Connected Vehicle Pilot Positioning and Timing Report

Summary of Positioning and Timing Approaches in CV Pilot Sites

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16. Abstract

This document summarizes positioning and timing related information from the three Connected Vehicle Pilot Deployment Sites (NYCDOT, Tampa/THEA, and WYDOT) as discussed during technical roundtables. Information is largely based on progress to date during Phase 2, and will be updated in the future once all sites have finalized their implementations.

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1 Introduction

Based on discussions among USDOT and the CV Pilots sites at the June 6-8, 2017 Face-to-Face technical meeting, a need was identified for the group to gain a better understanding of how positioning and timing accuracy are being approached across the sites. The purpose of this paper is to identify and document the relevant topics, offer summaries of related subtopics and resources, and review the relevant content from the three sites' available documentation to facilitate further discussion. While the objective relates primarily to interoperability across the sites, the material may also be of relevance for the individual sites as they proceed through the design phase.

The paper begins with background, reviews the sites' positioning and timing approaches, provides positioning and timing requirement details from referenced standards, summarizes positioning augmentation approaches using Radio Technical Committee for Maritime Service (RTCM) messages, identifies topics for further discussion, and finally concludes with an Appendix with relevant extracted text from site documentation (System Requirements Specification, SyRS -recognizing that additional documents are in progress).

2 Discussion at June 2017 Technical Roundtable

As part of the interoperability discussion, the topic of position and time accuracy, and the supporting mechanisms such as potential use of RTCM messages, was identified as needing clarification. The three sites intend to demonstrate interoperability for selected V2V applications that use the SAE J2735 Basic Safety Message (BSM), using performance requirements from SAE J2945/1, which is intended to cover a broad group of BSM-based V2V safety applications. All three sites will implement Forward Collision Warning (FCW), and Tampa/THEA and New York City will implement V2V Intersection Movement Assist (IMA) and V2V Electronic Emergency Brake Light (EEBL). These V2V applications depend on relative positioning (assessing the BSM-reported position and trajectory of the remote vehicle to the host vehicle's location/trajectory from its own positioning subsystem). However, it should be noted that although SAE J2945/1 provides a common basis, the underlying positioning requirements for an application may vary – for example knowing the relative (lateral) lane position is important for FCW but not so much for IMA where vehicle paths are crossing.

In recognition of the positioning challenges associated with "urban canyons", the sites agreed to limit V2V application interoperability testing to "open sky" conditions where positioning performance is expected to be adequate. The independent evaluator will pursue additional activity to characterize in more detail the positioning performance across the sites (including urban locations/NYC).

Two of the sites (NYC and Tampa/THEA) also plan to demonstrate limited V2I interoperability through the successful transmission, reception, and parsing of the SAE J2735 SPaT and MAP messages, which is used by several V2I applications. These applications are based on absolute positioning (relating the host vehicle's position to the absolute position as represented in the MAP message). The scope of V2I interoperability includes receiving and parsing messages such as MAP but the planned testing (including potentially the ability to use the message contents) has not yet been finalized.

3 General Approach

The general approach being applied by the sites includes the identification of requirements, which may directly or indirectly include timing and position accuracy requirements, that are expected to be satisfied by the vendors' equipment (i.e., vehicle devices or subsystems, OBUs/ASDs, etc.) as integrated by the site. Per discussion on the July 21, 2017 CV Pilots Technical Roundtable call, all three sites are planning to provide test reports (developed by the sites and/or vendors) that show conformance to the five test specifications (for IEEE 802.11, IEEE 1609.2, IEEE 1609.3, IEEE 1609.4, and SAE J2945/1) that were developed by the Certification Operating Council (COC) under sponsorship by USDOT. However, at the time of writing this paper, the sites had not received "certification" of devices by the COC at this stage. Many of the relevant requirements for positioning for the sites (see Appendix) are based on references to SAE J2945/1 (On-Board System Requirements for V2V Safety Communications) for devices being used for purposes of generating safety alerts to drivers. These requirements are summarized in the next section.

