Implementation of Analyzing MAC header of WSM using WAVE module and USRP-RIO with LabVIEW Communications

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***Abstract*—In this demonstration, we present the implementation of IEEE 802.11p receiver which consists of host and FPGA and the WSM(WAVE Short Message) types supported by WAVE module. We used the 802.11 Application Framework and FPGA-base USRP-RIO by using LabVIEW Communications and ARADA LOCOMATE as WAVE module. The 802.11 Application Framework is comprised of modular physical layer(PHY) and medium access control(MAC) blocks. ARADA LOCOMATE provides wireless connectivity in automobile environment with high rate and low latency communication between vehicle and road-side unit. It helps provide safety and data services to the vehicle users. Furthermore, in order to verify the system performance for the wireless channel environment and analyze MAC header of WSM in Wireless Access in Vehicular Environment, we added the wireless channel models in [1] and represent value in each frame of the received message to classify different kinds of WSMs and analyze MAC header sent by WAVE module.**

***Index Terms*—802.11p, WAVE, WSM**

I. Introduction

The U.S Federal Communication Commission(FCC) allocated 75 MHz spectrum from 5.850 GHz to 5.925 GHz for V2V and V2I communications. The transmission rates can be provided as ranging from 3 Mbps to 27 Mbps with 10 MHz bandwidth and the coverage can be supported up to 1km under a variety of environments, such as urban, rural, and freeway with relative vehicle velocities of up to 30 m/s. IEEE 802.11p/Wireless Access in Vehicular Environments(WAVE) was developed to support C-ITS based on V2V and V2I communications[3]. The IEEE 802.11p is considered as the de facto standard to implement several of the vehicular networking applications. The standard includes Physical(PHY) and Medium Access Control(MAC) layer specification as well as upper-layer protocols.

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IEEE 802.11p is essentially an IEEE 802.11-based standard adapted for the wireless environment with vehicles. It inherits several of the characteristics like simplicity and distributed medium access control mechanism. Mostly, in-vehicle on-board units(OBUs) and roadside units(RSUs) fixed with transport infrastructure like traffic signals utilize this standard.

Fig. 1. NI USRP 2943R & ARADA LOCOMATE & LabVIEW Communications with the 802.11 Application Framework.

In this demonstration, we implement 802.11p receiver utilizing NI-USRP-RIO with LabVIEW Communications and transmitter using WAVE module(ARADA LOCOMATE) which can support WAVE standard(802.11p, 1609.2/3/4, SAE J2735). The 802.11 Application Framework in LabVIEW Communications can support indoor wireless LAN Systems (a/b/g/n/ac). But the 802.11 Application Framework can't be directly applied to IEEE 802.11p. We modified the following 4 factors of the 802.11 Application Framework in order to receive WSM messages sent by WAVE module in 802.11p.

1. Shift the operating carrier frequency to around 5.9 GHz.

2. Extend symbol spacing from 4us to 8us.

3. Reduce Tx/Rx sample rate

4. Turn off the MPDU filter in order to receive the message based on 802.11p/1609.x

The following is the rationale behind this modification: first, using a dedicated part of the spectrum reduces interference with legacy systems, second, doubling the symbol duration also means doubling the cyclic-prefix-duration, i.e. decreasing the OFDM inter-symbol-interference(ISI) in

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outdoor channel.

II. System Description

In 802.11p environment, we utilize NI USRP-RIO with Lab VIEW Communications and ARADA LOCOMATE to check MAC header of different WAVE messages based on SAE J2 735.

A. USRP-2943R[8]

Built on the NI LabVIEW reconfigurable I/O (RIO) architecture, FPGA-based USRP-RIO delivers an integrated hardware and software solution for rapidly prototyping high performance and high-channel-count in wireless communication systems[8].

B. 802.11 Application Framework[10]

In LabVIEW Communications, we used the 802.11 Application Framework which can provide a real-time OFDM PHY and lower MAC implementation aligned with the IEEE 802.11 standard. It is available as open and modifiable source code that is ready to run on NI software defined radio hardware. The framework complies with a selected subset of the IEEE 802.11 standard. The supported features are chosen so that the code is simple enough to be modifiable while adhering to the main structure of the 802.11 standard.

The 802.11 Application Framework allows us to get real-time prototyping setup running more quickly, focus on the selected aspects of the protocol that we want to improve, easily modify the designs.

