# Appendix C:
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# 1 Background

In order to refine the initial communication requirements that were established in Task 3 for potential 5.9 GHz safety applications, the Vehicle Safety Communications Consortium (VSCC) developed a specialized Communications Test Kit (CTK) and a mobile communications network simulator. The test kits and simulator were used to validate the Task 3 communications parameters and provide informed input to the Dedicated Short Range Communications (DSRC) standards development efforts. All VSCC member-companies were provided with two CTKs for investigations within the VSC project, particularly the Task 4 testing activity.

## 1.1 Communication Test Kits

Though the DSRC standards were incomplete, it was feasible to use and modify existing 802.11a equipment to simulate performance in the DSRC band. In order to use the equipment for test purposes, original software had to be written to integrate the various components and provide the necessary test environment to configure, conduct, record, analyze, and display generated test results. The VSCC agreed to have DaimlerChrysler define, develop, and assemble the CTKs based on their past experience with similar equipment. The next step was to define essential CTK features required for baseline functionality.

The CTKs were intended to support testing of multiple vehicles' communications on roadways at normal driving speeds. In order to accomplish anticipated tests in a vehicular environment, the VSCC derived the following CTK functional requirements:

- Communications based on a representative 802.11a radio.
- Mobile computing platform interfaced with the radio to support test configuration, operation, and documentation.
- Measurable and recordable communications performance data.
- Optimized communication paths between radios.
- Accurate and recordable position knowledge of test vehicles that is synchronized with test data and updated frequently.
- A minimum of two test kits for performing wireless communication testing.
- Post-processing for data analysis.

A further requirement was that the 802.11a device should be able to connect directly with a host computer, and that the computer should be portable to allow easy transition between vehicles. External antennas for the 802.11a frequency should be mounted on the vehicle exterior, and a Differential Global Positioning System (DGPS) receiver would be needed for relatively accurate vehicle position readings.

### 1.1.1 Test Kit Hardware

Given the preceding requirements, DaimlerChrysler, with VSCC participation, assembled the following components to create the baseline CTK:

| Item | Brand and Model | Comments |
|---|---|---|
| 802.11a radio | Atheros model AR5211, mini-PCI format (MB23 board) | The mini-PCI format supports external antennas (note antenna connectors and cables on top right of photo). This format also provides a higher maximum transmit power than the PC card version. |
| GPS receiver | DGPS Max from Communications Systems International, Inc. | This differential GPS receiver determines position accuracy to 1 - 3 meters 95 per cent of the time. It also has a 5 Hz update rate. |
| Laptop | IBM T23 laptop | IBM T series laptops have a mini-PCI slot in the base that is user accessible. They also have a serial port for the DGPS interface. Note the installed 802.11a card and attached pigtail RF coaxial cables. |
| Antenna | Atheros Access Point antennas (AP21 antenna) | These strip antennas are optimized for 802.11a operation in the 5.1-5.3 and 5.8 GHz range. They also allow for mounting away from the 802.11a radio, but came as bare units with only an RF connector on the base. |
| Antenna enclosure | Hayes, custom design | Clear polycarbonate enclosures with magnetic mounts were designed and built specifically for the Atheros antennas. These were essential for tests with external antennas at vehicle speeds. |
| RF coaxial cables | Talley Communications, custom build | These low loss cables were custom built to remotely connect the antenna to the radio card. They also allow for the anticipated distance between the external antenna and the rest of the test kit inside the vehicle. |

A custom antenna housing and mount were needed to protect the 802.11a antennas at freeway speeds and to secure it to the vehicle exterior. Examples of the typical antenna mounting configurations on different vehicle types are shown below:

**Figure 1. Typical Antenna Mounting Configurations**

### 1.1.2 Test Kit Software

Test kit software for the host laptop computers needed to be developed. Initial testing was conducted with Version 2.3 software, and subsequent revisions were made to more closely resemble the anticipated DSRC standard and to improve the capabilities of the CTK. The latest revision used in formal evaluation (shown in the table below as Version 3.0) accommodated multi-sender testing.

| CTK S/W v2.3 | CTK S/W v3.0 | DSRC Standard |
|---|---|---|
| 25/50 mW default antenna input power settings | Programmable antenna input power (100 mW spec.) | Up to 750 mW variable antenna input power |
| 5.15-5.35, 5.725-5.825 GHz | 5.15-5.35, 5.725-5.825, 5.85-5.925 GHz | 5.85-5.925 GHz |
| 20 MHz channel | 10 MHz channel | 10/20 MHz channels |
| Single-sender capable | Multi-sender capable | Multi-sender capable |
| Real-time range | Real-time range/RSSI | N/A |
| Pre-set channel | Selectable channel | Channel switching |
| Diversity antennas | Diversity with manual override | N/A |
| IEEE 802.11 Ad hoc | DSRC Ad hoc | DSRC Ad hoc |
| 6-54 Mbps | 3-27 Mbps | 3-27 Mbps |

**Figure 2. CTK Features**

The software has several components, each with specific functions:

- GPS library for converting the DGPS receiver data to a compatible format within the test kit laptop.
- VSC Test Kit Sender for configuring communication and test parameters, recording sending vehicle position, and transmitting test data packets from a single CTK.
- VSC Test Kit Receiver for configuring communication and test parameters and recording received data packets and vehicle position.
- VSC Test Kit Notation for annotating specific events during testing.
- VSC Test Kit Diagram for post-processing and displaying the test data results.

### 1.1.3 Test Kit Diagramming Function

The CTK diagramming function provides a means to display the test data results in a graphical format. A sample diagram from the Version 2.3 software is shown below. In this test, 236 packets were sent, 206 packets were received, and 30 packets were lost over a 26 second test duration and vehicle separation distances ranging from 85 to 105 meters. The test was conducted on a test track with one vehicle slowly moving away from the other.

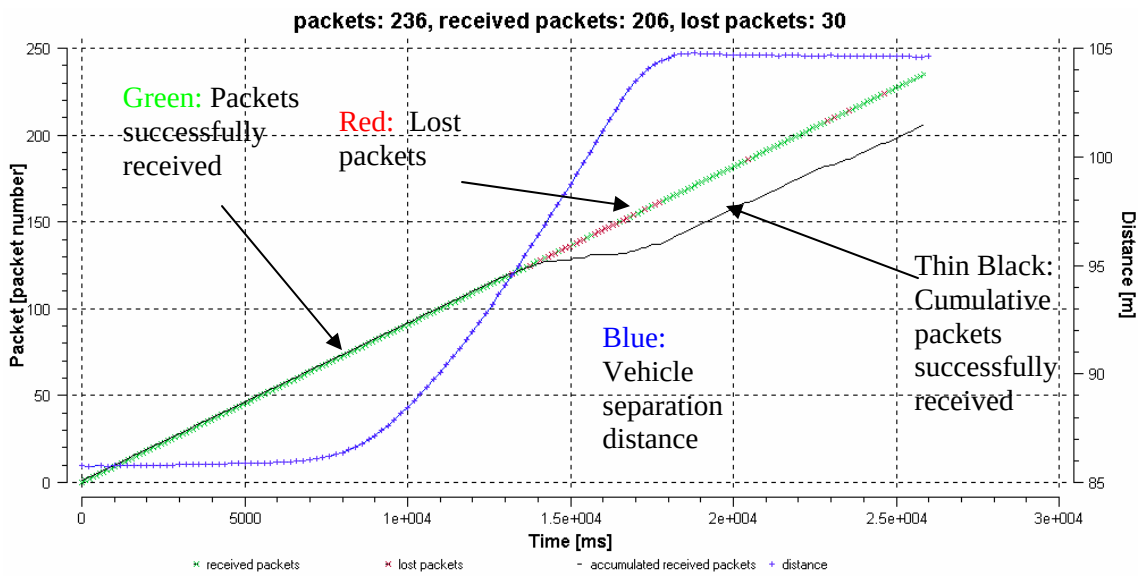



**Figure 3. Test Kit Diagramming Key**

Additional data capture capabilities were added during the course of the project. One of the major improvements was the addition of the received signal strength indication (RSSI). The RSSI is not plotted against specific values shown on an axis, but it provides an indication of the received power (sensitivity between –96 dBm and –36 dBm). This allows for more detailed analyses of the correlations between packet loss and

obstructions, for example. A significant convenience feature has also been added to the test kits: a dynamic display of the distance between test vehicles in field test situations. This feature made field-testing much more precise, by allowing separation distances between moving vehicles to be maintained within the desired scenario values.

The diagram below shows the RSSI feature along with the addition of the multiple sender functionality. In order to clearly show the data received from both sending vehicles, note that the data from Sender 1 is offset from that of Sender 2. The use of offsets is evidenced by the negative values that appear on the Y-axis of the graph. The range and packet offset levels for Sender 1 are 50 meters and 200 packets.

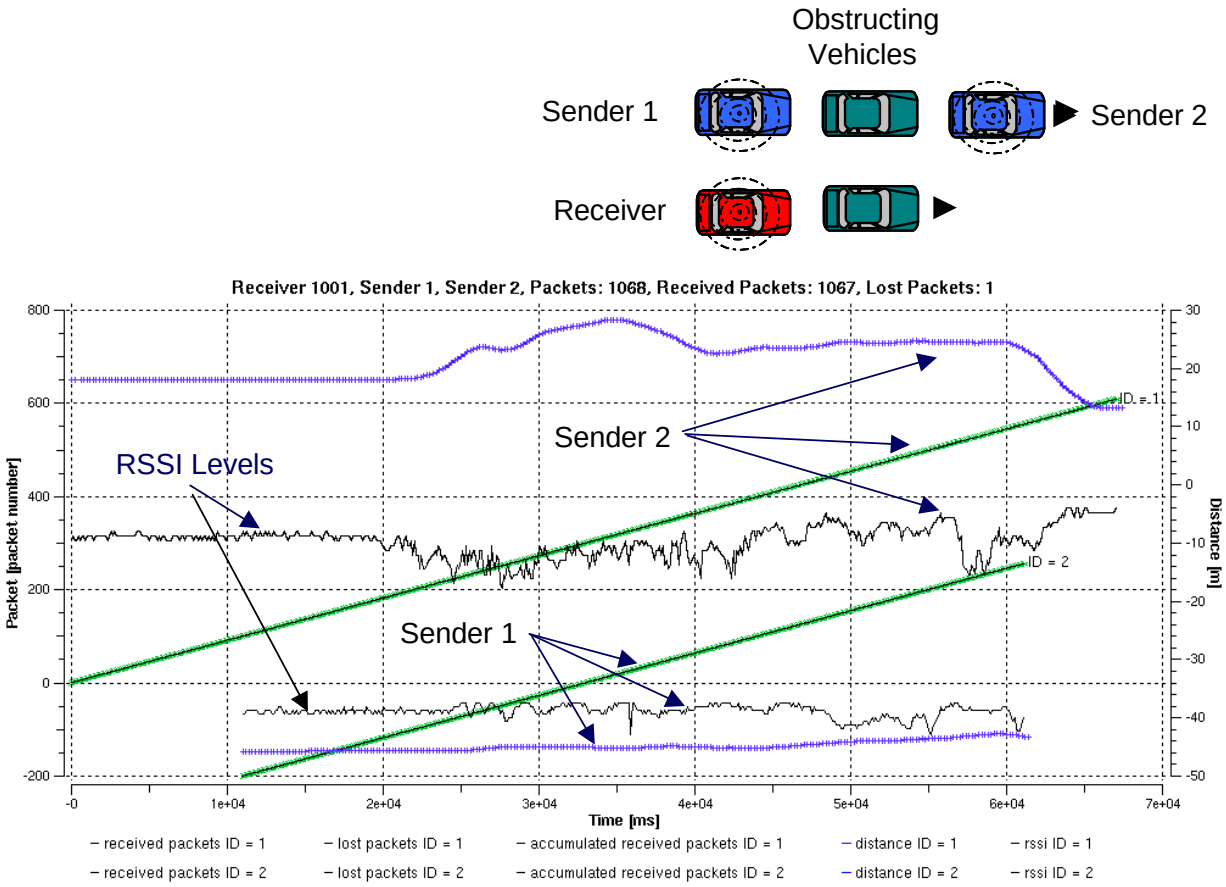



**Figure 4. Multi-Sender Diagramming Key**

## 1.2 Test Plan

Test scenarios have been defined by delineating the Technical Parameters and Environment Effects required to create the Requirements Summary (see the figure below). This has led to the definition of evaluation items within each application, scenario, and associated tests, and subsequently scripting the example test scenarios to address those areas of focus. The goals of the Task 4 example test scenarios were to create a testing procedure that could evaluate the test kits' development and provide timely feedback to the DSRC Standards development.

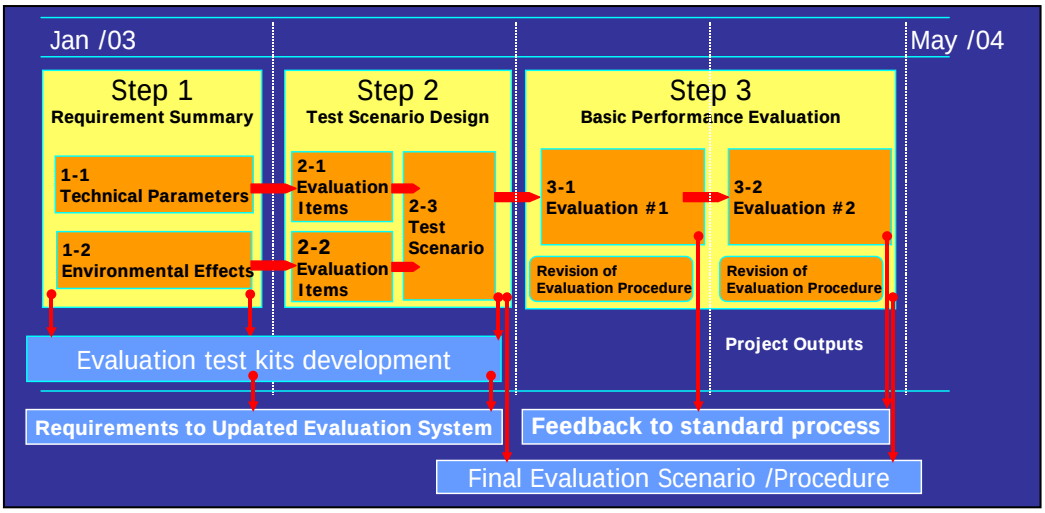



**Figure 5. Evaluation Flow Overview for Task 4**

### 1.2.1 Scenario Definition

The word "scenario" could have multiple meanings since every unique variable change within an environment creates a different scenario. After evaluating the aforementioned factors, VSCC grouped blocks of similar situations by the quantity of "sending" antennas required (*the eight priority applications from Task 3 require, at times, multiple sending antennas) and their relative movement, and described each assemblage with a "base scenario." To this base scenario, other technical parameters and environmental effects were added to define various test situations and sketches.

### 1.2.2 Technical Parameters

Technical parameters are defined herein as a subset of the overall variables within or between the test kits that may be considered when given a sterile or laboratory environment. Those variables that are introduced once the test kits and vehicles are introduced into "real-world" conditions are deemed environmental effects and are described in section 1.2.3.

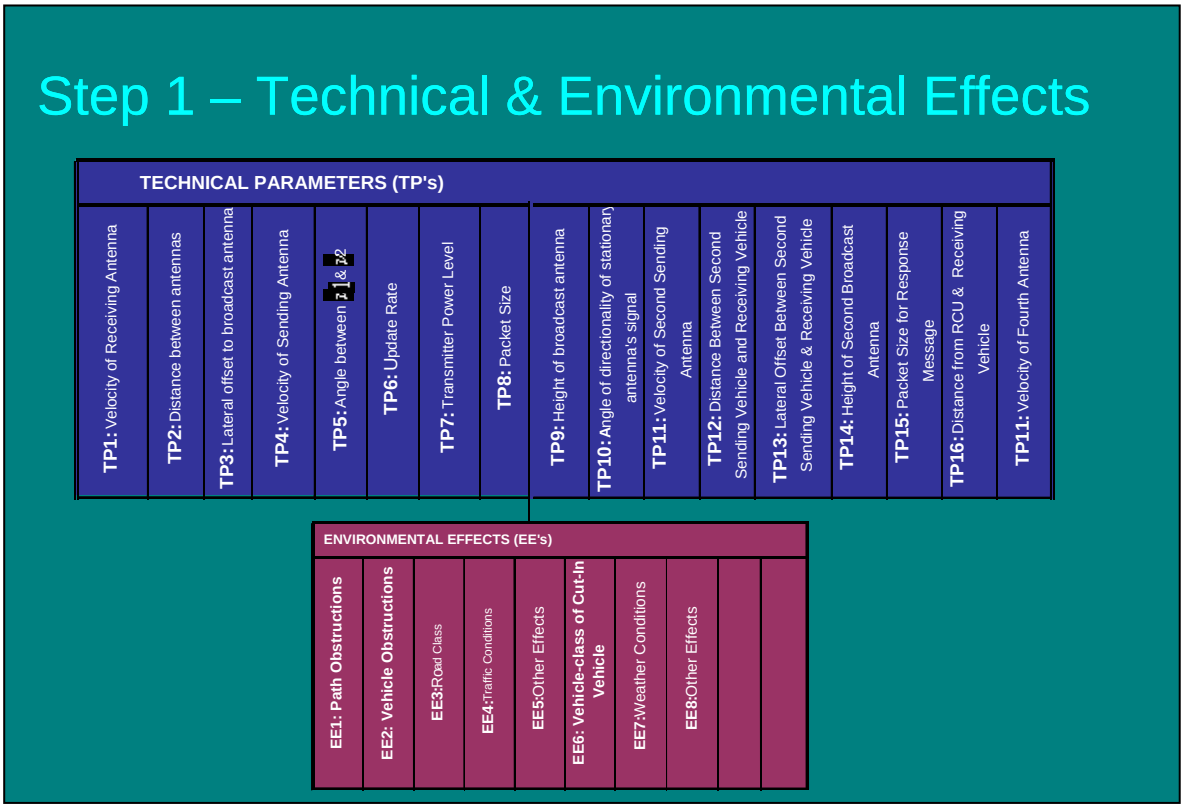



**Figure 6. Technical and Environmental Effects**

The variables shown below are the technical parameters that will be varied during Task 4 and, mostly likely, future tests:

- **$v_1$: Velocity of Receiving Antenna** – This value represents the speed (in miles per hour) of the receiving antenna; coupled with the sketch creates the velocity. The receiving antenna may be stationary in some tests ($v_1$ = 0 mph), thereby simulating an RSU.
- **$d_{y1}$: Distance Between Antennas** – This represents the distance (in meters) between the receiving antenna and the first sending vehicle along the y-axis.
- **$d_{x1}$: Distance Between Antennas** – This represents the distance (in meters) between the receiving antenna and the first sending vehicle along the x-axis. Four meters is meant to simulate one car lane.
- **$v_2$: Velocity of Sending Antenna** – This value represents the speed (in miles per hour) of the sending antenna; coupled with the sketch creates the velocity. The sending antenna may be stationary in some tests ($v_2$ = 0 mph), thereby simulating an RSU.
- **$\alpha$: Angle Between $v_1$ & $v_2$ –** This angle describes the difference in direction between the sending & receiving antenna's velocity, and serves simply as a numerical reinforcement of the test sketches' velocities.

- **$\xi$: Update Rate –** This represents the inverse of the number of times per second the test kits are sending the packets of information, and is expressed in milliseconds.
- **$P_t$: Transmitter Power Level –** This percentage describes at what relative level the sender is broadcasting the communication with respect to full potential power.
- **$s_1$: Packet Size** – The test kits broadcast a message of specified packet size (in bytes) wirelessly to the receiving antenna which may be varied by the engineer.
- **$d_{z1}$: Distance Between Antennas** – This represents the distance (in meters) between the receiving antenna and the first sending vehicle along the z-axis (see sketches). The z-axis height for all antennas will be fixed throughout Task 4 for testing simplicity.
- **$d_{x2}$, $d_{y2}$, & $d_{z2}$,: Distance Between Antennas** – This represents the distance (in meters) between the receiving antenna and the second sending vehicle along all three axes.
- **$\phi$: Angle of Directionality of Stationary Antenna's Signal–** This angle designates the directionality of the sending antenna.
- **$v_3$: Velocity of Second Sending Antenna** – This value represents the speed (in miles per hour) of the second sending antenna; coupled with the sketch creates the velocity. The sending antenna may be stationary in some tests ($v_2$ = 0mph), thereby simulating an RSU.
- **$v_4$: Velocity of Fourth Antenna** – This value represents the speed (in miles per hour) of the fourth antenna; coupled with the sketch creates the velocity. The sending antenna may be stationary in some tests ($v_2$ = 0mph), thereby simulating an RSU.

### 1.2.3 Environmental Effects

Environmental effects are defined herein as the variables that are introduced once the test kits and vehicles are introduced into “real-world” conditions. The variables shown below are the environmental effects that will be varied during Task 4 and, mostly likely, future tests:

- **Path Obstructions** – This is a reference indicator of whether a building or roadside structure shall be within the intended path of communications.
- **Vehicular Obstruction(s)** – This is a reference indicator of whether a vehicle shall be within the intended path of communications. This vehicle may be designated as a “cut-in” (temporary) or “sustained” (continuous) obstruction.
- **Road Class** – This designates the general category of road design (arterial, highway, test track) that shall be used for the specified test.

- **Traffic Conditions** – This loosely designates the relative volume of uncontrolled traffic desired while conducting the test (e.g., light, heavy).
- **Vehicle Class Of Cut-in Vehicle –** This loosely describes the size of vehicular obstruction (e.g., sedan, SUV, truck).
- **Weather** – This variable loosely describes the ambient conditions (e.g., raining, snowing, sunny) required to run the test.
- **Other** – Other variables which should be considered once Task 4 evaluations have shed light on conditions beyond the vehicle's design.

### 1.2.4 Scenario Definition

The figure below shows four test scenarios with their representative vehicle configurations. Testing for the first three scenarios was conducted using CTK v2.3 software, while tests for Scenario 4 were conducted with CTK v3.0 software.

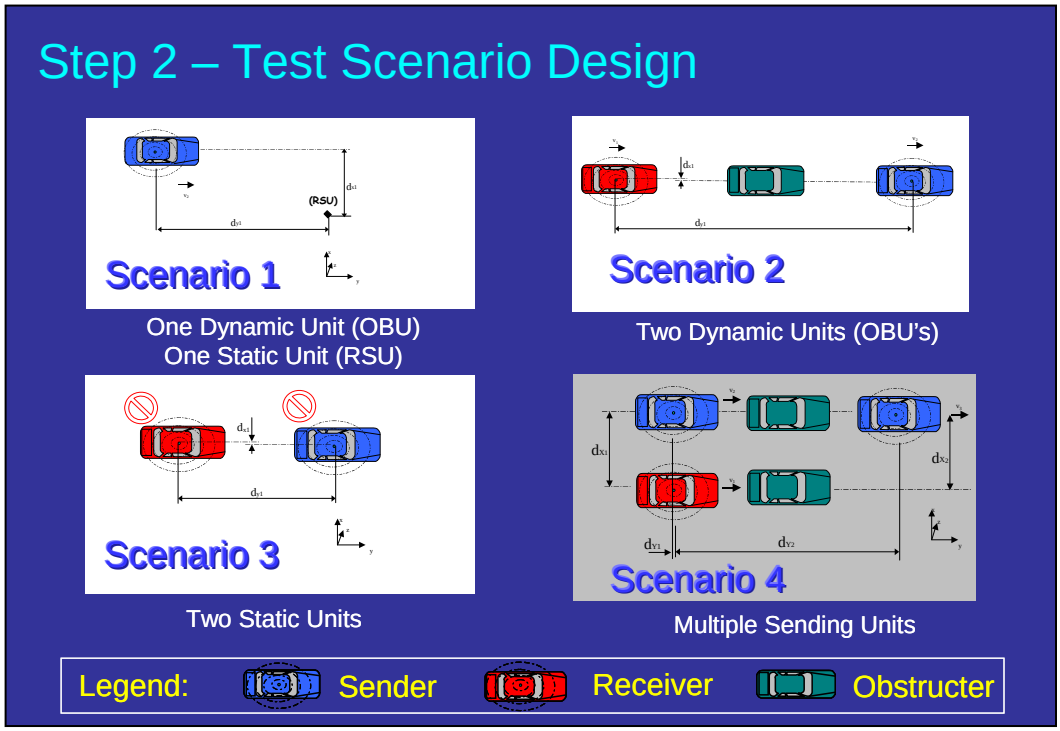



**Figure 7. Test Scenario Design**

### 1.2.5 Basic Performance Evaluation

The test plan was constructed based upon multiple field trials under each of the Task 4 test scenarios described in a test matrix. These test scenarios were chosen by the technical team to allow thorough field-testing and validation of the communications requirements for the eight high-priority application scenarios identified in Task 3.

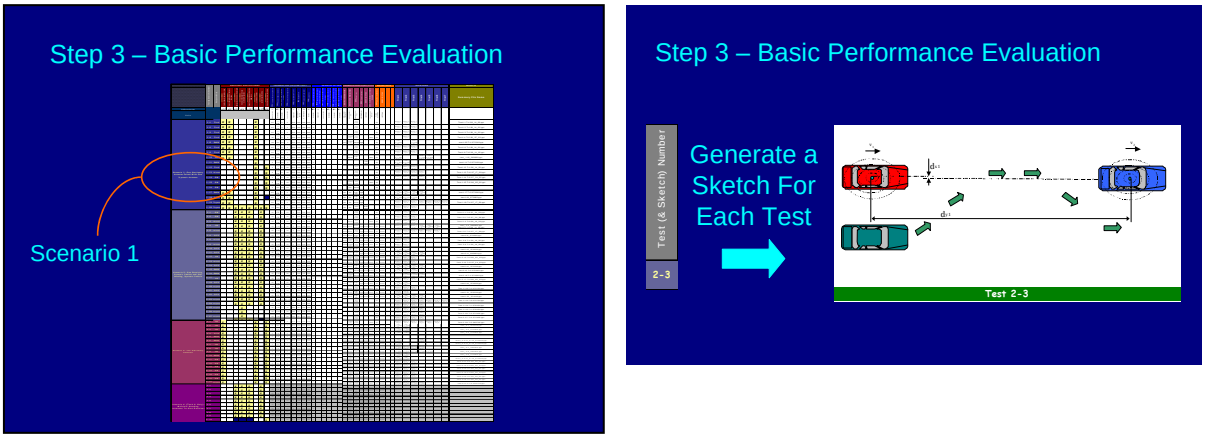



**Figure 8. Test Matrix and Vehicle Configuration**

The test data was collected during the field-testing. After analysis of multiple trials for each test scenario, a summary was prepared to illustrate the test results.

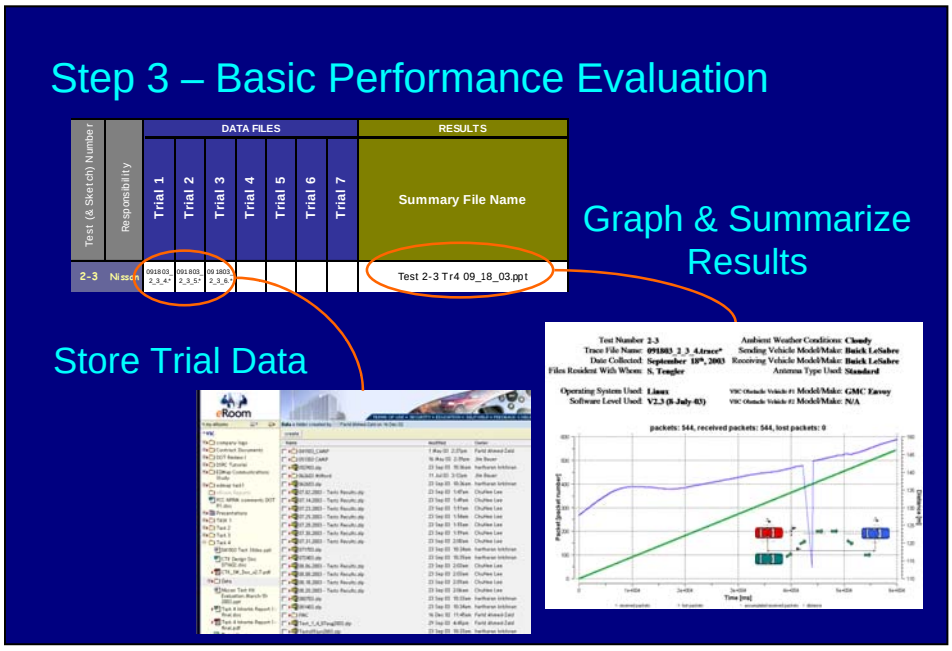



**Figure 9. Summary Development**

# 2 Field Test Results

The field-testing program was conducted using test track facilities at GM's Milford Proving Ground as well as testing on public roadways. The testing was conducted in accordance with the test scenarios described in the test plan, as well as detailed explorations of several factors that emerged from the initial test results.

Since DSRC equipment was not yet available, 802.11a was used to approximate DSRC operations. The general conditions throughout all the field-testing (with the exception of several tests with power control and multiple sender scenarios), included: broadcast of repetitive small packets (100-400 bytes), update rates of 50-100 milliseconds, ranges exceeding 300 meters, 5.15-5.25 GHz (802.11a) transmission frequencies, 20 MHz channel width, around 50 milliwatt transmission power (at the output port of the radio card), dry weather, and 6 Mbps data rate.

In general, multiple test runs were completed for each test scenario. After the test runs were completed for each scenario, the test data were analyzed and evaluated. A summary of the test results was then prepared for each of the test scenarios.

The test scenarios can be divided into five main categories:

- Dynamic Vehicle-Roadside Communications
- Dynamic Vehicle-Vehicle Communications
- Stationary Vehicle Communications
- Multiple Sender Communications
- Multipath Considerations

The following sections summarize the test results in each category by presenting examples of the test results on a scenario-by-scenario basis within each of the main categories. Further details of each particular test can be found at the end of this appendix. An illustration of each scenario graphically portrays the test result summary for the examples shown.

## 2.1 Dynamic Vehicle-Roadside Communications

The testing of dynamic vehicle-roadside communications within the scope of Task 4 consisted of using a stationary test vehicle located beside the roadway as a surrogate for the roadside unit (RSU). The main limitations that were imposed by this arrangement were the constraints on antenna height and placement.

Tests performed in a test track environment showed excellent communication performance for transmissions having both direct line-of-sight (LOS), and also a single vehicle obstructing the LOS between the sending and receiving antennas. The following diagrams illustrate the results found during these tests. The diagram below (Test 1-2) shows a receiving vehicle traveling at 60 mph with no packet loss 300 meters before passing the stationary sending antenna, and 300 meters after.

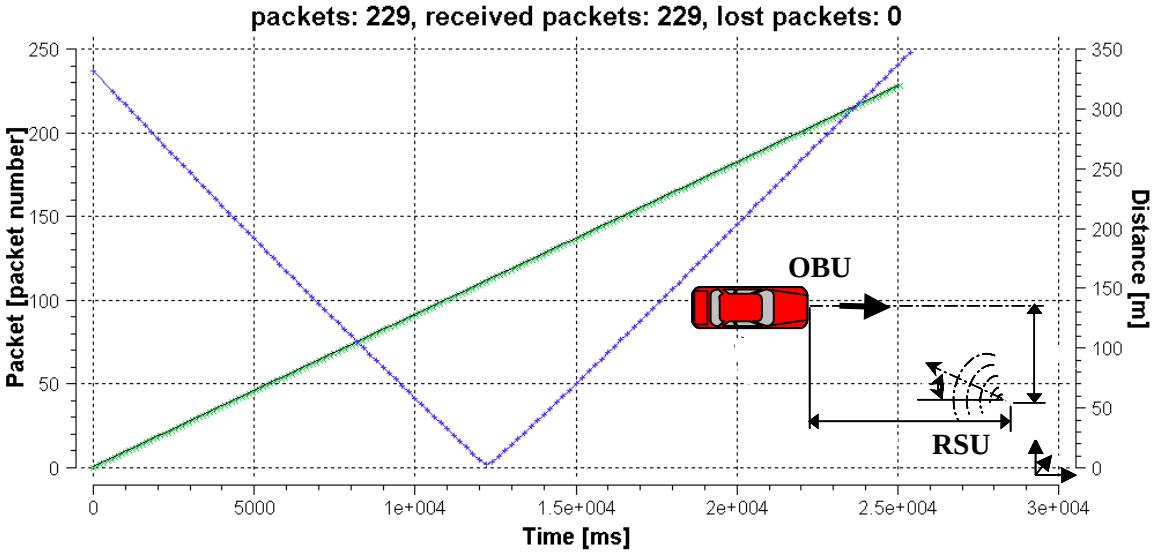



**Figure 10. Test 1-2 Results**

A similar test was conducted in which the moving vehicle transmits packets instead of receiving them (Test 1-12). In this trial, a few packets were lost at a range of about 90 meters, but over 99 percent of the packets were still received.

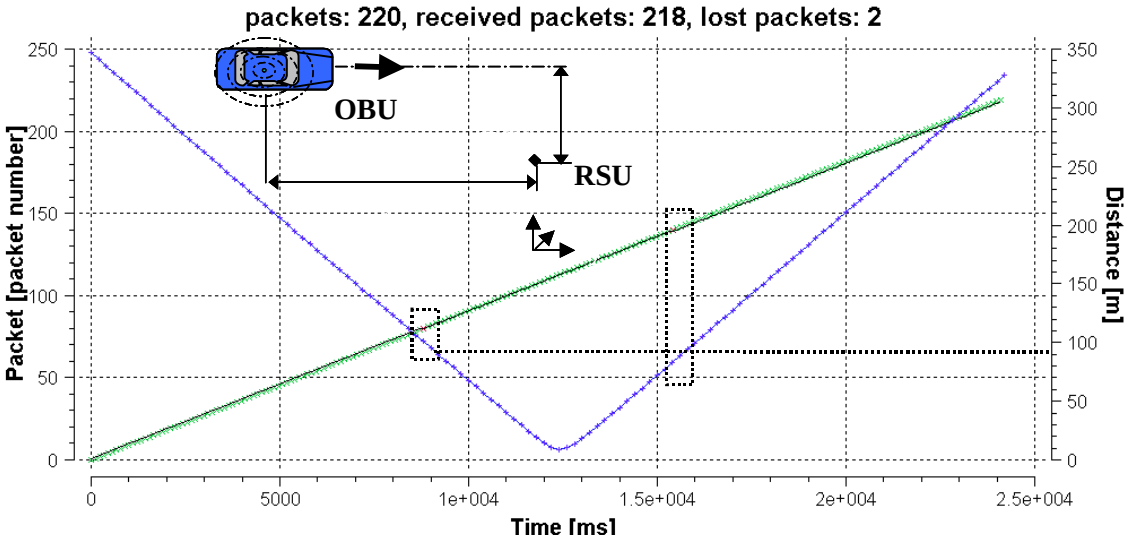



**Figure 11. Test 1-12 Results**

Similar results were found in a test in which the moving vehicle slows down to 20 mph (Test 1-14). In this case, a few packets are lost at a range close to 80 meters both before and after the transmitting vehicle passes the stationary antenna.

