Analysis of Detroit POC trial results and use in validating a DSRC simulator

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Background

1.1 DSRC and the POC VII system

The data used in this report was obtained from field testing of a DSRC system deployed in the northwestern suburbs of Detroit, Michigan. The system was developed after the Federal Communications Commission allocated a dedicated 75 MHz spectrum band around 5.9 GHz for the purpose of allowing vehicles to communicate with road infrastructure and with each other in real time. The testing site is part of a cooperative agreement between the Vehicle Infrastructure Integration Consortium (VIIC) and the U.S. Department of Transportation (USDOT). The testing equipment includes a fleet of vehicles equipped with on-board units (OBUs), which communicate with 55 road-side units (RSUs) placed at various intersections in northwestern Detroit [1].

![Figure 1. Map of the RSU locations in northwestern Detroit](image)

The data in this report was collected by examining the log data generated by the OBUs and RSUs as they were executing the Probe Data Service application (See section 1.2). This data was obtained
from the IntelliDrive Data Capture and Management Portal [2]. In addition to the log data collected from the Probe Data Service application, this report uses trajectory data for different vehicles provided by the same portal.

The communication between the RSUs and OBUs was performed in accordance to the IEEE 1609 family of standards [3] [4]. In particular, the UDP protocol was used in order to transmit probe data from the vehicles to the roadside infrastructure. The security of the data was preserved by using the V-DTLS protocol. In addition to providing security, the use of the V-DTLS protocol also provided additional communication reliability by establishing a connection before any probe data was exchanged. Originally the researchers performing the testing noticed that the OBUs were receiving WAVE Service Announcements from the RSUs at distances of up to 1100m, while the OBUs could communicate reliably with the infrastructure at distances of only about 400m [5]. As a result, the OBUs were trying to send probe data at distances that were not likely to result in successful transmission. Moreover, since privacy rules require the OBUs to delete probe data from their buffers after they transmit it, the data was not retransmitted at a later point and was never delivered. The introduction of V-DTLS required the OBUs and RSUs to undergo a handshake protocol before the OBUs could transmit probe data. The handshake protocol, therefore, forced the OBUs to transmit probe data only at distances at which they could reliably communicate with the RSUs, which in turn increased reliability [6].

1.2 Probe Data Service
The probe data service works by collecting vehicle “snapshots” at different times. A “snapshot” includes various vehicle operating parameters such as location, speed, heading, acceleration and braking information. The snapshots can be generated in three different manners – periodically, based on event triggers and based on starts and stops of the vehicle. The periodic snapshots are generated at different periods between 4 and 20 seconds depending on the speed of the vehicles. At speeds of 20mph or lower the snapshots are generated every 4 seconds, while at speeds greater than 60mph the snapshot generation period is 20 seconds. For all speeds between 20mph and 60mph the period increases linearly between 4 and 20 seconds. In addition to these snapshots, the vehicles create event triggered snapshots whenever a certain condition changes such as turning the headlights on and off. Finally, each vehicle also generates a snapshot each time it starts or stops.

Once the OBU enters the range of an RSU and receives a WAVE Service Announcement, the OBU transmits its snapshots by first transmitting event triggered snapshots, followed by start and stop snapshots and then periodic snapshots. Each message sent by the OBU can contain between 1 and 4 snapshots and each OBU is required to keep 30 snapshots in its buffer. Any newly generated snapshots that cannot fit into an empty slot in the OBU’s buffer would overwrite the oldest snapshot currently recorded. In addition, the RSU can change many of the service parameters such as the snapshot generation and transmission periods and the event triggers by sending a probe generation management message to the OBUs.

1.3 Gathered Data
The data provided by the Intellidrive management portal is divided into several different types of files. Those files were either directly generated by the RSUs and OBUs or required post-processing in
order to extract the data from the original files. The data included in the files was part of one of three sets of tests – POC 2008, NCAR 2009 and NCAR 2010.

1.3.1 RSE Location Files
These files include the locations of the RSUs. The location of some of the provided road side equipment changed between the 2008 POC trials and the 2009 NCAR trials. Therefore, there is one file for each of those configurations. The files include the ID number of each RSU as well as its latitude and longitude.

