Updating the Basic Safety Message to communicate Vulnerable Road User (VRU) information using Bluetooth 5

A Tome Software White Paper from the 2019 Bicycle-to-Vehicle (B2V) Workshop

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Contents

Glossary

Automatic Driver Assistance System (ADAS) - Electronic systems that aid a vehicle driver intended to increase car safety and more generally road safety.

Basic Safety Message (BSM) - A BSM is used in a variety of applications to exchange safety data regarding vehicle state. Reference: SAE J2735

Coded PHY - Changes to the Bluetooth specification at the physical (“PHY”) layer to extend signal range.

Extended Advertisements - Changes to the Bluetooth specification that provide up to 255 bytes within advertisement packets.

Global Navigation Satellite System (GNSS) - A constellation of satellites providing signals from space that transmit positioning and timing data to receivers to determine a precise location.

Inertial Measurement Unit (IMU) - A device that measures the specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and magnetometers.

Personal Safety Message (PSM) - A PSM is used to broadcast safety data regarding the kinematic state of various types of vulnerable road users (VRUs), such as pedestrians, cyclists, or road workers. Reference: SAE J2945/9

Roadside Unit (RSU) - A device that provides connectivity support to passing vehicles.

Telematics Control Unit (TCU) - The embedded system onboard a powered vehicle that controls tracking of the vehicle.

Vulnerable Road User (VRU) - Non-automobile road users, such as pedestrians, road workers, and cyclists, as well as animal-drawn vehicles and persons with disabilities or reduced mobility and orientation.

B2V Background

In 2017, we began working on projects within a larger program at Tome related to bicycle-to-vehicle (B2V) safety. We have engaged with multiple entities in the cycling, automotive, governmental and smart city sectors to identify solutions for creating communication systems between vulnerable road users (VRUs) and vehicles.

Our B2V Advisory Board consists of representatives from Accell Group, Bosch, Dorel Sports, Ford, Giant, Orbea, Panasonic, QBP, Shimano, Specialized, SRAM, Stages Cycling, Subaru, Tome, and Trek.

The B2V mission is simple: Make roads safer for cyclists.

In 2019, we worked alongside Ford and the Crash Avoidance Metrics Partnership (CAMP) to create a demonstration that showed key use cases and a solution where B2V communication can provide automotive value. An e-scooter was also included in this demonstration.

This whitepaper describes our demonstration, which was publicly shown in August 2019 at the Bicycle-to-Vehicle Safety Workshop in Detroit, Michigan. The developed prototype provided methods and techniques (Technical Readiness Level 5) for sending a personal safety message (PSM) from one or more VRU devices to a vehicle using Bluetooth 5 with Coded PHY and Extended Advertisements. In addition to the technical documentation, this whitepaper includes known issues, future plans, and reference links.

For more information, or if your group is interested in contributing to open B2V standards, please contact our B2V team at b2v@tomesoftware.com. To access materials and resources from the workshop, please visit https://www.tomesoftware.com/2019-b2v-workshop/

Abstract

We demonstrated that Bluetooth 5 with Coded PHY and Extended Advertisements is an effective way to represent VRUs within a traditionally vehicle-centric safety context. Previously, it was widely assumed that dedicated vehicle-to-vehicle (V2V) messages required specific V2V RF components. This demonstration showed that V2V messaging could be accomplished with standard, off-the-shelf components.

Range

The overall test area was an open, paved area approximately 200 feet by 400 feet, with no buildings. The signals were easily monitored far from the location of each scenario engagement. The demonstration was executed without any special antennae or accommodation. Maximum range testing of Bluetooth 5 using Coded PHY was not performed.