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4 Timing Accuracy

Based on the sites' reference to SAE J2945/1, the timing accuracy requirements in the standard are likely to govern the application-level minimum timing accuracy. SAE J2945/1 Section 6.2.4 states that the reference clock within the vehicle device is to be tied to UTC (Coordinated Universal Time), and that the clock is accurate to within 1 millisecond of UTC time. However, it should also be noted that some of the DSRC communications standards relating to channel switching may also be relevant. For example, in IEEE 1609.4, section 6.2.5 and Appendix H discuss the synchronization tolerance for channel switching, where DSRC radios transmit in precisely defined time slots. The SAE requirement is absolute (always within 1 ms) while the underlying IEEE reference in IEEE 802.11 is probabilistic (based on a standard deviation of error in time value), and it is not clear how these are measured in practice. On the infrastructure side, sites broadcasting SPaT messages (NYC and Tampa/THEA) will need to ensure that time references embedded in the SPaT message are sufficiently accurate to be used by vehicle devices. Source data from signal controllers and any processing/translation will likely need to be checked as part of this.

5 Positioning Requirements

For V2V safety applications, the expected requirement is to satisfy SAE J2945/1 section 6.2, which covers Positioning and Timing Requirements. This requirement is based on achieving "WhichLane" performance in V2V safety applications. The standard specifies position accuracy requirements tested in open sky conditions, also specified in the standard (J2945/1 section A.7); dilution of precision is a calculated value based on the geometric relationship of the current locations of the satellites, which affects accuracy:

# of satellites being tracked >=7

Horizontal Dilution of Precision (HDOP) <= 1.5

Vertical Dilution of Precision (VDOP) <=3

The 2-D accuracy requirement is specified as 1.5 m for 68% of test measurements under these conditions. The elevation accuracy requirement is specified as 3 m for 68% of test measurements under these conditions. It should be noted that the scope of SAE J2945/1 is limited to light vehicles. It does not address positioning performance or accuracy of truck trailer representations, for example.

Other SAE J2945/x series documents are not yet available to cover other applications including V2I. However, information from ISO/TS 19091 notes that positioning performance of the vehicle system needs to be adequate to match vehicle with the lane-specific signal phases, if applicable. Not all intersections/locations/applications being implemented by the three sites that require lane-level absolute positioning accuracy (e.g., Tampa/THEA wrong way entry approach lanes, turn lane governed by leading protected turn phase) have been reviewed or assessed at this time. The nature of absolute positioning means that the accuracy of the MAP (e.g., lane delineation) needs to be taken together with the vehicle positioning performance in meeting application requirements. This is an area where discussion of a potential assessment would be beneficial.

6 Potentially Relevant Types of Positioning Augmentation

"RTCM" has been used to refer to positioning corrections generally, but there is a need to be more precise in the usage since the various messages defined by RTCM Special Committee 104 (SC-104) cover more than one approach. RTCM versions (i.e., version 2.x "RTCM standard 10402.x" and version 3.x "RTCM Standard 10403.x") also differ in the support for different types of correction messages. Both versions are supported in the SAE J2735 standard (MSG_RTCMcorrections), which defines a wrapper for RTCM messages to be transmitted over DSRC. There are several types of differential positioning augmentation techniques that are potentially relevant to the CV pilots. These approaches all involve providing the local positioning receiver with correction information collected from other fixed locations to improve the local receiver's accuracy by minimizing various error components in the position calculation.

7 Methods of Positioning Correction

The NYC pilot site, in recognition of the GNSS (Global Navigation Satellite System - a broader term including GPS and other similar systems) challenges in the proposed deployment areas (extreme urban canyon[1]), has additional system requirements defined for location augmentation, which reference RTCM standards. The draft NYC documents mention broadcast of Wide Area Augmentation System(WAAS) corrections from RSUs, but it is not clear if these are really intended as WAAS corrections (which are satellite-based), or other types of corrections. Currently, the NYC team is assessing the positioning strategy as part of the design phase. In reviewing the THEA and WYDOT planned deployment locations, there do not appear to be significant urban canyon challenges where tall buildings block satellites, but it may be beneficial to conduct a limited scope GNSS assessment in the downtown Tampa segments (e.g., Kennedy Blvd.) if not already done.

