radios already operate at 5 GHz and it is not difficult to configure the radios to operate in the 5.9 GHz band in the U.S. and similar bands internationally. It is also desirable and sensible because of the technical challenges involved in radically amending a wireless PHY design. While MAC level amendments are fundamentally software updates that are relatively easy to make, PHY level amendment necessarily should be limited in order to avoid designing an entirely new wireless air-link technology. Accordingly, three changes are made and are described in the following subsections.

3.1.1 10 MHz channel

IEEE 802.11p is essentially based on the OFDM PHY defined for IEEE 802.11a, with a 10 MHz wide channel instead of the 20 MHz one usually used by 802.11a devices.

IEEE 802.11 already defines 10 MHz wide channels, and it is straightforward in implementation since it mainly involves doubling of all OFDM timing parameters used in the regular 20 MHz 802.11a transmissions.

The key reason for this scaling of 802.11a is to address the increased RMS delay spread in the vehicular environments. A recent study by CMU and General Motors [8] shows that

- Guard interval at 20 MHz is not long enough to offset the worst case RMS delay spread (i.e. the guard interval is not long enough to prevent inter-symbol interferences within one radio’s own transmissions in the vehicular environments).
- If choice is simply between scaled versions of 802.11a, then 10 MHz is a reasonable choice.

3.1.2 Improved receiver performance requirements

While there are a number of channels available in the US and (expectedly) internationally for IEEE 802.11p deployment and usage, the nature of closely distributed vehicles on the road creates increased concern for cross channel interferences. The measurements presented in [9] demonstrated the potential for immediate neighboring vehicles (i.e., next to each other in adjacent lanes) to interfere each other if they are operating in two adjacent channels. For example, a vehicle A transmitting in channel 176 (see Figure 2) could interfere and prevent a vehicle B in the next lane (i.e. 2.5 m apart) from receiving safety messages sent by vehicle C that is 200 m away in channel 178.

Cross channel interference is a well known and natural physical property of wireless communications. The most effective and proper solution to such concerns is through channel management policies that is completely outside of the scope at IEEE 802.11. Nevertheless, IEEE 802.11p introduces some improved receiver performance requirements in adjacent channel rejections. There are two categories of requirements listed in the proposed standard. Category 1 is mandatory and generally understood to be reachable with today’s chip manufacturers. Category 2 is more stringent and optional. It is likely to be more expensive to realize in the next few years.

3.1.3 Improved transmission mask

Specific to the usage of IEEE 802.11p radios in the U.S. ITS band (i.e., the 5.9 GHz DSRC spectrum), four spectrum masks are defined that are meant for class A to D operations. These constraints are issued in FCC CFR47 Section 90.377 and Section 95.1509.

- For Class A operation using 10 MHz channel spacing, the transmitted spectrum shall have a 0 dBr bandwidth not exceeding 9 MHz, and shall not exceed -10 dBr at 5 MHz frequency offset, -20 dBr at 5.5 MHz frequency offset, -28 dBr at 10 MHz frequency offset, -40 dBr at 15 MHz frequency offset and above.
- For Class B operation using 10 MHz channel spacing, the transmitted spectrum shall have a 0 dBr bandwidth not exceeding 9 MHz, and shall not exceed -16 dBr at 5 MHz frequency offset, -20 dBr at 5.5 MHz frequency offset, -28 dBr at 10 MHz frequency offset, -40 dBr at 15 MHz frequency offset and above.
- For Class C operation using 10 MHz channel spacing, the transmitted spectrum shall have a 0 dBr bandwidth not exceeding 9 MHz, and shall not exceed -26 dBr at 5 MHz frequency offset, -32 dBr at 5.5 MHz frequency offset, -40 dBr at 10 MHz frequency offset, -50 dBr at 15 MHz frequency offset and above.

- For Class D operation using 10 MHz channel spacing, the transmitted spectrum shall have a 0 dBr bandwidth not exceeding 9 MHz, and shall not exceed -35 dBr at 5 MHz frequency offset, -45 dBr at 5.5 MHz frequency offset, -55 dBr at 10 MHz frequency offset, -65 dBr at 15 MHz frequency offset and above.

Generally speaking, these spectrum masks are more stringent than the ones demanded of the current IEEE 802.11 radios. There are debates regarding whether and when chip makers would be able to meet such requirements.

4. SUMMARY

Wireless access in vehicular environment imposes a set of new requirements on the communications system that led to the introduction of the WAVE operating mode and of the WAVE BSS in IEEE 802.11p.

When operating in WAVE mode, stations do not need to join a BSS as they can exchange data using a wildcard BSSID that is available at all times. This dramatically reduces the connection setup overhead and suits vehicular safety applications well.

Private services offered over the DSRC spectrum service channels benefit from a reduced connection setup overhead through mechanisms defined for a WAVE BSS. Joining a WAVE BSS only requires receiving a single WAVE Advertisement message from the initiating station. A station in a WAVE BSS is further enabled to still send and receive data frames with the wildcard BSSID.

While the IEEE 802.11p standardization process is moving closer to pass a letter ballot in the general IEEE 802.11 working group, there are also industry efforts in implementing and field testing such radios. Prototype IEEE 802.11p radios have been developed by the Vehicle Infrastructure Integration Consortium (VII-C) in 2007 both for on-board and roadside units. Likewise, interoperable radios are being built by the Crash Avoidance Metric Partnership (CAMP) for collision avoidance and vehicle-to-vehicle safety applications.

It should be noted that while IEEE 802.11p describes how the communications take place over each individual channel of the DSRC spectrum, a complete communications system for WAVE needs to include support for multi-channel operations, security, and other upper layer operations. These are addressed by the IEEE 1609 trial-use standards, which are expected to be substantially updated in the near future.

5. REFERENCES

[1] "FCC Report and Order 03-324: Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band," December 17, 2003.

[2] "FCC Report and Order 06-110: Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band," July 20, 2006.

[3] "IEEE Std. 802.11-2007, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications," IEEE Std. 802.11, 2007.

[4] "IEEE P802.11p/D3.0, Draft Amendment for Wireless Access in Vehicular Environments (WAVE)," July 2007.

[5] "Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems - 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications", ASTM DSRC STD E2313-02, 2002

[6] "IEEE 1609.3-2007 WAVE Networking Services", 2007

[7] "IEEE 1609.4-2007 WAVE Multi-Channel Operation", 2007

[8] D. Stancil, L. Cheng, B. Henty and F. Bai, "Performance of 802.11p Waveforms over the Vehicle-to-Vehicle Channel at 5.9 GHz ", IEEE 802.11 Task Group p report, September 2007

[9] V. Rai, F. Bai, J. Kenney and K. Laberteaux, "Cross-Channel Interference Test Results: A report from the VSC-A project", IEEE 802.11 Task Group p report, July 2007