Data Rate

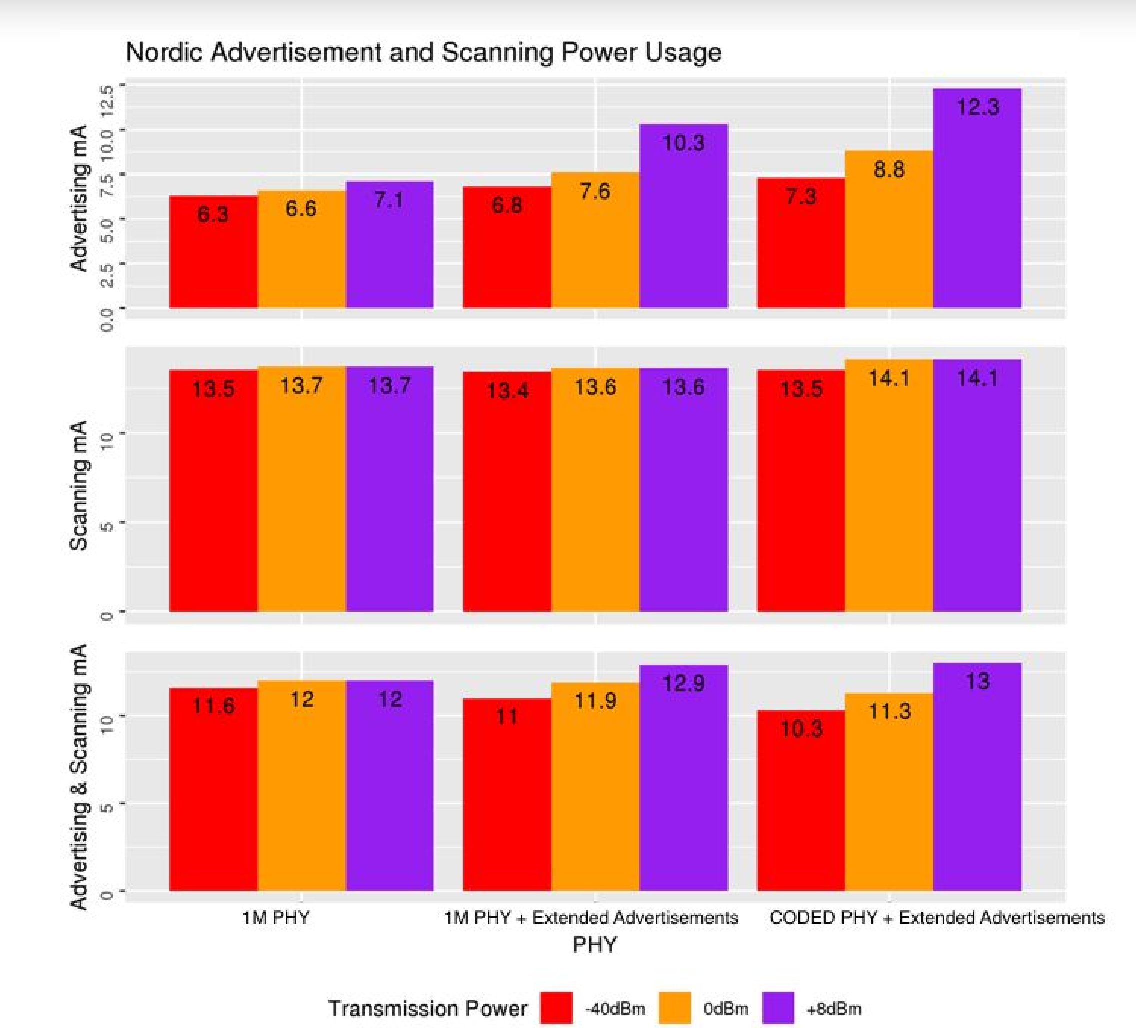
A basic safety message (BSM) was transmitted at 10 Hz, as specified by SAE J2735 and used within two automatic driver assistance systems (ADAS) applications: left turn assist (LTA) and intersection movement assist (IMA).

Power Consumption

The VRU device uses 12.3 mA while advertising Bluetooth 5 with Coded PHY and Extended Advertisements. That measurement does not include power used by the u-blox module. The demo used a 12V 6Ah lithium battery with the assumption that it would be sufficient for the demo. No specific testing was performed on power consumption of the prototype used in the demo. Further testing is planned for Q4 ‘19.

Below is a summary and chart of nRF52840 battery consumption performed during bluetooth testing in a prior evaluation. This does not include power consumption used by the u-blox module.

1. Using the nordic power profiler, current used was measured at different transmission powers in different Bluetooth modes.
2. 1M PHY, 1M PHY+ extended advertisements, and coded PHY+extended advertisements were tested.
3. The highest power measured while advertising was 12.3 mA at 3.0V, so .037W. That's with no power optimization, and at the highest transmission power.