1.3.2 OBE Trajectory Files
These files include the trajectory of the OBUs for each day of testing. Most of the files include one measurement of the position of each OBU for each second of operation. Each entry includes the 4 character OBE ID, the time the measurement occurred as well as the latitude and longitude. In addition, post-processing was applied to the files in order to convert the provided latitude and longitude positional information into a Cartesian representation based on feet. This representation allows for the distance between two points to be obtained using the Euclidian distance formula, which is not possible with a latitude and longitude representation.

1.3.3 OBE Event Files
These files are based on post-processing the raw log files generated by each OBU. They contain a distinct set of events depicting the operation of each OBU. In particular, these files contain events indicating starting and stopping, communication with the VDTLS server and communication with the probe data service. The files contain a set of events which indicate each time an OBU sent a probe data snapshot message to the sever and another set of events which indicate whether these probe snapshot messages were successfully received by the RSU.

1.3.4 RSE and OBE Snapshot Files
These files contain the snapshots generated by the OBUs and received by the RSUs. Since the data analysis in this report extracts all location information based on the OBU trajectory files and all communication information based on the OBU event files, these files were not utilized in the analysis.
Data Processing

In order to convert the data into a format which would allow it to be easily analyzed several post-processing steps were undertaken. The sequence of steps performed on the data is shown in the figure below:

Figure 2. Post-processing of data files acquired from the IntelliDrive portal

2.1 Parsing of the data files

The data files obtained from the portal were parsed into 4 distinct tables: a table containing POC RSU locations, a table containing NCAR RSU locations, a table containing vehicle trajectory data and a table containing vehicle event data. The locations of the RSUs in the RSU location tables were converted into the same Cartesian coordinates based on feet that were used in the OBE event files in order to obtain a standardized coordinate system that allowed easy calculation of distances. The rest of the RSU location files and the OBU trajectory files were recorded in the database without altering their format.

The OBU event files were parsed by extracting the events that dealt with sending probe data messages. The event files contain a pair of events for each probe data message that is sent – a first event which indicates the time when the message is sent and a second event which indicates whether the message transmission succeeded or failed. Each pair was recorded as a single entry in the database. Each entry contains the time when the first and second events of each pair occurred. In addition, each entry in the database contains a field which indicates whether the message transmission was successful.

2.2 Determining vehicle locations

After the OBU trajectories and events were recorded in the database, the OBU event table in the database was altered to include the locations of the vehicles at the time each of the events occurred. These locations were determined by consulting entries of the trajectory table in the database for the given date and time. The majority of records contained a trajectory entry which matched the time at which each OBE message was sent. However, on multiple occasions some of the trajectory data was missing for a given event. In that case, if the database contained records before and after the event occurred that spanned no more than 25 seconds, linear interpolation was used in order to determine the location of the vehicle. However, if the interval between the two closest trajectory records was
longer than 25 seconds, the location of the vehicle was not recorded and the entry was not included in
the final data analysis. Out of the 129,733 total entries in the database, the location of the OBE could
not be determined for 2046 entries. The majority of these entries were part of the 2008 POC trial as only
57 entries of the NCAR trials lacked proper trajectory information.

2.3 Determining the closest RSU and the distance between the OBU and RSU

The original event files provided on the IntelliDrive portal did not include the ID number of the
RSU to which each OBU was sending messages. In order to determine that, the RSU closest to the
location of each OBU at the moment when the OBU sent a probe data message was determined. The
date of each event was used in order to determine whether the POC or the NCAR set of RSU locations
needed to be utilized in order to determine the closest RSU. This data was then added to the OBU event
table. In addition, the actual distance between the OBU and the RSU was also calculated and added to
the table. The distance was determined by using the Euclidean distance formula on the Cartesian
coordinates that were included in the RSU and OBE location entries.
Data Analysis

3.1 Observations based on the data

3.1.1 Amount of data gathered and overall success rate

The total amount of data that was gathered included 127,687 messages that included all needed trajectory and distance information. The messages from the three trials were distributed in the following manner:

Out of all the usable messages 86,995 were found to be successfully transmitted. This means that the overall success rate of all messages was around 68%.