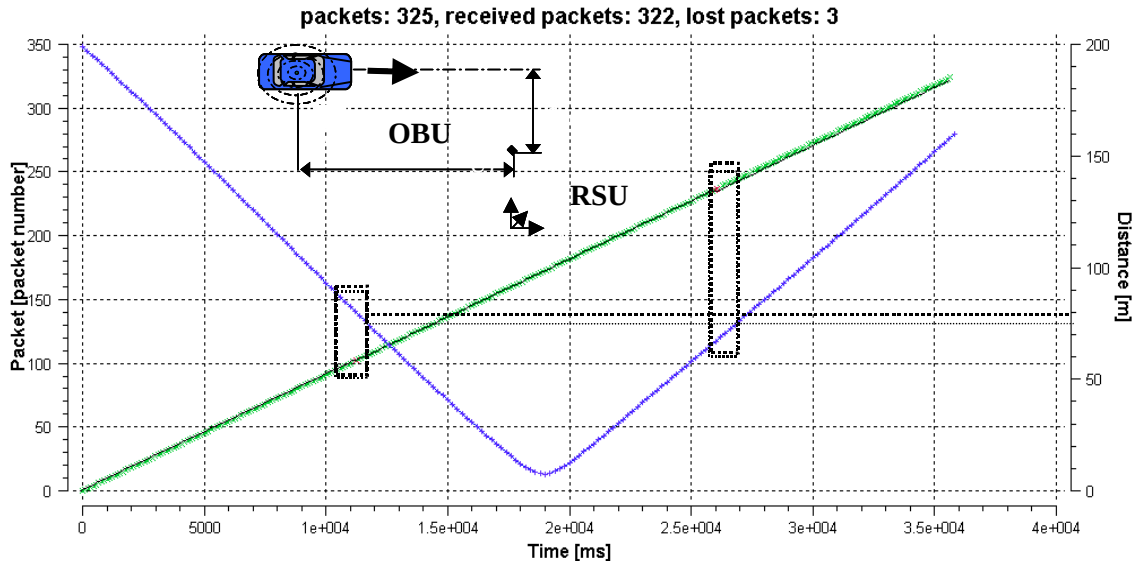
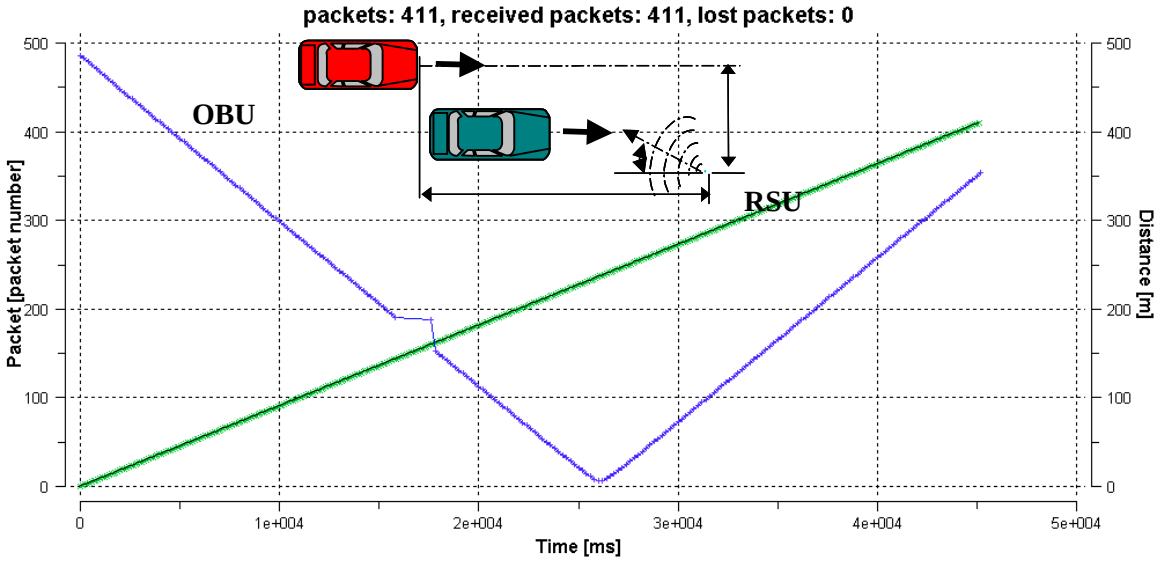



**Figure 12. Test 1-14 Results**




This pattern of lost packets at distances close to 80-90 meters was investigated further, and the findings are described in Section 2.5: Multipath Considerations. The results were similar when an obstructing SUV moving at the same speed as the receiving sedan blocked the direct line-of-sight to the stationary antenna (Test 1-4). There were no lost packets with the vehicles moving at 40 mph.

**Figure 13. Test 1-4 Results**

The same was true when the moving vehicle changed its role from the receiver to the transmitter (Test 1-15). There were no lost packets while traveling at 40 mph.

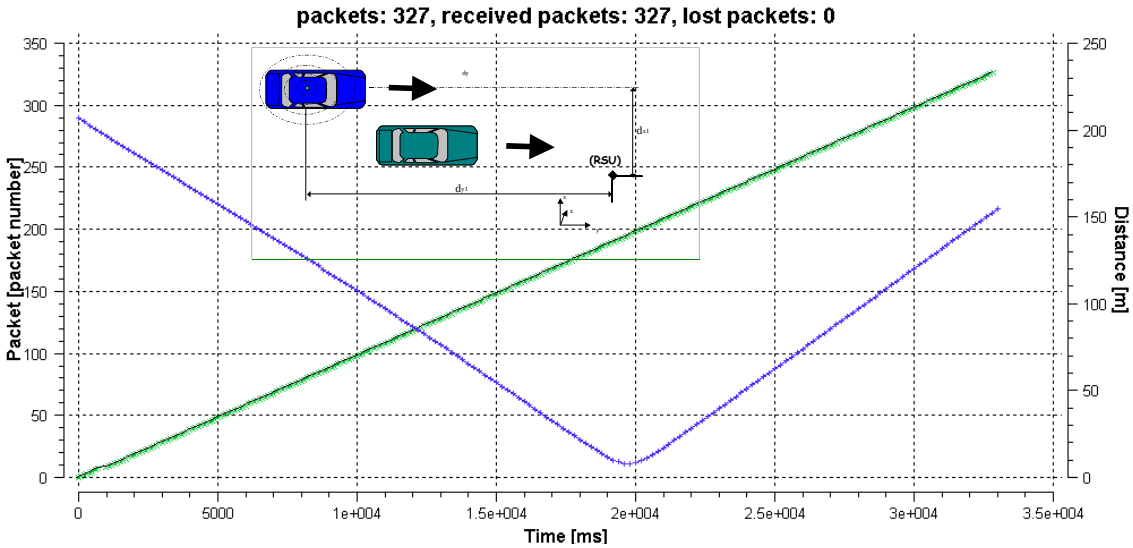



**Figure 14. Test 1-15 Results**

The public road tests featured results with passing vehicles, cut-in vehicles, and other variables to complicate the transmission environment. The diagram below shows a receiving vehicle passing a stationary sending antenna at 60 mph along a highway with light traffic conditions (Test 1-17). Almost no packets were lost on the straight-away for the middle section of the test. There was no reception before and after the straight-away where the road makes sharp bends and obstruction blocked the antennas.

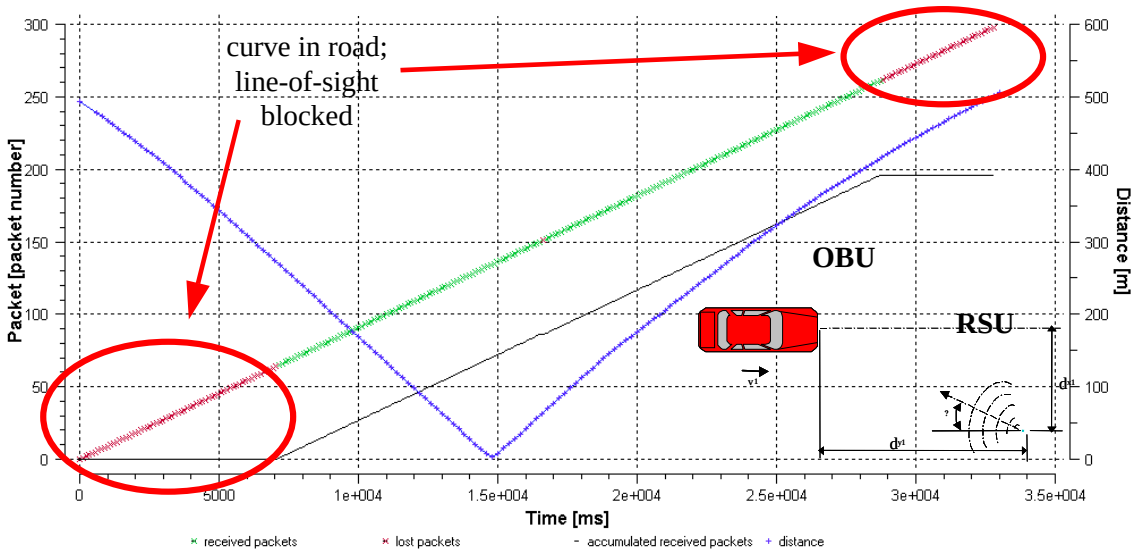



**Figure 15. Test 1-17 Results**

More packets were lost in heavier vehicle traffic, as the diagram below illustrates (Test 1-22). This test took place on an arterial road in a rural environment at 30 mph, and heavy traffic periodically blocked the line-of-sight while the receiving vehicle approached the roadside unit. After the vehicle passed the RSU, it went over a hill and out of line-of-sight.

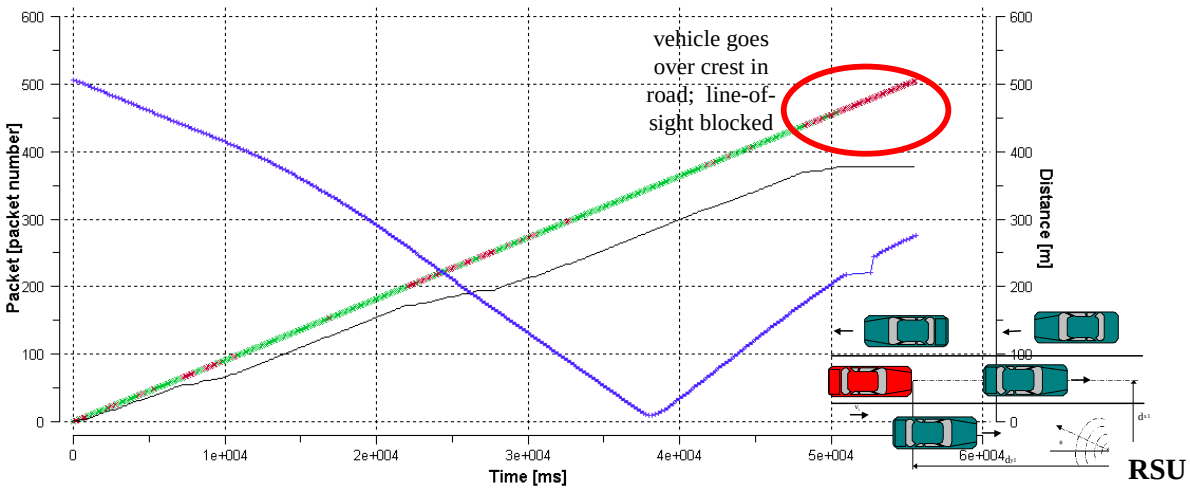



**Figure 16. Test 1-22 Results**

Another test showed similar results with the line-of-sight being blocked by a truck in addition to the SUV used for the trial (Test 1-10). As the sender goes out of line-of-sight, the RSU started losing packets.

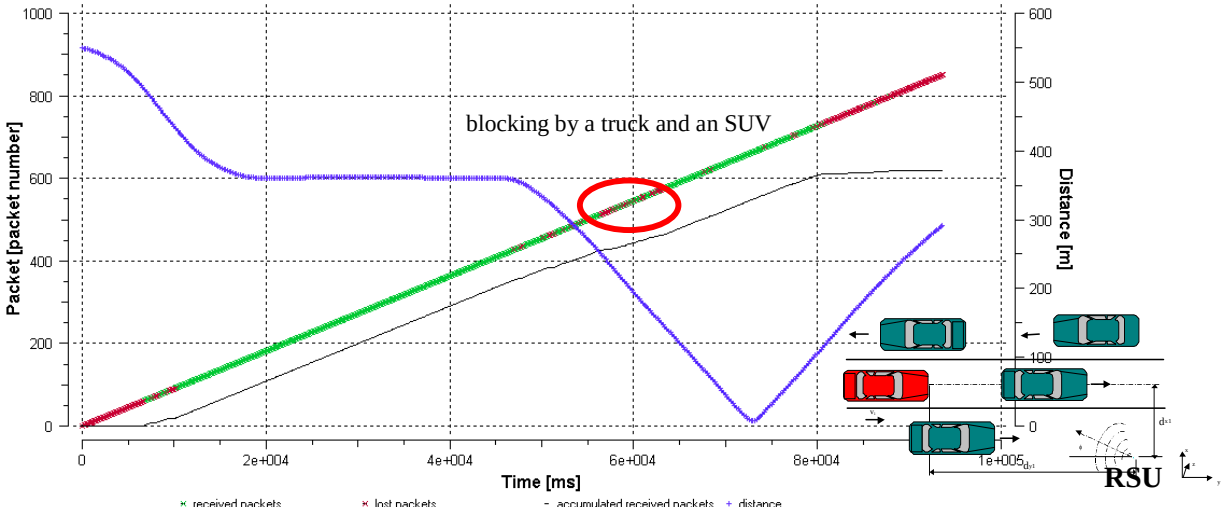



**Figure 17. Test 1-10 Results**

## 2.2 Dynamic Vehicle-Vehicle Communications

This section discusses the results with two dynamic antennas representing vehicle-to-vehicle communications. In the diagram shown below, there were no lost packets with two vehicles traveling in the same direction with a distance between them of about 150 m (Test 2-2). The test was conducted on a test track at speeds up to 60 mph.

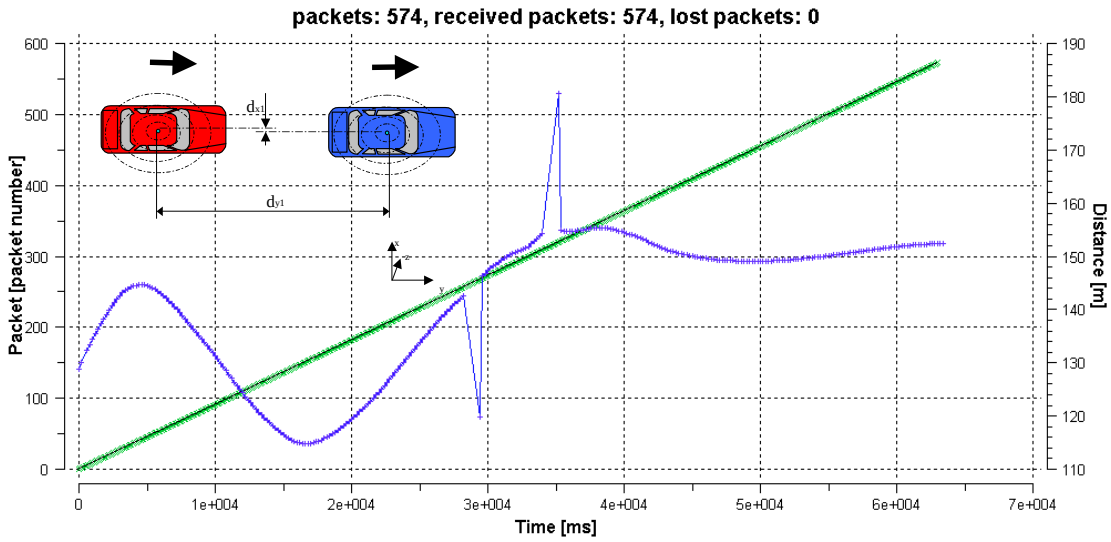



**Figure 18. Test 2-2 Results**

In a similar test track trial, there were also no packets lost when an SUV temporarily cut in between the vehicles (Test 2-3).

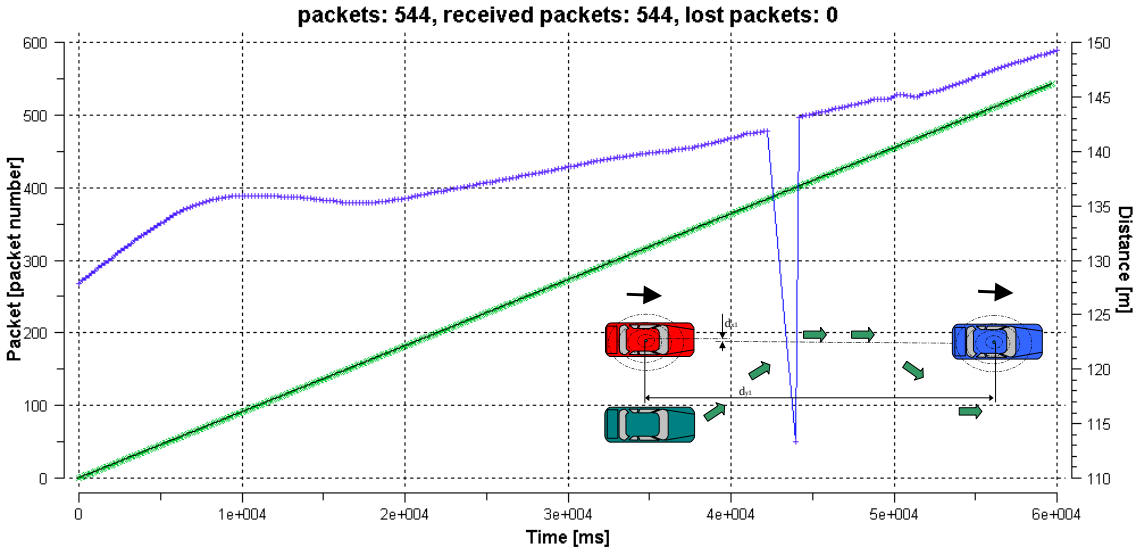



**Figure 19. Test 2-3 Results**

The test below approximates the driving characteristics of an application like Emergency

Electronic Brake Lights (Test 2-28). The sender vehicle and an obstructing SUV brake to a stop while the receiving vehicle passes them at 50 mph. In this particular trial about 5 percent of the packets were lost, and this packet loss appeared to be due to the obstructing SUV. The test results were repeatable over several trials.

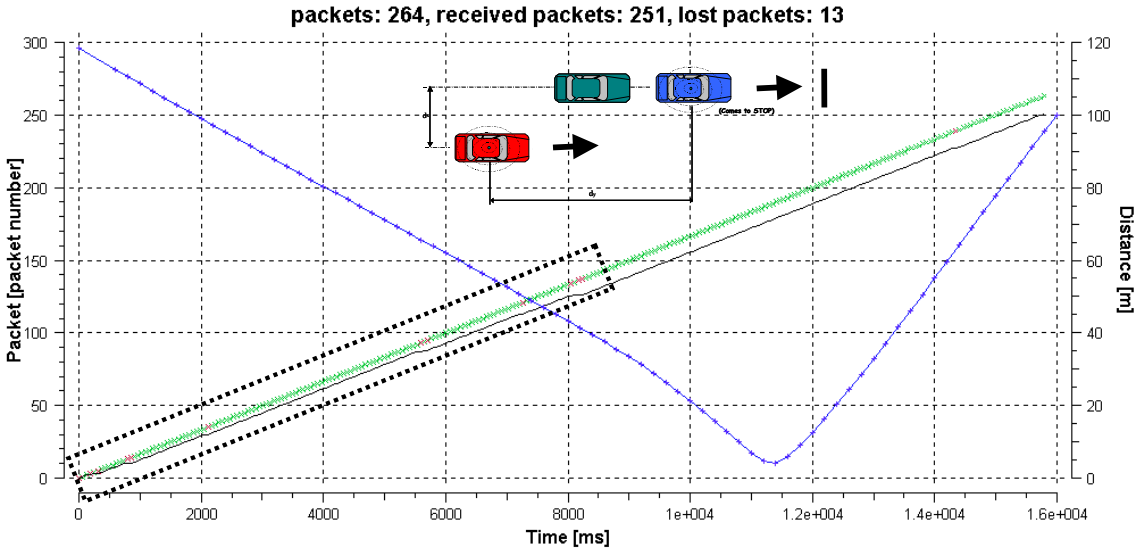



**Figure 20. Test 2-28 Results**

In this next test the obstructing vehicle was removed. The results improved significantly with only a few lost packets occurring at a range of about 90 meters (Test 2-24).

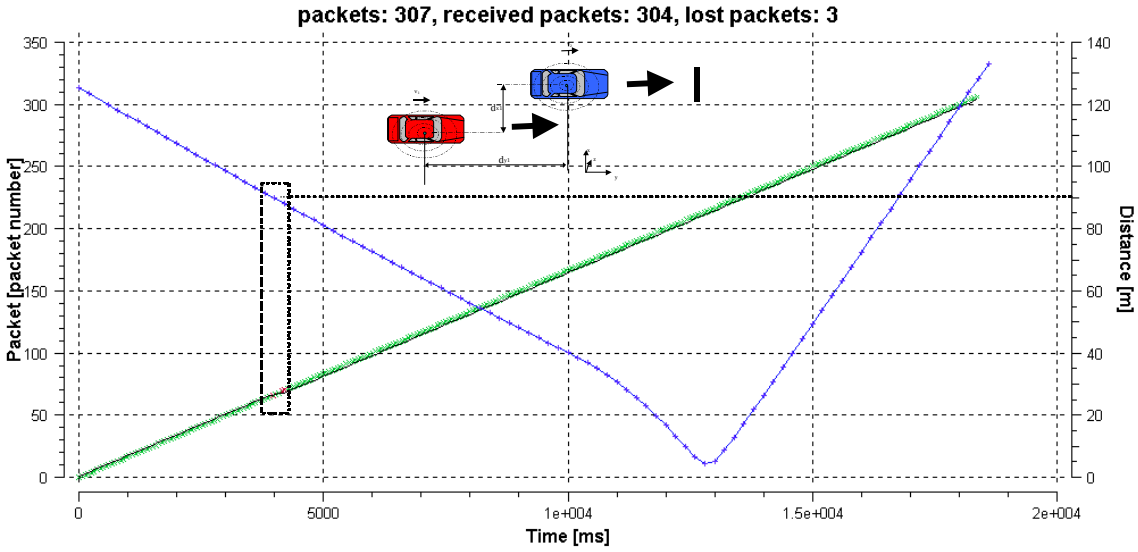



**Figure 21. Test 2-24 Results**

The next test approximates the driving characteristics of an application like Pre-Crash Sensing by having the sending and receiving vehicles pass by each other at 50 mph, simulating a head-on collision (Test 2-27). The test also was meant to stress the system with a high delta-velocity and a 50 msec update rate. Even at distances up to 400 m, there was no packet loss.

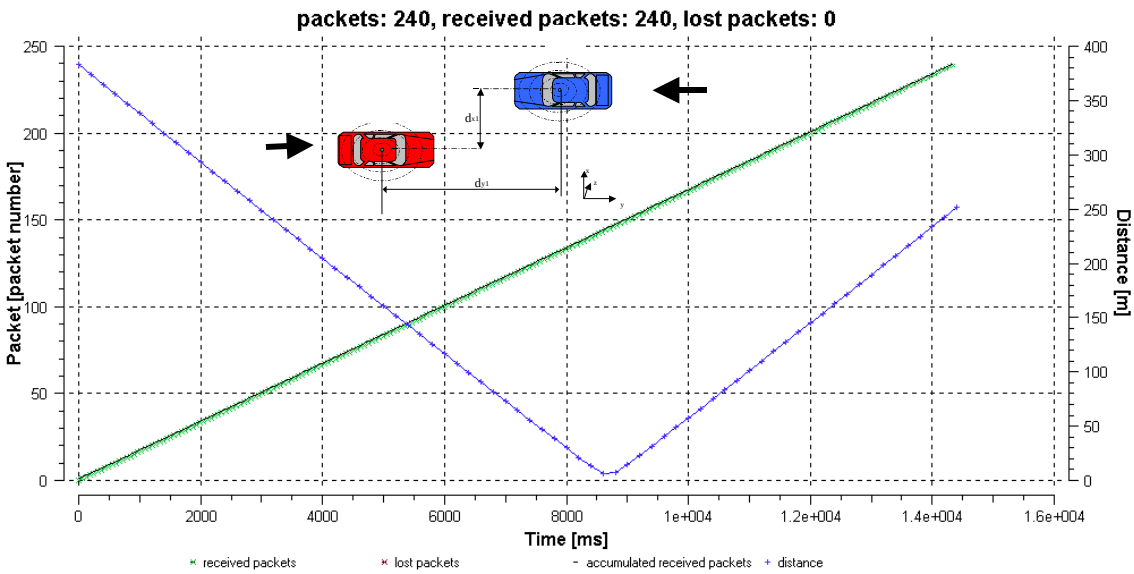



**Figure 22. Test 2-27 Results**

Interestingly, there was packet loss during a less stressful test with the vehicles traveling at 30 mph (Test 2-25). Once again the packet loss occurred when the vehicles were at a distance of about 90 m.

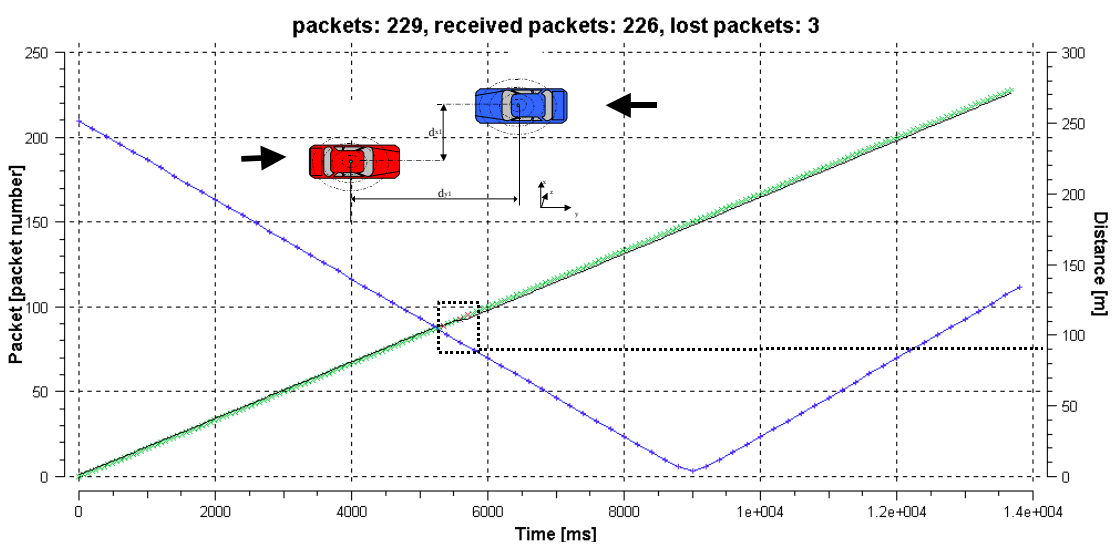



**Figure 23. Test 2-25 Results**

In the public road testing, basic communication at separation distances of around 100 meters experienced less than 3 percent packet loss (Test 2-6). The vehicles were traveling on a highway at 60 mph in light vehicle traffic conditions. The packet loss in this case is most likely due to a truck moving in between the two cars and blocking the line-of-sight.

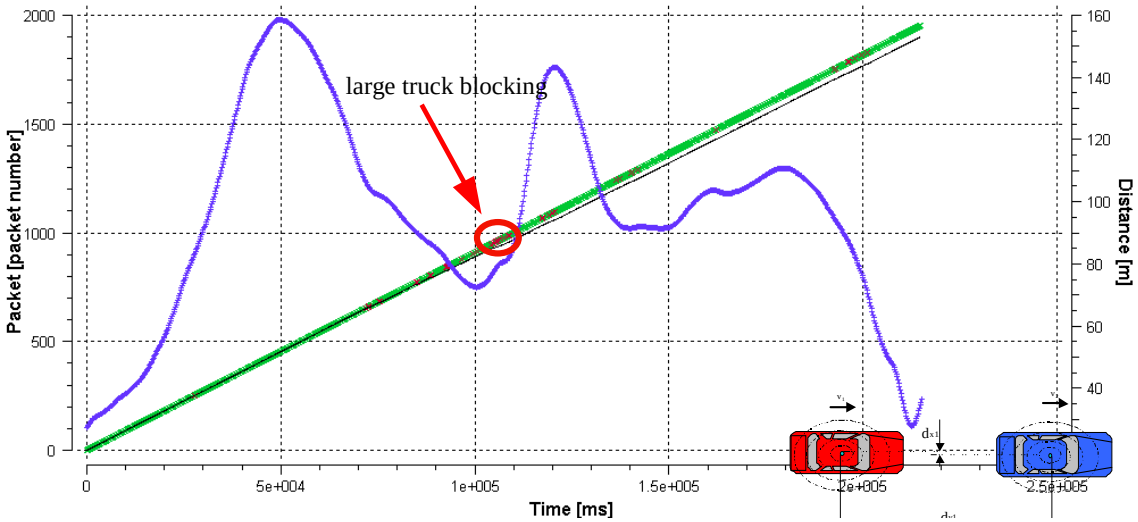



**Figure 24. Test 2-6 Results**

Similar results were found when the vehicles had a two-highway lane offset while traveling at 60 mph (Test 2-14). There was noticeable packet loss due to line-of-sight blockage between the test vehicles while driving on opposite sides of a hillcrest.

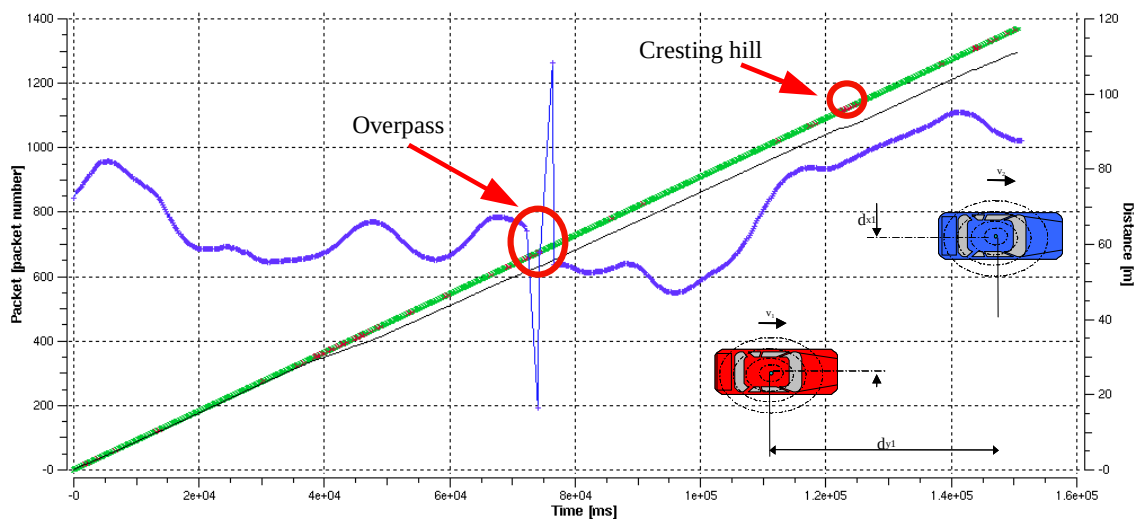



**Figure 25. Test 2-14 Results**

Momentary packet losses were also experienced with blocking sedans between the sending and receiving vehicles while traveling at 40 mph in light traffic conditions, as shown below (Test 2-25). The GPS outages were due to many thick overhanging trees.

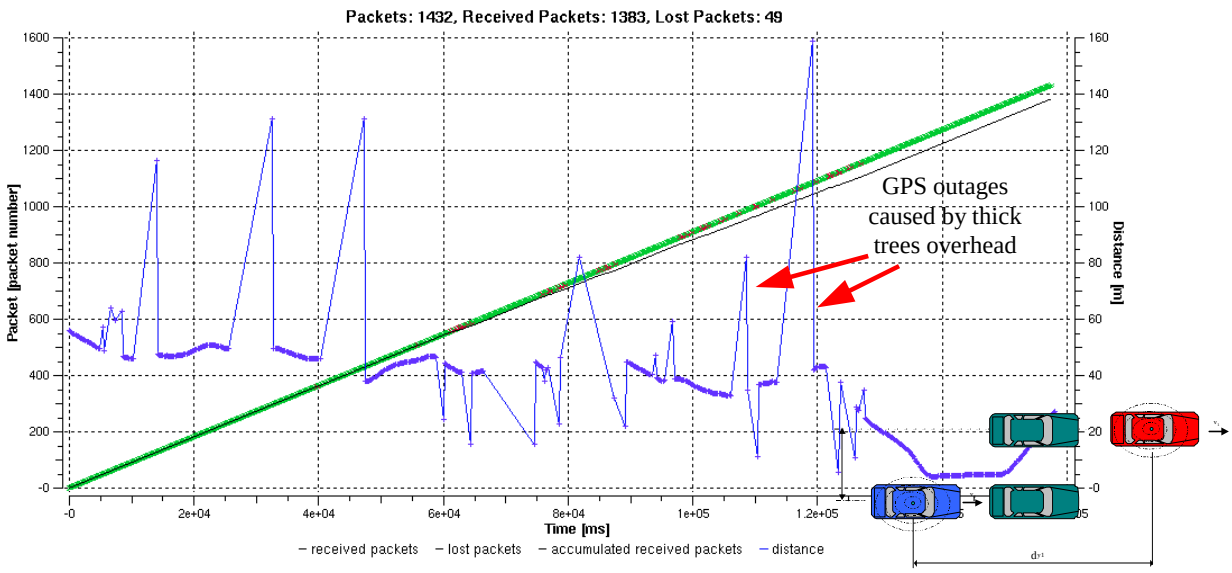



**Figure 26. Test 2-25 Results**

Two blocking SUVs between the sending and receiving vehicles caused more significant packet losses as shown in the trial below (Test 2-11). The vehicle formation was traveling at 60 mph in light traffic conditions. Packet transfer seemed more successful at longer distances, possibly due to reduced field of view blockage compared to that of a tightly packed formation.

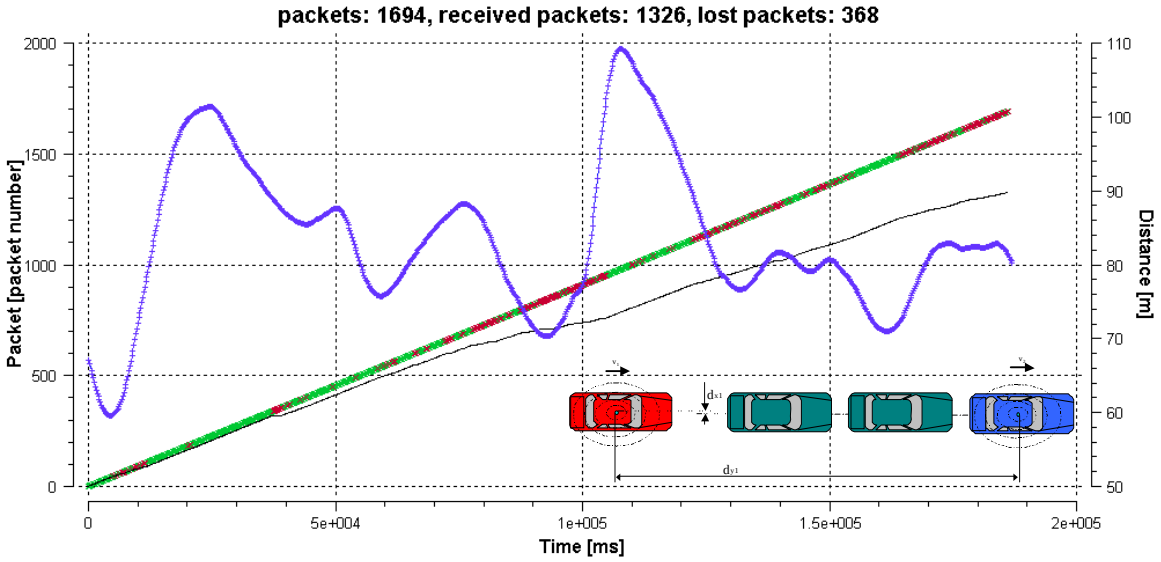



**Figure 27. Test 2-11 Results**

## 2.3 Stationary Vehicle Communications

The static tests considered communication range and the effect of other vehicles obstructing the line-of-sight between the antennas. The test below shows that no packets were lost at a distance of 200m with the vehicles in direct line-of-sight (Test 3-4). The message size was 200 bytes with a 100 msec update rate.