Code-based differential GPS uses corrections from a fixed location nearby to correct the receiver's position based on the calculated pseudoranges to satellites. Carrier-phase differential GPS used for the Real-Time Kinematic (RTK) method (note, not all receivers are capable of RTK), uses the measurements of the satellite signal carrier from a nearby fixed location to improve the precision of error estimates. Notably, RTK requires a minimum of 5 common satellites in view between the local receiver and the correction source while Code-based differential GPS requires a minimum of 4. Within the RTK category, there are approaches that use a single base (fixed location) station and also a method called Network RTK that uses a network of base stations in determining the corrections. Finally, the Precise Point Positioning (PPP) method uses data from a network of many fixed locations to calculate corrections that reduce additional types of error (e.g., satellite clock error), and disseminate these calculated state space representation corrections to receivers. This differs from conventional differential GPS in that there is no differencing using observations from local or nearby base stations. It is important to note that receivers using PPP require a significant amount of time for initialization, and not all receivers are capable of PPP. There are also post-processing approaches that use GNSS to calculate static position more accurately, but do not pertain to vehicles which require real-time positioning.

SAE J2945/1 section 6.2.2 specifies that Wide Area Augmentation System (WAAS) corrections, which are broadcast from specific satellites and used directly by the GNSS receiver, are to be used when available, but other augmentation is permitted. WAAS is a satellite based augmentation system (SBAS) developed for North American civil aviation, but may be used for surface GNSS receivers that can use the corrections, broadcast by the WAAS satellites, in calculating the position solution (current

[1] As background, recognizing the challenges of blocked satellite views, the Japanese Quasi-Zenith Satellite System (QZSS) aims to increase the number of satellites overhead (at high elevation angles) in view for urban areas of east Asia by setting the satellite orbits with a regional focus. However, this does not help with US positioning. See
http://www.denshi.e.kaiyodai.ac.jp/jp/assets/files/pdf/content/201001.pdf

location). Non-GNSS augmentation techniques may include sensor fusion with dead reckoning, use of Inertial Measurement Units (IMU), localization with WiFi signal tracking, camera or LIDAR based systems, etc.

Across all positioning correction techniques, it should be noted that the local receiver needs to be able to handle the type of corrections needed for a given method. Not all GNSS receivers are capable of using all corrections, and not all GNSS receiver and antenna combinations perform equally well under different conditions (e.g., rejection of multi-path signals). Different GNSS receivers also have varying capability to receive GNSS signals at different frequencies and from other non-GPS sources (e.g., GPS-like systems such as the Russian GLONASS or EU Galileo satellite systems). Receiving additional signals from other satellites can help to mitigate urban canyon issues since there are more potential satellites that are not blocked by buildings. Historically, the higher capability receivers and antennae are higher cost units aimed at the surveying market.

8 Positional Accuracy in SAE J2735 BSM

One of these topics is the method of setting the SAE J2735 BSM field named DF_PositionalAccuracy, which is described in SAE J2945/1 section 6.3.6.7 as including values corresponding to one standard deviation of error ellipsoid for each axis. This field is intended to be dynamic, to reflect the current level of uncertainty of the location represented in the BSM (i.e., considering all positioning corrections and supplements being applied), and is necessary for the receiving vehicle to determine whether the BSM data should be used, and if so how. For example, if the BSM position is not known to sufficient accuracy, it cannot be used in warning a driver since the vehicle may not be at the stated location. Notably, this means that if the accuracy is not known, the BSM likely cannot be used by itself, i.e., without corroboration through alternate sensing such as radar. Since the scope of interoperability testing includes V2V testing, a common understanding of the method to dynamically set PositionalAccuracy is needed. This will likely benefit from discussions on whether the device vendor or site is defining how application decisions are being made, and an assessment of the accuracy-related information available from positioning subsystems.