Pairing-free Communication

VRU information was transmitted using Bluetooth 5 Extended Advertisements. The information was broadcast as part of the advertising protocol and received through the scanning protocol. There is not a requirement for pairing or bonding in order for this information to be accessed, allowing it to be used by multiple receivers including multiple vehicles and stationary roadside unit (RSU) devices.

Bluetooth 5 Packet Size

Packet size limits have increased from Bluetooth 4.0 to Bluetooth 5.0, particularly due to the introduction of the data length extension. This increase has enabled the ability to send all required fields for the PSM (~40 bytes). For comparison:

- Bluetooth Low Energy 4.0 Advertisement - 37 bytes
- Bluetooth Low Energy 5.0 Advertisement - 255 bytes
- Bluetooth Low Energy 5.0 Advertisement with Data Length Extension (DLE) - 1650 bytes*

*Sent across multiple, sequential advertising packets, this allows for convenient advertising of larger data chunks (but does not result in increased throughput) -- the DLE is compatible with long-range CODED_PHY extension, concurrently.

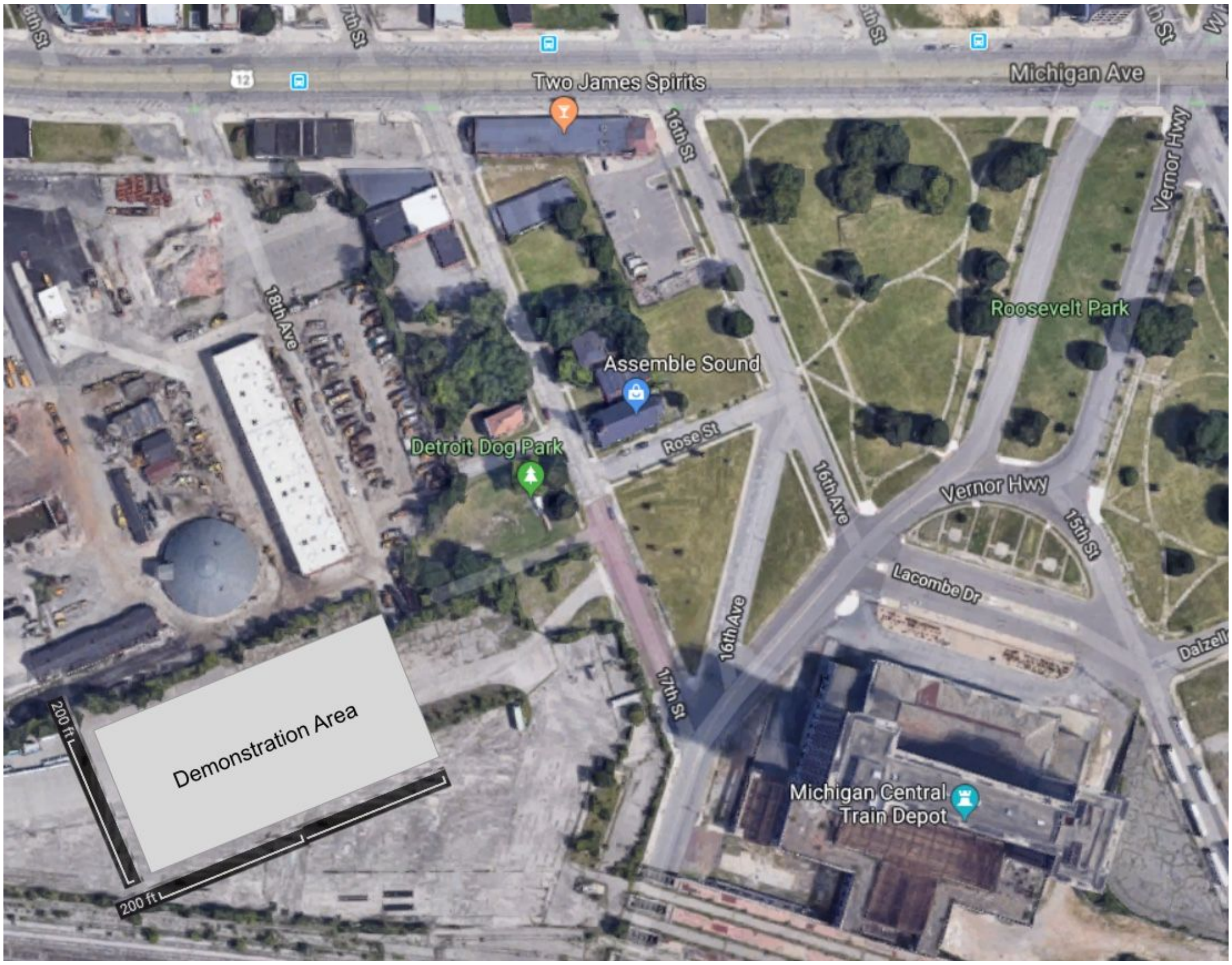
https://blog.nordicsemi.com/getconnected/bluetooth-5-advertising-extensions