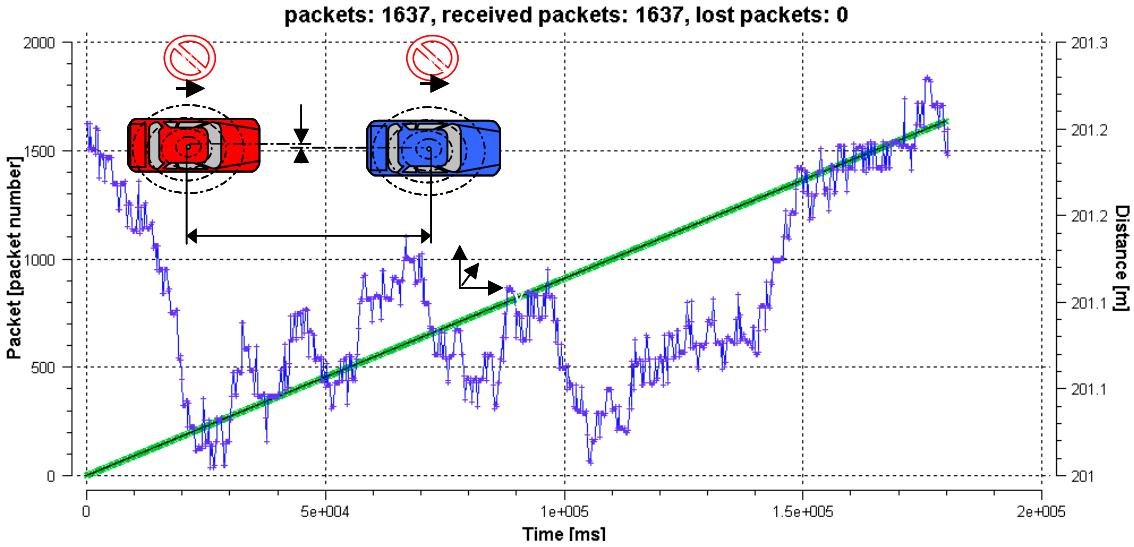



**Figure 28. Test 3-4 Results**

Another test considered a large, box-type truck parked laterally between the test vehicles (Test 3-14). There were no lost packets with this arrangement.

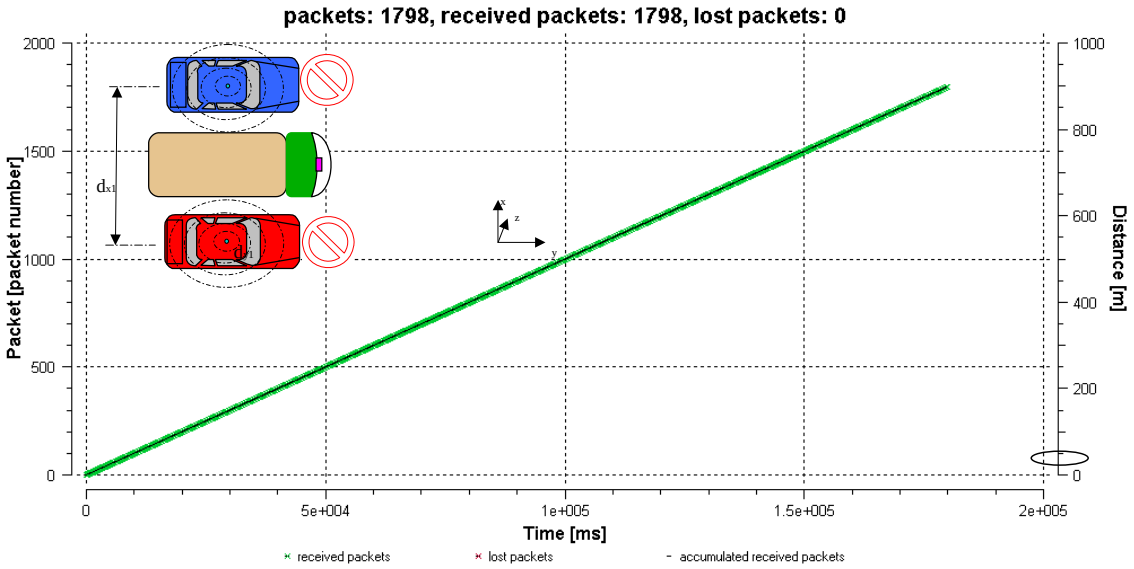



**Figure 29. Test 3-14 Results**

A similar test where the vehicles were parked longitudinally at a distance of 39 meters with the truck between them found some packet losses, though 93 percent of the packets were still received (Test 3-12).

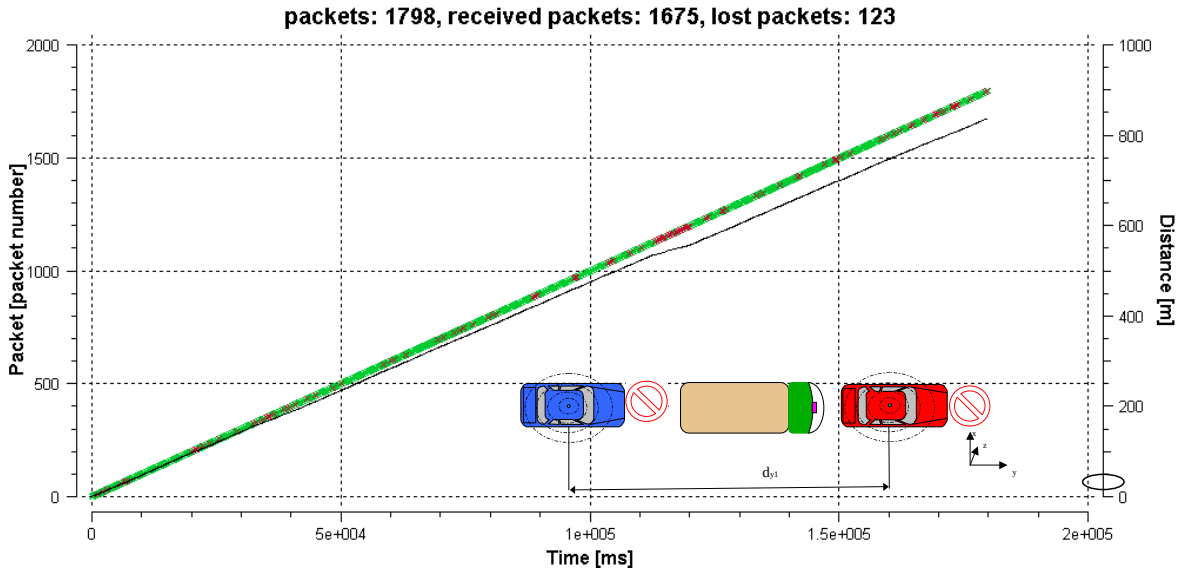



**Figure 30. Test 3-12 Results**

Transmissions were excellent between two stationary vehicles in a public parking lot (Test 3-3). No packets were lost at a distance of 148 meters.

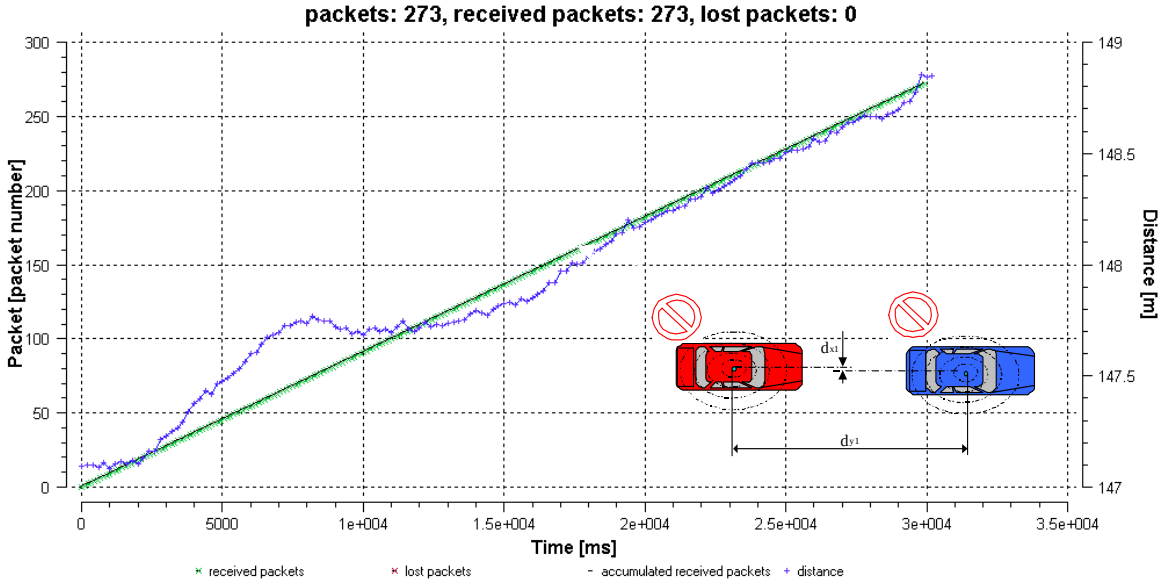



**Figure 31. Test 3-3 Results**

Another test conducted in a parking lot had the sending and receiving vehicles separated by an SUV parked between them (Test 3-9). No packets were lost during the test. The distance between the test vehicles based on GPS data fluctuated from ~9 ~10 meters.

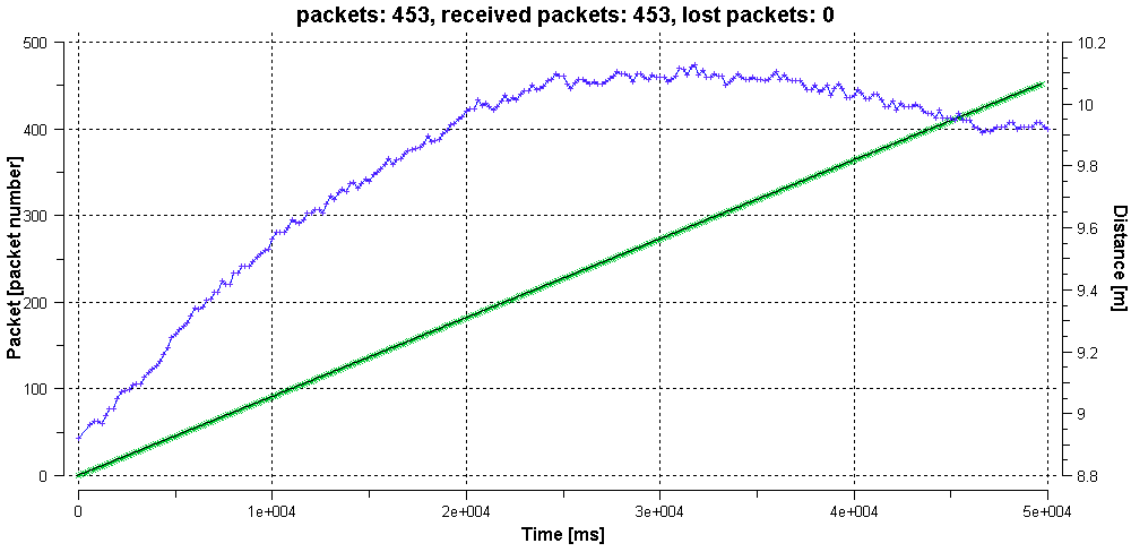


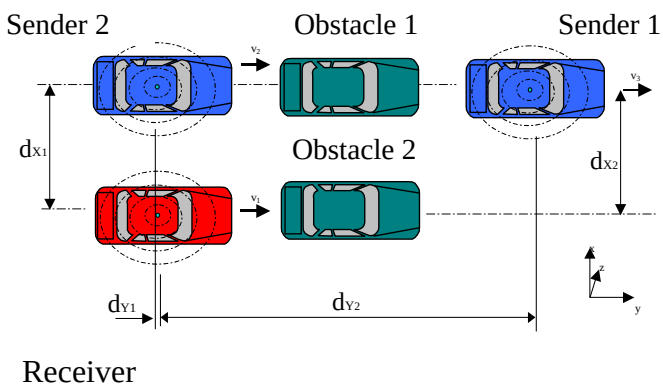

**Figure 32. Test 3-9 Results**

**Figure 33. Test 3-9 Vehicle Configuration**

## 2.4 Multiple-Sender Communications

Tests that included both three and four CTKs were conducted to evaluate multi-sender capabilities in various driving configurations. In order to differentiate the data that was received from more than one sender unit, the respective data plots for different senders are often shifted to a lower location on the diagram, with negative values on the Y-axis indicating the amount of the offsets.

The test below was conducted at arterial speeds close to 25 mph (Test 4-4). A tight formation was maintained with distances of less than 20 m between Sender 1 and the Receiver. Two obstructing vehicles were sustained throughout the test (Obstacle 1 was an SUV, and the other vehicles in the test were sedans). Overall, over 99 percent of the packets sent during all three trials of the test were received. The obstructing vehicles did not cause any significant loss of reception from Sender 1. The Sender 2 values are shifted on the diagram from those of Sender 1 with packet and range offsets of 200 packets and 50 meters.



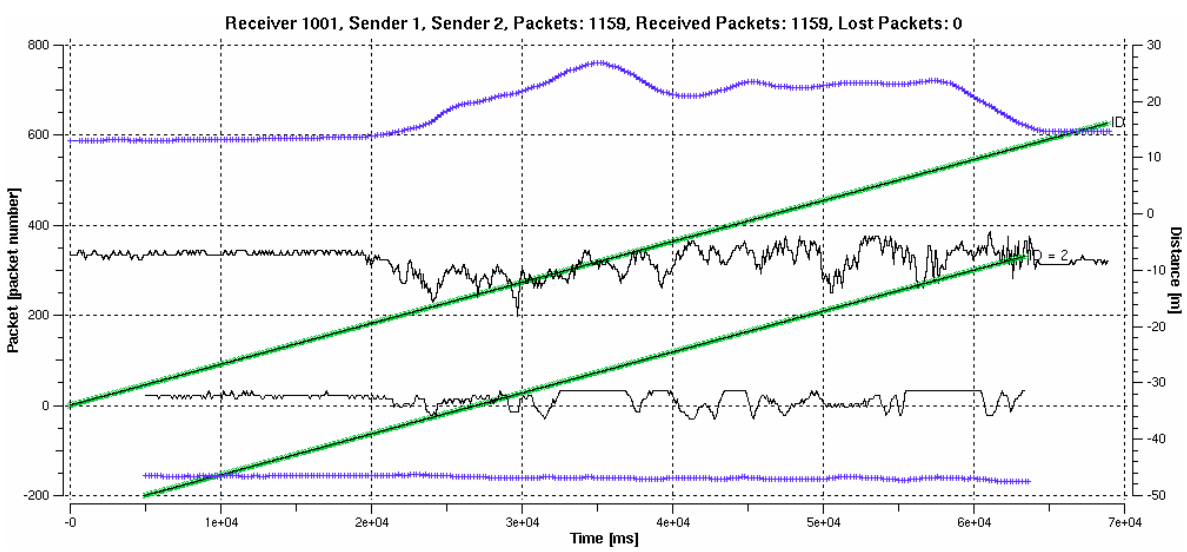




**Figure 34. Test 4-4 Results**

The same test was performed with the SUV driving directly in front of the receiver sedan (Test 4-6). Similar results were found and no more than one packet was lost out of the thousand packets that were sent during each of the three trials.

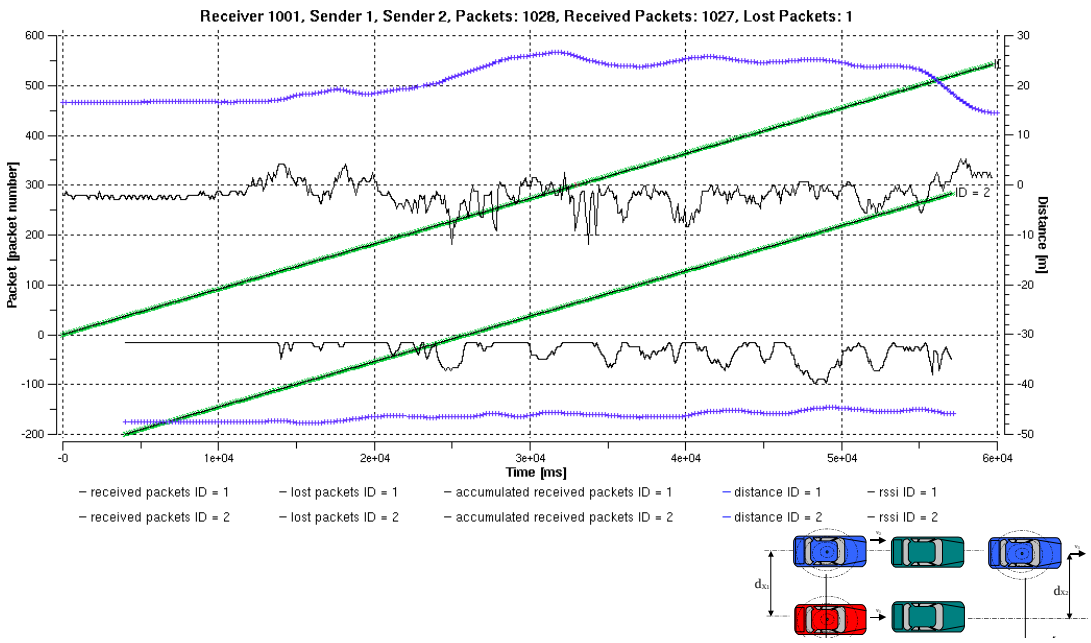



**Figure 35. Test 4-6 Results**

Another test on an arterial road in light traffic conditions specified the sending vehicles moving slightly faster than the receiving vehicle (Test 4-1). The band of lost packets shown on the diagram below was due to a number of vehicles that came in between the receiver and lead sender vehicle. The offsets used for the graph are 20 packets, 200 meters, and 200 RSSI.

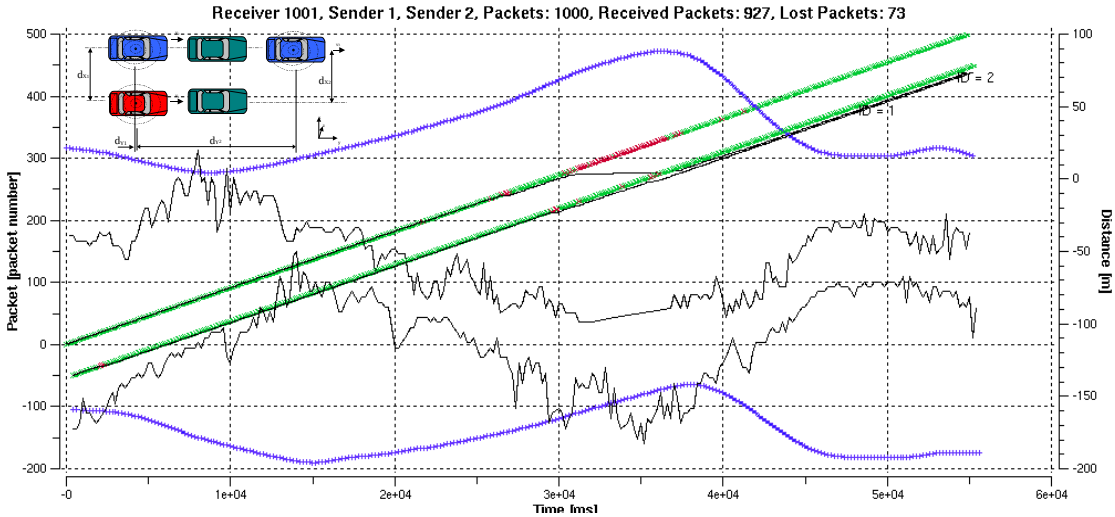



**Figure 36. Test 4-1 Results**

In testing conducted at highway speeds with the senders slowly passing a receiver (one-lane separation), non-test vehicles occasionally entered the test pattern and blocked some packets, as shown in the diagram below (Test 4-2).

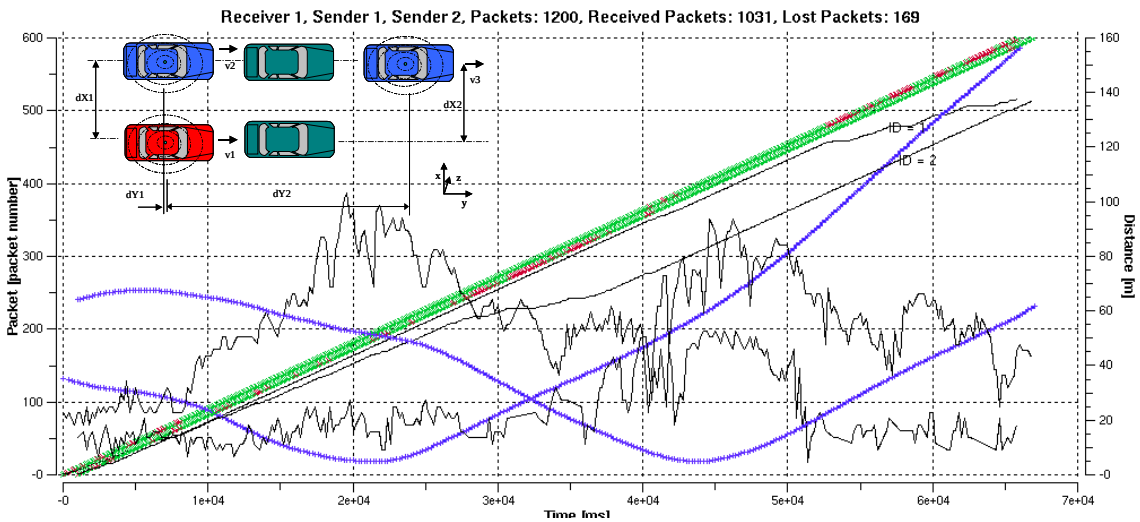



**Figure 37. Test 4-2 Results**

In a similar test with a two-lane separation between the senders and the receiver there was substantial packet loss due to a large truck passing between test vehicles and blocking the senders' line-of-sight to receiver (Test 4-9). There was also occasional line-of-sight blockage by obstructing SUVs.

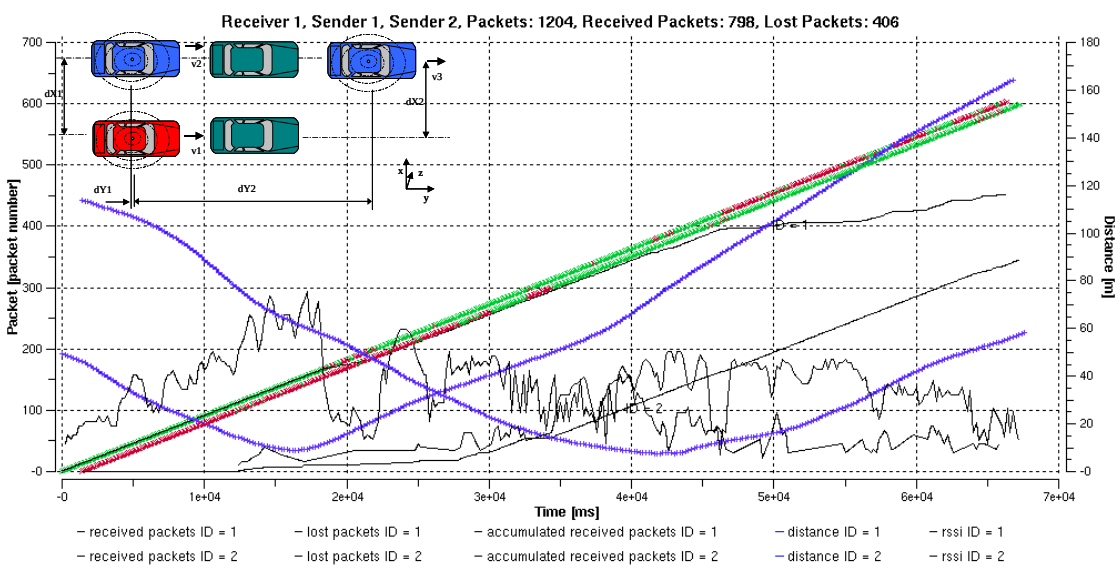



**Figure 38. Test 4-9 Results**

In a highway test that showed the effect of distance upon packet reception, there was approximately 100 meters of separation between the front sender (Sender 1) and the Receiver, while Sender 2 and the Receiver remained side-by-side (Test 4-7). Almost all packets from Sender 2 were received, but many packets from Sender 1 were lost.

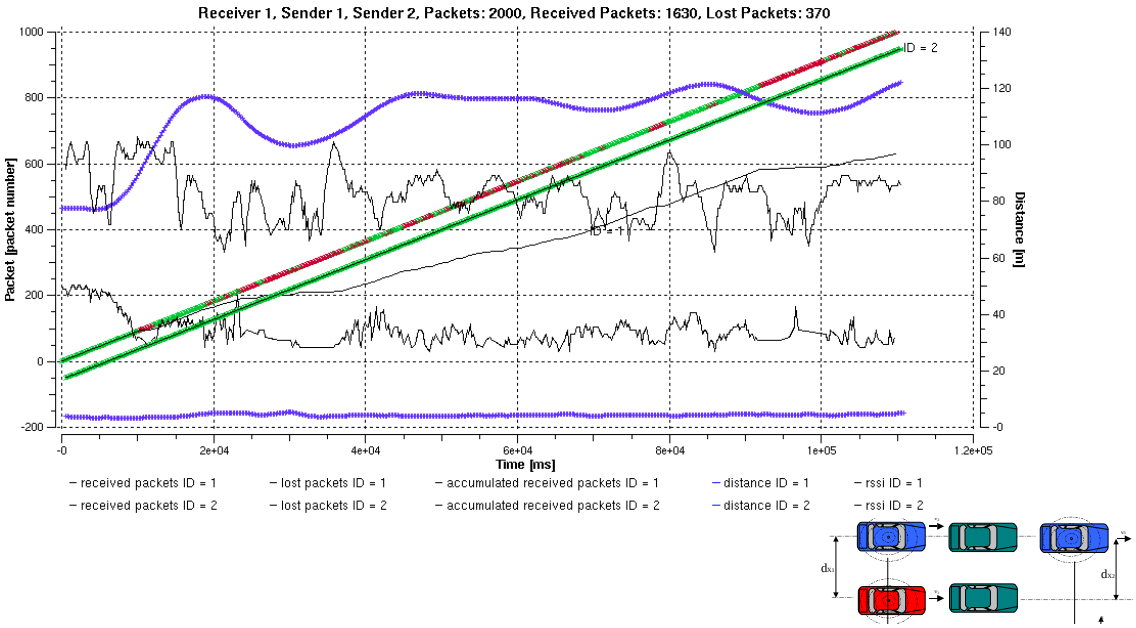



**Figure 39. Test 4-7 Results**

A longer duration test conducted at highway speeds found that 96 percent of the packets sent during the test were received (Tests 4-3 and 4-5). The majority of the lost of packets (circle 1) were caused by an obstacle 18-wheeler in close proximity (under 25 m).

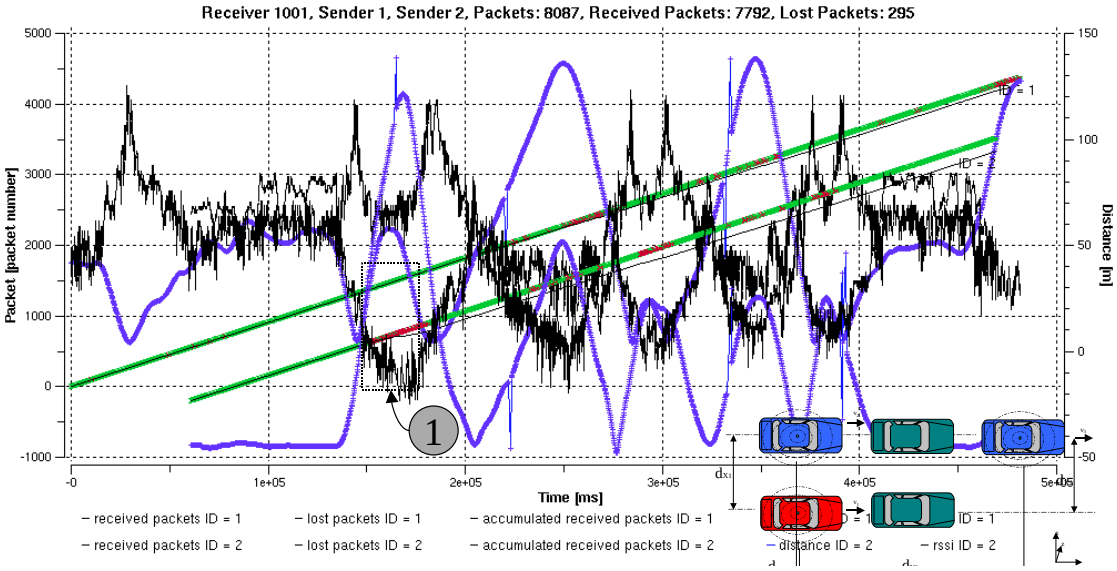
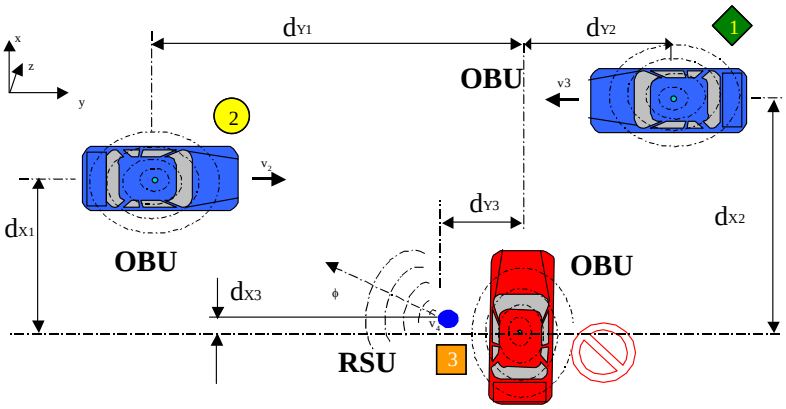



**Figure 40. Test 4-3 and 4.5 Results**

Tests were also conducted to simulate an intersection environment with both on-board units and a roadside unit simultaneously transmitting data. In the test shown below, the sender OBUs (triangle 1 and circle 2) were traveling at 25 mph while the receiving vehicle was parked next to another sender vehicle (square 3) that represented the RSU (Test 4-11). The distance between the stationary sender and the receiver was about 10 m, and moving senders were one lane apart.

Overall, over 99 percent of the packets sent during all three trials of the test were received. The test shows that having 3 senders in an intersection type scenario has no effect on packet loss of reception. The Sender 2 values are offset from the Sender 1 values by 200 packets, 50 meters, and 500 RSSI. The Sender 3 values are offset from the Sender 2 values by 200 packets, 50 meters, and 500 RSSI.



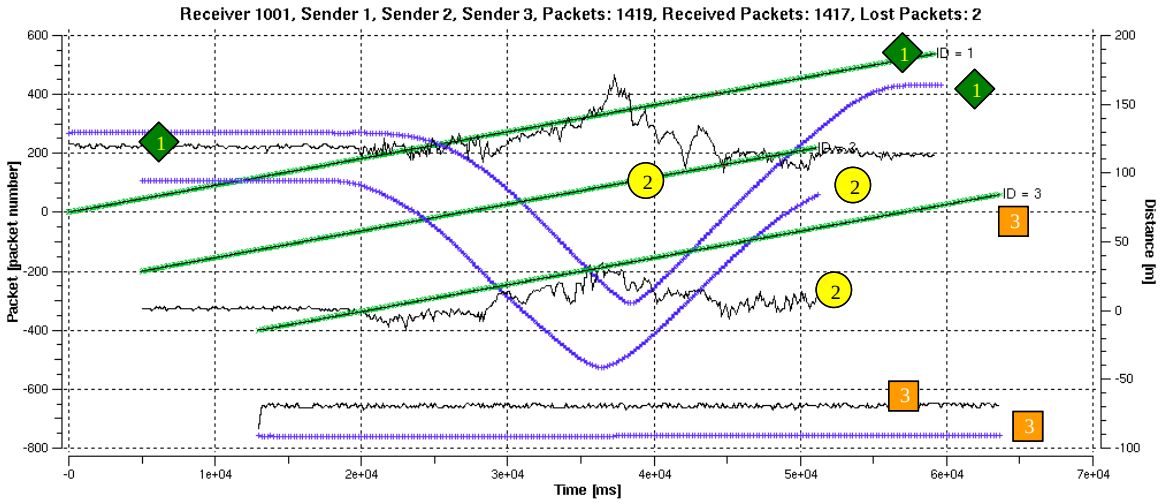
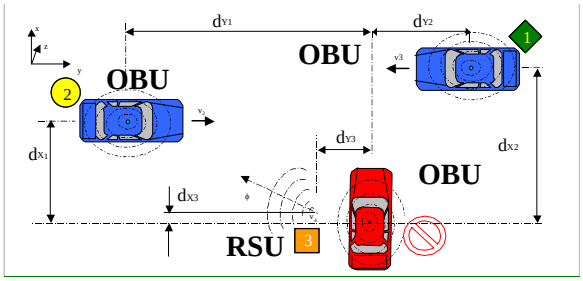




**Figure 41. Test 4-11 Results**

The same test was conducted with Senders 1 and 2 traveling at speeds close to 50 mph (Test 4-12). The distance between (stationary) Sender 3 and the Receiver was ~10 m, and Senders 1 and 2 were initially stationary for a significant period of time while waiting for unexpected traffic to clear from the test zone. Also, Sender 2 began well beyond the line-of-sight of the Receiver. Aside from this, very few packets were lost during the actual drive by. It should be further noted that there was significant roadside clutter in the form of trees and parked cars, which may have partially contributed to the few lost packets. Note that the data curves are offset for clarity, with a shift of 200 packets, 50 meters, and 500 RSSI units between each.



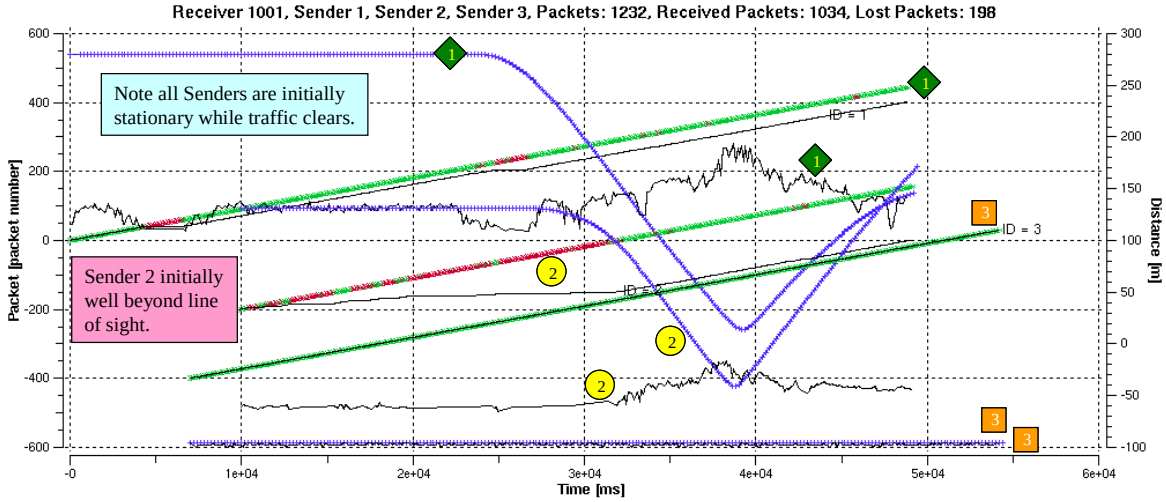




**Figure 42. Test 4-12 Results**

## 2.5 Multipath Considerations

During analysis of the test scenario results incorporating a moving vehicle or vehicles, a zone of minor packet loss was identified at around 90 meters separation. This anomaly was further investigated by placing two vehicles approximately 90 meters apart, then slowly moving one vehicle forward and backward while monitoring the packet reception indication on the CTK screen. Using this "Slow Rolling Test" (see figure below), a specific point could generally be found where nearly all packets would be lost, but moving forward or backward as little as one meter would re-establish reliable communications. This result was repeatable on subsequent trials.