9 Cross-site Use of RTCM Corrections

While NYC is planning to broadcast corrections from RSUs for use by the site's equipped vehicles, the other two sites have stated that their vehicles are not planning to use these messages. This suggests that the positioning performance of Wyoming and Tampa/THEA vehicles in lower Manhattan will be low, and is part of the reason that open sky testing was selected. It should also be noted that depending on the positioning capability of the NYC vehicle devices, their positioning performance in non-equipped locations in other urban canyon locations in NYC may not be adequate for V2V applications. However, NYC vehicles in Wyoming or Tampa/THEA should generally experience good positioning performance despite lack of RTCM corrections from RSUs. The device designs, once known, should be assessed in more detail for positioning capability. It is not yet clear to what degree RTCM may ultimately be used, as NYC recognizes that the urban canyon environment poses challenges to position accuracy that may be of a magnitude larger than correctable by RTCM.

10 Tradeoffs

Finally, it should be noted that as the state of positioning technology evolves over time, the capabilities, costs, and availability of solutions will change. Research is ongoing for improving positioning performance in urban environments. Currently, there are significant tradeoffs in cost versus performance, as the size of the surveying receiver market is orders of magnitude lower than the size of the automotive market. However, this has potential to change as the market changes due to automation, satellite constellation enhancements, etc.

In the case of NYC, the NYCDOT team considered several options and required potential vendors to consider a variety of techniques (e.g., RSU triangulation, INS, Map Matching) to improve the overall location accuracy. These techniques may result in the need for standardization, connection to vehicle data buses, and establishment of accuracy performance requirements that consider when multiple inputs or methods are combined and address potential loss of one or more inputs.

11 Potentially Useful References

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12 Appendix – Positioning Related Excerpts from CV Pilots SyRS documents

WYDOT
SyRS – FHWA-JPO-16-291

[SAE J2945/1 sections incorporated via certification requirement]
6.2 Positioning and Timing Requirements
6.2.1 Position Determination
6.2.2 Wide Area Augmentation
6.2.3 Coordinate System and Reference
6.2.4 System Time Coordination
TRA-REQ-2.1.2 Transmit Probe Data – Position (Source: J3067, 3.5.5.2.1.2). A connected device shall include its position (latitude, longitude, elevation), based on the WGS-84 coordinate system, at the time of the transmission as part of the probe data message transmitted to an RSU.
MNG-REQ-2.1.1 Requirements to Broadcast Vehicle Information (Source: J3067, G.2.1.1). A connected vehicle shall broadcast its vehicle information to other connected devices only if all of the following conditions are met:
1.The vehicle ignition is ON.
2.The vehicle's reported time is valid (See 3.5.1.1.3.3);
3.The vehicle's reported position (latitude, longitude, elevation) is valid (See3.5.1.1.3.4);
4.The vehicle's reported positional accuracy is valid (See 3.5.1.1.3.5);
Location and Time Service (LTS) – This one-way interface provides location and time information, which is later used to geotag and timestamp all information produced by the systems of interest. The location is obtained from a GPS using WGS-84 coordinates system, and time is provided using UTC from GPS time.
3.2 Location and Time Source (LTS)
Location and time are obtained in accordance with J2945/1 and J2735.
LTS-REQ-1 WCVS LTS Time – The Wyoming CV System shall acquire time from the LTS interface in accordance with J2945/1 section 6.2.4.
LTS-REQ-2 WCVS LTS Time Standard – The Wyoming CV System shall use Coordinated Universal Time (UTC) time for all logged data (e.g., events logs, probe vehicle data) based on the format defined in J2735 section 6.19 and epoch of January 1st 1970.
LTS-REQ-3 WCVS LTS Location – The Wyoming CV System shall acquire location from the LTS interface in accordance with J2945/1 section 6.2.1.
LTS-REQ-4 VS LTS Time – The Vehicle System shall acquire time from the LTS interface in accordance with J2945/1 section 6.2.4, as presented in Figure 2-3.
LTS-REQ-5 VS LTS Time Standard – The Vehicle System shall use Coordinated Universal Time (UTC) time for all logged data (e.g., events logs, probe vehicle data) based on the format defined in J2735 section 6.19 and epoch of January 1st 1970.

LTS-REQ-6 VS LTS Location – The Vehicle System shall acquire location in accordance with J2945/1 section 6.2.1 from the LTS interface, as presented in Figure 2-3.