Production Components

The demonstration used only commercially available components. Any chipset that supports Bluetooth 5 with Coded PHY and Extended Advertisements is sufficient for this application.

Demonstration

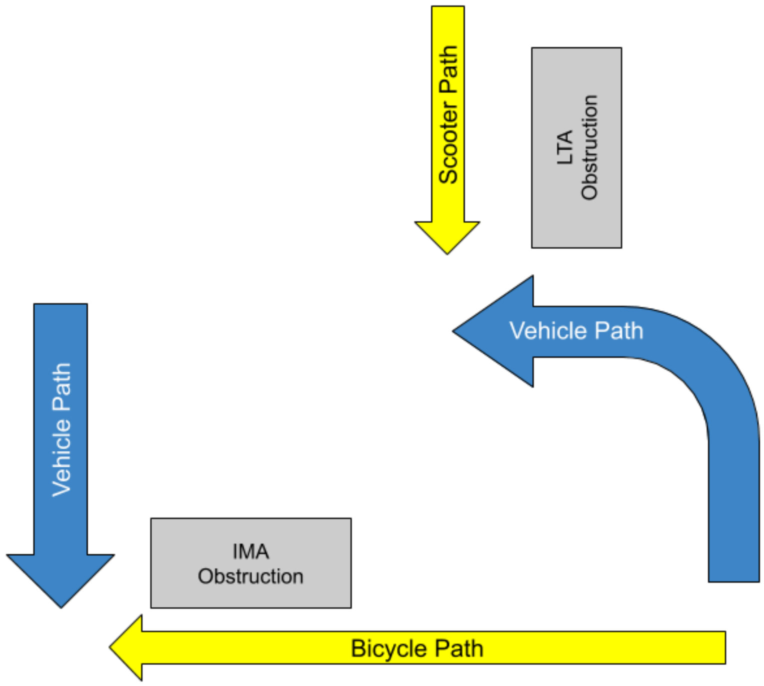
The demonstration took place on Tuesday, August 13, 2019 in Detroit, Michigan. A small road course was created to illustrate two common ADAS scenarios using a vehicle, e-scooter and a bicycle.



Conference participants were permitted to ride in the vehicle and experience a VRU triggering an ADAS alert.

Key Use Cases

For each maneuver demonstrated, a message from the VRU device caused the vehicle to display an alert in time to avoid a collision.



Left Turn Assist (LTA)