The Two-Ray Model was used to predict multipath interference at the frequencies and antenna heights being used in the field-testing. In general, this model predicted a large degree of interference in the approximate range of 90 meters. Based upon this prediction and the results of the field-testing, the high packet loss zone is presumed to be due to multipath interference between the direct line-of-sight transmission and a reflection of the transmission from the roadway surface. Further testing will be necessary to determine if the antenna mounting location on the vehicle can be optimized to minimize this presumed multipath interference.

This multipath packet loss has been a very small percentage of packets in test scenarios between moving vehicles, or between moving vehicles and stationary roadside units. Even in slow speed test scenarios, only two or three packets were generally lost (out of hundreds of sent packets). Further testing is required to determine the potential impact on the operation of vehicle safety applications.

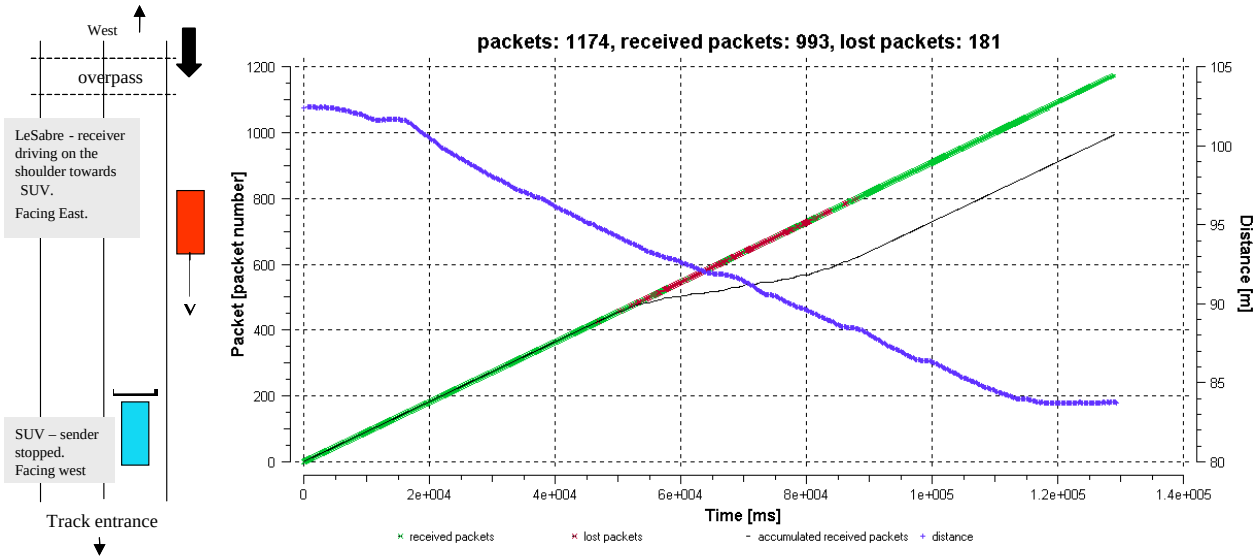



**Figure 43. Slow Rolling Test in a Multipath Zone**

# 3 Simulation Architecture and Test Results

Task 4 included simulation studies in vehicle communications. A DSRC simulator was therefore developed to perform the required simulation testing. The simulator architecture was designed to focus on research topics that are readily addressed through a simulation environment, but difficult, if not impossible, to replicate in a real world vehicle environment. Therefore, areas such as scalability and potential channel capacity constraints, multichannel operations, prioritization schemes, and dynamic power control were primary simulation topics.

## 3.1 Simulation Architecture

The VSC DSRC simulator was designed to be used for research in various subjects, including the following:

- **Scalability.** This is an obvious and major challenge in using DSRC for vehicle safety communications. When the DSRC penetration level becomes high, it is important to ensure that the system will still effectively support safety applications even in very dense traffic environments. A simulator is particularly useful for this work, since there are few, if any, alternative evaluation tools for the analysis of VSC protocol designs.
- **Multi-Channel Operation.** DSRC is an explicitly multichannel oriented design. RSUs advertise their services on the control channel, while potentially providing the content and/or interaction on service channels. On the other hand, safety messages are constantly transmitted on the control channel. So there is a conflict between safety applications' need to stay in the control channel for safety message monitoring, and private applications' need to provide value in service channels.
- **Safety Application Evaluation.** The design of the simulator is such that it could mimic the communication channel for safety application communications. This would incorporate various protocol mechanisms and constraints such as dynamic power control, multichannel operations, and other real-world variables.

### 3.1.1 Simulator Design

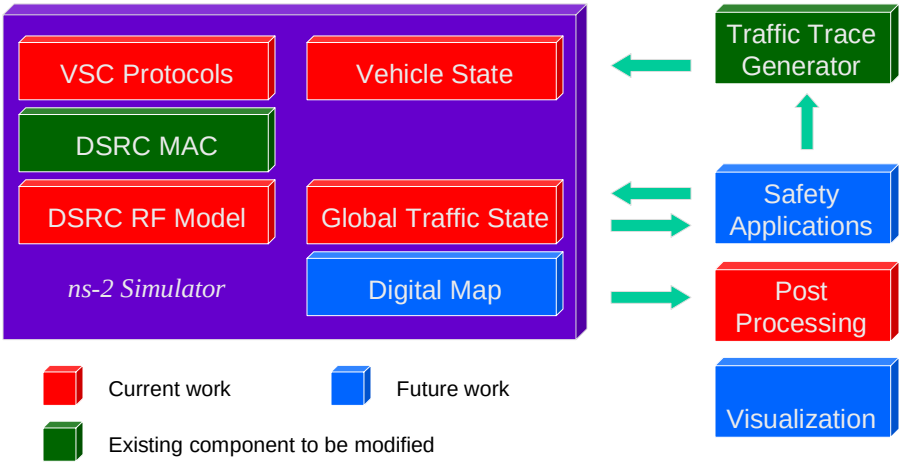



**Figure 44. Simulator Components**

As shown in the figure above depicting the simulator architecture, this DSRC simulator was built on top of the NS-2 simulation platform. NS-2 is a C++ based network communication simulator developed at the University of California at Berkeley. It was historically used in computer network research for many years and is widely distributed and respected among researchers. A support forum exists in the form of a mailing list, through which a huge archive of solutions and helpful comments are available. Additionally, NS-2 is "open source" software and is continuously updated. Its independence from a commercial source makes it a no-cost and flexible solution. NS-2 works well on various UNIX systems, including Linux. The Win32 platform is also supported.

NS-2 is a basic and non-graphical tool. The input to NS-2 is provided by an OTcl (Object Oriented Tcl) script, which contains all topology and node information. These scripts are, depending on the scale of the scenario, very complex and large input sources. The output NS-2 provides is very detailed. It can give per packet information at MAC, agent, or router levels.

#### *3.1.1.1 Vehicle Traffic Trace as Input for Simulator*

The simulator is designed to take external input for the vehicle traffic movement during the simulation. This traffic movement input could be a file, TCP/IP socket connection, or even an actual safety application implementation that generates vehicle movements dynamically.

In comparison, Carnegie Mellon University's Monarch Group added a mobility extension to NS-2, which allows mobile nodes to move within the boundaries of a predefined scenario. This extension, however, is not sufficiently flexible for a

vehicle safety communication simulation tool. Before starting the simulation, the movements of all nodes must be set up. It is not possible to interactively adjust the movement in the simulation as a result of communications among nodes.

The figure below shows a screen shot of the traffic trace configuration window. The design and implementation of the simulator allows for traffic traces in a very flexible format. For example, any delimited text file with necessary (but arbitrarily ordered and formatted) data fields could be used in this simulator.

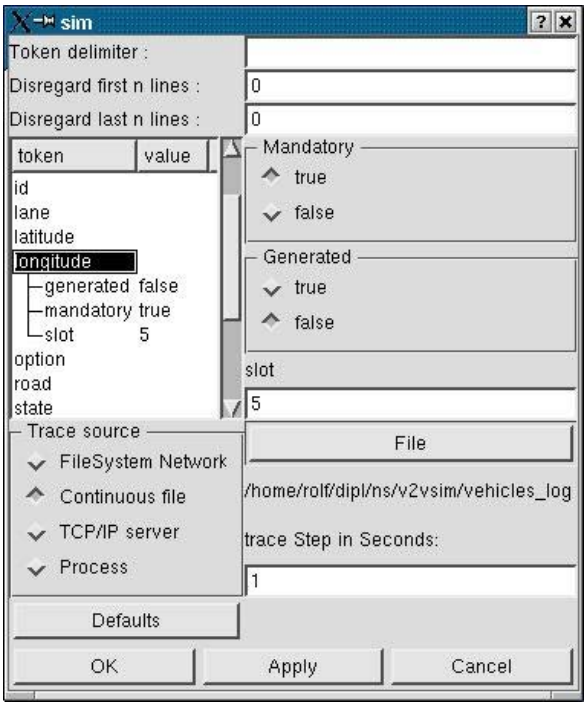



**Figure 45. Traffic Trace Configuration Window**

#### *3.1.1.2 Simulation Configuration and Operation*

The usage of the simulator is generally an iterative process, an example of which follows:

1. Design and implement components for protocols and agents at various layers in the NS-2 system.
2. Match up particular instances of components in each layer.
3. Configure and adjust parameter values in each component.
4. Run simulation and produce output traces.
5. Repeat from step 1 or 2.

A GUI (graphic user interface) was implemented to simplify configuration in steps 2 to 5. As shown in the screen capture below, one could pick any instance of a component in any layer and adjust the parameters arbitrarily. All such configurations can be saved in an XML formatted file. Batch operation of several simulation sessions is also supported.

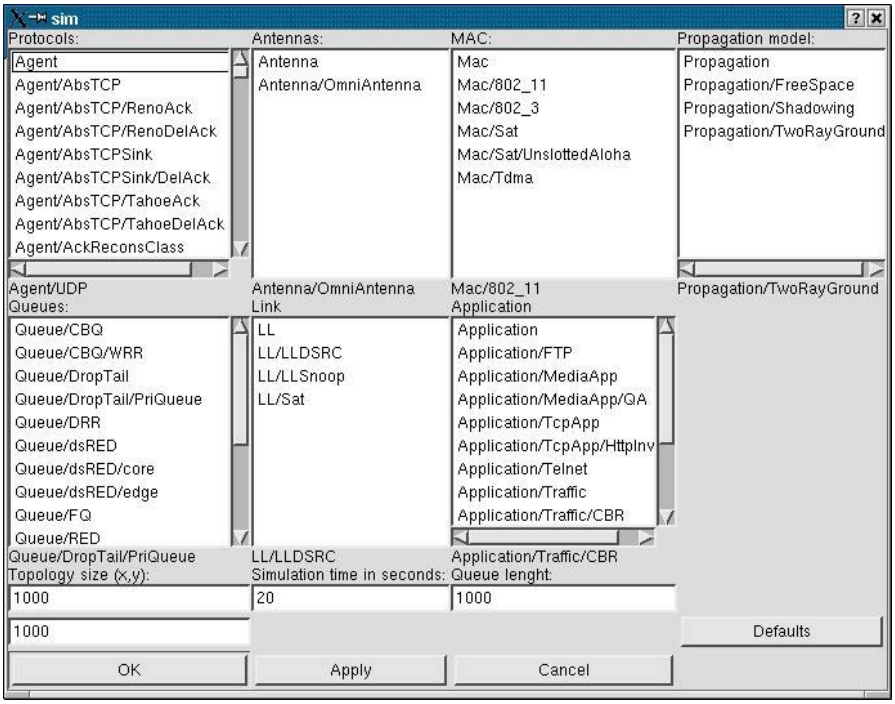



**Figure 46. Graphical User Interface**

### 3.1.2 Channel Capacity Evaluations

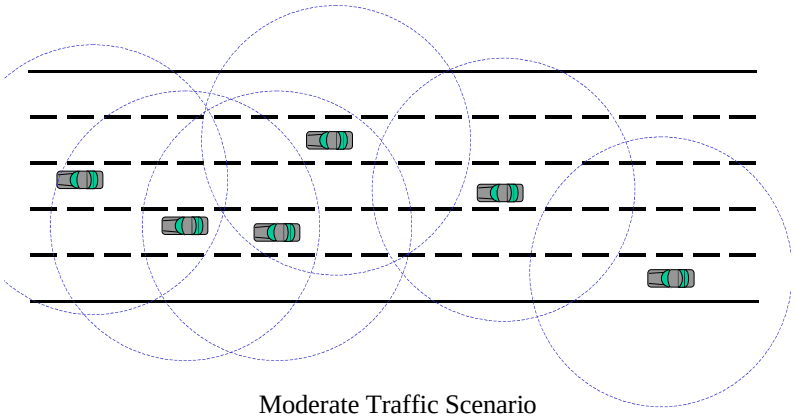
Simply put, channel capacity could be described as how often and how loud can vehicles transmit, at what packet size, in what traffic density, and environment while preserving certain tolerable levels of reliability and channel access delay. Given the complexities of interrelating so many parameters, it is important to use limited but representative values for the simulations. The following list describes the parameters in more detail.

- **Packet Size**. Most safety messages are expected to contain some minimum amount of information such as position, velocity, time stamp, etc. So a very simple message may have a packet size of 64 bytes at the low end of the scale. Beyond this, packets at 128, 256 and 512 bytes are examined. In particular, such simple variations of large packet sizes could provide some first order evaluation of the impact created by some form of security mechanism overhead.
- **Transmission Frequency.** It seems that 100 ms is a reasonable time interval since it is often mentioned in various safety application

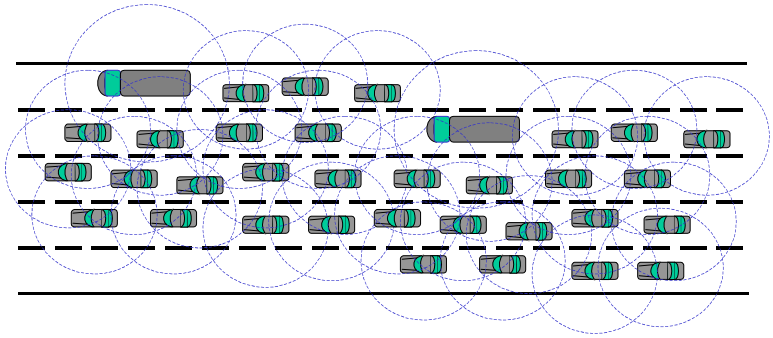
communication requirements. Values at 150 and 200 ms may also be of some relevance.

- **Transmission Power**. Transmission power determines both the reach of expected communication reception and the interference range at which others are prevented from transmitting. Since Task 4 simulations depend on detailed testing and modeling in Task 6A to provide an understanding of actual power level versus communication reach, transmission power variations are simplistically simulated to adjust the range of communication and interference.

There are innumerable ways to model traffic densities and environments. Since this is a high level study of channel capacity, the initial simulation focuses on simple scenarios with traffic densities that range from “moderate” to “heavy,” as shown in the following figures. The actual figures of traffic flow are based on typical statistics collected from representative major commuting highways for non-rush and rush hours. The actual traffic trace will be synthetically generated, since only the average flow and vehicle separation are important for the high level capacity evaluations.



Moderate Traffic Scenario



Heavy Traffic Scenario

Conceptually, an obvious evaluation metric in the simulation is channel occupancy. However, it is not exactly clear how such a figure should be computed. The roadway environment is large and by definition is not an enclosed system in which everyone can hear everyone. If two cars far apart can talk at the same time, should this be counted twice? If so, the channel occupancy could easily exceed 100 percent, given a large enough area of simulation.

For this reason, the simulator uses other evaluation parameters. In particular, it tracks the average channel access delay and packet loss rate.

### 3.1.3 Power Control Evaluations

Simulation results in channel capacity evaluations are likely to show that naïve usage of the channel will cause problems in congested situation. The next step will be the evaluation of proposed techniques to resolve the capacity concern in these situations. In general, power control is expected to be an important approach in any solution. However, there may be some hidden limitations in this approach.

The general concept for power control is the following:

- If there are many vehicles around, they will move slowly as in a traffic jam. In this case, scaling back each vehicle's transmission power would work well since in slowly moving traffic, there is no great need for safety messages to reach beyond one's immediate neighbors.
- If vehicles are moving fast, they should be reasonably far apart. Therefore, capacity is less of a concern, even if all of them need to transmit at higher power for the longer ranges.

Problems arise if these two scenarios are merged into one, as shown above. The slow moving vehicles on one side of the freeway could be working quite well with each other using low power, whereas the fast moving vehicles on the other side communicate effectively among themselves at high power. However, if both scenarios coexist as in the figure, then there is the danger that high-powered transmissions, even though low in number, could interfere with a disproportionate number of low powered transmissions.

## 3.2 Simulation Test Results

Initial simulation testing focused on a significant concern for the proper support of message prioritization. This is critical for the effectiveness of vehicle safety applications, and especially so when channel loading is high. Consequently, simulation testing was conducted to evaluate the DSRC priority mechanism in increasingly stressful communication contexts.

### 3.2.1 Simulation Test Setup

The basic configuration assumed for the purpose of the simulation test was ten concentric roadway lanes (see illustration below). The innermost lane was set with an inner radius of

150 meters. This circular configuration was chosen to allow full vehicle motion within the roadway lanes, without entering and leaving the simulation.

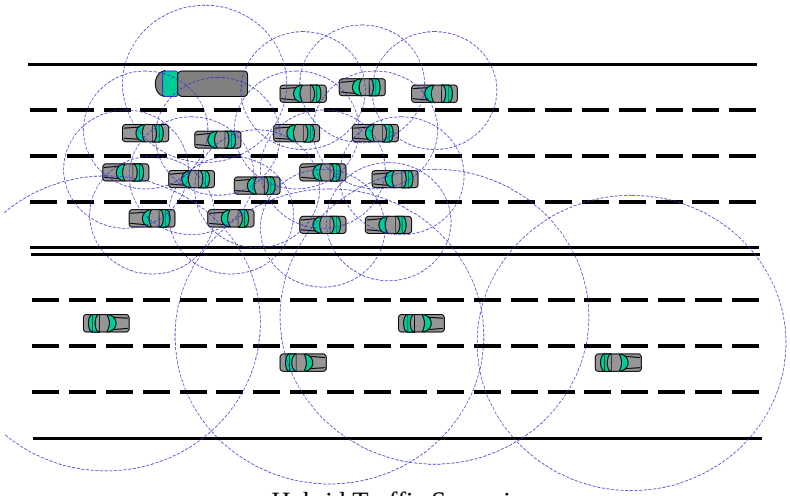
Simulation test runs were conducted with three different vehicle density assumptions. These vehicle density assumptions were: 20, 30, and 40 meters per car per lane.

The simulation test runs assumed the communication range at three different levels: 50, 100, and 200 meters. This provided a simplified surrogate for power control (see Section 1.1.3).

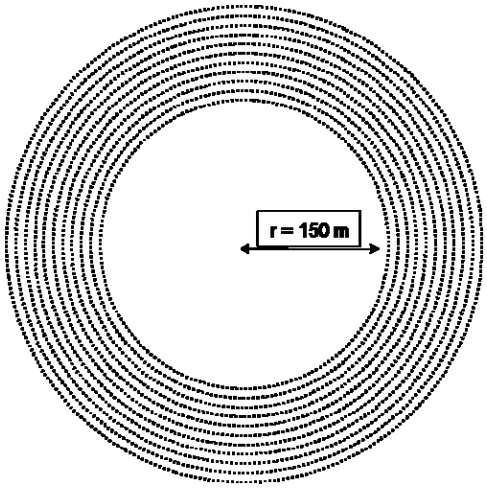
In the simulation test runs, the packet size was varied. The three packet sizes used were: 100, 200, and 500 Bytes.

The simulation test assumption of transmission frequency was consistent with the communications requirements expected for many of the identified vehicle safety applications: 1 message per car per 100 ms.

**Illustration of Simulation Test Setup**



Hybrid Traffic Scenario

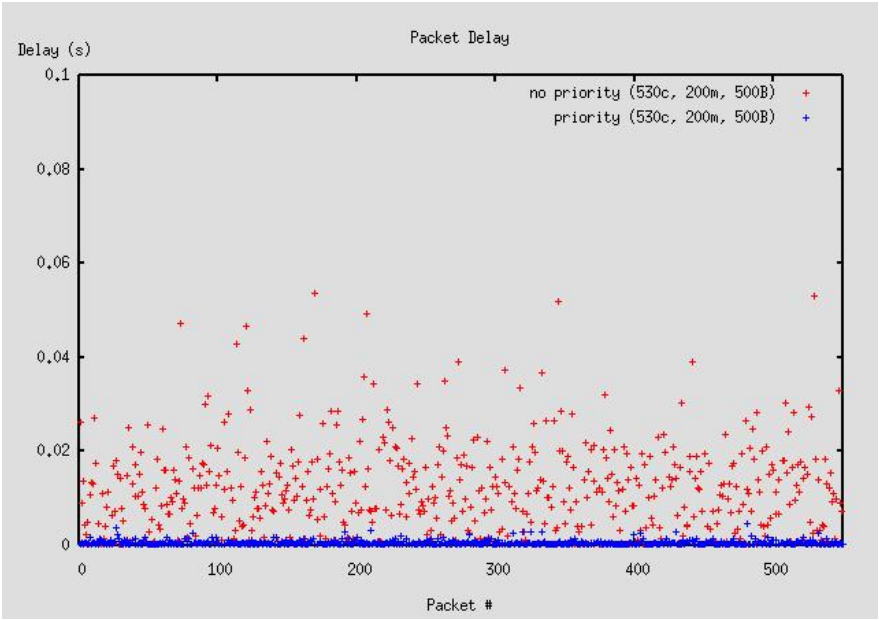



### 3.2.2 Priority Process

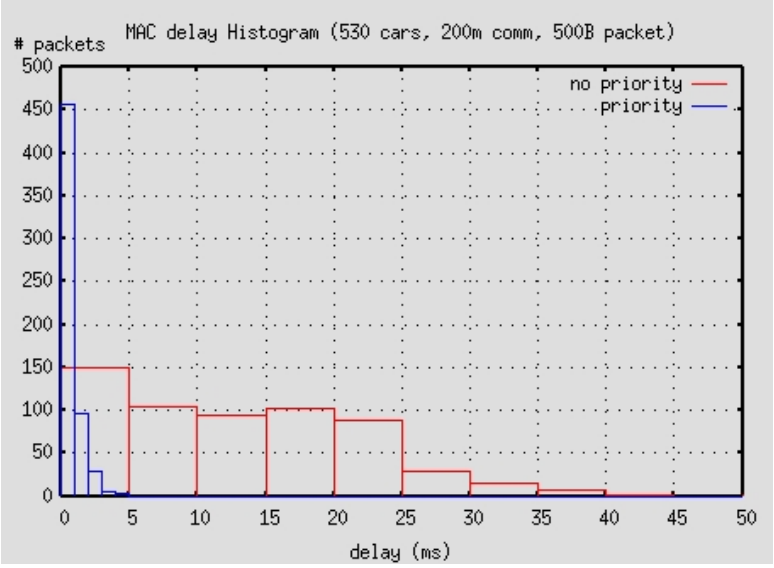
For the purpose of this simulation testing, the VSC used the Enhanced Distributed Coordination Function (EDCF) as the priority mechanism for DSRC. The EDCF was introduced as a part of the IEEE 802.11e Quality of Service standardization effort. EDCF is designed to prevent collisions between packets in the communications medium. The process can be described in the following, basic way:

- Listen: each transmitter listens for the channel to become idle
- Wait: based on priority, then wait a random, but again prioritized back-off time
- Talk: after the wait times expire and if no other transmissions are heard, the packet is sent

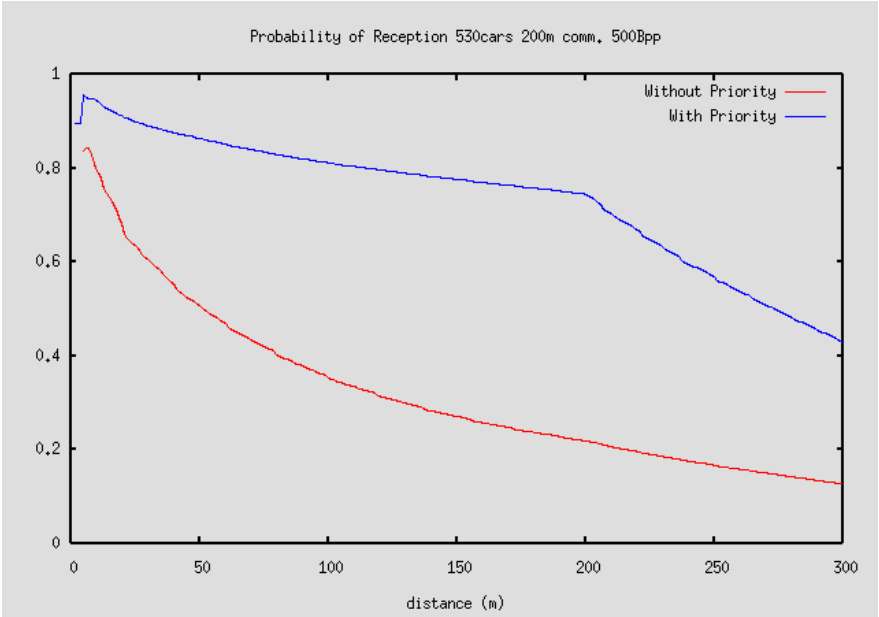
EDCF is designed to specify the random back-off time according to the message priority. This means that lower-priority messages should have a longer back-off time. By using this process, high-priority messages should have much better chances to get on the channel before messages with lower priority. The following results illustrate the potential benefits to safety applications from such a prioritization mechanism.




The EDCF priority mechanism is illustrated in the above simulation test result. In this case, there are 530 cars in the simulation with 20 m separation distance per car per lane. Transmission power is set for a distance of 200 m and packet size is 500 bytes. Out of the 530 cars, one car (blue data points) is given high priority while all others have no priority. The red data points show results for a representative car with no priority. Virtually all of the high-priority messages are sent with less than 5 ms delay. Conversely, non-priority messages encounter delays of up to approximately 50 ms.



In another perspective, the same data is shown below. It is very clear in this perspective that priority for this particular case significantly reduces message transmission delays. This result has apparent implications for high-priority vehicle safety applications.




The final graph above shows the same results, but now depicts broadcast effectiveness. It specifically shows the percentage of cars at various ranges that successfully receive the priority and non-priority messages. This simulation test result demonstrates significant potential impact to safety messaging success rates through the application of a single protocol mechanism, message prioritization.

# Field Test Scenarios

# 4 Dynamic Vehicle-to-Vehicle Communications

## 4.1 Test Scenario

### 4.1.1 Test Scenario 1-1

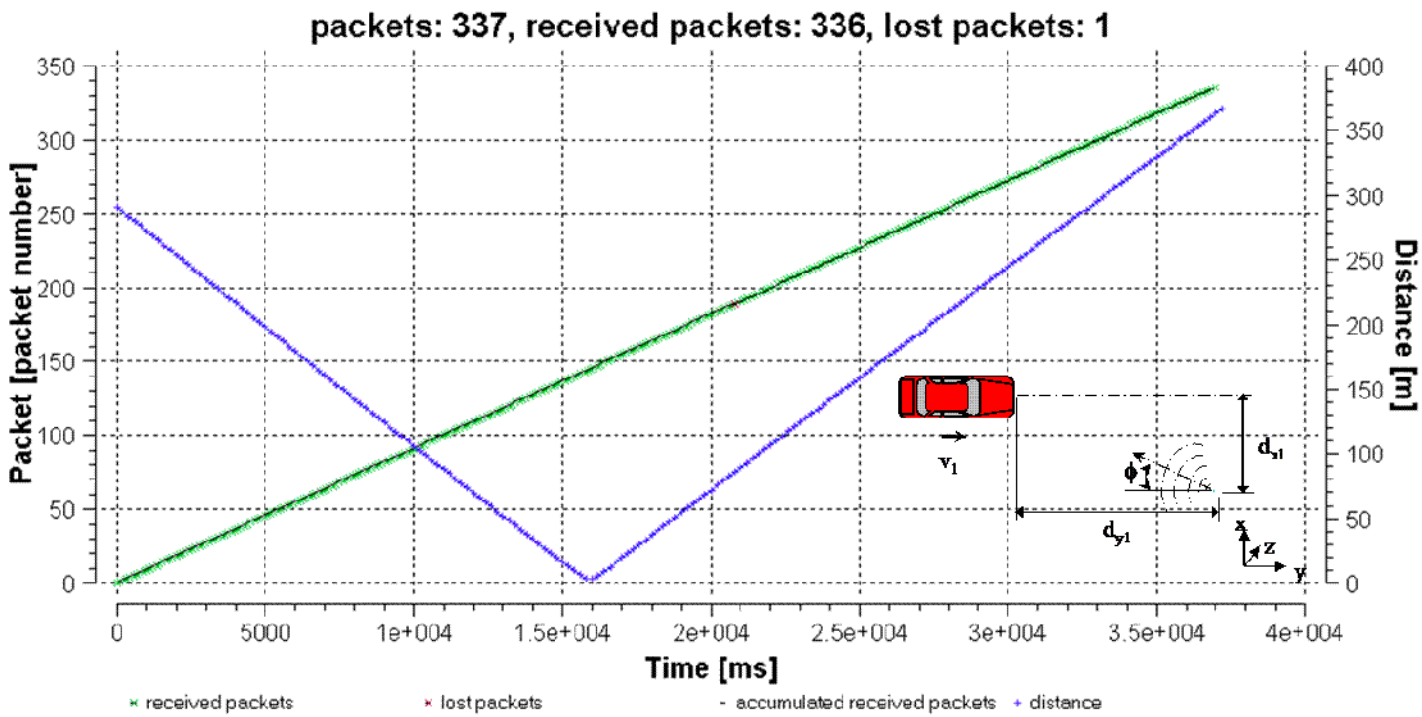
| **Test Scenario** | **1-1** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 1. Test Scenario 1-1**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (200 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 40 mph in a lane adjacent to the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only one packet was lost per run.

Figure 47. Test Number 1-1 Results

| | | | |
|---|---|---|---|
| Test Number | 1-1 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_1_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.2 Test Scenario 1-2

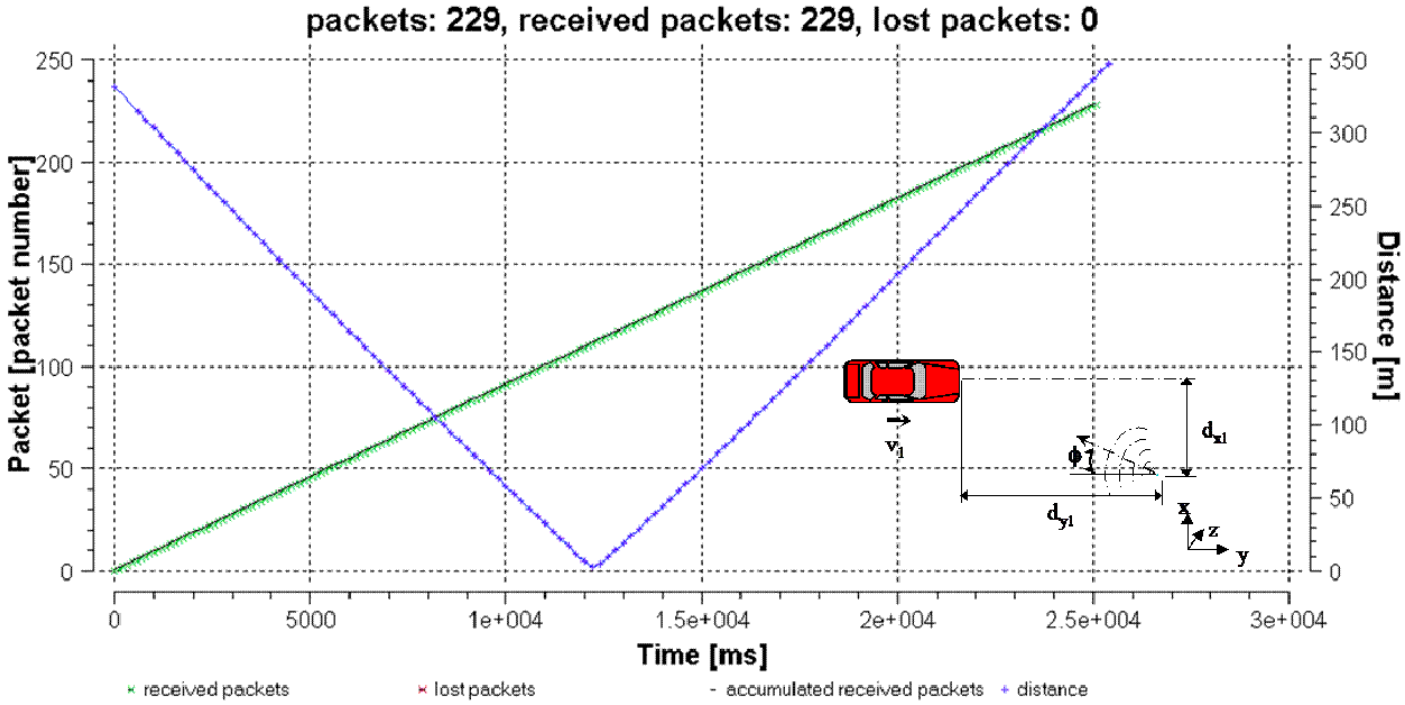
| **Test Scenario** | **1-2** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 2. Test Scenario 1-2**

Test Comments: In this test the RSU (GMC Envoy) sends messages (200 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 60 mph in a lane adjacent to the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only 5 packets were lost per run.