NYCDOT

ASD Procurement Specification V2.3: 3.6.11.4
The vehicle location mechanism shall use a variety of techniques to improve the location accuracy as determined by the vendor. It is expected that this will include use of the RTCM message, odometer readings (wheel ticks), dead-reckoning, yaw rates, speed, map matching, and triangulation of external known RF sources as well as GNSS tracking.

SyRS – FHWA-JPO-16-303

2.1.2 Location and Time
In the NYC CVPD system, location augmentation will occur through corrections by the Radio Technical Commission for Maritime Services (RTCM) standards. As shown in Figure 2-1, the ASD and RSU will depend on the Global Navigation Satellite System (GNSS) or Global Positioning System (GPS) time source for determining their time and position (latitude, longitude, and elevation). The Network Time Protocol (NTP) messages will serve as an external time source for synchronizing the location and time of non-CV equipment (i.e. Advanced Solid-State Traffic Controllers (ASTC), Traffic Control System (TCS), National Weather Service (NWS)) with the NYC CVPD infrastructure.
3.8.1 Common Application
110.1.4
The Safety Application shall obtain vehicle position data whose accuracy supports the application's calculations for issuing advisories and alerts.
110.3.1
The safety applications listed in Table C-1 shall acquire vehicle position accuracy, speed, and heading to the ASD.
110.3.2
The safety application listed in Table C-1 shall determine if the ASD Position, speed and heading information provided is sufficiently accurate to support the ASD's advisory and alert calculations. (TBD: this will be detailed in the design phase.)

4.1 Global Navigation Satellite System (GNSS)
401.17.1
Each DSRC device shall obtain its time and position from the GNSS per the requirements of J2945/1 Section 6.2.

4.2.1 Wide Area Augmentation System (WAAS)
401.15.1
Each DSRC device shall use WAAS corrections per J2945/1 Section 6.2.2.
401.15.2
Each RSU shall broadcast WAAS corrections per its Store and Repeat configuration.

4.2.2 Triangulation for ASD Location Accuracy
401.15.3
RSUs shall exceed 802.11 ACK requirements in the following manner: Antenna referenced ACK turnaround time must be in (SIFS-12.5, SIFS+12.5) ns 95% for cable tested non-CSD signals. Note that any RSU employing the NXP based SAF5200 will support this by default. The position provided by the WSA shall be provided by the central system based on the 3D surveyed position.

Network Time Reference

401.16.1
Devices unable to receive timing information per J2945/1 Section 6.2 shall set their time from an authenticated time reference using the Network Time Protocol Version 4 per Internet Engineering Task Force RFC 5905-5908.

Appendix D. Definitions
101.2.6, 102.6.7
Sufficiently accurate position
Road-level accuracy (which needs to be defined at the system level for use in other apps)

Tampa/THEA
SyRS – FHWA-JPO-16-315

THEA-UC5-001
Street car OBUs shall determine the position of received vehicle BSMs within DSRC range.
THEA-UC5-002
Street car OBUs shall determine the position of received participant PSMs within WiFi range.
THEA-UC5-007
Street car OBUs shall analyze its current position in relation to right turning vehicles to determine if right turning vehicle is in conflict to the street car's position.
THEA-UC5-010
Street car OBUs shall analyze its current position in relation to pedestrians in intersection crossings.
THEA-UC2-003
Vehicles traveling in the legal direction shall identify crash trajectory of cross street vehicles
Calculates crash threat based on the location, heading, speed and elevation of both vehicles
THEA-UC2-012
Red Light Violation application at the REL entrance shall warn drivers predicted to violate the RED phase.
OBUs compare their location, heading, speed and elevation to the RSU SPAT and MAP to predict RED violation indicating that the vehicle is on a wrong-way trajectory
THEA-UC4-001
Transit vehicle shall send Signal Request Message (SRM) to RSU when vehicle matches the location of the intersection approach.
A signal green is requested at approach to the intersection by the transit vehicle, or the current green
[RSU] GPS antenna shall be positioned to have a clear view of the sky.

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