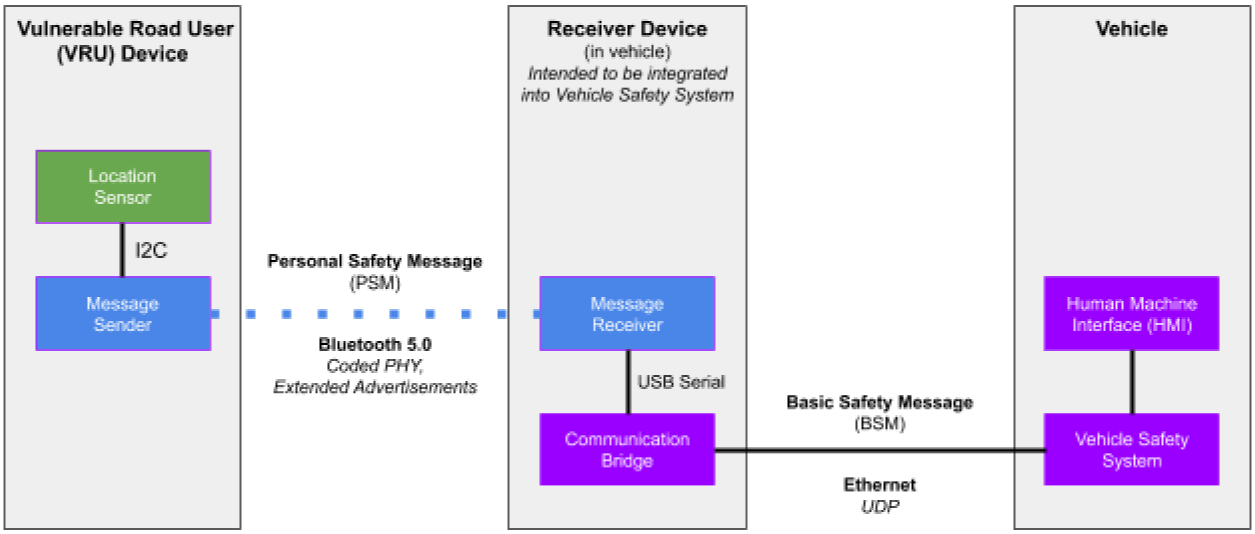
The vehicle is executing a left turn where an obstruction prevents the driver from seeing an oncoming scooter rider.

Intersection Movement Assist (IMA)

A vehicle is entering an intersection where an obstruction prevents the driver from seeing a bicycle rider who is also entering the same intersection.

Technical Overview

The system demonstrated was a VRU device that broadcasts PSMs via Bluetooth 5 with Coded PHY and Extended Advertisements.



A VRU device was created that accesses information from its GNSS device and packages it into a PSM and advertises it over Bluetooth 5 with Coded PHY and Extended Advertisements.
A second device receives each PSM, constructs a BSM and sends it to a vehicle ADAS system using an existing ethernet interface. Message communication is one-way, from VRU to vehicle. The VRU does not receive nor process any data from the vehicle.

Hardware

The primary basis of each device is a widely available development platform from **Nordic Semiconductor**. Detailed positioning information is provided by a global navigation satellite system (GNSS) evaluation kit provided by **u-blox**. This kit also uses an onboard gyroscope and accelerometers to provide heading and speed of the device. This is used by the VRU device to populate the PSM.

A Raspberry Pi device was also used to implement a communication bridge to the vehicle. This was a stopgap solution, and is planned to be removed in future versions.

VRU Device

1. Nordic Semiconductor nRF52840-DK boards (PCA10056)
2. u-blox EVK-M8U-0-00 GNSS evaluation kit with untethered dead reckoning
    2.1. GPS antenna (included with EVK-M8U)
3. Battery & 5V regulator
    3.1. Any battery that doesn't turn off at low current draw would work.

Vehicle Device

1. Nordic Semiconductor nRF52840-DK boards (PCA10056)
2. Raspberry Pi 3, Model B
3. Vehicle-provided power

Software

The software for each device is built using the freely-available SDK and libraries provided by Nordic Semiconductor. The VRU and receiver software use the same codebase with the particular functional mode (sending or receiving) selected by a toggle switch prior to operation.

PSM and BSM messages are defined by the Society of Automotive Engineers (SAE) in SAE J2735. The specification, Dedicated Short-Range Communications (DSRC) message set dictionary J2735_201603, was acquired from SAE for a nominal fee.

Both PSM and BSM definitions contain current location, heading and path prediction, which are the most relevant fields for this application. However, the vehicle currently only accepts a BSM, which represents a vehicle status and not a VRU.

For a detailed comparison of the PSM and BSM, please see the Appendix of this document.