C. ARADA LOCOMATE[11]

LOCOMATE provides wireless connectivity in automobile environment with high rate and low latency communication between vehicles or between vehicle and road-side unit. It can transmit and receive the packets at 5.7 GHz to 5.925 GHz with 10 MHz and 20 MHz channel bandwidth. In the software, it can support for WAVE standard(802.11p/1609.x/SAE J2735), multi-channel synchronization between service users, exclusive packet control, WAVE data and management frame, etc.

III. Demonstration

A. Receiver Part

FPGA performs all baseband computations for signal reception and decoding, such as packet detection and synchronization, OFDM demodulation, channel estimation and equalization, and decoding. The decoded data is transferred to the host. The host optionally writes the received data to a UDP socket. Furthermore, the FPGA communicates additional data to the host such as received I/Q samples and demodulated I/Q constellations of detected packets. This additional data can be used for debug logging and for displaying spectrum or received constellation.

We implement IEEE 802.11p real-time receiver using FPGA-based USRP-RIO with LabVIEW Communications. USRP-RIO has Tx/Rx and some problem. If Tx normally implements function in 802.11 Application Framework, Rx is affected by a little leakage from Tx since USRP-RIO Tx part is not isolated with Rx completely. So, we make Tx part of USRP-RIO disabled through LabView Communications in order to check Rx Power Spectrum and Rx Constellation rigorously and use ARADA LOCOMATE as Tx.

Furthermore, in order to verify the reception of messages sent by WAVE module in IEEE 802.11p, we changed 802.11a mode to 802.11p mode by modifying 2 things of physical layer. 802.11 Application Framework support Wireless LAN subcarrier format of 802.11a(20MHz) and 802.11ac(20MHz, 40MHz). In order to set up 802.11p(10MHz) environment, we modified FPGA codes of USRP-RIO Hardware in Fig. 2.

From Table I, we can see that there are 2 values to compare Channel Spacing value in 10MHz with 20MHz in IEEE 802.11. So, we changed OFDM symbol duration[s] value to 8u from 4u at USRP RIO.gvi in LabVIEW Communications to support 10MHz Bandwidth by decreasing OFDM Inter-Symbol-Interference(ISI). Also, we cut sample rate of IQ data in 802.11 Tx/Rx chain down to 40MHz from 80MHz.

802.11 Application Framework has some limit to receive messages based on 802.11p/1609.x from ARADA module since 802.11 Application Framework is the framework supporting only IEEE 802.11a and 802.11ac.

Table I. Duration of the OFDM symbol in 802.11 standard

Parameter	Value (20 MHz channel spacing)	Value (10 MHz channel spacing)
T_{SIGNAL}:Duration of the SIGNAL BPSK-OFDM symbol	4.0 μs(T_{GI}+ T_{FFT})	8.0 μs(T_{GI}+ T_{FFT})

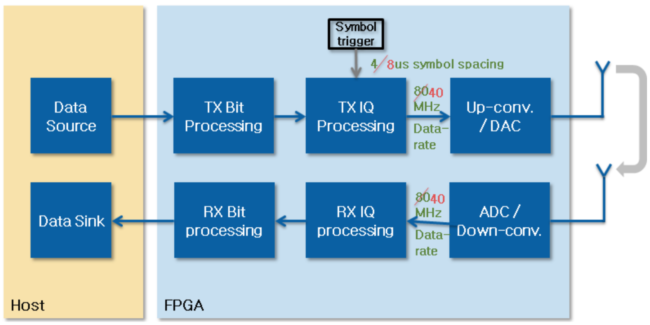

Fig. 2. Block diagram of Data processing

There are several functions about the received MPDUs into MPDU Filter module of MAC layer such as MAC header block and Unsupported frame block, etc. we should turn off the block functions so that the receiver can get MPDUs supported 802.11p/1609.x.

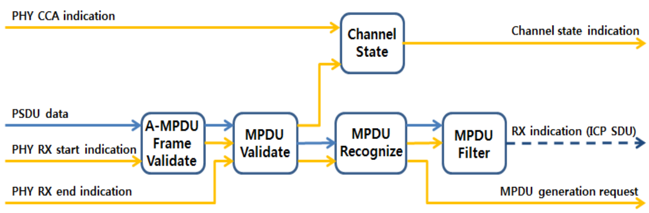

Fig. 3. MAC RX Block Diagram

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B. Transmitter Part

There are 4 type messages including WSM data sent by LOCOMATE DSRC OBU like Basic Safety Message(BSM), Intersection Collision Alert(ICA), Probe Vehicle Data(PVD), Road Side Alert(RSA). The followings are WSM types supported by ARADA LOCOMATE.

