

Performance of DSRC during Safety Pilot Model Deployment

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ABSTRACT

This paper provides an analysis of how communication performance between vehicles using Dedicated Short-range Communication (DSRC) devices varies by antenna mounting, vehicle relative positions and orientations, and between receiving devices. DSRC is a wireless technology developed especially for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. A frequency band near 5.9 GHz has been set aside in the US and other countries for exploring safety and other uses for road vehicles. DSRC devices installed onboard vehicles broadcast their location using global navigation space systems (GNSS), speed, heading, and other information. This can be used to study communication performance in many scenarios including: car-following situations, rear-end crash avoidance, oncoming traffic situations, left turn advisory, head-on crash avoidance and do-not-pass warnings. Message Capture Fraction and Packet Loss Duration highlight how these measures change with distance and orientation of the vehicles. Data used in this study address four years of real-world use with over 2500 vehicles, with antennas primarily in an aftermarket-style installation.

CITATION: Bogard, S., Bao, S., LeBlanc, D., Li, J. et al., "Performance of DSRC during Safety Pilot Model Deployment," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 10(1):2017, doi:10.4271/2017-01-0077.

INTRODUCTION

This analysis uses data from an ongoing deployment of prototype DSRC systems that spans four years of continuous operation. This deployment began with the Safety Pilot Model Deployment (SPMD), the largest naturalistic study of V2V and V2I wireless technology to date. Sponsored by the US Department of Transportation (USDOT), the SPMD involved fielding over 2800 DSRC devices -- provided by several industry entities -- including vehicle-based onboard units (OBU) devices and 29 sets of roadside units (RSU). Data was collected for over 1.5 years starting in August 2012. The test itself was led by University of Michigan Transportation Research Institute (UMTRI) with several partners. The devices exchanged wireless messages with each other and infrastructure units. The objectives of SPMD addressed demonstration and evaluation of real-world performance of DSRC, including data collection to support USDOT safety benefits analyses for a set of driving safety applications; operation of an early security system; exposure of V2X applications to the driving public with subjective data collected from many drivers; and the creation of data archives to support further development. The SPMD ended in spring 2013, but operation continued, supported in part by a three year USDOT project called Ann Arbor Connected Vehicle Test Environment (AACVTE), as well as support from the University of Michigan's Mobility Transformation Center. The results reported in this paper use data from this entire period of data collection, as well as data from another study that compared roof-mounted and interior-mounted DSRC antenna performance.

As of October, 2016 the total distance travelled for both SPMD and AACVTE is 41.8 million miles in 6.4 million trips (ignition-on to off). Total driving time accumulated during this period was 1.48 million hours. The bulk of the data collected during the study is at 10 Hz and includes measures of time, GPS location and heading, speed, acceleration, yaw-rate, brake pedal status and vehicle length and width. These data are stored in a set of relational databases. The principal time-series table contains 53.4 billion records.

This paper focuses on V2V performance. Prior studies of DSRC V2V communication performance have established important insights for understanding how this communication can support safety applications. This includes awareness that packet loss occurs, and is an important consideration for applications dependent on DSRC ([3], [4]). The influences on packet loss, and the duration of those losses have been studied in most cases with roof-mounted antennas and with limited numbers of vehicles. In this paper, the data set is large, incorporating billions of messages collected over years. The receiving units have DSRC antennas inside the vehicle, and most but not all transmitting device antennas are also inside. A limited experiment where the antenna is moved from inside to a roof-mounted location is included. Thus this study has hallmarks of a possible "aftermarket" installation. We note that these units are not OEM installed and are of a 2012 vintage, but the basic performance influences of the 5.9 GHz wavelength are thought to be useful for current developments.

PROTOTYPE SYSTEMS

Vehicle Platforms and Device Pedigree

During the SPMD and AACVTE studies, the DSRC equipment was installed on heavy- and medium-duty trucks, transit and school buses, passenger and delivery vehicles, motorcycles, bicycles and Segway PTs. In total, 3,518 vehicles have participated in the project. The vast majority of these vehicles (approx. 3,300) were passenger cars, sport utility vehicles and large vans. Transit and school buses constitute the next largest population of about 120 vehicles; 65 were medium-duty trucks; and 25 heavy trucks (class 7 and 8). Eight motorcycles participated in the study.