Message Format

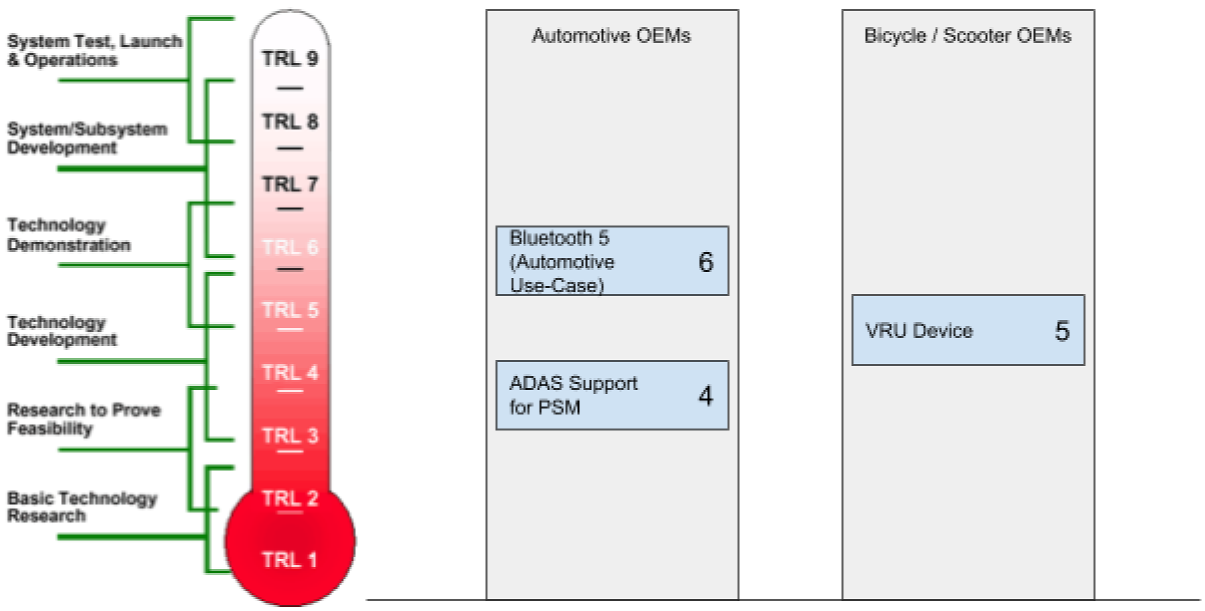
We used an open-source ASN1 compiler to turn the ASN1 spec into a C source code library that makes it easy to create, populate with data, encode and decode personal safety messages and basic safety messages. The ASN1 compiler is freely available at https://github.com/mouse07410/asn1c. This specific fork resolves issues with parsing the J2735 ASN1 file.

Communication Bridge

The receiver device uses a discrete component as the communication bridge to the vehicle and is intended to be integrated into the receiver device. A Raspberry Pi was used because of time constraints in preparation for the demo.

Technical Readiness Level

Technical Readiness Levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program. The method was developed by NASA during the 1970s. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology. A technology's TRL is determined during a technology readiness assessment (TRA) that examines program concepts, technology requirements and demonstrated technology capabilities. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.



Known Issues

PSM and BSM

Currently, the vehicle can only parse a BSM, which was defined for vehicle-to-vehicle communication while the PSM was defined to represent a VRU. In order to communicate with VRUs, the vehicle will need to be able to parse a PSM, as well. (Please see the Appendix of this document for a detailed comparison of PSM and BSM.)

Discrete Communication Bridge

The PSM/BSM message must be received by the built-in vehicle BLE hardware or the BLE receiver device in the vehicle. The data received via BLE should be interfaced with the vehicle ADAS system or a prototype ADAS hardware/software. In the implementation described, the vehicle BLE receiver device used ethernet and UDP to send the PSM/BSM messages to the vehicle ADAS system.

Detailed Range Testing

We have not yet performed extensive range testing of Bluetooth 5 with Coded PHY, relying instead on published results of others and the practical demonstration testing. There were no issues receiving the PSM transmissions in the entire demo area.

Security

No security requirements have been investigated. The need needs to be determined first and then determine the mechanism to implement a security methodology.

Note: Congestion testing development is required and the degree of any potential issues is unknown at this point. Nordic Semiconductor testing results has shown that this should not be a problem.

Future Plans

During the workshop, participants validated the need for future work and cross-industry collaboration on VRU use cases and activity. We have a roadmap for further work in multiple areas.

PSM information for VRUs in BSM

Current Technical Readiness Level: 4

1. Clarify minimum requirements for VRU information for delivery to vehicles.
2. Reviewing security considerations for transmitting safety information into cars.

NOTE: Production Vehicles support BSM (TRL 9) but currently do not process PSM information.