- BSM(Basic Safety Message) : It includes safety service data according to vehicle state and used by various applications. It is always sent in the manner of Broadcast communication.
- PVD(Probe Vehicle Data) : It is used to communicate with DSRC OBUs in different vehicles in order to trade the information of vehicle state and collect vehicle's movement information.
- ICA(Intersection Collision Alert) : It is utilized to construct the vehicle collision detection system at intersection and distinguish the point of intersection, the last path and acceleration of vehicle.
- RSA(Road Side Alert) : It includes information of the surrounding dangerous elements in order to alert to driver. It is sent by using WSM format and XML(eXtensible Markup Language) format.

Fig. 4 shows WSM data and each headers. After MAC header, there are LLC header, SNAP header and WSM field in the order named. WSM is divided by WSMP header and WSM data field. In this demonstration, we received the real-data of fields in LLC header and identified that these fields value are correct with each of the fields in LLC header which is represented in IEEE 1609.3 standard.

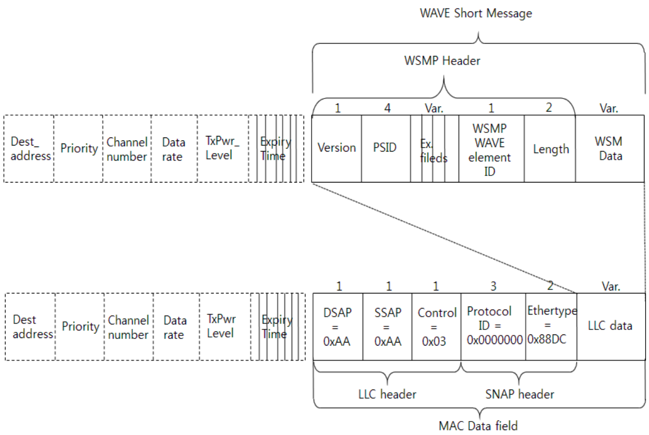

Fig. 4. Building the WSM package

BSM(Basic Safety Message) Format is divided by two such as Part1, Part 2 which are shown in Fig. 5[7]. The Part 1 is always included in BSM and the Part 2 might apply to the needed case according to the policy.

The ARADA LOCOMATE DSRC OBU sends some messages after setting up message type, service channel, Tx/Rx option and data rate. Each of message types is distinguished by DSRCmsgID value defined in SAE J2735 and Fig. 5 explains each of the fields in BSM.

After setting up laptop computer, ARADA LOCOMATE and USRP-RIO like Fig. 1, The WAVE module sends each WSM using broadcast communication and then we can check the received messages and each of message's MAC header field. The WSM means QoS data and the Frame Control field is divided by 2 bytes. The first byte of the Frame Control field in MAC header is defined to 10001000 which is binary value as QoS data in IEEE 802.11 standard. We can check it in Fig. 7. All of WSMs such as BSM, PVD, ICA, RSA have 10001-000 in the Frame Control field as QoS data. Since all of WS-Ms are sent in broadcast way, they all have 255 as decimal, that is, 11111111 as binary number in Address field of MAC header.

```
ASN.1 Representation:
BasicSafetyMessage ::= SEQUENCE {
   -- Part I
   msgID        DSRCmsgID,                  -- 1 byte

   -- Sent as a single octet blob
   blob1        BSMblob,

   --
   -- The blob consists of the following 38 packed bytes:
   --
   -- msgCnt       MsgCount,                -x- 1 byte
   -- id           TemporaryID,             -x- 4 bytes
   -- secMark      DSecond,                 -x- 2 bytes

   -- pos       PositionLocal3D,
     -- lat        Latitude,                -x- 4 bytes
     -- long       Longitude,               -x- 4 bytes
     -- elev       Elevation,               -x- 2 bytes
     -- accuracy   PositionalAccuracy,      -x- 4 bytes

   -- motion    Motion,
     -- speed      TransmissionAndSpeed,    -x- 2 bytes
     -- heading    Heading,                 -x- 2 byte
     -- angle      SteeringWheelAngle       -x- 1 bytes
     -- accelSet   AccelerationSet4Way,     -x- 7 bytes

   -- control   Control,
   -- brakes       BrakeSystemStatus,       -x- 2 bytes

   -- basic     VehicleBasic,
   -- size         VehicleSize,             -x- 3 bytes

   -- Part II, sent as required
   -- Part II,
   safetyExt      VehicleSafetyExtension OPTIONAL,
   status         VehicleStatus          OPTIONAL,

   ... -- # LOCAL_CONTENT
   }
```