3.1.2 Distance distribution of transmitted messages

The analysis of the messages showed that most of them were transmitted at small distances. As discussed in Section 1.1 this is a direct result of the V-DTLS implementation and the capabilities of the OBU and RSU radios. However, it was also found that there was a set of about 6500 messages in the NCAR 2009 trial that was recorded at locations much further north (about 9000m) than any of the RSUs in the database. Since many of these messages indicated successful transmission, it is likely that some of the RSU data was missing or the OBU location data was incorrect. The distances at which the messages were transmitted are distributed in the following way:

![Distribution of messages according to trial](image.png)

*Figure 3. Distribution of messages according to trial*
3.1.3 Amount of messages sent at the same time

The database was also queried in order to determine how many probe data messages were sent simultaneously and could have resulted in collisions. Here it is important to note that the V-DTLS implementation at the testing site could only support a single thread which might have affected the success rate of these messages [6]. The database indicated that a total of 4534 messages were sent at times where more than one OBU sent a message to a particular RSU at a given second. This accounts for 3.5% of the total number messages. However, the data files include timestamps rounded to the nearest whole second it is impossible to tell whether these messages could be a part of a packet collision. Since each second contains 10 service channel intervals it can be estimated that 0.35% of all messages were sent at the same service channel interval as another message from a different OBU directed to the same RSU.

3.1.4 Correlation between distance and transmission success rate

The collected data allowed for the calculation of the probability to successfully transmit a message at a given distance. The data indicates that as the distance between the OBU and RSU increased, the probability of successfully transmitting a message decreased sharply. The probability dropped from 83% at an average distance of 50m to about 18% at an average distance of 850m. The following graph was obtained by averaging the successful probability ratio of each distinct 100m segment between 0 and 900m:

![Distribution of messages vs distance](image)
3.2 Comparisons to simulation data

Currently the power of the OBU and RSU transmitters and retransmission policies that were utilized to generate the data is unknown. However, the data can be compared to multiple simulated data sets in order to determine the feasibility of the simulations. All of the simulations exhibited similar characteristics to the real data. A sharp drop-off of the probability of successful communication as distance increases is observed in all cases. The following graph shows the comparisons of the data with different simulations:

Figure 5. A 95% Confidence interval of the probability of successful message transmission at different distances

Figure 6. Comparison of analyzed data to simulation data
All of the simulations included above assumed a transmitter power of 33.0 dBm for the OBUs and RSUs. In addition, a free space and shadowing model with a path loss exponent of 2.4 and a shadowing standard deviation of 9.0 was used along with a Nakagami model for small-scale fading. The BSM test case included a set of 130 vehicles simultaneously sending WSM broadcast messages during every service channel interval. This scenario is intended to simulate real traffic conditions. As seen above, the probability of successful communication of this scenario is lower than the analyzed data, which is expected since the 130 vehicle scenario would encounter a lot of packet collisions. The UDP single transmission scenarios include a single vehicle transmitting either 150 byte or 1000 byte packets to an RSU at different distances. This scenario more closely resembles the scenario in which the data was gathered as discussed in section 3.1.3. The simulated scenario exhibited success rates that were between 2 and 11 percent higher than the success rate of the analyzed data. The graphs of these scenarios indicate the probability of successfully transmitting the message but do not factor in the probability of successfully receiving an acknowledgment message afterwards.

The following graph compares the analyzed data with simulations that factor in the acknowledgments and retransmission policies into the probability of successful communication:

![Comparison of Retransmissions](image)

Figure 7. Comparison of the analyzed data with simulations that consider acknowledgements and retransmissions

The graph indicates that simulations that use acknowledgement and retransmissions would generally produce curves with sharper slopes, which is expected since they have to factor in the probability the transmission of the acknowledgment could fail. In addition, the graph shows an expected increase in the probability of successful communication as the number of retransmissions increases. The simulations with no or 1 retransmission are closer to the actual data analyzed, which indicates that the analyzed data may not have included any retransmissions. Since [5] suggests that retransmission is against the privacy rules of the probe data service and that the radios of the OBUs and RSUs might not have the same power, it is possible that the testing data was generated by a single transmission,
acknowledgement based scenario where the RSU has a higher powered radio than the OBU. Such a scenario would result in a simulation which would have a curve somewhere in between the “0 retransmissions” curve of Figure 7 and the “UDP 150 byte single transmission” curve of Figure 6, which would match the real data curve.
References