Testing Methodology & Standardization

Current Technical Readiness Level: 4

1. Impacts of buildings and other obstructions on range and suitability.
2. Congestion and performance as the number of VRU devices increase.
3. Formalized testing for power consumption.

System Design

Current Technical Readiness Level: 5

1. Integrate communication bridge into the vehicle device.
2. Data logging for debugging, simulation and analysis.
3. Utilize smaller form factor options from Nordic Semiconductor.
4. Release the test device as a reference design.

Software Development

Current Technical Readiness Level: 4

1. Release code under an open-source license.
2. Provide applications for testing, debugging, monitoring.
3. Aggregated applications for analytics and trend analysis.

User Experiences

Current Technical Readiness Level: 3

1. Identification of potential consumer privacy concerns.
2. Opportunities for feedback for the VRU.
3. Other types of VRU definitions, including pedestrians.

Appendix: Summary of the Basic Safety Message and the Personal Safety Message

Abstract

We implemented two fundamental safety message frameworks as defined in the SAE J2735 standard for this prototype: The basic safety message (BSM) and the personal safety message (PSM).

The data structures of the messages communicate the position, heading, and other location details of a vehicle or person to other vehicles/persons as an electronic version of “see and be seen.” The transmission path that carries these messages can be DSRC, C-V2X, or Bluetooth 5 with Coded PHY and Extended Advertisements, as the latter was used for this prototype.

The BSM is designed for describing a powered vehicle, such as a car or truck, where as the PSM describes a vulnerable road user, such as a pedestrian, scooter, horse and buggy, bicycle, powered wheelchair, etc.

Industry manufacturers have committed considerable resources to accurately send and receive BSMs in their commercial products, but development of protocol stacks for transmitting and receiving PSMs has lagged. We have converted its PSM data into compatible BSM data so the message can be processed in a powered-vehicle’s telematics.

The basic safety message (BSM) *is used in a variety of applications to exchange safety data regarding vehicle state. This message is broadcast frequently to surrounding vehicles with data content as required by safety and other applications. Transmission rates are beyond the scope of this standard, but a rate10 times per second is typical when congestion control algorithms do not prescribe a reduced rate. Part I data shall be included in every BSM. Part II data items are optional for a given BSM and are included as needed according to policies that are beyond the scope of this standard. A BSM without Part II optional content is a valid message.*
---Surface Vehicle Standard J2735, *Dedicated Short-Range Communications (DSRC) Message Set Dictionary;* Mar 2016; Section 5.2 page 30.

The Personal Safety Message (PSM) *is used to broadcast safety data regarding the kinematic state of various types of Vulnerable Road Users (VRU), such as pedestrians, cyclists or road workers. Data items which are optional are included in a PSM as needed according to policies that are beyond the scope of this standard.*

This message is under development, and is included in this standard to support field trials. Changes in the specification of the message and/or its constituent elements may occur in the future.
----Ibid. Section 5.8 page 34.

Table of comparison between PSM and BSM

This table shows data common to both PSM and BSM, and data that is unique to each.
Green indicates a required element, **Tan** indicates an optional element.
Section references are to the SAE Surface Vehicle Standard J2735, March 2016 (available for purchase at SAE.)

PSM Section 5.8 p34	**BSM Part I** Section 5.2 p30	**Remarks / J2735 Reference Section**
msgCnt	msgCnt	DE_MsgCount, Section 7.104
id	id	DE_TemporaryID, Section 7.187
secMark	secMark	DE_DSecond, Section 7.39
**see below*	lat	DE_Latitude, Section 7.91
**see below*	long	DE_Longitude, Section 7.95
**see below*	elev	DE_Elevation, Section 7.44
Lat, Long, *Elevation (optional in spec but required by Ford)*	*see lat,long,elev above	PSM bundles Lat, Long, and (optional) Elevation into a *Position3D* structure, unlike a BSM that provides discrete Lat, Long, Elevation fields.
accuracy	accuracy	DF_PositionalAccuracy, Section 6.88
	transmission	Vehicle transmission state (Neutral, park, etc)
**see velocity*	speed	DE_Speed Section 7.179 "This element has been maintained for use by the BSM message. For all new work, the entry DE_Velocity shall be used."
velocity	**See speed*	DE_Velocity Section 7.216 scalar value
heading	heading	DE_Heading Section 7.53
	angle	DE_SteeringWheelAngle Section 7.185