Figure 48. Test Number 1-2 Results

| | | | |
|---|---|---|---|
| Test Number | 1-2 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_2_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.3 Test Scenario 1-3

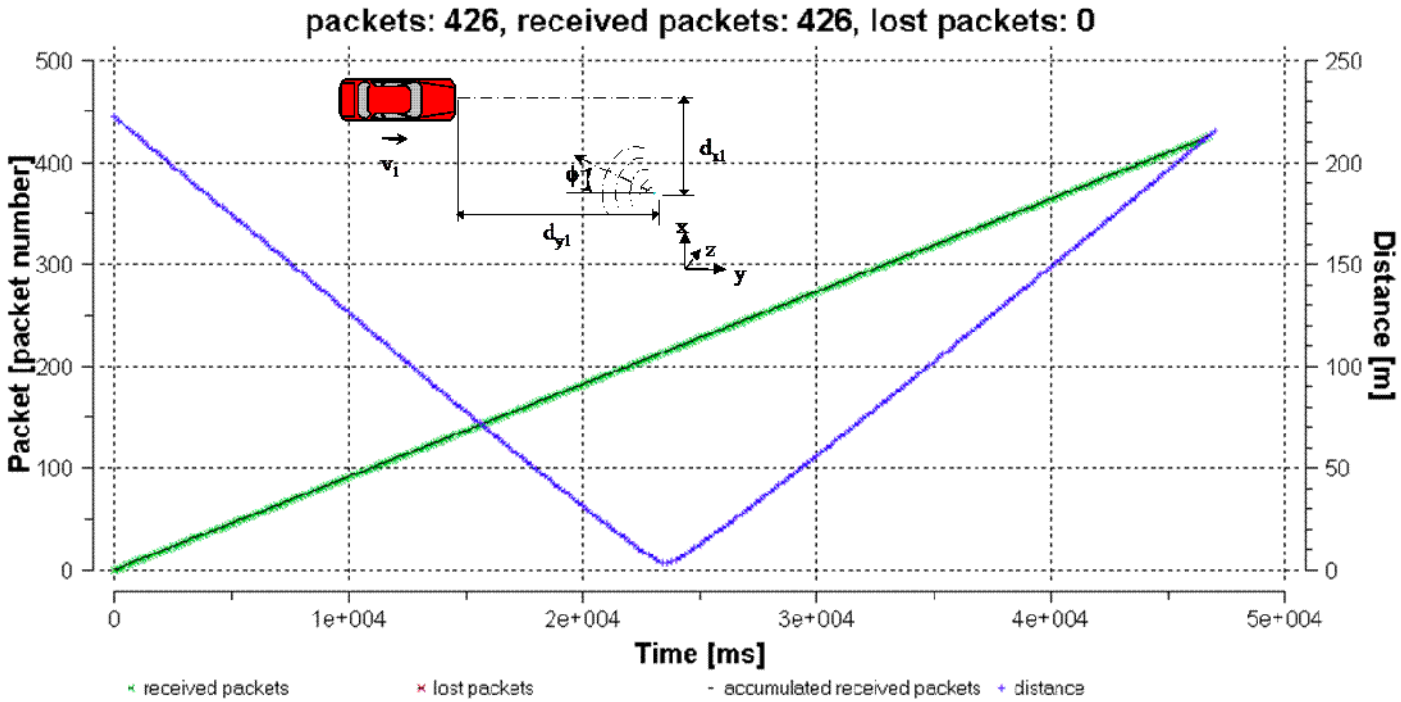
| **Test Scenario** | **1-3** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 20 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 3. Test Scenario 1-3**

Test Comments: In this test the RSU (GMC Envoy) sends messages (400 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 20 mph in a lane adjacent to the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only 2 packets were lost per run.

Figure 49. Test Number 1-3 Results

| | | | |
|---|---|---|---|
| Test Number | 1-3 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_3_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.4 Test Scenario 1-4

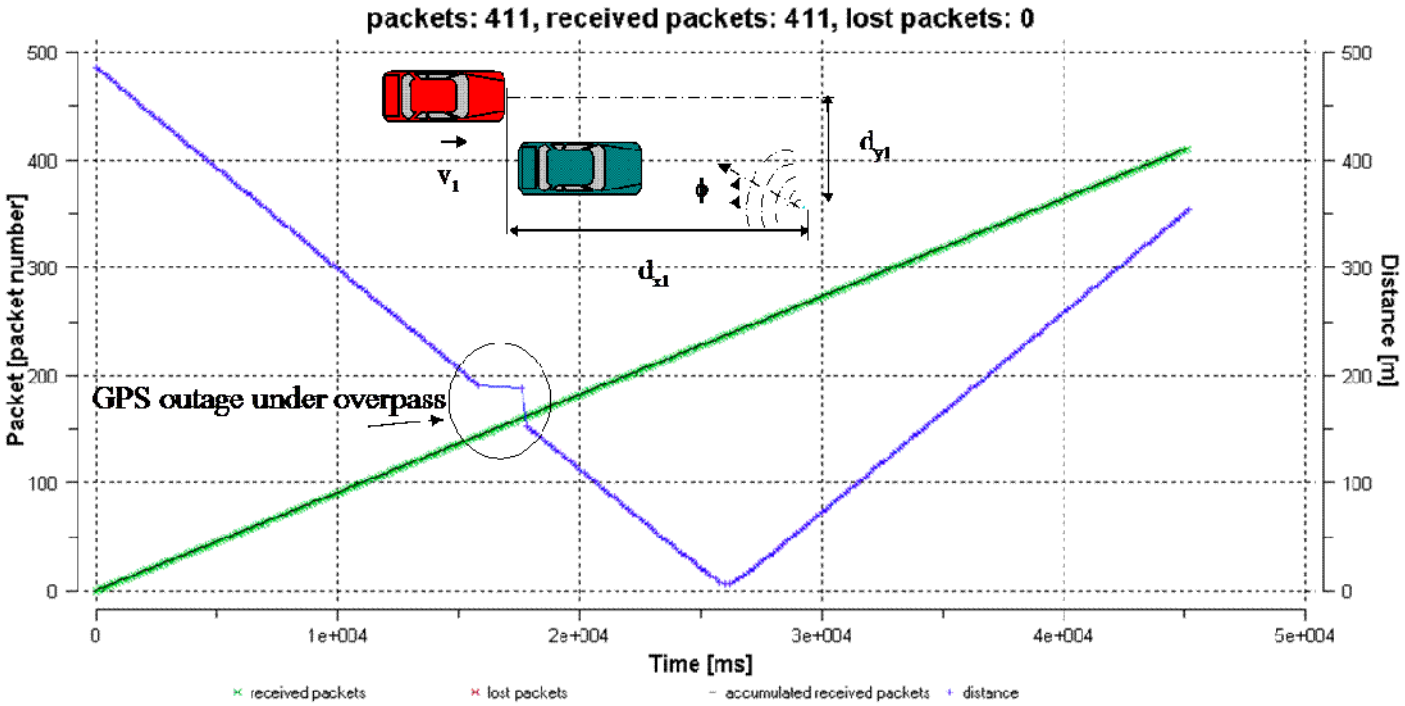
| **Test Scenario** | **1-4** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 4. Test Scenario 1-4**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (200 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 40 mph, two lanes over from the RSU. Both units are in a clear line-of-sight except when they are obstructed by a stopped SUV (GMC Envoy). The communication link was very reliable since no packets were dropped.

Figure 50. Test Number 1-4 Results

| | | | |
|---|---|---|---|
| **Test Number** | **1-4** | **Ambient Weather Conditions:** | **Sunny** |
| **Trace File Name:** | **080703_1_4_2.trace*** | **Sending Vehicle Model/Make:** | **Buick LeSabre** |
| **Date Collected:** | **August 7, 2003** | **Receiving Vehicle Model/Make:** | **Buick LeSabre** |
| **Files Resident With Whom:** | **F. Ahmed-Zaid** | **Antenna Type Used:** | **Standard** |
| **Operating System Used:** | **Linux** | **VSC Obstacle Vehicle #1 Model/Make:** | **GMC Envoy** |
| **Software Level Used:** | **V2.3 (8-July-03)** | **VSC Obstacle Vehicle #2 Model/Make:** | **N/A** |



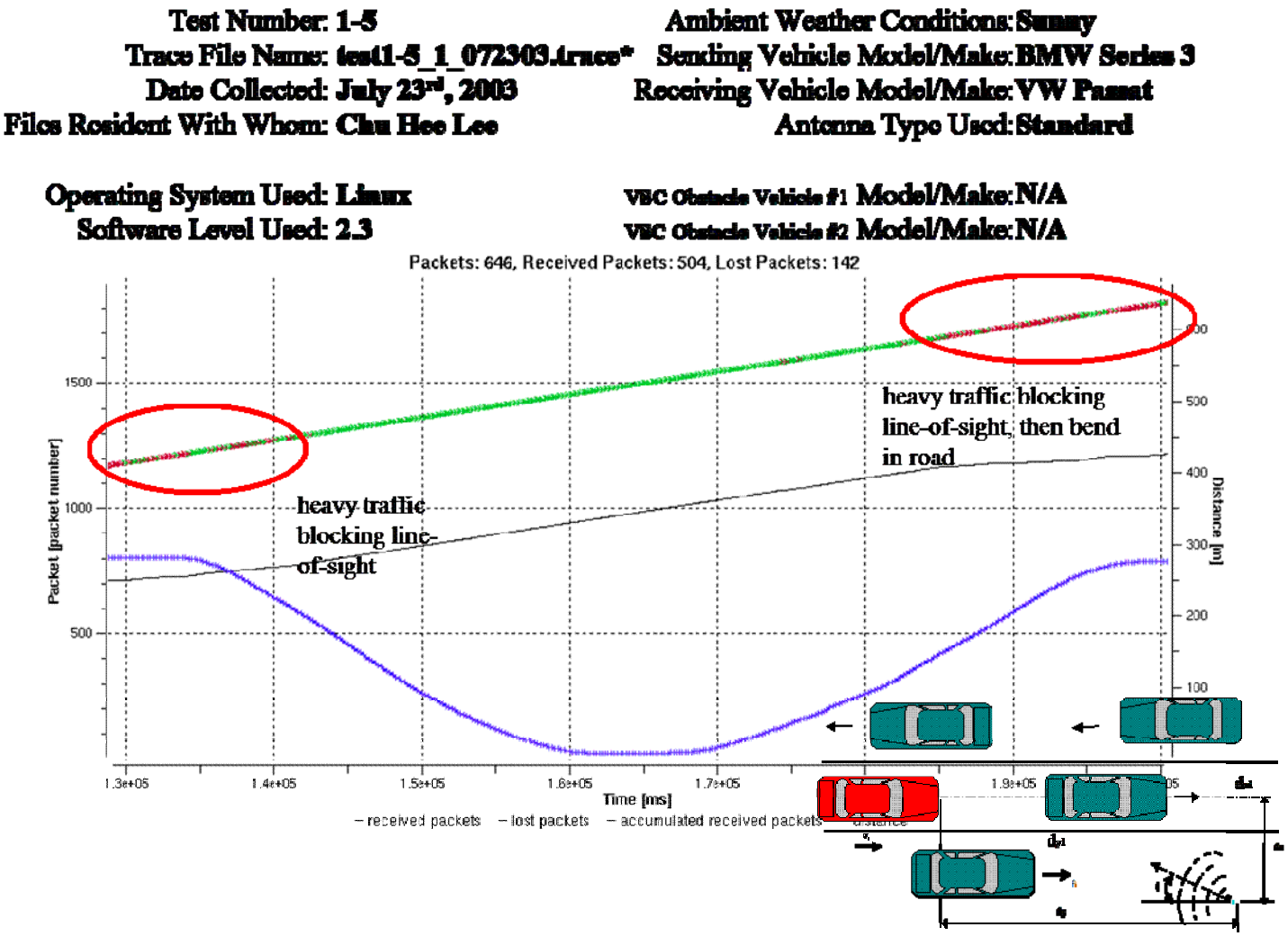
### 4.1.5 Test Scenario 1-5

| **Test Scenario** | **1-5** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | var |
| Distance Between Antennas (meters) | var |
| Lateral Offset to Broadcast Antenna (meters) | var |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | Yes |
| Vehicle Obstructions | Sustained |
| Road Class | Arterial |
| Traffic Conditions | High |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 5. Test Scenario 1-5**

Test Comments: The outages shown in the illustration are due to traffic, trees, and buildings that are in the way before and after the vehicle passes the other one on the side of the road. The road curves slightly after the vehicle passes, so that the maximum line-of-sight is shorter in that direction. The moving vehicle was in the lane closest to the curb.

Figure 51. Test Number 1-5 Results



### 4.1.6 Test Scenario 1-6

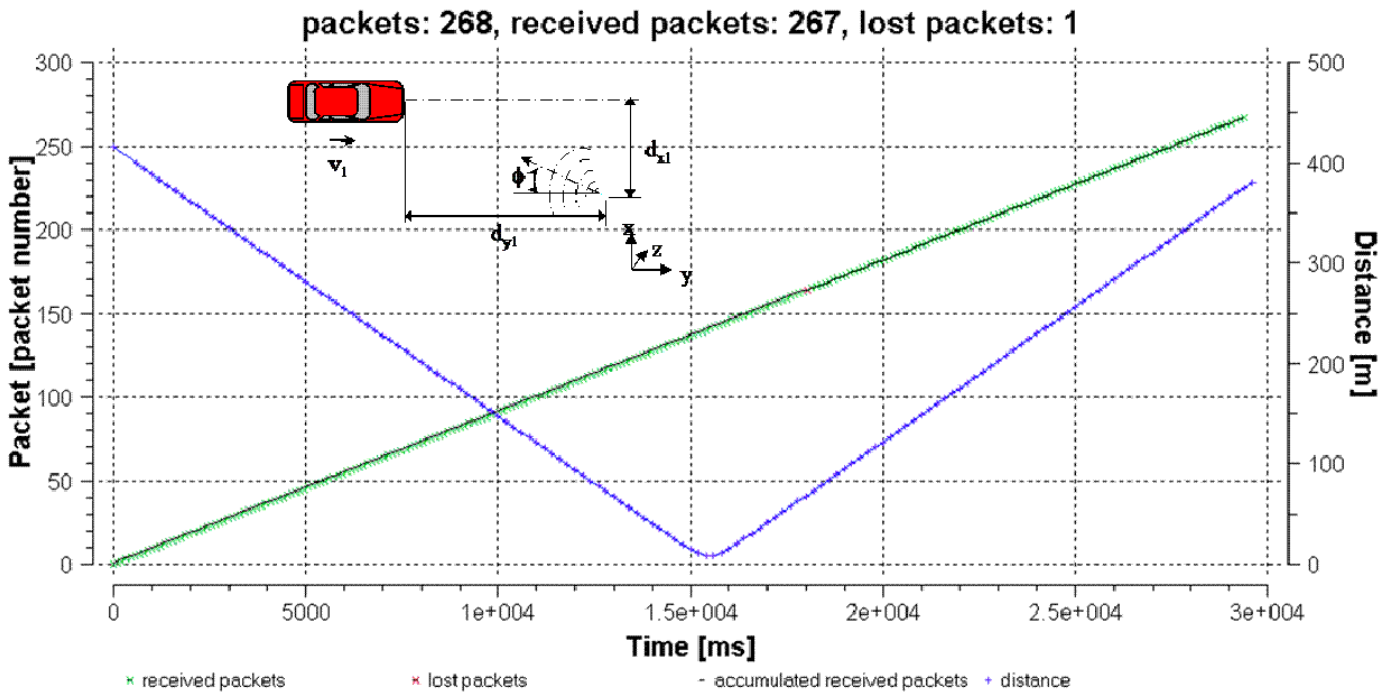
| **Test Scenario** | **1-6** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 6. Test Scenario 1-6**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (400 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 60 mph, two lanes over from the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only 4 packets were lost per run.

Figure 52. Test Number 1-6 Results

| | | | |
|---|---|---|---|
| Test Number | 1-6 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_6_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.7 Test Scenario 1-9

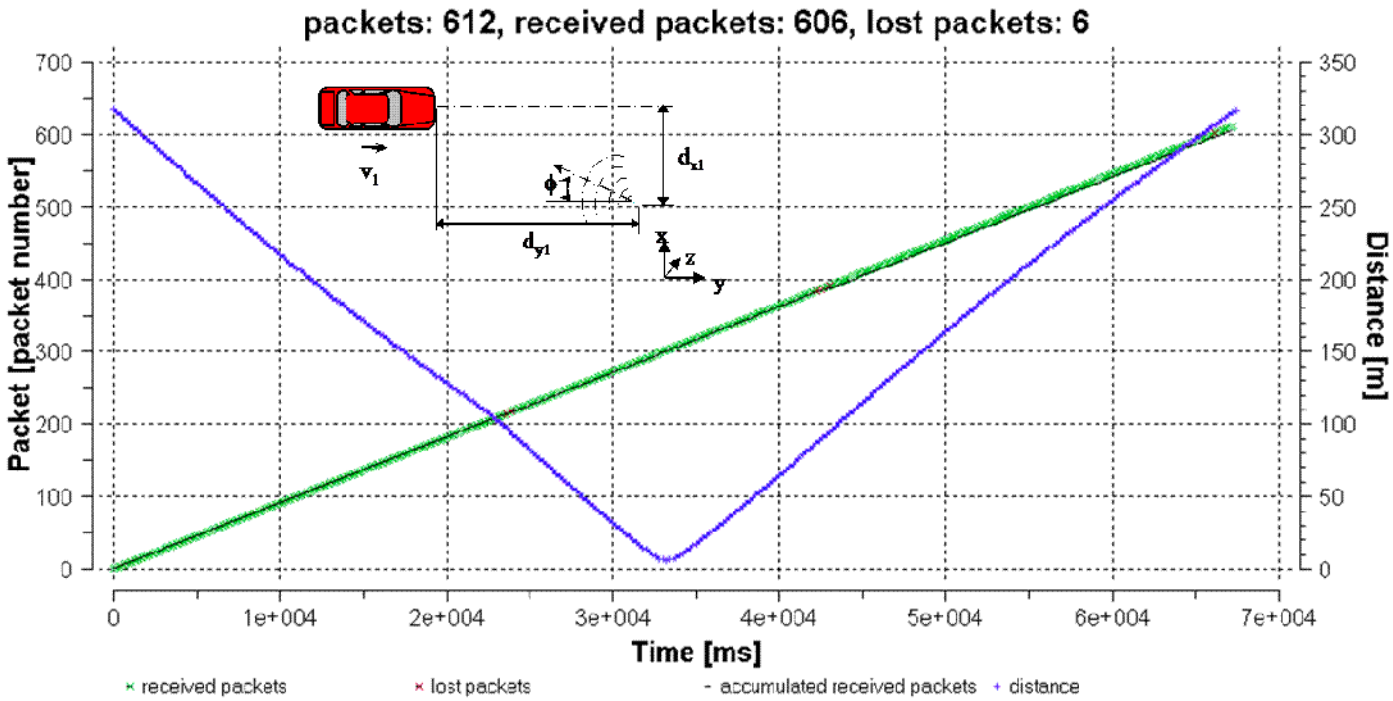
| **Test Scenario** | **1-9** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 20 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 7. Test Scenario 1-9**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (400 bytes) every 100 msec. The receiving vehicle (LeSabre) is traveling at 20 mph, two lanes over from the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only 10 packets were lost per run.

Figure 53. Test Number 1-9 Results

| | | | |
|---|---|---|---|
| Test Number | 1-9 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_9_3.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.8 Test Scenario 1-10

| **Test Scenario** | **1-10** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | var |
| Distance Between Antennas (meters) | var |
| Lateral Offset to Broadcast Antenna (meters) | var |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Cut-in |
| Road Class | Highway |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 8. Test Scenario 1-10**

Test Comments: The receiver started from a distance about 550 meters from the sender. The sender was at the traffic light. When the receiver approached the RSU, a big truck, in addition to the SUV used for the test, was in between the receiver and the RSU (sender) causing packet drops. As the receiver traveled out of the line-of-sight, the RSU started losing packets (packet number >700).

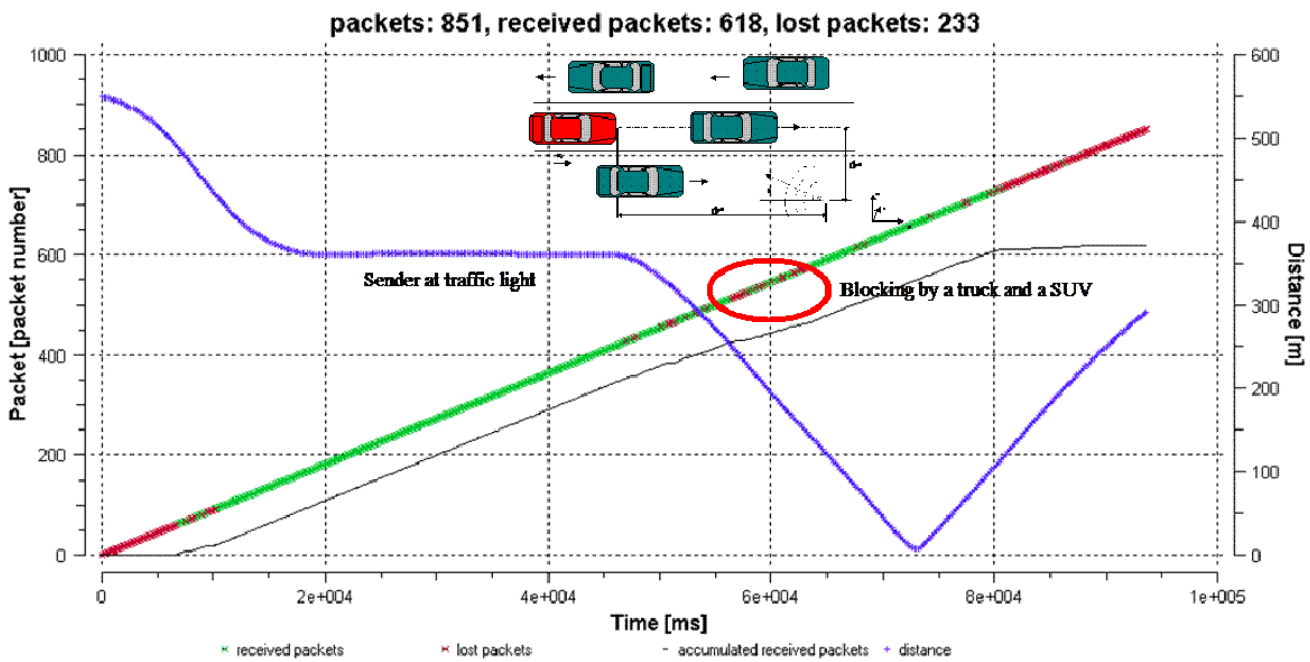
Figure 54. Test Number 1-10 Results

**Test File: 1-10**
**Trace File Name: test1-10_1_080603.trace***
**Date Collected: August 6th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: BMW 330**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: BMW X5**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.9 Test Scenario 1-11

| **Test Scenario** | **1-11** |
|---|---|
| Relevant Applications | Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 5 |
| Distance Between Antennas (meters) | < 20 |
| Lateral Offset to Broadcast Antenna (meters) | var |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | |
| Traffic Conditions | N/A |
| Other Effects | Left Turn |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 9. Test Scenario 1-11**

Test Comments: All packets were received during this test. The vehicles were within the line-of-sight for the entire test.

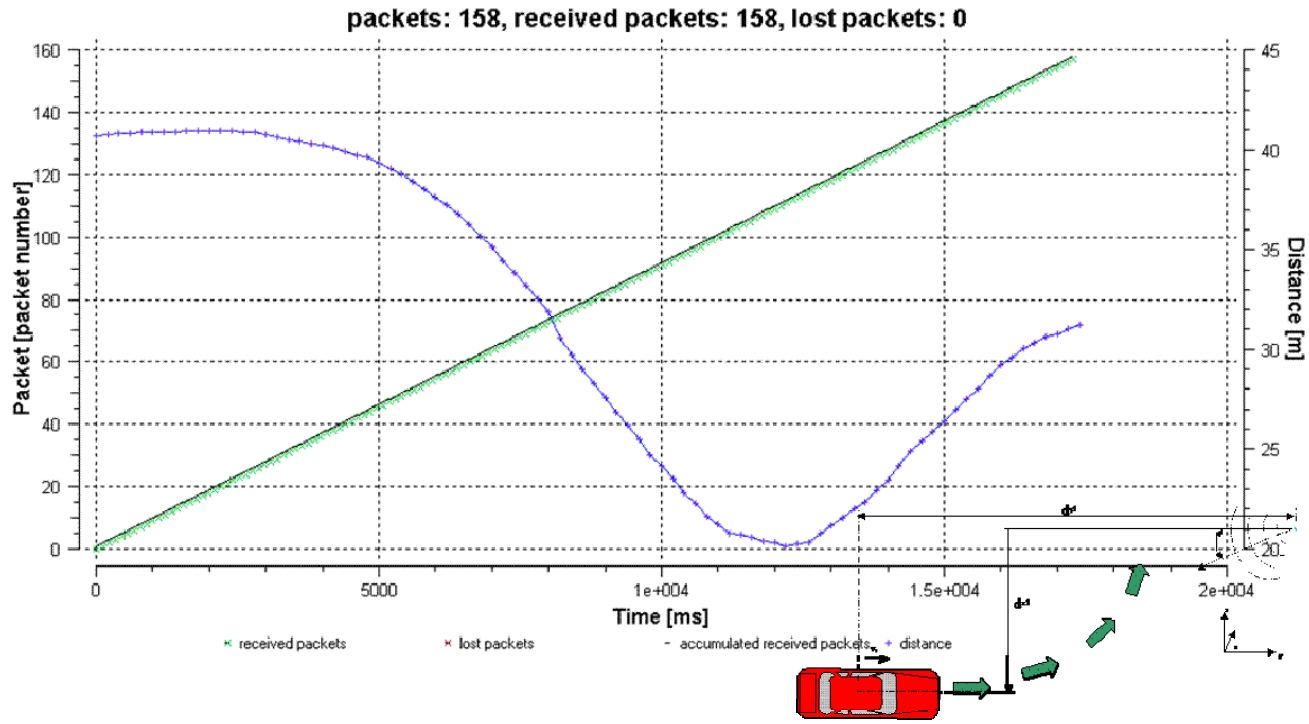
Figure 55. Test Number 1-11 Results

**Test Number: 1-11**
**Trace File Name: test1-11_2_073103.trace***
**Date Collected: July 31st, 2003**
**Files Resident With Whom: Chu Hee Lee**

**Ambient Weather Conditions: Light rain**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.10 Test Scenario 1-12

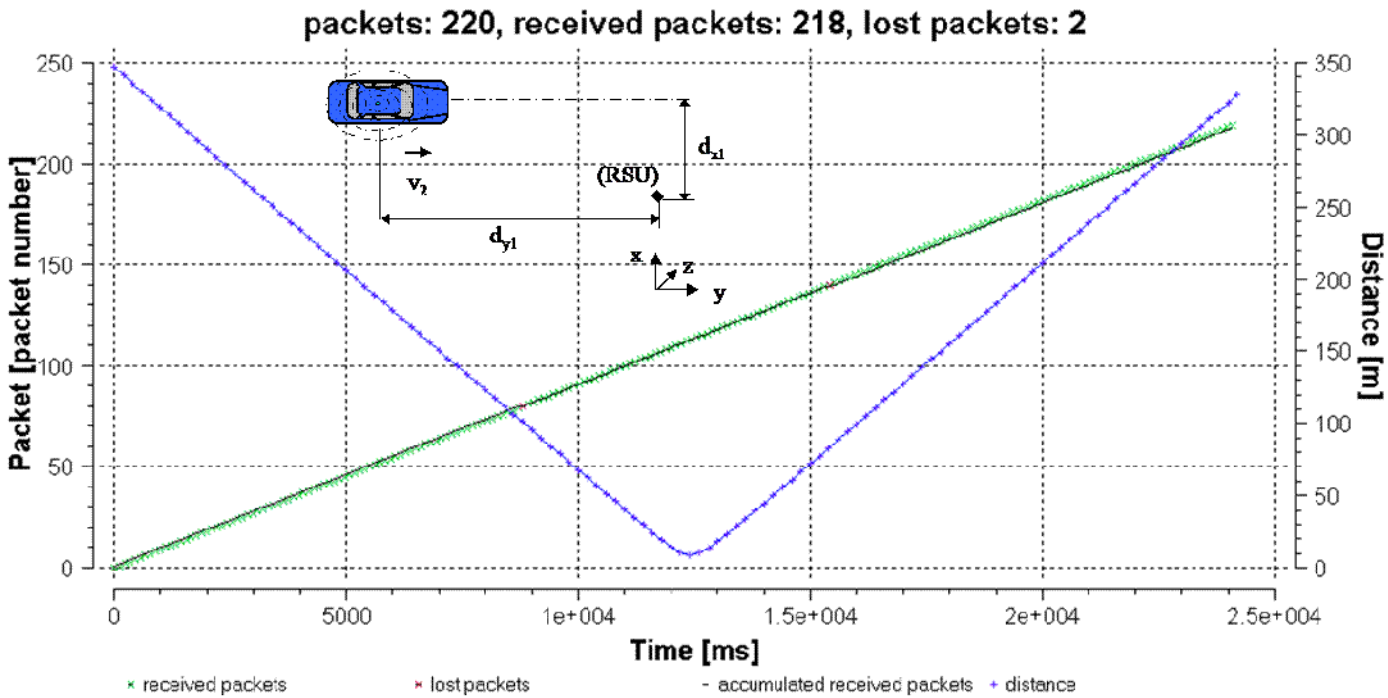
| **Test Scenario** | **1-12** |
|---|---|
| Relevant Applications | Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 10. Test Scenario 1-12**

Test Comments: In this test, the OBU (LeSabre) sends messages (300 bytes) every 100 msec. The receiving vehicle (GMC Envoy) is traveling at 60 mph, two lanes over from the RSU. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, at the most, only 4 packets were lost per run.

Figure 56. Test Number 1-12 Results

| | | | |
|---|---|---|---|
| Test Number | 1-12 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_1_12_3.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | GMC Envoy |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.11 Test Scenario 1-13

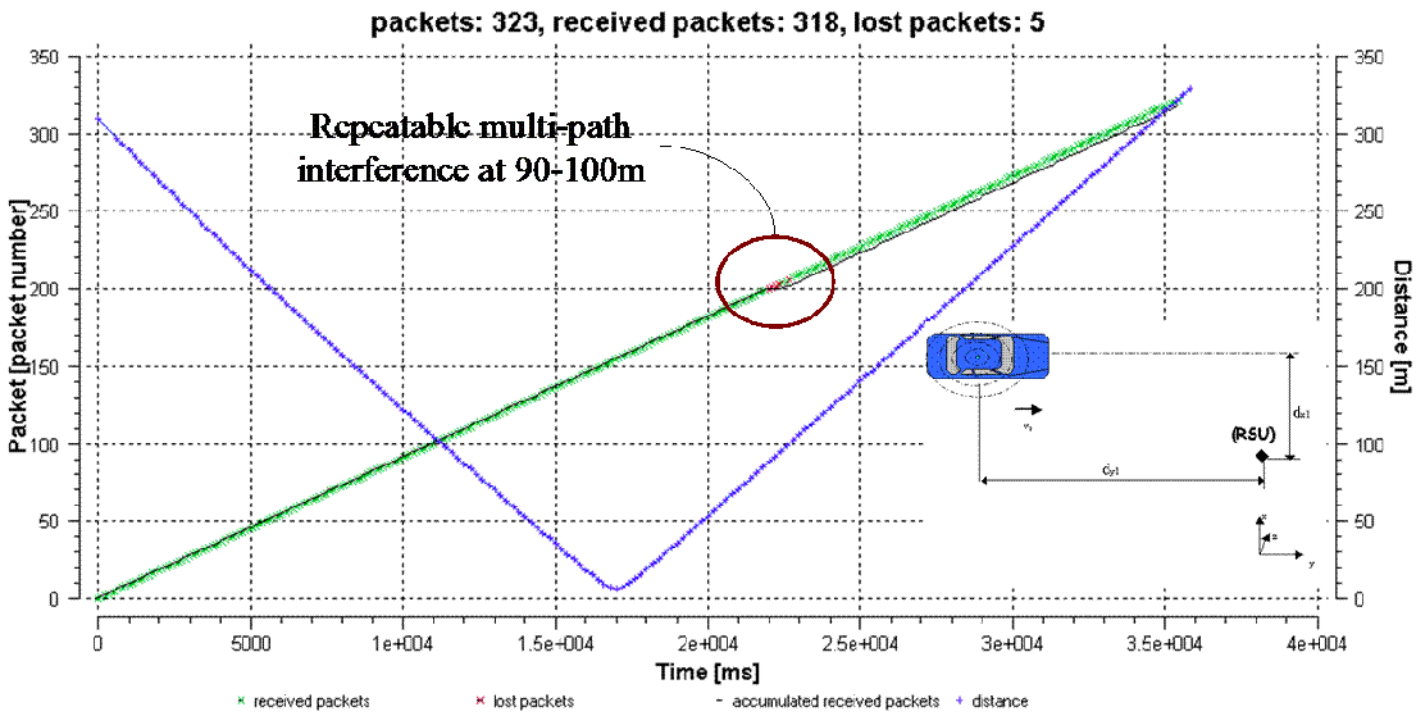
| **Test Scenario** | **1-13** |
|---|---|
| Relevant Applications | Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 40 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 11. Test Scenario 1-13**

Test Comments: There was a clear line-of-sight for the duration of this test between the sending vehicle and the stationary RSU. One reception outage was observed in the same location for all three trials (90-100 m away from the RSU), which was proven in Test 1-20 to be a multipath interference. Overall, 98 percent of the packets (1369 of 1391) sent during the four trials of the test were successfully received.

Figure 57. Test Number 1-13 Results

| | | | |
|---|---|---|---|
| Test Number | 1-13 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_1_13_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.12 Test Scenario 1-14

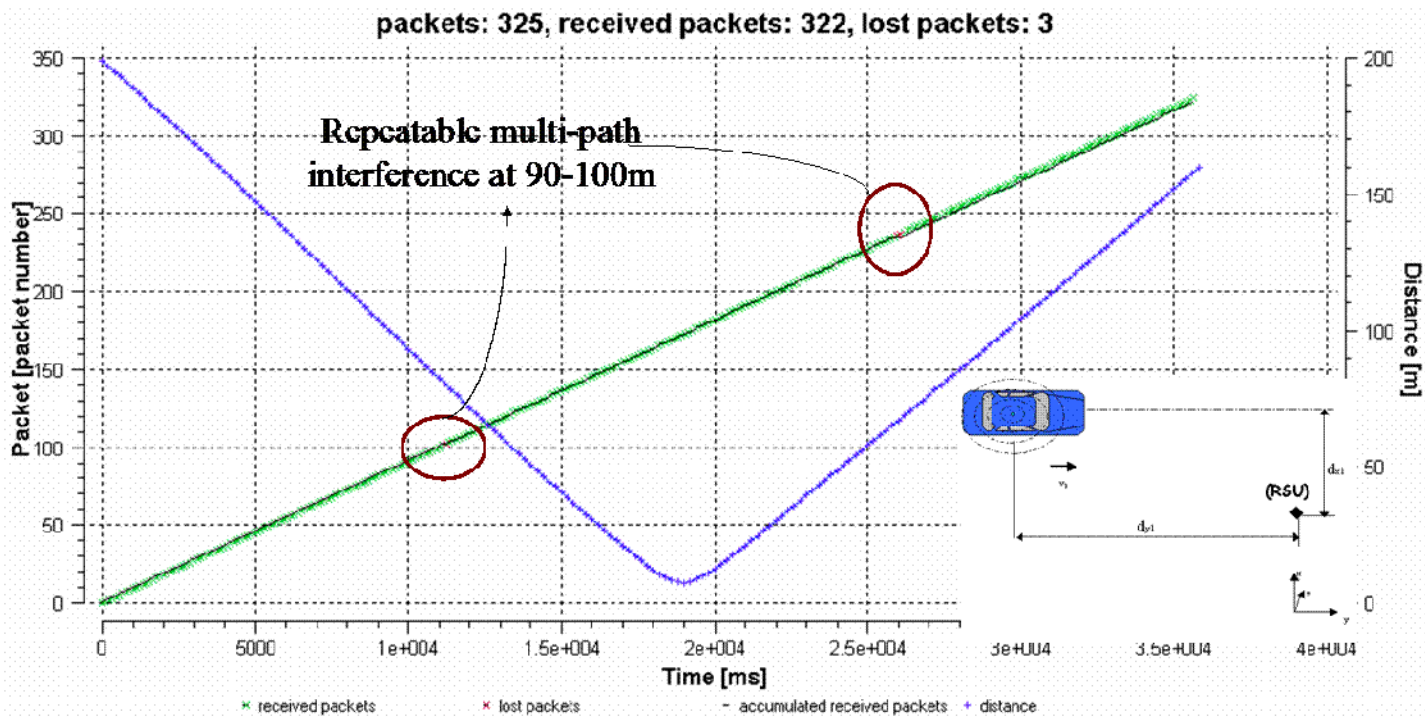
| **Test Scenario** | **1-14** |
|---|---|
| Relevant Applications | Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 20 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 12. Test Scenario 1-14**

Test Comments: There was a clear line-of-sight for the duration of this test between the sending vehicle and the stationary RSU. Two reception outages (1 packet and 2 packets) were observed (70-80 m away from the RSU), which is explained in Test 1-20 as a NULL due to multipath interference.