The OBUs were installed in three distinct levels or pedigree. The most common OBU was a Vehicle Awareness Device (VAD). Vehicles with these units performed a ‘broadcast’ only function. They served as remote vehicles broadcasting the Basic Safety Message (BSM) for the safety and convenience applications running on other equipped vehicles. During these studies, there were approximately 3,076 distinct VAD deployed with a peak deployment of approximately 2500 units at one time. In addition to broadcasting a BSM, VAD also logged all broadcasted messages. The next OBU was called the After-market Safety Device (ASD). These units processed both sent and received BSM, for safety applications and used an audible interface to warn the driver of potential conflicts with other equipped vehicles. There were approximately 375 ASD vehicles deployed during the study. The third and most integrated devices were called Integrated Safety Devices (ISD), these devices were developed and installed by a consortium of automakers under the Crash Avoidance Metrics Partnership (CAMP), with support from USDOT. The 67 ISD vehicles were equipped with an advanced Human-Machine Interface (HMI) with both visual and audible alerts in potential conflicts with other equipped vehicles. The ISD pedigree were modeled after a production system designed and integrated into the vehicle instrumentation cluster. Installation on heavy-trucks and transit vehicles followed a similar three level pedigree structure.

DSRC devices (aka “radios”) from three suppliers were used in this analysis. In addition to the logging capability of the OBU, all of which recorded transmitted messages, a subset of ASD and all ISD vehicles were up-fit with an independent Data Acquisition System (DAS). These units recorded measures of time; GPS location, heading, quality; speed, acceleration; yaw-rate; brake and cruise control status; forward object detection; lane tracking; Inform and imminent warnings; remote vehicle BSM and classification; and forward, cabin, rear-left, rear-right video along with triggered audio during a warning. For this study both the DAS recorded archives from ASDs (and not OEM ISDs) and the Sent (or broadcast) BSM data archives from all units was used. Note: this analysis does not address OEM-style installations (ISD) as receiving units, and OEM-style installations are only a small fraction of transmitting units.

The safety applications deployed in these studies included:

1. FCW—Forward Collision Warning
2. EEBL—Electronic Emergency Brake Light
3. CSW—Curve Speed Warning
4. IMA—Intersection Movement Assist

5. BSW—Blind Spot Warning

Note: Radio suppliers and device pedigree determined the list of safety applications deployed on any given vehicle. Safety applications common to all vehicles included CSW, FCW, and EEBL.

DSRC and GPS Antenna Location

Most vehicles in SPMD were privately owned and could not be permanently modified by the Test Conductor. This constraint had a large impact on mounting locations of both DSRC and GPS antennas for ASD and VAD units. In general most VAD and ASD sedan vehicles used a Hirschmann Sharkfin antenna mounted on the rear package shelf inside the vehicle. For larger passenger vehicles, vans and SUVs, a MobileMark glass mounted antenna was placed on the driver’s side rear window near the tailgate. The GPS antenna was mounted on the trunk lid or on the roof near the tailgate of larger vehicles. [Figures 1, 2, and 3](#) below show typical antenna mounting locations used in SPMD. DSRC wavelengths do not travel well through solid objects and so use of interior-mounted DSRC antennas can suffer in performance.



Fig. 1. Package Shelf DSRC Location



Fig. 2. Window DSRC Location

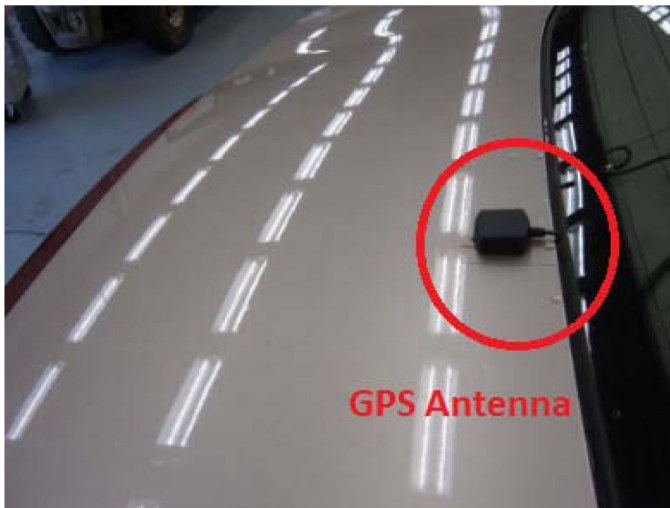


Fig. 3. Trunk Lid GPS Location

ANALYSIS METHODOLOGY AND MEASURES OF COMMUNICATION PERFORMANCE

Methodology

For this analysis, data from 105 passenger vehicles that were equipped with UMTRI data acquisition systems (DAS) and DSRC platforms (ASD) from two suppliers (called Radios 1 and 2 in the figures) were used. These vehicles were chosen because they were passenger vehicles with similar installations in terms of antenna location and type. The remote vehicles used in this analysis are any of the over 2800 vehicles in SPMD (predominately passenger vehicles) broadcasting the BSM during the periods that the host vehicles were driven.