PSM Section 5.8 p34	**BSM** Section 5.2 p30	**Remarks / J2735 Reference Section**
accelSet (optional)	accelSet	DF_AccelerationSet4Way Section 6.1
	brakes	DF_BrakeSystemStatus Section 6.7
	size	DF_VehicleSize Section 6.149
basicType		DE_PersonalDeviceUserType, Section : Not Avail, Ped, pedalcyclist, safety worker, animal
pathHistory (optional)	*VehicleSafetyExt.pathHistory* *(optional)*	DF_PathHistory Section 6.82 Not used in this project. (BSM Part II)
pathPrediction (optional)	*VehicleSafetyExt. pathPrediction (optional)*	DF_PathPrediction Section 6.85 *See* BSM Part II table (below).
propulsion (optional)		DF_PropelledInformation Section 6.92 Human, Animal, Motorized types with subtypes.
useState (optional)		DE_PersonalDeviceUsageState Section 7.136 Other, idle, listeningToAudio, typing, calling, playingGames, reading, viewing It can be used to indicate the level of **pedestrian** distraction.
crossRequest (optional)		DE_PersonalCrossingRequest, Section 7.135 boolean
crossState (optional)		DE_PersonalCrossingInProgress Section 7.134 boolean
clusterSize (optional)		DE_NumberOfParticipantsInCluster, Section 7.113 Small(2-5), medium(6-10), large(>10)

PSM Section 5.8 p34	**BSM** Section 5.2 p30	**Remarks / J2735 Reference Section**
clusterRadius (optional)		DE_PersonalClusterRadius Section 7.133
eventResponderType (optional)		DE_PublicSafetyEventResponderWorkerType Section 7.147
activityType (optional)		DE_PublicSafetyAndRoadWorkerActivity Section 7.145
activitySubType (optional)		PublicSafetyDirectingTrafficSubType
assistType (optional)		7.132 DE_PersonalAssistive otherType, vision, hearing, movement, cognition
sizing (optional)		7.207 UserSizeAndBehaviour: smallStature, largeStature, erraticMoving, slowMoving
attachment (optional)		7.12 Attachment: stroller, bicycleTrailer, cart, wheelchair, otherWalkAssistAttachments, pet
attachmentRadius (optional)		7.13 AttachmentRadius
animalType (optional)		7.9 AnimalType serviceUse, pet, farm

BSM Part II, *VehicleSafetyExtension*

Conveying PathPrediction from PSM to BSM

Use: The DF_VehicleSafetyExtensions data frame is used to send various additional details about the vehicle. This data frame is used for vehicle safety applications to exchange safety information such as event flag and detailed positional information. This data frame is typically sent in conjunction with BSM Part I or used in other messages at the same or reduced frequency.
---Ibid. Section 6.148 page 108.

BSM Part II Extension Section 5.2 pp 30-31	**Remarks / J2735 Reference Section**
VehicleSafetyExt.	DF_VehicleSafetyExtensions Section 6.148 page 108.
VehicleSafetyExt.events (optional)	DE_VehicleEventFlags, Section 7.208 Not used in this project.
VehicleSafetyExt.PathHistory (optional)	DF_PathHistory, Section 6.82 Not used in this project
VehicleSafetyExt.PathPrediction (optional)	DF_PathPrediction, Section 6.85 Use requested for automotive ADAS use
VehicleSafetyExt.lights (optional)	DE_ExteriorLights, Section 7.46 Not used in this project

Use: The **DF_PathPrediction** data frame allows vehicles and other types of users to share their predicted path trajectory by estimating a future path of travel. This future trajectory estimation provides an indication of future positions of the transmitting vehicle and can significantly enhance in-lane and out-of-lane threat classification. Trajectories in the PathPrediction data element are represented by the RadiusOfCurvature element. The algorithmic approach and allowed error limits are defined in a relevant standard using the data frame. To help distinguish between steady state and non-steady state conditions, a confidence factor is included in the data element to provide an indication of signal accuracy due to rapid change in driver input. When driver input is in steady state (straight roadways or curves with a constant radius of curvature), a high confidence value is reported. During non-steady state conditions (curve transitions, lane changes, etc.), signal confidence is reduced.
---Ibid. Section 6.85 page 80.