Figure 58. Test Number 1-14 Results

| | | | |
|---|---|---|---|
| Test Number | 1-14 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_1_14_3.trace* | Sending Vehicle Model/Make: | Buick LaSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LaSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.13 Test Scenario 1-15

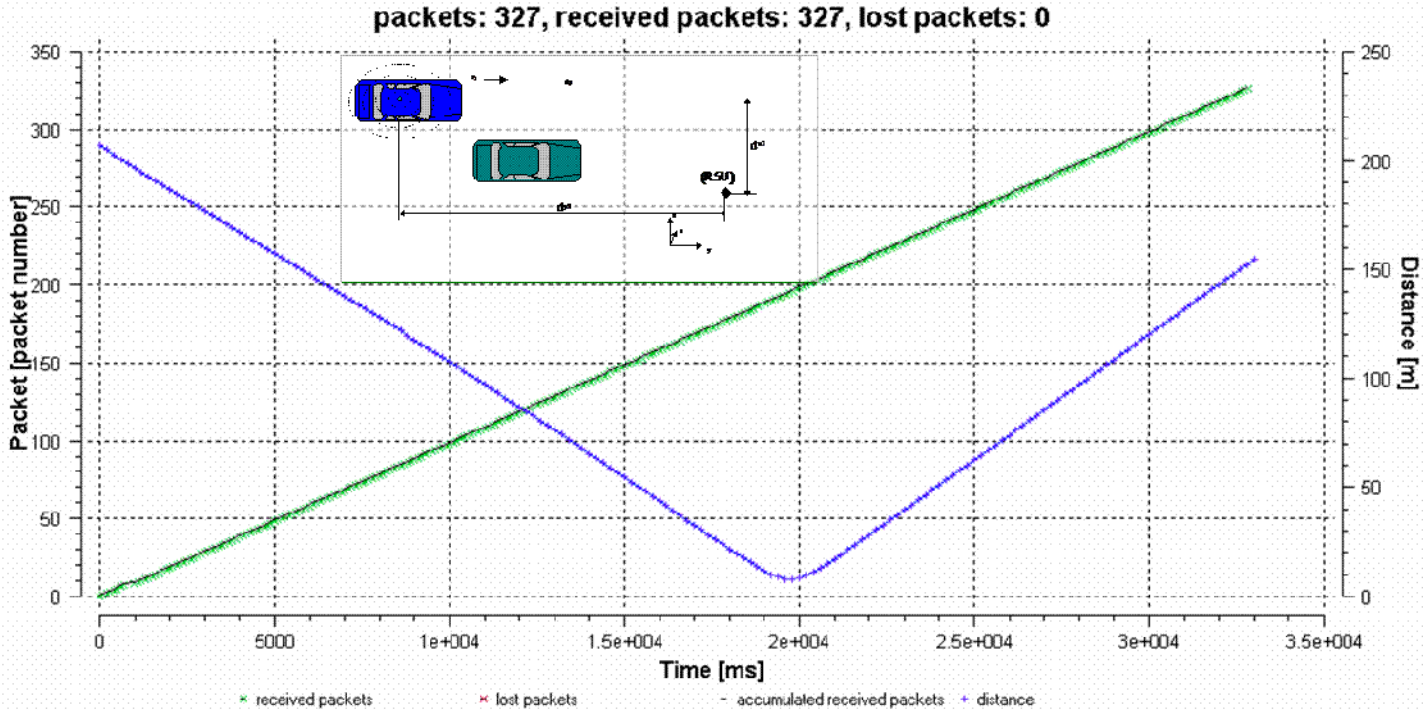
| **Test Scenario** | **1-15** |
|---|---|
| Relevant Applications | Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 20 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 13. Test Scenario 1-15**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Chevy Suburban SUV. There was no loss of reception due to the SUV interception. No packets were lost in all trials of this test.

Figure 59. Test Number 1-15 Results

| | | | |
|---|---|---|---|
| Test Number | 1-15 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_1_15_3.trace* | Sending Vehicle Model/Make: | Buick Lesabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick Lesabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Chevy Suburban |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.14 Test Scenario 1-17

| **Test Scenario** | **1-17** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

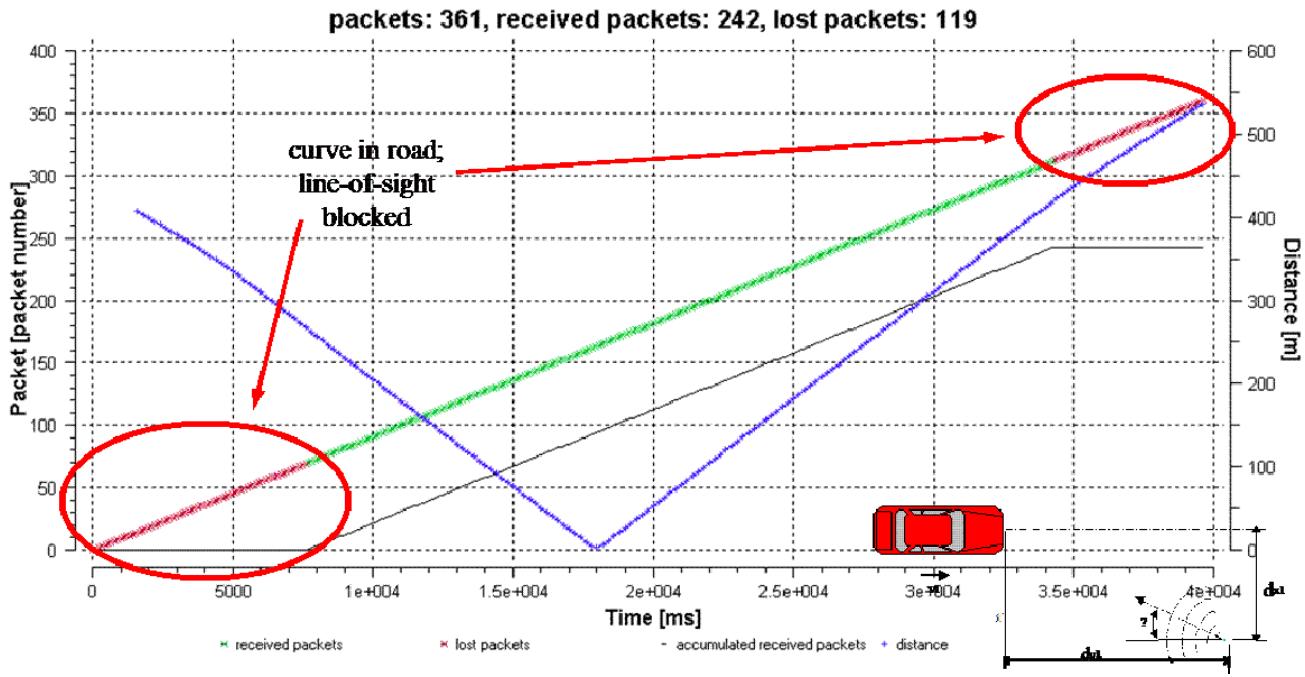
**Table 14. Test Scenario 1-17**

Test Comments: Perfect line-of-sight for the middle section of the test, on the straight-away. Road makes sharp bends before and after the straight-away, and there is no reception beyond those bends.

Figure 60. Test Number 1-17 Results

**Test Number: 1-17** **Ambient Weather Conditions: Sunny**
**Trace File Name: test1-17_2_073003.trace*** **Sending Vehicle Model/Make: VW Passat**
**Date Collected: July 30th, 2003** **Receiving Vehicle Model/Make: BMW Series 3**
**Files Resident With Whom: Chu Hee Lee** **Antenna Type Used: Standard**

**Operating System Used: Linux** **VSC Obstacle Vehicle #1 Model/Make: N/A**
**Software Level Used: 2.3** **VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.15 Test Scenario 1-18

| **Test Scenario** | **1-18** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 80 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 15. Test Scenario 1-18**

Test Comments: This was a 80 mph drive-by test on a country road with no buildings, but with terrain blockage beyond the range limits of the scenario. Virtually no packet loss was experienced within the line-of-sight. However, there was essentially total packet loss when the receiver was blocked by the terrain.

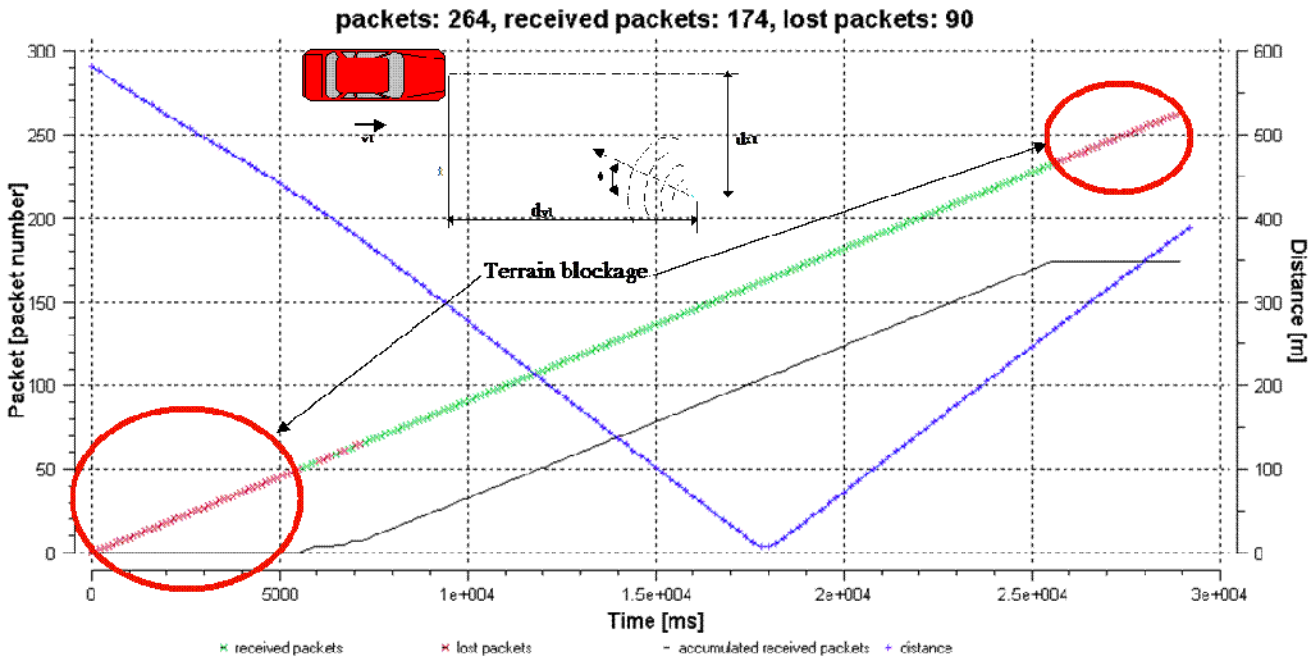
Figure 61. Test Number 1-18 Results

**Test Number 1-18**
**Trace File Name: test1-18_1_073003.trace***
**Date Collected: July 30th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.16 Test Scenario 1-19

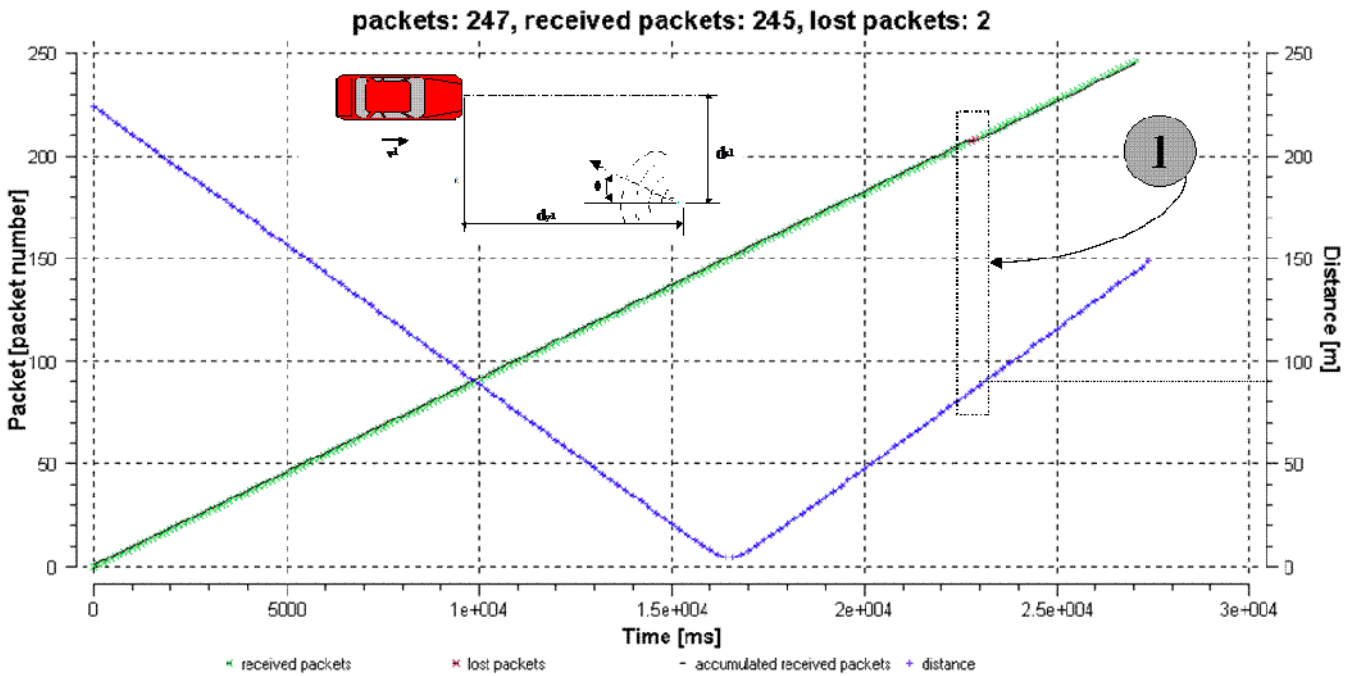
| **Test Scenario** | **1-19** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 30 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Rural |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 16. Test Scenario 1-19**

Test Comments: This test considers a receiving vehicle that passes a stationary antenna at 30 mph. There was a clear line-of-sight throughout the duration of this test. Packets were lost in five of the six trials, and this loss always took place at the range of ~90m. The packet loss can be attributed to multipath cancellation that occurred consistently at that general range, as demonstrated in Test 1-20. Overall, 98.8 percent of the packets sent during the test were received (1,772 out of 1,794 packets).

Figure 62. Test Number 1-19 Results

| | | | |
|---|---|---|---|
| Test Number | 1-19 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_1_19_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.17 Test Scenario 1-20

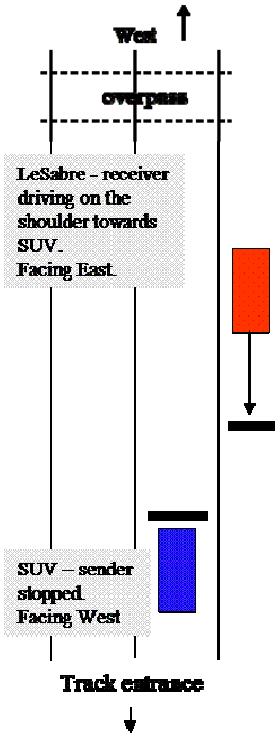
| **Test Scenario** | **1-20** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Left-Turn Assistant<br>Lane Change Warning<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | <5 |
| Distance Between Antennas (meters) | vary |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | Multi-path |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 17. Test Number 1-20**

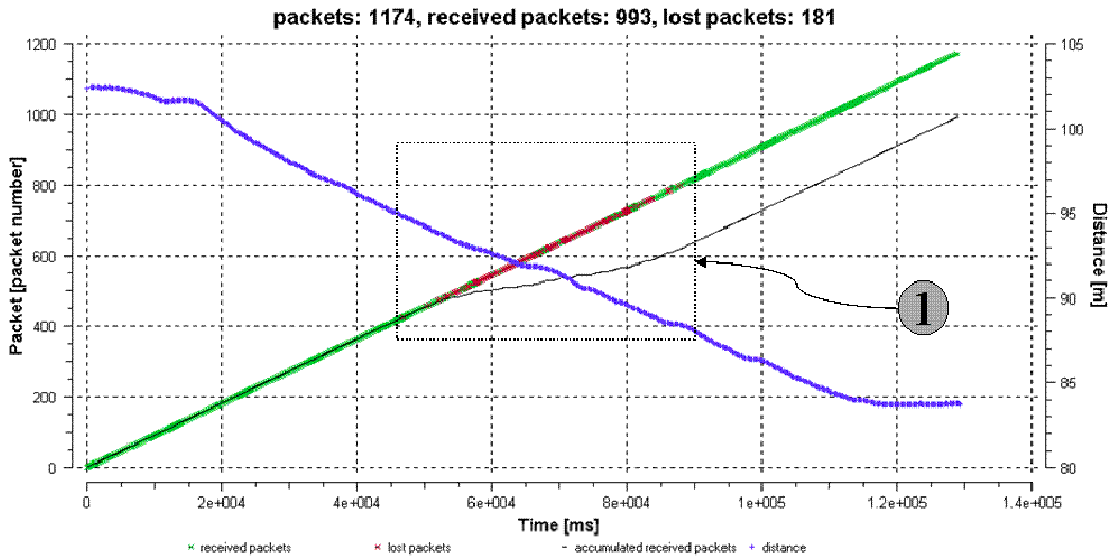
Test Comments: This test was conducted to investigate packet loss that took place at a range of ~90 m during several other tests. The test consisted of a stationary vehicle and a vehicle moving slowly over a distance of ~20 m. The loss of packets highlighted in (1) can be attributed to multipath that occurred consistently at that general range, as shown in the next slides. There was a clear line-of-sight for the duration of this test.

Figure 63. Test Number 1-20 Results

| | | | |
|---|---|---|---|
| Test Number | 1-20 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_1_20_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |




## Null zone due to multi-path reflections



### 4.1.18 Test Scenario 1-21

| **Test Scenario** | **1-21** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | Yes |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Hvy |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 18. Test Scenario 1-21**

Test Comments: The sender was coming from a curve out of line-of-sight. This explains the packet drop at the beginning of the test. As the sender approached to the RSU (receiver), the RSU starts receiving (<375 m) packets until the sender goes out of line-of-sight again (>425 m).

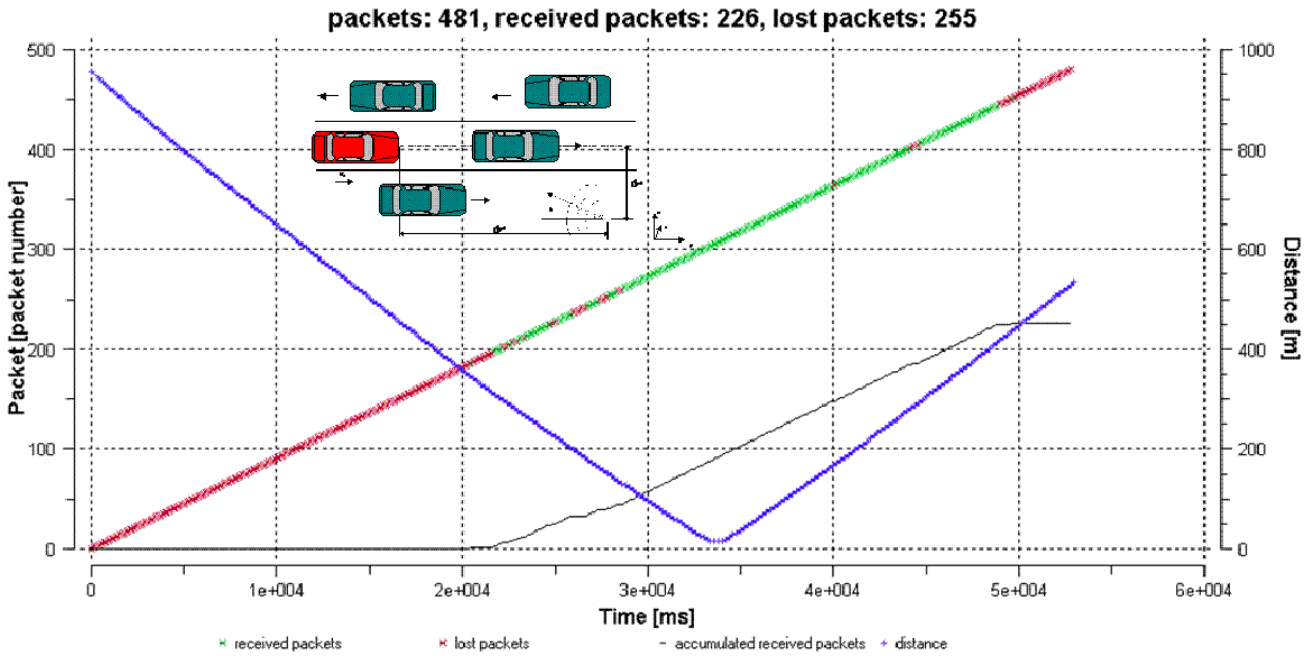
Figure 64. Test Number 1-21 Results

**Test Number: 1-21**
**Trace File Name: test1-21_1_080803.trace***
**Date Collected: August 8th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.19 Test Scenario 1-22

| **Test Scenario** | **1-22** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 30 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | Yes |
| Vehicle Obstructions | Sustained |
| Road Class | Rural |
| Traffic Conditions | Hvy |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 19. Test Scenario 1-22**

Test Comments: Heavy traffic periodically blocked the line-of-sight when the vehicle was approaching the RSU. After the vehicle passed the RSU, it went over a hill and out of line-of-sight.

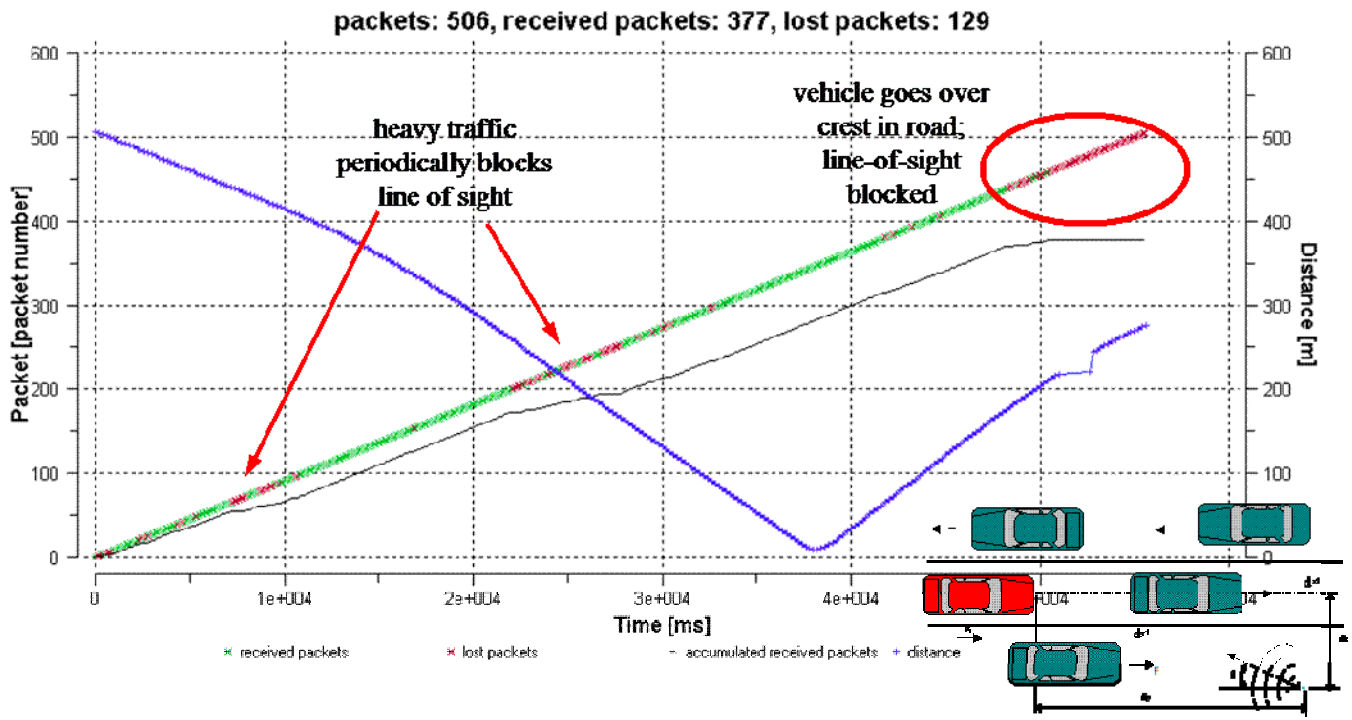
**Figure 65. Test Number 1-2 Results**

NVP w.org (.5) (7am)

NVP w.org (.5) (7pm)NVP w.org (.5) (7am)
NVP w.org (.5) (7pm)

**Test Number: 1-22** **Ambient Weather Conditions: Sunny**
**Trace File Name: test1-22_2_080603.trace*** **Sending Vehicle Model/Make: BMW Series 3**
**Date Collected: August 6th, 2003** **Receiving Vehicle Model/Make: VW Passat**
**Files Resident With Whom: Chu Hee Lee** **Antenna Type Used: Standard**

**Operating System Used: Linux** **VSC Obstacle Vehicle #1 Model/Make: N/A**
**Software Level Used: 2.3** **VSC Obstacle Vehicle #2 Model/Make: N/A**



### 4.1.20 Test Scenario 1-23

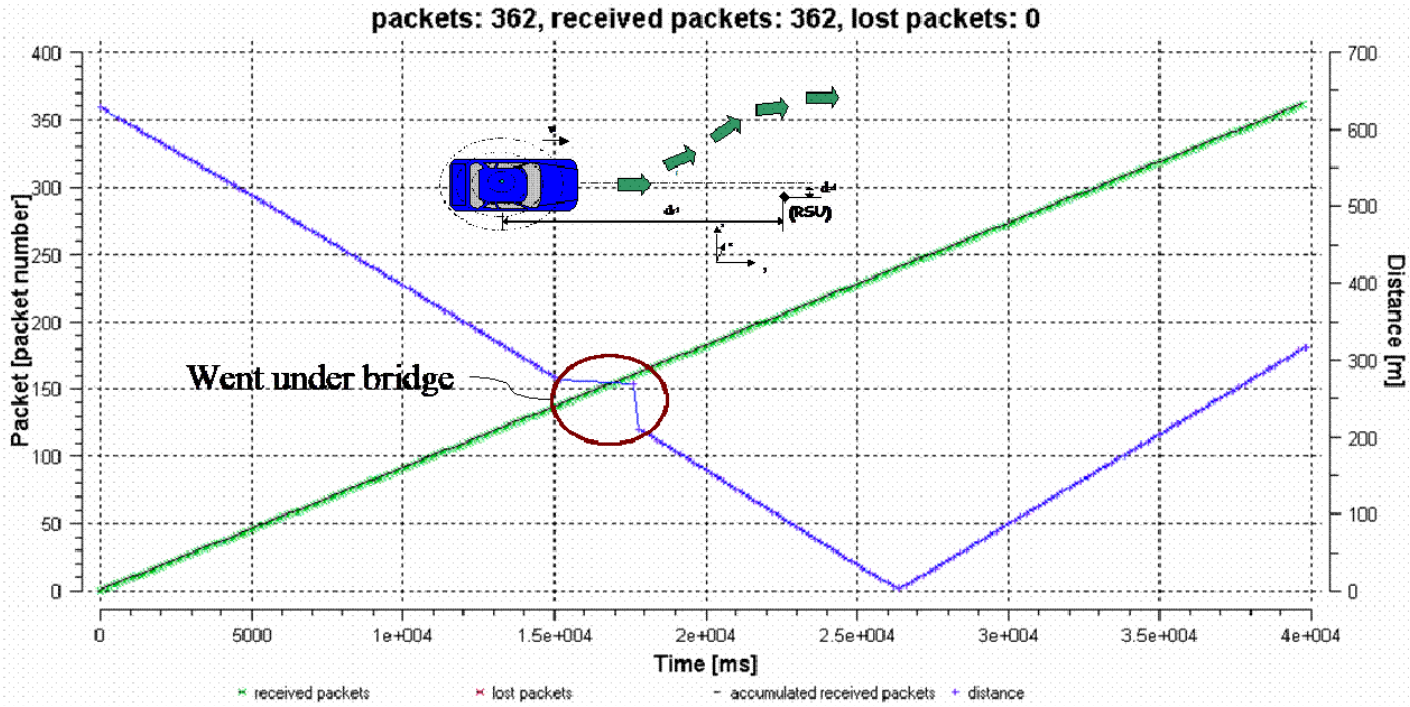
| **Test Scenario** | **1-23** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 20. Test Scenario 1-23**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

Figure 66. Test Number 1-23 Results

| | | | |
|---|---|---|---|
| Test Number | 1-23 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_1_23_4.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.21 Test Scenario 1-24

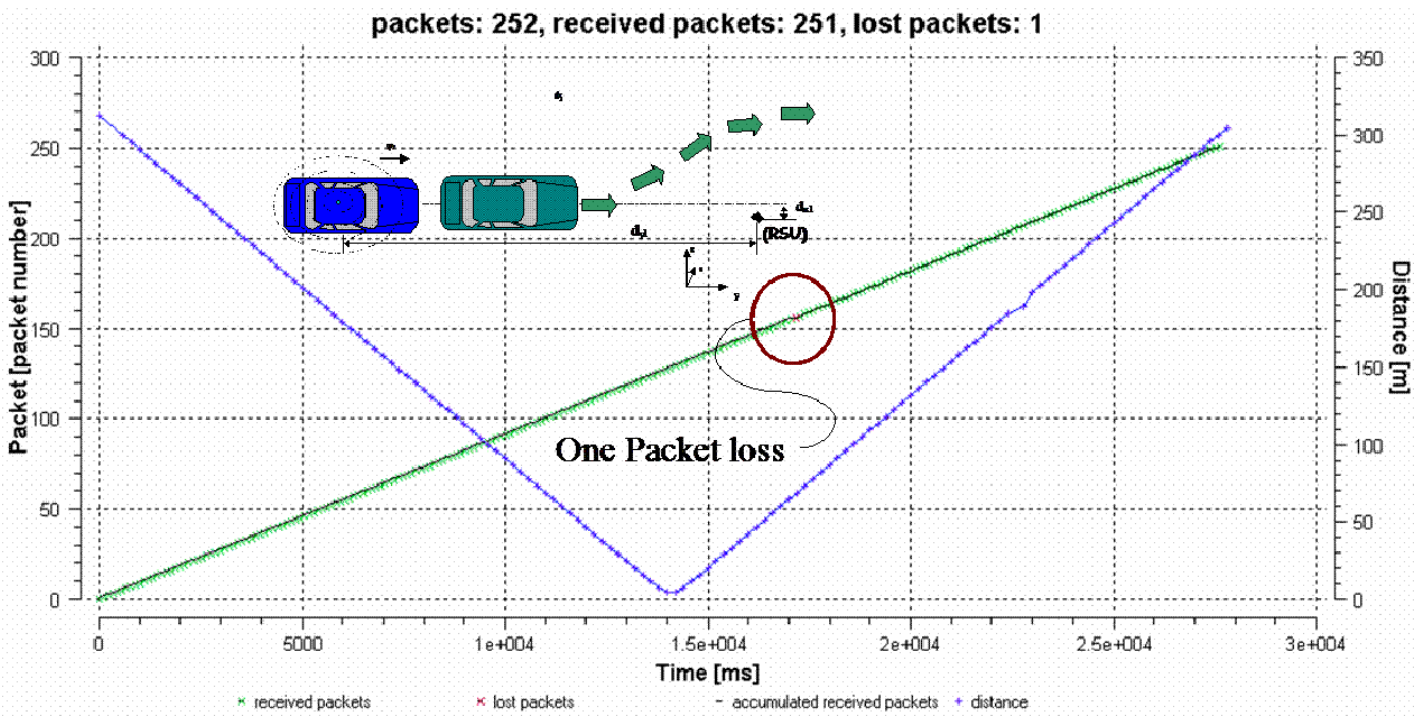
| **Test Scenario** | **1-24** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Cut-out |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 21. Test Scenario 1-24**

Test Comments: There was a clear line-of-sight for the duration of this test. One packet loss outage was observed (perhaps due to multipath), but no significant communication loss occurred due to the SUV obstruction. Overall, most of the packets sent during the test were received.

Figure 67. Test Number 1-24 Results

| | | | |
|---|---|---|---|
| Test Number | 1-24 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 091803_1_24_8.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | Sep 18th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | GMC Envoy |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.22 Test Scenario 1-25

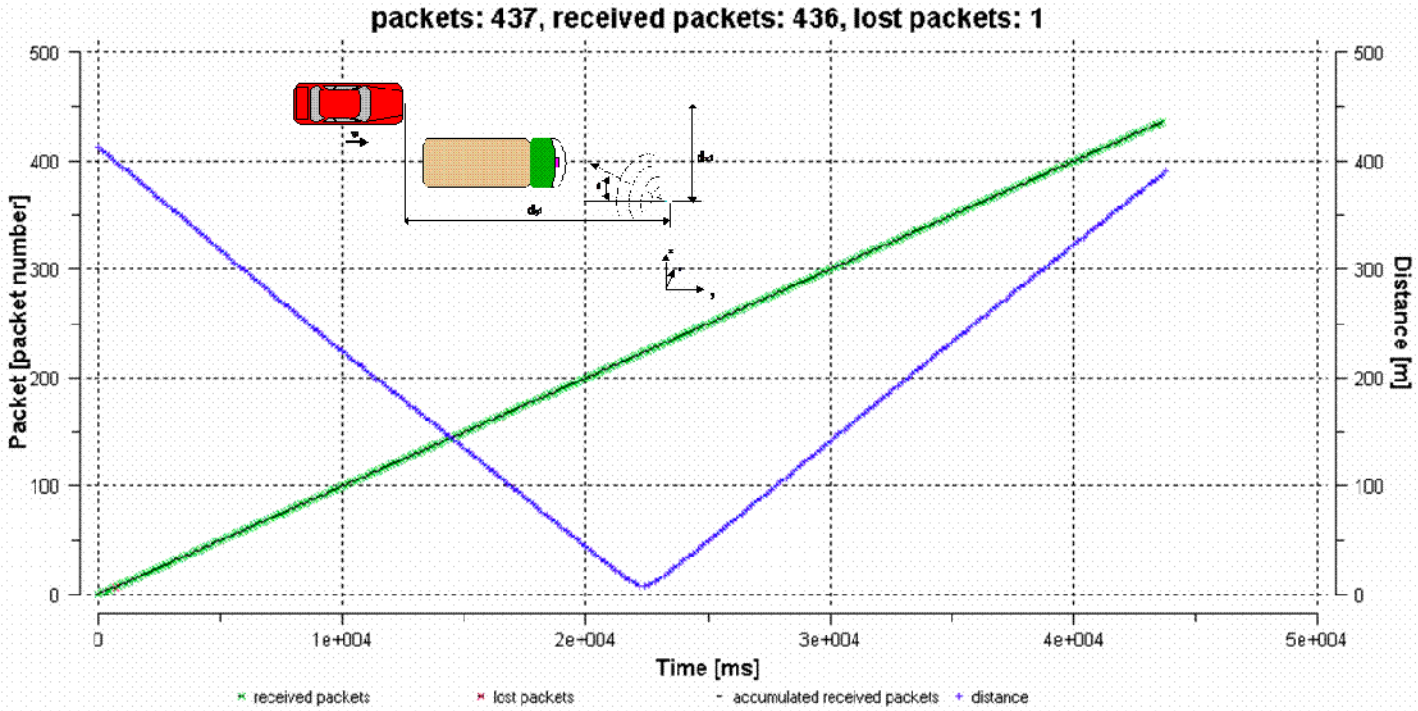
| **Test Scenario** | **1-25** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Curve Speed Warning / Rollover Warning<br>Left-Turn Assistant |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 22. Test Scenario 1-25**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a large truck. There was no significant loss of reception due to the large truck interception. Only one packet was lost in this trial and all trials of this test showed similar performance.