The primary data filtering for this analysis identifies messages that were sent from remote vehicles near the host vehicles, as well as messages received by the 105 ASD vehicles. These data were aggregated as a function of the location and orientation of the remote vehicles, relative to the receiving host vehicle. The methodology used to calculate the performance measures is outlined below:

1. Using received BSMs from remote vehicles (RV) (uniquely identified in every BSM) logged by the DAS on-board the host vehicle (HV), to create a set of interaction events for all HV trips, which are time periods during which the host vehicle is receiving messages from the RV.
2. For each HV trip containing at least one BSM from an RV, search the Sent BSM database and identify all messages from the RV (regardless of location) between the start and end time of the HV trip.
3. At every time step (0.1 s), find the remote vehicle BSMs that were broadcast at that same time (temporal alignment of data) and calculate the geographical distance between the host and remote vehicle using GPS coordinates. If the straight-line distance is less than 1000 m save the RV BSM to a permanent table.
4. Flag all RV messages that match the list of received messages recorded by the HV. Figure 4 shows an example of this method. The map shows an instant in time when host vehicle 15101 was surrounded by eight remote vehicles (within 1000 m).

5. Calculate the East and North vectors of the remote vehicle location, using derived gain values specific to the area to convert latitude and longitude coordinates (degrees) to a relative East/North distance (m).
6. Perform a coordinate transformation rotating the relative locations of all remote vehicle vectors to a vehicle-fixed X/Y coordinate system, with X as the host longitudinal axis and Y pointing to the left (ISO coordinate system). This transformation is shown in the boxes below the map in Figure 4.

Measures of DSRC Performance

Two performance measures are discussed. They are defined as:

- Message Capture Fraction (MCF): is the total number of messages logged by the HV divided by all the RV messages sent and is shown as a function of the distance between the HV and RV.
- Packet Loss Duration (PLD): is the amount of time between subsequent messages received by the HV. Nominally messages are being broadcast in 0.1 s intervals and if all broadcast messages are received then the loss duration is 0 s. A packet loss duration of 0.4 s indicates that three sequential messages were not seen by the HV indicating that the time-gap between received messages was 0.4 s.

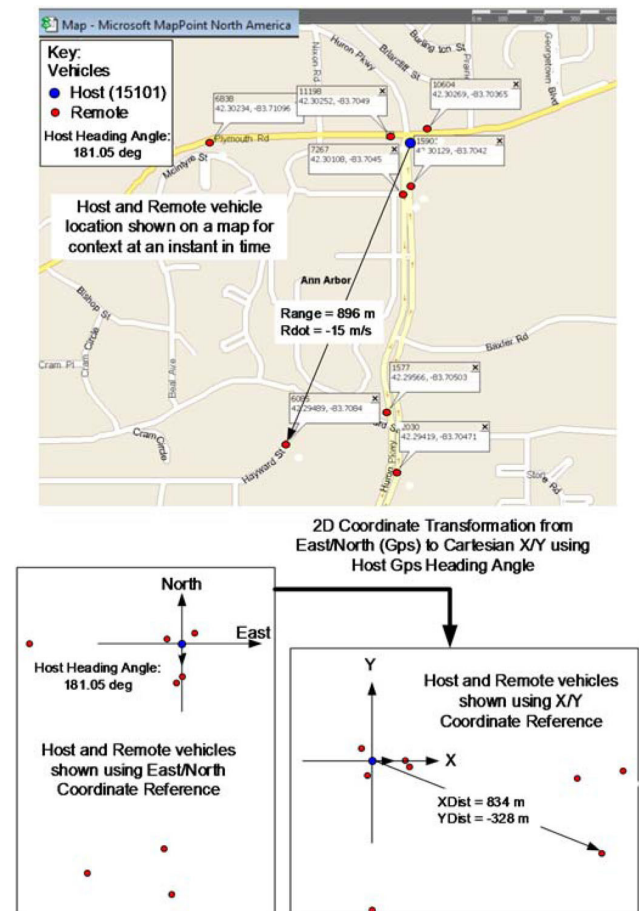


Fig 4. Example showing process for calculating the Cartesian distance from the host to remote vehicles for the BSM communication analysis.