Fig. 5. Representation of BasicSafetyMessage(BSM)

```
ASN.1 Representation:
  DSRCmsgID2 ::= INTEGER (0..255)
   -- DER forms
   reservedMessageId-D             DSRCmsgID2 ::=  0 --'00'H
   alaCarteMessage-D               DSRCmsgID2 ::=  1 --'01'H ACM
   -- alaCarteMessage-D is Retired, not to be used
   basicSafetyMessage-D            DSRCmsgID2 ::=  2 --'02'H BSM, heartbeat msg
   basicSafetyMessageVerbose-D     DSRCmsgID2 ::=  3 --'03'H For testing only
   commonSafetyRequest-D           DSRCmsgID2 ::=  4 --'04'H CSR
   emergencyVehicleAlert-D         DSRCmsgID2 ::=  5 --'05'H EVA
   intersectionCollisionAlert-D    DSRCmsgID2 ::=  6 --'06'H ICA
   mapData-D                       DSRCmsgID2 ::=  7 --'07'H MAP, intersections
   -- mapData-D is Retired, not to be used
   nmeaCorrections-D               DSRCmsgID2 ::=  8 --'08'H NMEA
   probeDataManagement-D           DSRCmsgID2 ::=  9 --'09'H PDM
   probeVehicleData-D              DSRCmsgID2 ::= 10 --'0A'H PVD
   roadSideAlert-D                 DSRCmsgID2 ::= 11 --'0B'H RSA
   rtcmCorrections-D               DSRCmsgID2 ::= 12 --'0C'H RTCM
   signalPhaseAndTimingMessage-D   DSRCmsgID2 ::= 13 --'0D'H SPAT
   -- signalPhaseAndTimingMessage-D is Retired, not to be used
   signalRequestMessage-D          DSRCmsgID2 ::= 14 --'0E'H SRM
   signalStatusMessage-D           DSRCmsgID2 ::= 15 --'0F'H SSM
   travelerInformation-D           DSRCmsgID2 ::= 16 --'10'H TIM
   uperFrame-D                     DSRCmsgID2 ::= 17 --'11'H UPER frame
   -- UPER forms
   mapData-P                       DSRCmsgID2 ::= 18 --'12'H MAP, intersections
   signalPhaseAndTimingMessage-P   DSRCmsgID2 ::= 19 --'13'H SPAT

   -- values to 127 reserved for std use
   -- values 128 to 255 reserved for local use
```

Fig. 6. DSRCmsgID of each message

We can identify this value from all of WSMs and distinguish each of messages from DSRCmsgID value in WSM data frame. DSRCmsgID values of each message are represented in Fig. 6[7].

In Fig. 7, we can check values in each of the fields like MAC header, LLC header, WAVE Short Message. We used array function of LabVIEW Communications in 802.11 framework application so that each of the field values in a frame can be displayed in sequence. And we converted decimal number to binary number in order to understand each fields as unit of bit.

Field value	Binary number	Field Name	Header Name
136	10001000	Frame Control	MAC Header
0	00000000		
0	00000000	Duration/ID	
0	00000000		
255	11111111	Address 1	
255	11111111		
255	11111111		
255	11111111		
255	11111111		
255	11111111		
0	00000000	Address 2	
5	00000101		
230	11100110		
59	00111011		
130	10000010		
18	00010010		
255	11111111	Address 3	
255	11111111		
255	11111111		
255	11111111		
255	11111111		
255	11111111		
32	00100000	Sequence Control	
209	11010001		
34	00100010	QoS Control	
0	00000000		
170	10101010	DSAP	LLC Header
170	10101010	SSAP	
3	00000011	Control	
:	:	:	:
2	00000010	DSRCmsgID field	BSM

Fig. 7. BSM message header

IV. Conclusion

In this paper, we implement IEEE 802.11p real-time receiver using FPGA-based USRP-RIO with LabVIEW Communications. Furthermore, in order to verify the system performance for the wireless access in vehicular environment, we sent WSM messages from WAVE module and analyzed MAC header of each WSM messages. In this paper, only WSM messages from WAVE module are considered. In order to analyze MAC header of various communication module like Wi-Fi, LTE, etc., it is required to study to scan automatically the frequency bandwidth and center frequency of the received message to represent what communication module was used in the future.

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