Figure 68. Test Number 1-25 Results

| | | | |
|---|---|---|---|
| Test Number | 1-25 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_1_25_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.23 Test Scenario 1-26

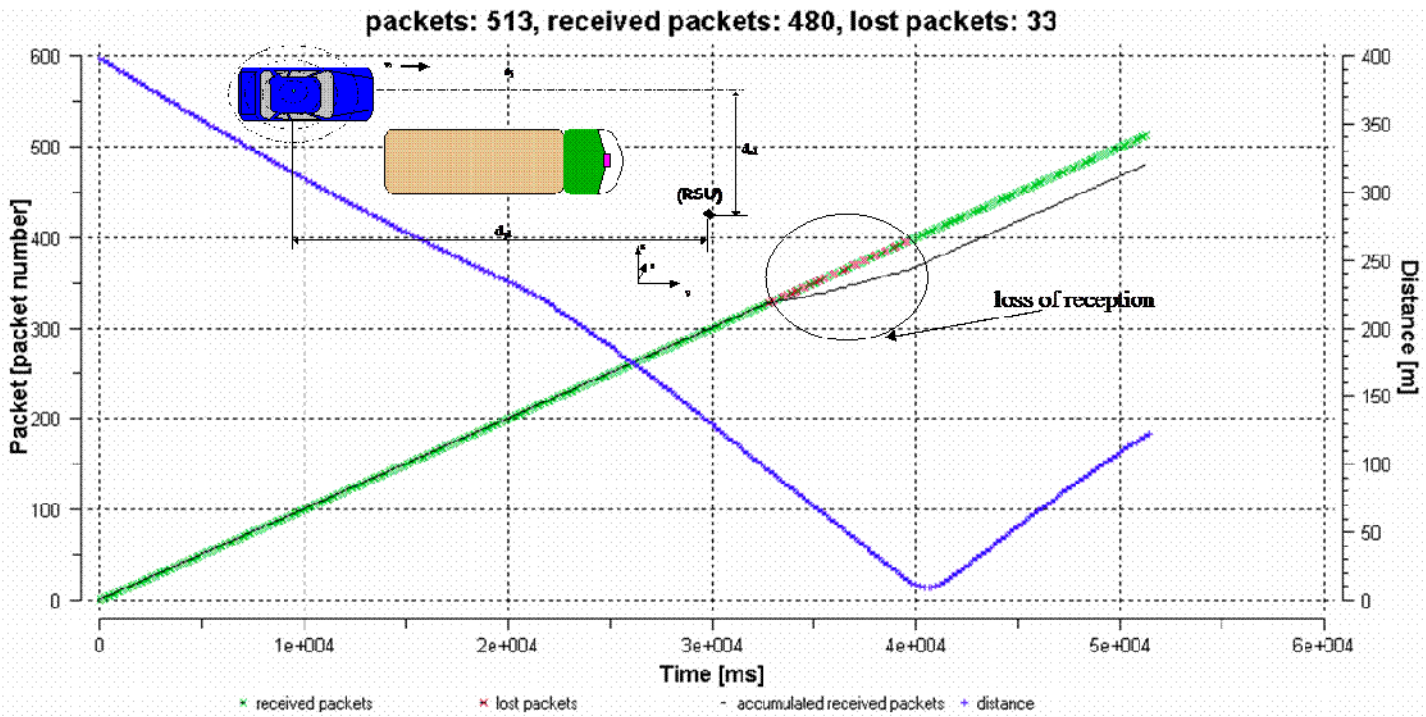
| **Test Scenario** | **1-26** |
|---|---|
| Relevant Applications | Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 20 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 23. Test Scenario 1-26**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a large truck. There was significant loss of reception due to the large truck interception when the sender and receiver were obstructed by the truck.

Figure 69. Test Number 1-26 Results

| | | | |
|---|---|---|---|
| Test Number | 1-26 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_1_26_3.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 4.1.24 Test Scenario 1-27

| **Test Scenario** | **1-27** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | <5 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

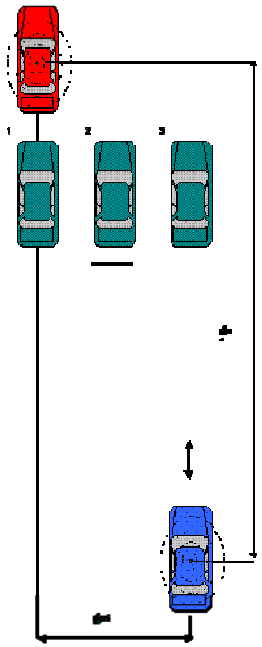
**Table 24. Test Scenario 1-27**

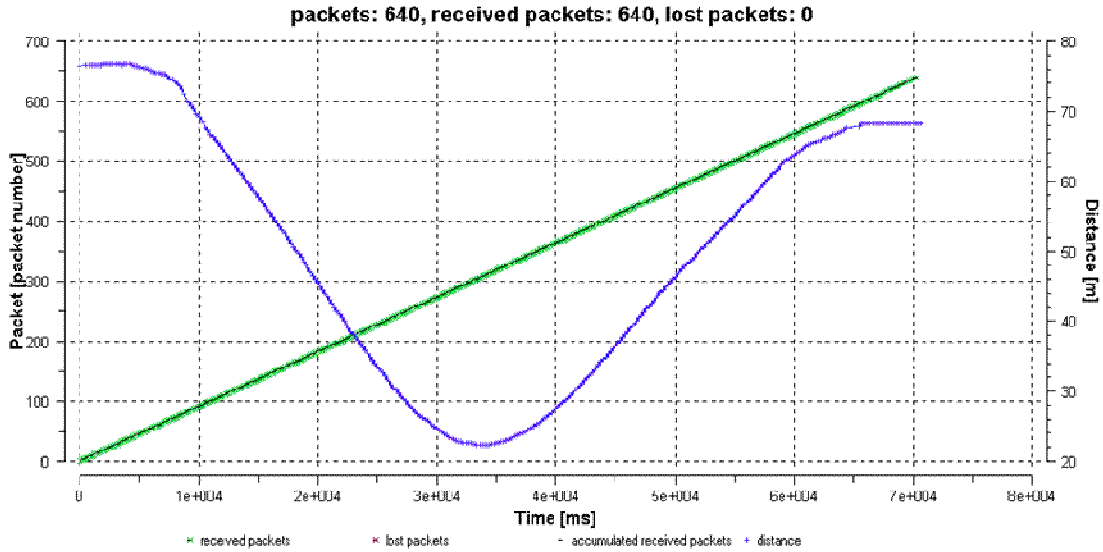
Test Comments: This test considers the effect of three side-by-side SUVs parked between a stationary receiving vehicle and a slowly moving sender vehicle. Obstacle Vehicle #2 blocked the line-of-sight during the test. Overall, 100 percent of the packets sent during the test were received.

Figure 70. Test Number 1-27-1 Results

| | |
|---|---|
| Test Number: | 1-27-1 |
| Trace File Name: | 082703_2_19_7_SUV.trace* |
| Date Collected: | August 27th, 2003 |
| Files Resident With: | Jim Bauer |
| Operating System Used: | Linux |
| Software Level Used: | Version 2.3 |

| | |
|---|---|
| Ambient Weather Conditions: | Mostly Sunny |
| Sending Vehicle Model/Make: | Toyota Prius |
| Receiving Vehicle Model/Make: | Lexus GS300 |
| Antenna Type Used: | Standard |
| Obstacle Vehicle #1 Model/Make: | Toyota Sequoia |
| Obstacle Vehicle #2 Model/Make: | Toyota Sequoia |
| Obstacle Vehicle #3 Model/Make: | Toyota Highlander |



### 4.1.25 Test Scenario 1-28

| **Test Scenario** | **1-28** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | <5 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 25. Test Scenario 1-28**

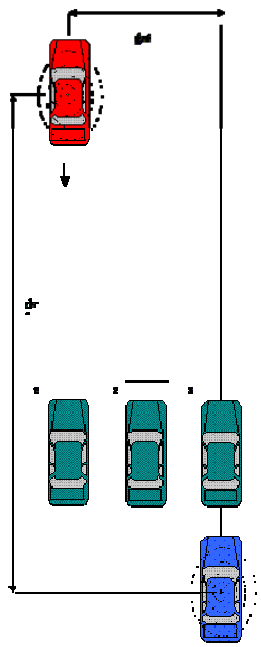
Test Comments: This test considers the effect of three side-by-side SUVs parked between a stationary sending vehicle and a slowly moving receiver vehicle. Obstacle Vehicle #2 blocked the line-of-sight during the test. Overall, 100 percent of the packets sent during the test were received.

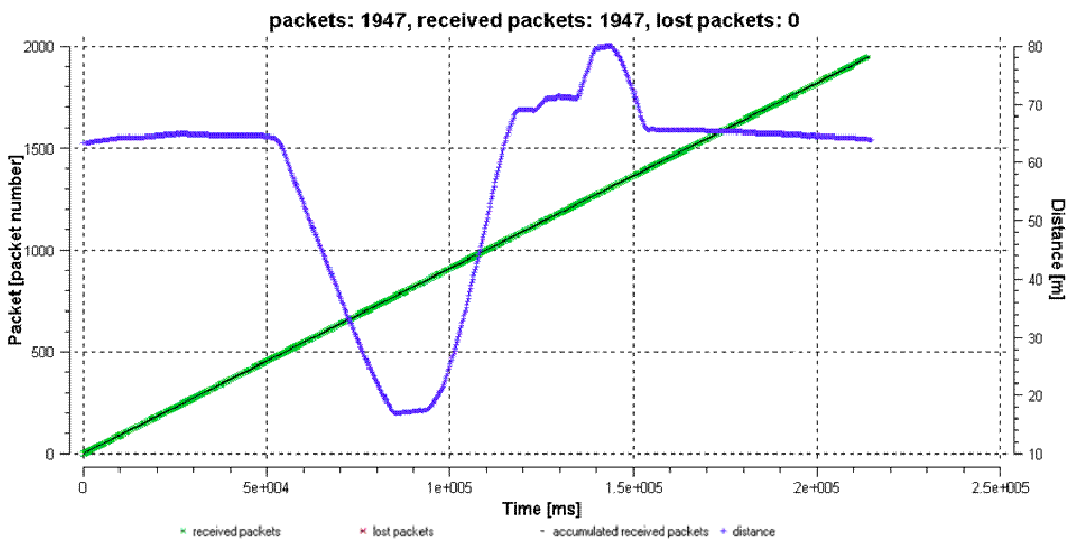
Figure 71. Test Number 1-28-1 Results

**Test Number:** 1-28-1
**Trace File Name:** 082703_2_19_11_SUV.trace*
**Date Collected:** August 27th, 2003
**Files Resident With:** Jim Bauer

**Operating System Used:** Linux
**Software Level Used:** Version 2.3

**Ambient Weather Conditions:** Mostly Sunny
**Sending Vehicle Model/Make:** Toyota Prius
**Receiving Vehicle Model/Make:** Lexus GS300
**Antenna Type Used:** Standard
**Obstacle Vehicle #1 Model/Make:** Toyota Sequoia
**Obstacle Vehicle #2 Model/Make:** Toyota Sequoia
**Obstacle Vehicle #3 Model/Make:** Toyota Highlander





# 5 Dynamic Vehicle-Vehicle Communication

## 5.1 Test Scenarios

### 5.1.1 Test Scenario 2-1

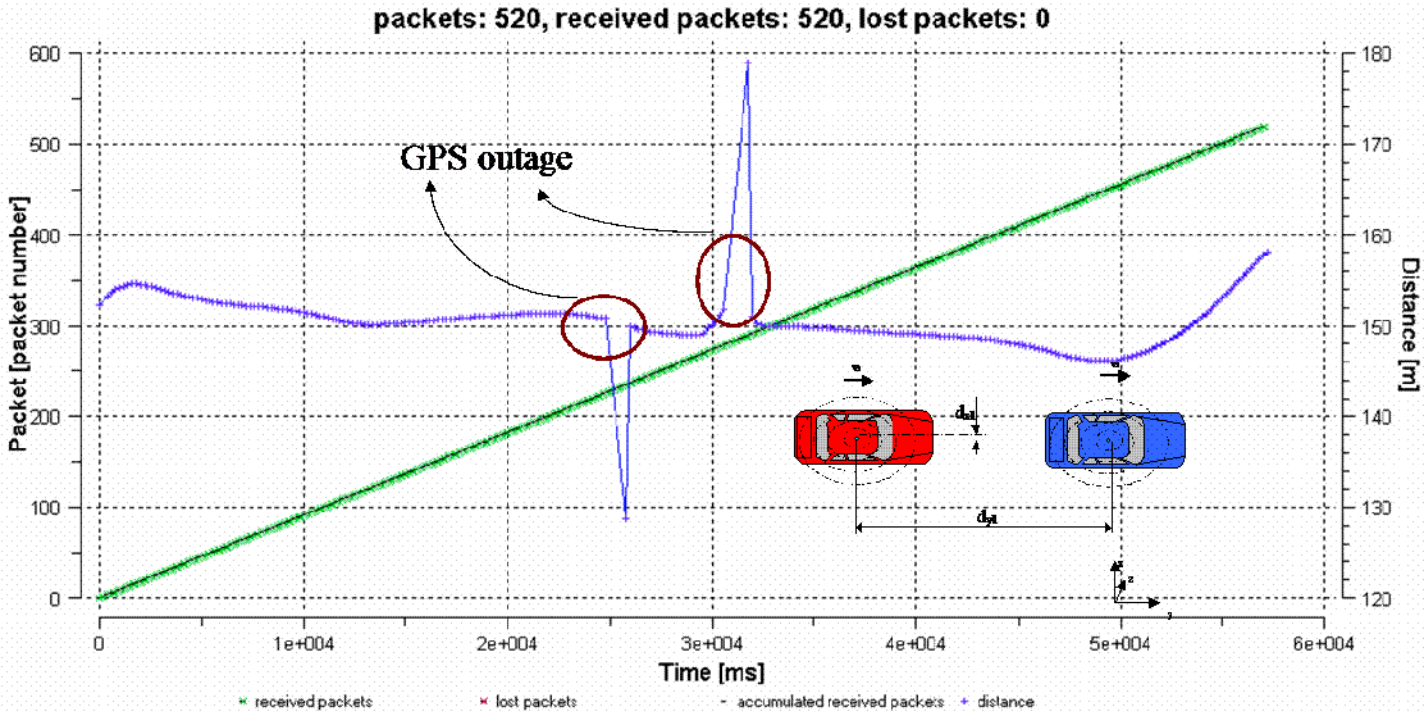
| **Test Scenario** | **2-1** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 150 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 26. Test Scenario 2-1**

Test Comments: There was a clear line-of-sight for the duration of this test between the sending vehicle and the receiving vehicle. Two GPS outages were observed as the vehicles went under a bridge in the test track. There were no lost packets in all three trials of the test.

Figure 72. Test Number 2-1 Results

| | | | |
|---|---|---|---|
| Test Number | 2-1 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_1_3.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.2 Test Scenario 2-2

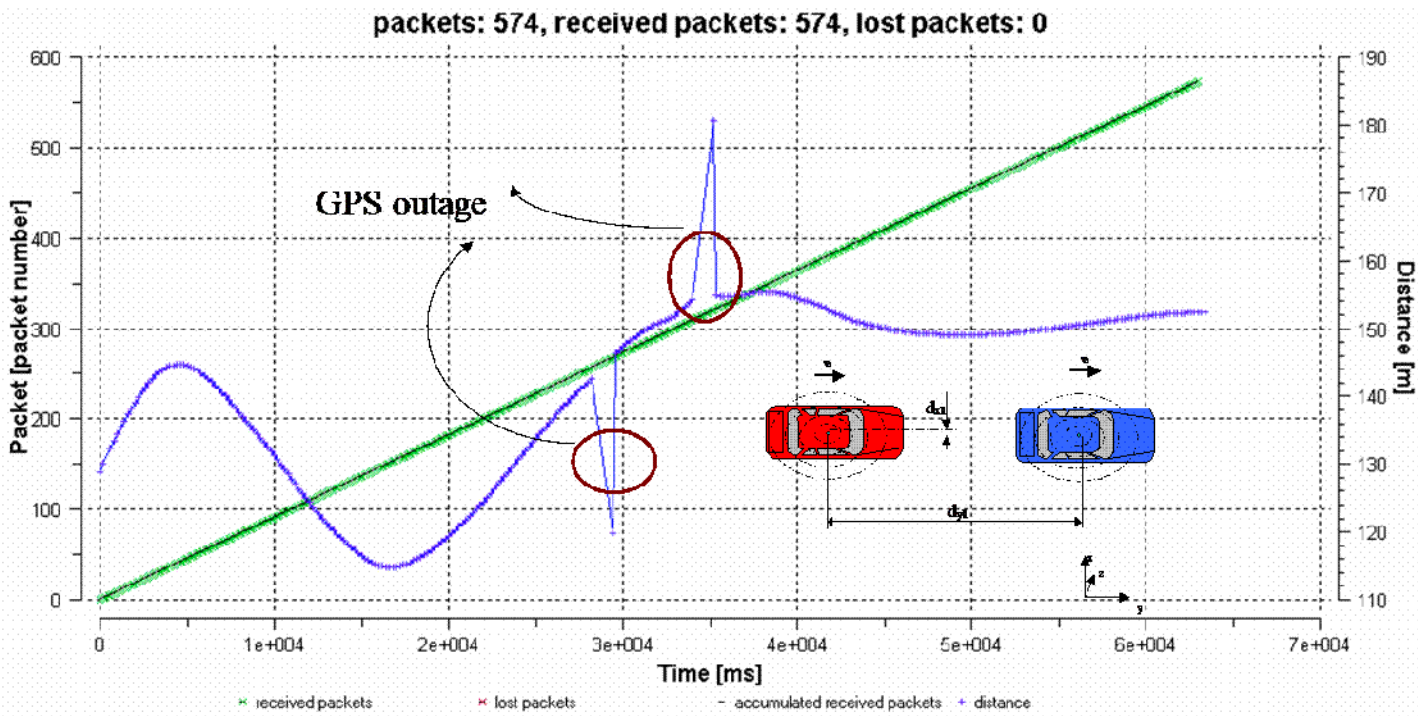
| **Test Scenario** | **2-2** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 150 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 27. Test Scenario 2-2**

Test Comments: There was a clear line-of-sight for the duration of this test between the sending vehicle and the receiving vehicle. Two GPS outages were observed as the vehicles went under a bridge in the test track. There were no lost packets in all three trials of the test.

Figure 73. Test Number 2-2 Results

| | | | |
|---|---|---|---|
| Test Number | 2-2 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_2_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.3 Test Scenario 2-3

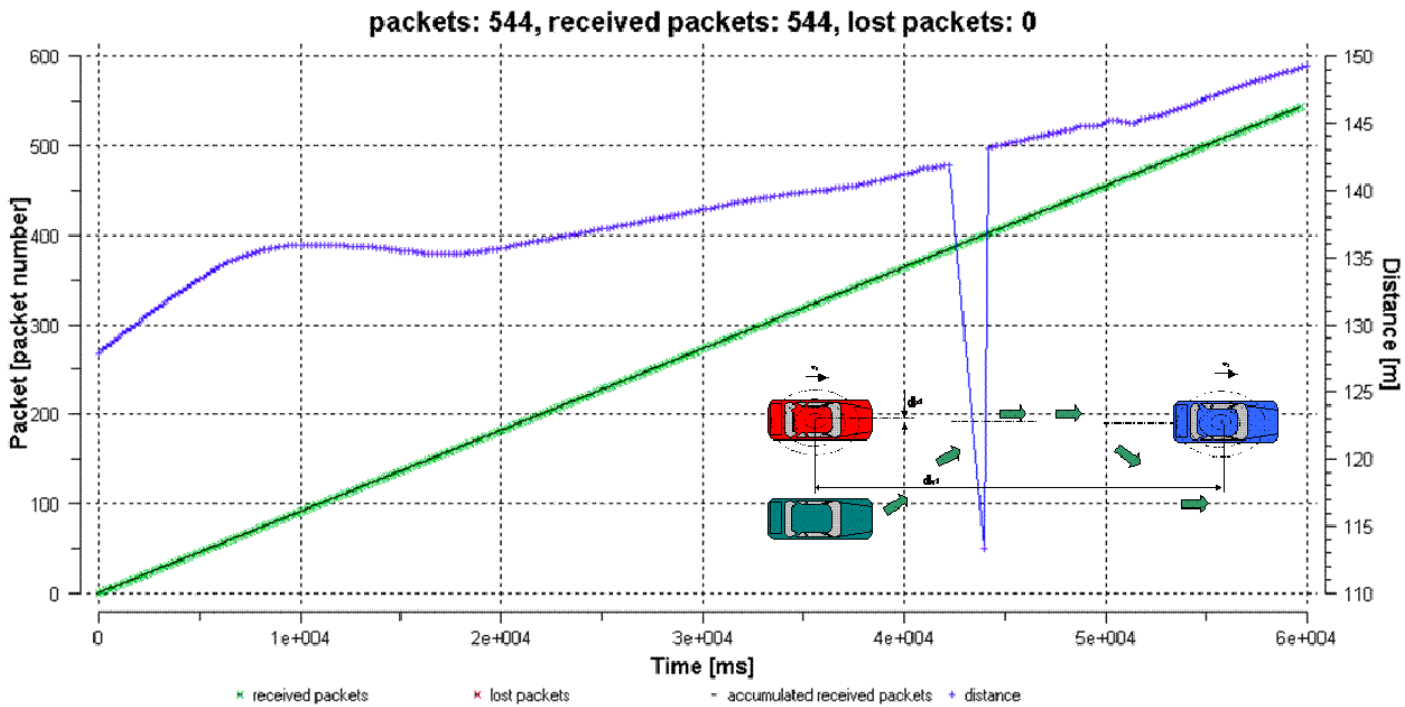
| **Test Scenario** | **2-3** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 150 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 40 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Cut-in |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 28. Test Scenario 2-3**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed in the same location for all three trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

Figure 74. Test Number 2-3 Results

| | | | |
|---|---|---|---|
| Test Number | 2-3 | Ambient Weather Conditions: | Cloudy |
| Trace File Name: | 091803_2_3_4.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | September 18th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | S. Tengler | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | GMC Envoy |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.4 Test Scenario 2-4

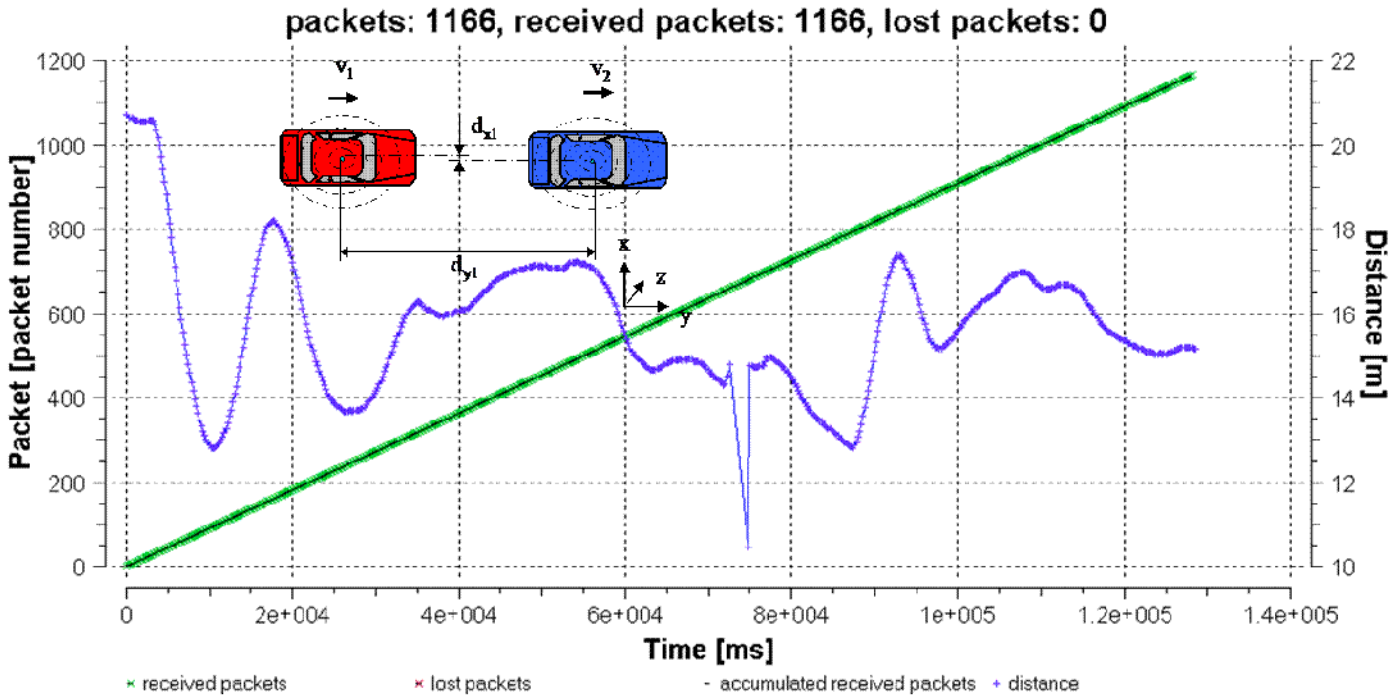
| **Test Scenario** | **2-4** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 15 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Residential |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 29. Test Scenario 2-4**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (400 bytes) every 100 msec. Both vehicles are traveling at ~25 mph, unobstructed and < 20 m apart. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, no packets were dropped.

Figure 75. Test Number 2-4 Results

| | | | |
|---|---|---|---|
| Test Number | 2-4 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_2_4_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.5 Test Scenario 2-5

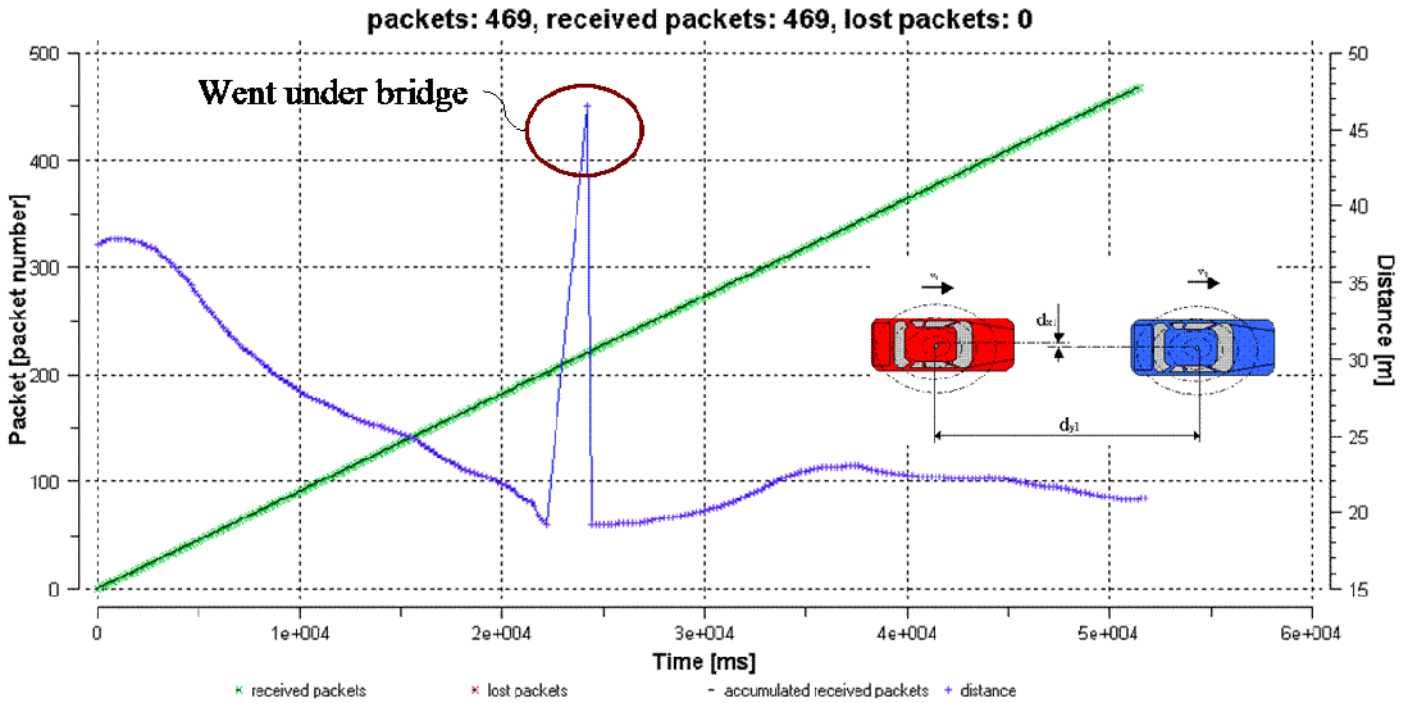
| **Test Scenario** | **2-5** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 20 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 30. Test Scenario 2-5**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed in the same location for all three trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received with both MS Windows and Linux.

Figure 76. Test Number 2-5 Results

| | | | |
|---|---|---|---|
| Test Number | 2-5 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_2_5_1.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.6 Test Scenario 2-6

| **Test Scenario** | **2-6** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 31. Test Scenario 2-6**

Test Comments: Basic communication at ~100 m is working pretty well with less than 3 percent packet loss. The packet loss is most likely due to a truck moving in between the two cars and cutting the line-of-sight.

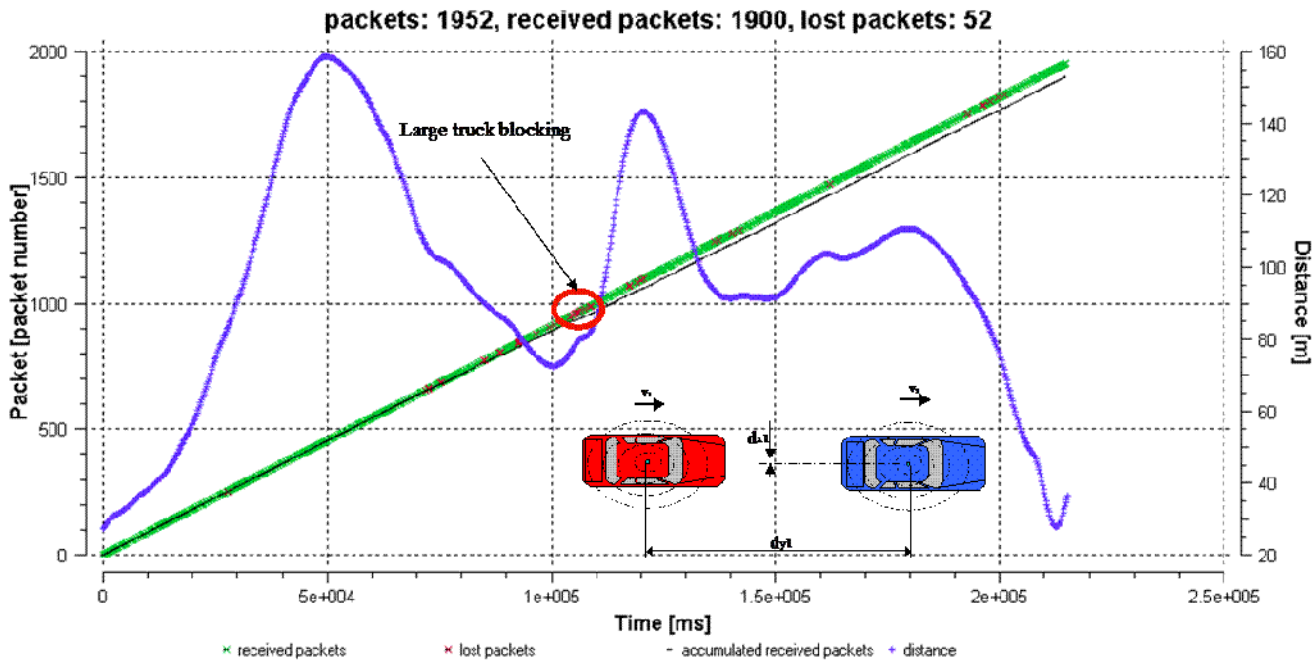
Figure 77. Test Number 2-6 Results

**Test Number 2-6**
**Trace File Name: test2-6-1_070203.trace***
**Date Collected: July 2nd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: sedan**
**Receiving Vehicle Model/Make: sedan**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.1**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.7 Test Scenario 2-8

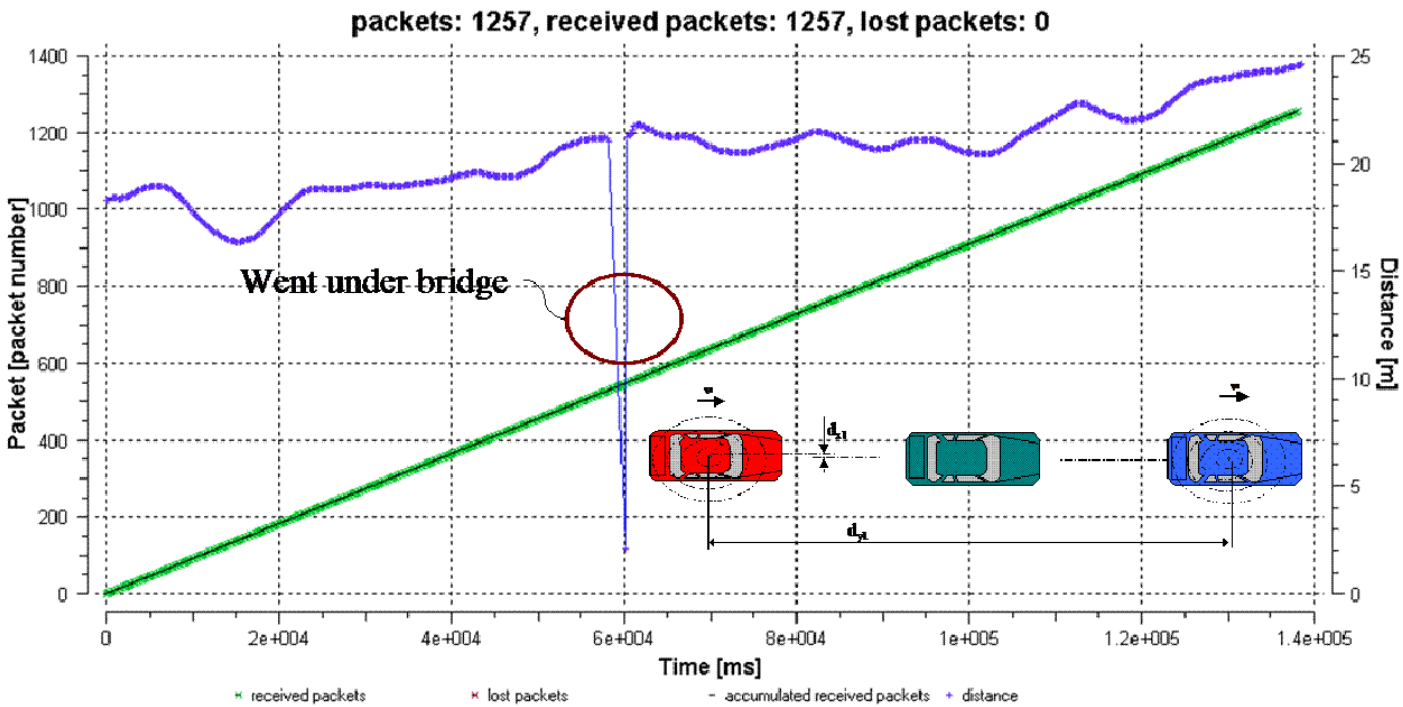
| **Test Scenario** | **2-8** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 20 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 32. Test Scenario 2-8**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed in the same location for all four trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

Figure 78. Test Number 2-8 Results

| | | | |
|---|---|---|---|
| Test Number | 2-8 | Ambient Weather Conditions: | Cloudy |
| Trace File Name: | 091803_2_8_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | September 18th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | S. Tengler | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | GMC Envoy |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.8 Test Scenario 2-9

| **Test Scenario** | **2-9** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 33. Test Scenario 2-9**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed in the same location for all four trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

**Figure 79. Test Number 2-9 Results**

| | | | |
|---|---|---|---|
| Test Number | **2-9** | Ambient Weather Conditions: | **Cloudy** |
| Trace File Name: | **091803_2_9_1.trace*** | Sending Vehicle Model/Make: | **Buick LaSabre** |
| Date Collected: | **September 18th, 2003** | Receiving Vehicle Model/Make: | **Buick LaSabre** |
| Files Resident With Whom: | **S. Tengler** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **GMC Envoy** |
| Software Level Used: | **V2.3 (8-July-03)** | VSC Obstacle Vehicle #2 Model/Make: | **N/A** |

(NO GRAPH AVAILABLE due to suspected corruption of the GPS files from the test)

### 5.1.9 Test Scenario 2-10

| **Test Scenario** | **2-10** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 34.Test Scenario 2-10**

Test Comments: Some periods of packet loss, but no continuous outages. Losses seemed to vary due to road curvature and the resulting position of the blocking vehicle relative to the test vehicles.

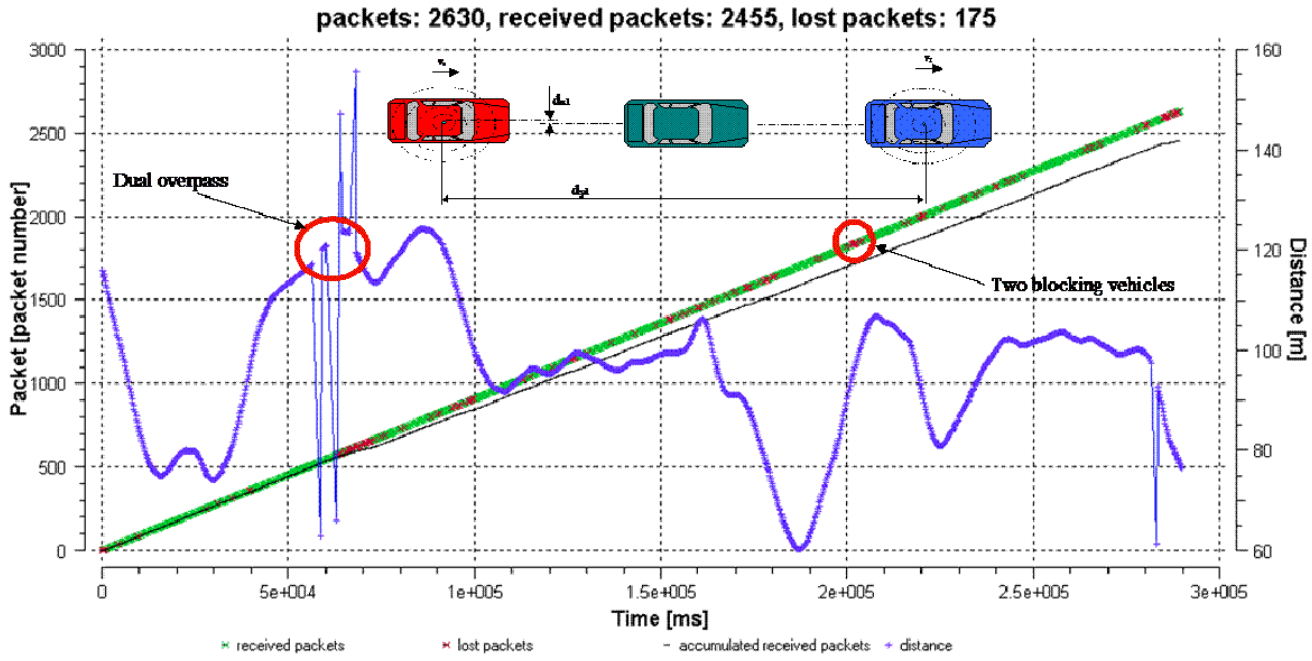
Figure 80. Test Number 2-10 Results

**Test Number 2-10**
**Trace File Name: test2-10_1_073003.trace***
**Date Collected: July 30th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: BMW X5**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.10 Test Scenario 2-11

| **Test Scenario** | **2-11** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 35. Test Scenario 2-11**

Test Comments: Two blocking SUVs caused significant, though not complete, packet loss, due primarily to relative positions and not overall separation distance. In fact, packet success seemed better at longer distances, possibly due to reduced field of view blockage compared to that of a tighter packed formation.

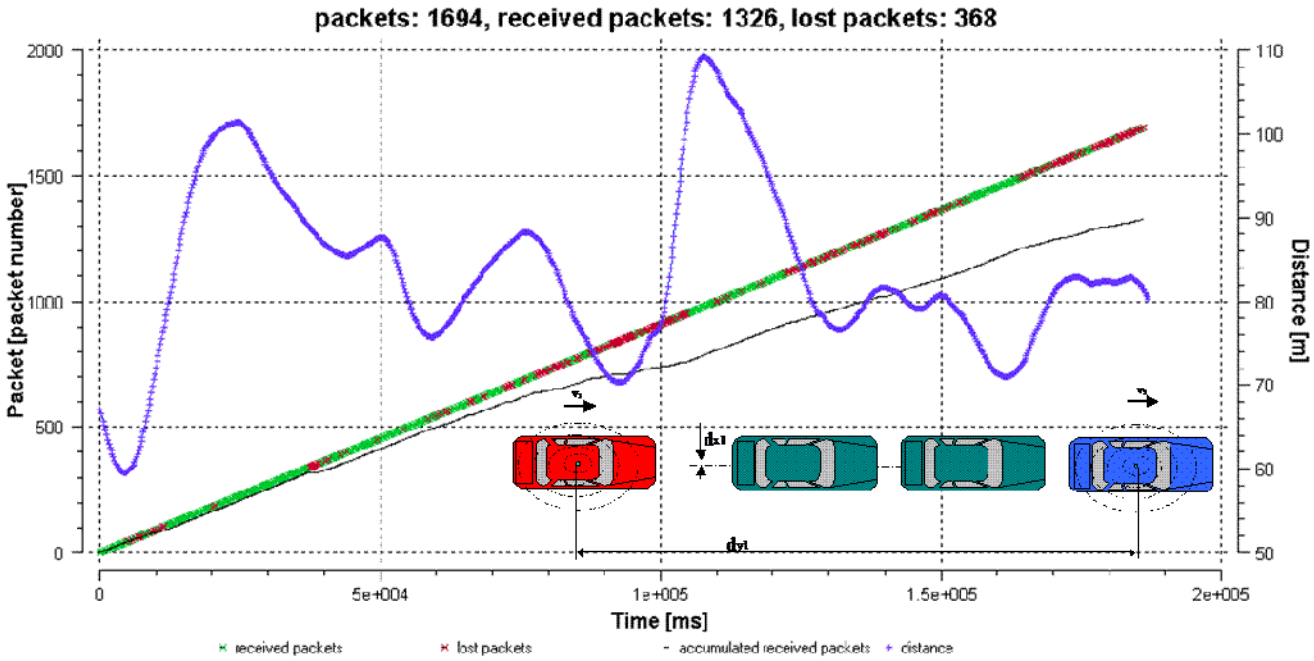
Figure 81. Test Number 2-11 Results

Test Number 2-11
Trace File Name: test2-11_3_080603.trace*
Date Collected: August 6th, 2003
Files Resident With Whom: Chu-Hee Lee

Ambient Weather Conditions: Sunny
Sending Vehicle Model/Make: BMW Series 3
Receiving Vehicle Model/Make: VW Passat
Antenna Type Used: Standard

Operating System Used: Linux
Software Level Used: 2.3

VSC Obstacle Vehicle #1 Model/Make: BMW X5
VSC Obstacle Vehicle #2 Model/Make: Mercedes M-class



### 5.1.11 Test Scenario 2-12

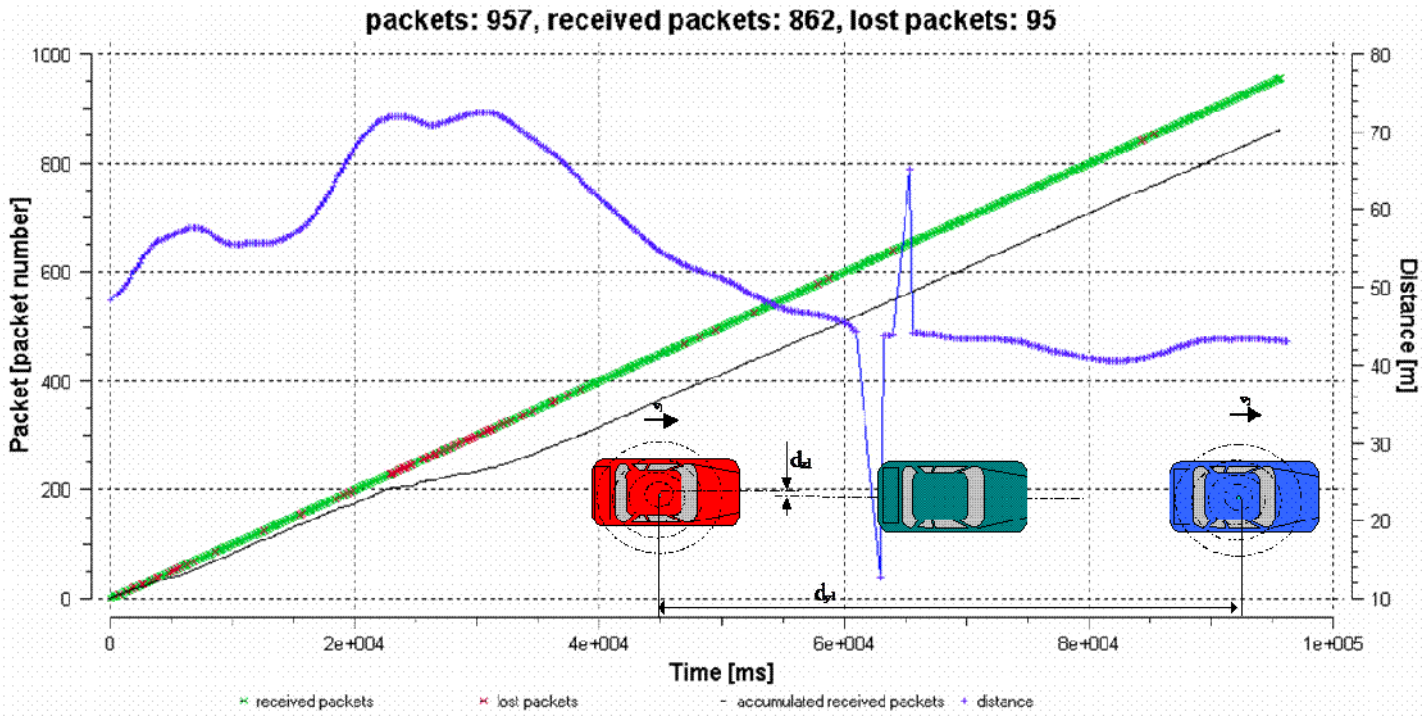
| **Test Scenario** | **2-12** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 70 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 40 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 36. Test Scenario 2-12**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a large truck. There were significant losses of reception due to the large truck interception and all trials of this test showed similar performance.

Figure 82. Test Number 2-12 Results

| | | | |
|---|---|---|---|
| Test Number | 2-12 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_2_12_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.12 Test Scenario 2-13

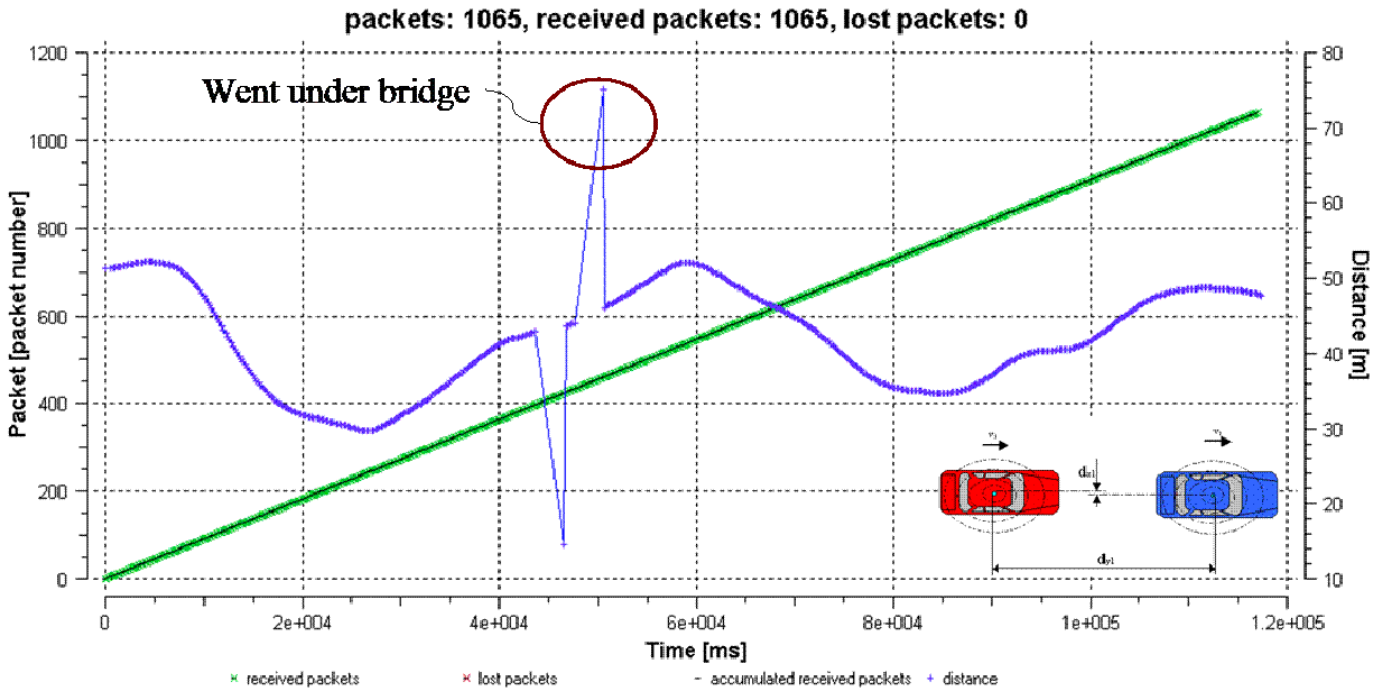
| **Test Scenario** | **2-13** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 37. Test Scenario 2-13**

Test Comments: There was a clear line-of-sight for the duration of this test. One GPS outage was observed in the same location for all three trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

Figure 83. Test Number 2-13 Results

| | | | |
|---|---|---|---|
| Test Number | 2-13 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_13_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | S. Teagler | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.13 Test Scenario 2-14

| **Test Scenario** | **2-14** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 38. Test Scenario 2-14**

Test Comments: Brief GPS outage due to overpass. Noticeable, but not complete, packet loss due to loss of line-of-sight between test vehicles while on opposite sides of hill crest.

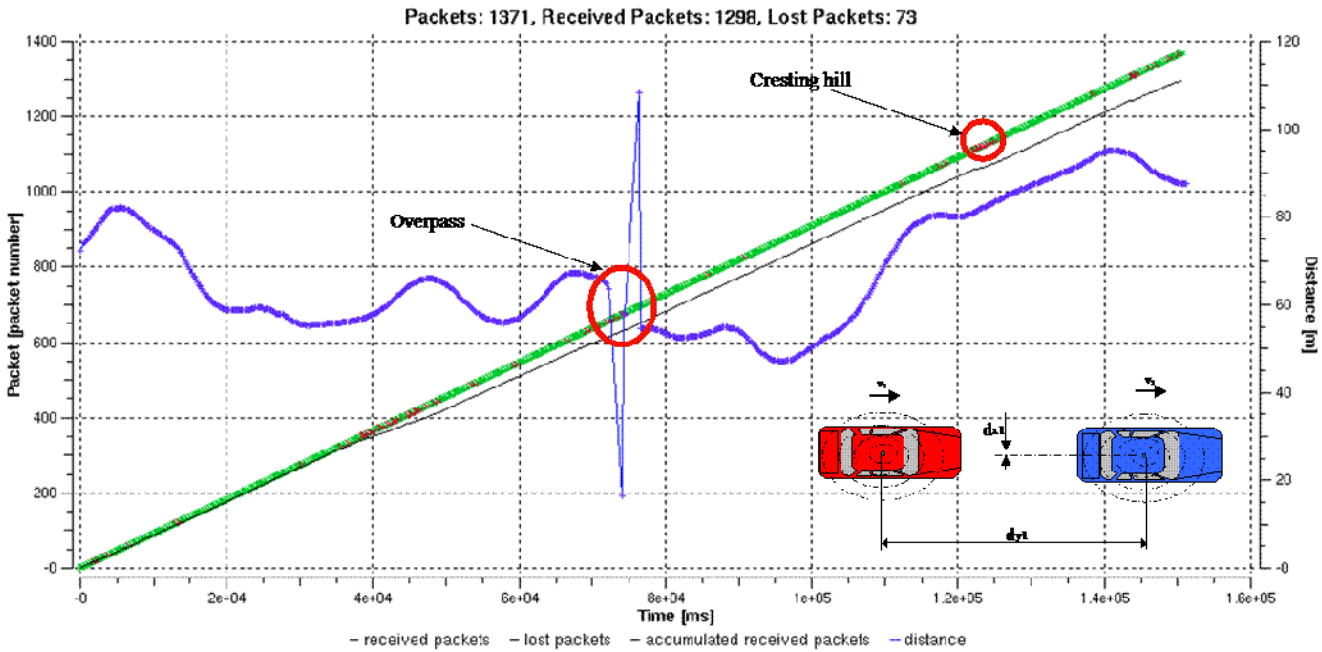
Figure 84. Test Number 2-14 Results

**Test Number 2-14**
**Trace File Name: test2-14_3_072303.trace***
**Date Collected: July 23rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.14 Test Scenario 2-15

| **Test Scenario** | **2-15** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 20 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 40 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Sedan |

**Table 39. Test Scenario 2-15**

Test Comments: GPS outages likely due to many thick overhanging trees. Also went under an underpass at one point in the first third of the run. The few vehicle-to-vehicle outages that were observed were due to the blocking vehicle.

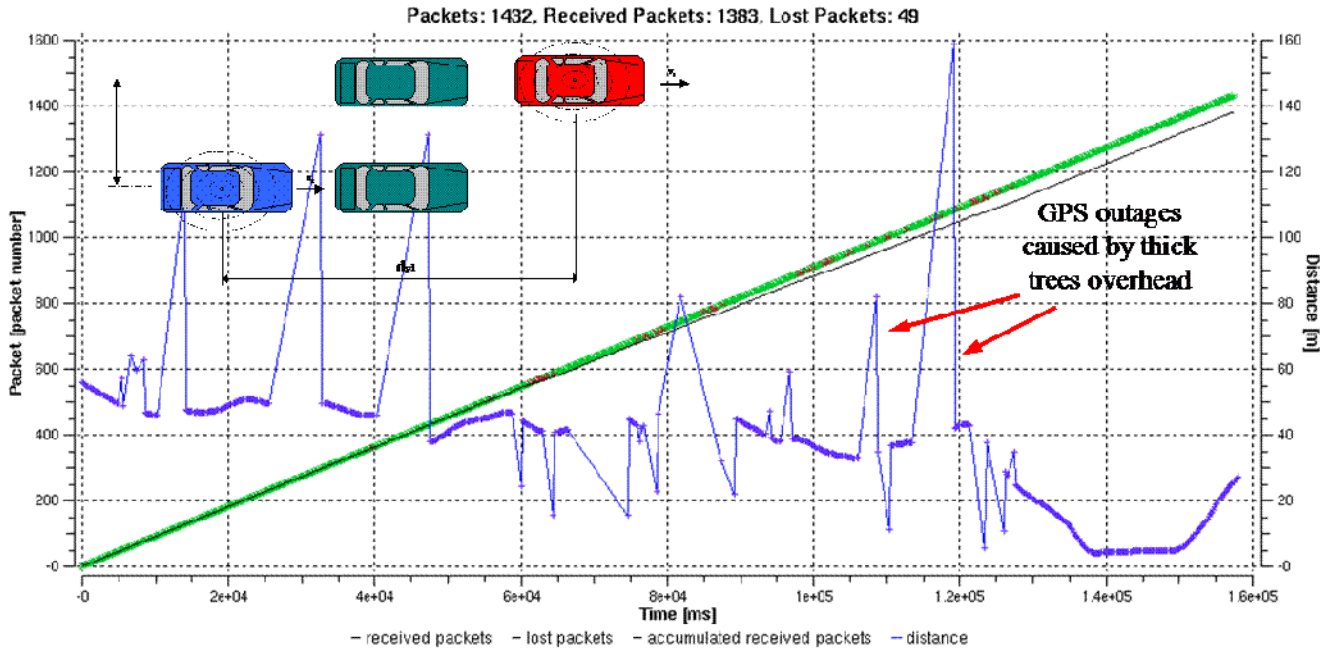
Figure 85. Test Number 2-15 Results

**Test Number: 2-15**
**Trace File Name: test2-15_3_072303.trace***
**Date Collected: July 23rd, 2003**
**Files Resident With Whom: Chu Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: BMW Series 3**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: Audi A4 Quattro**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.15 Test Scenario 2-16

| **Test Scenario** | **2-16** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 20 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 40 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 40. Test Scenario 2-16**

Test Comments: GPS outages are likely due to many heavy trees overhanging the road. The few vehicle-to-vehicle outages that were observed were due to the blocking vehicle.

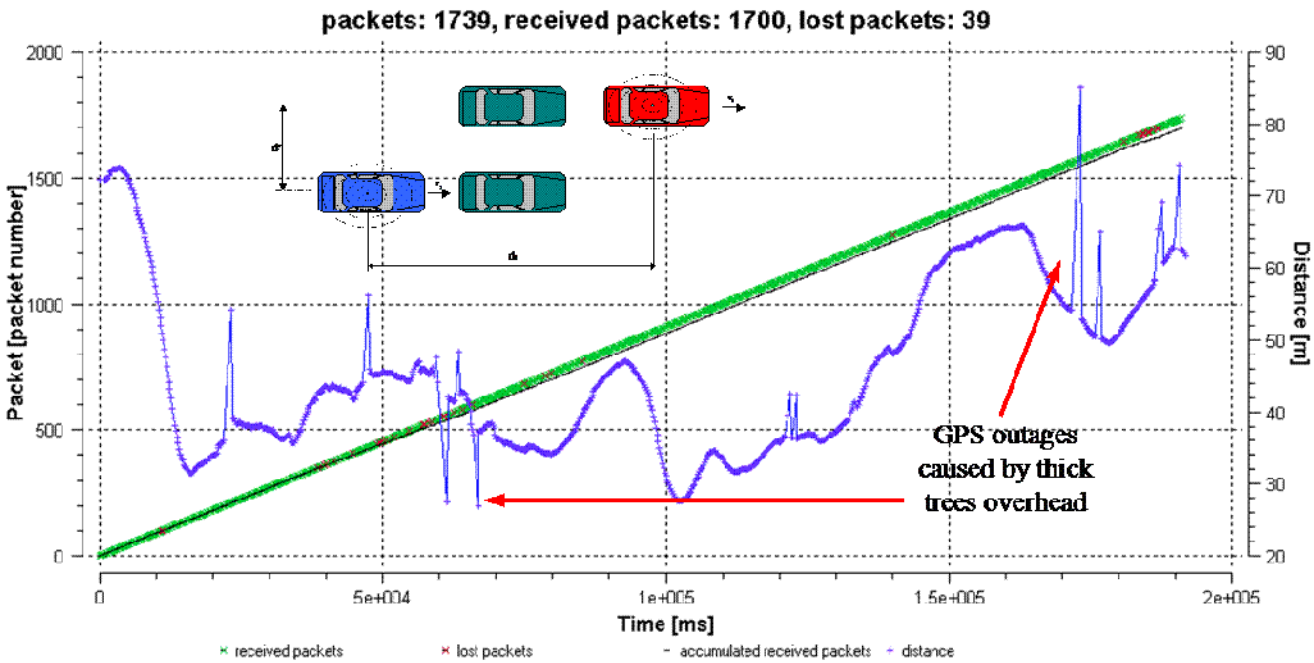
Figure 86. Test Number 2-16 Results

Test Number: 2-16
Trace File Name: test2-16_2_073003.trace*
Date Collected: July 30th, 2003
Files Resident With Whom: Chu Hee Lee

Ambient Weather Conditions:Sunny
Sending Vehicle Model/Make:VW Passat
Receiving Vehicle Model/Make:BMW Series 3
Antenna Type Used:Standard

Operating System Used: Linux
Software Level Used: 2.3

VSC Obstacle Vehicle #1 Model/Make:BMW X5
VSC Obstacle Vehicle #2 Model/Make:N/A



### 5.1.16 Test Scenario 2-17

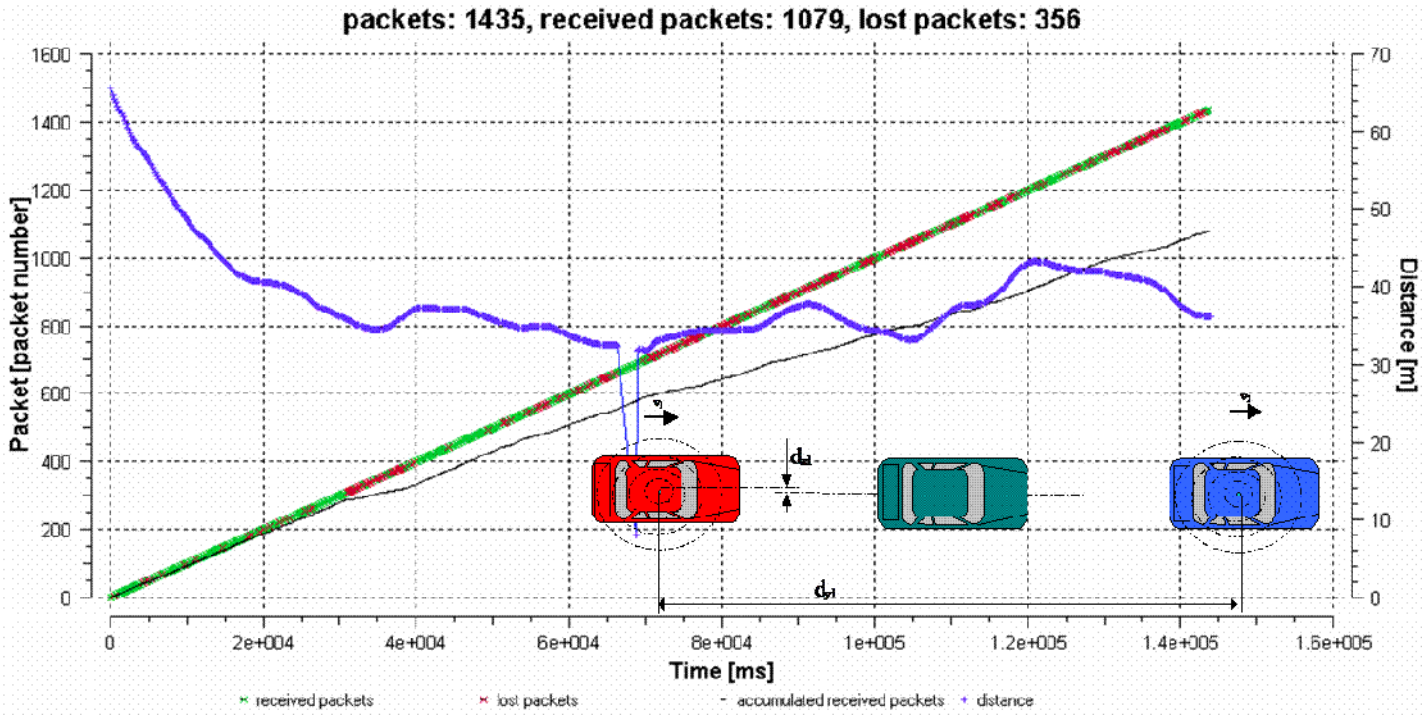
| **Test Scenario** | **2-17** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 41. Test Scenario 2-17**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a large truck. There were significant losses of reception due to the large truck interception and all trials of this test showed similar performance.

Figure 87. Test Number 2-17 Results

| | | | |
|---|---|---|---|
| Test Number | 2-17 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_2_17_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.17 Test Scenario 2-18

| **Test Scenario** | **2-18** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 42. Test Scenario 2-18**

Test Comments: Significant, but not complete, blockage due to combination of curving terrain and blocking SUV.

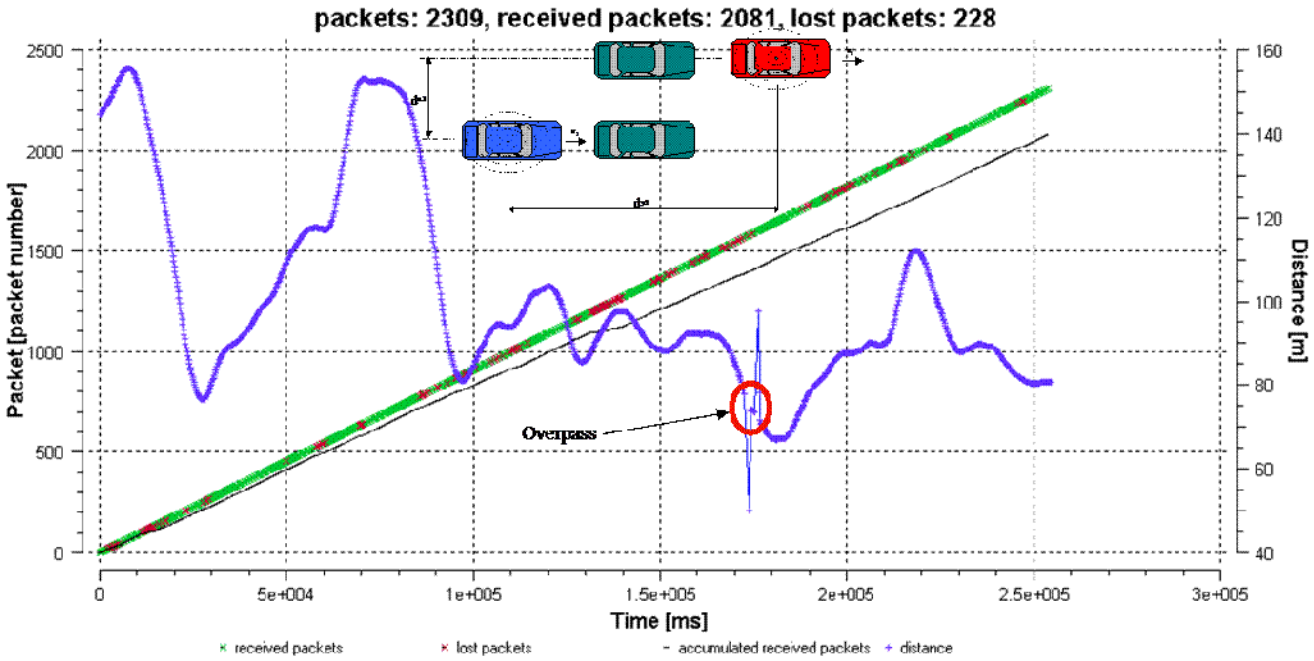
Figure 88. Test Number 2-18 Results

**Test Number 2-18**
**Trace File Name: test2-18_2_073003.trace***
**Date Collected: July 30th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: BMW X5**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.18 Test Scenario 2-20

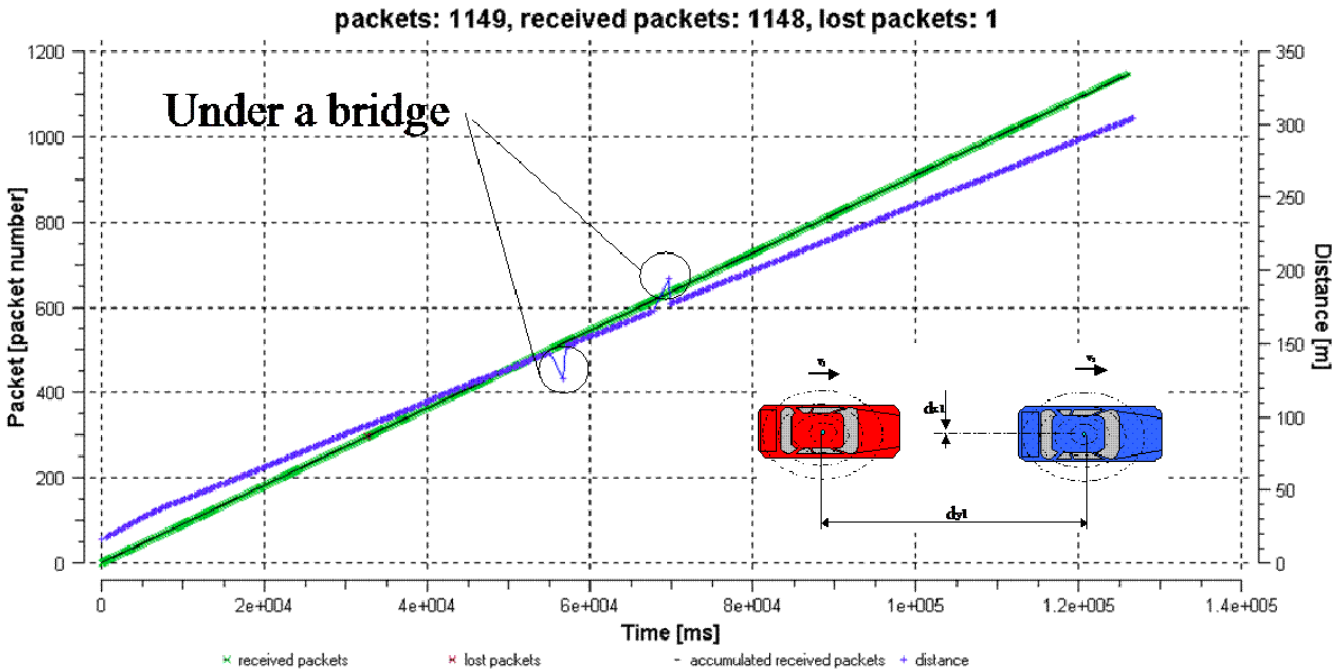
| **Test Scenario** | **2-20** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 43. Test Scenario 2-20**

Test Comments: This test considers a sending vehicle traveling at 30 mph that is slowly separating from a receiving vehicle moving at 25 mph. There was a clear line-of-sight for the duration of this test. A GPS outage was observed for all three trials while passing underneath a bridge, but no packets were lost. One packet was lost in Trial 3 at the range where multipath interference commonly occurs. Overall, 99.9 percent of the packets (3410 out of 3411) sent during the test were received.

Figure 89. Test Number 2-20-3 Results

| | | | |
|---|---|---|---|
| Test Number | 2-20-3 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_2_20_3.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.19 Test Scenario 2-21

| **Test Scenario** | **2-21** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 65 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 44. Test Scenario 2-21**

Test Comments: Overall, this test was successful, except for an extended outage (no clear cause) around the middle of the test period.

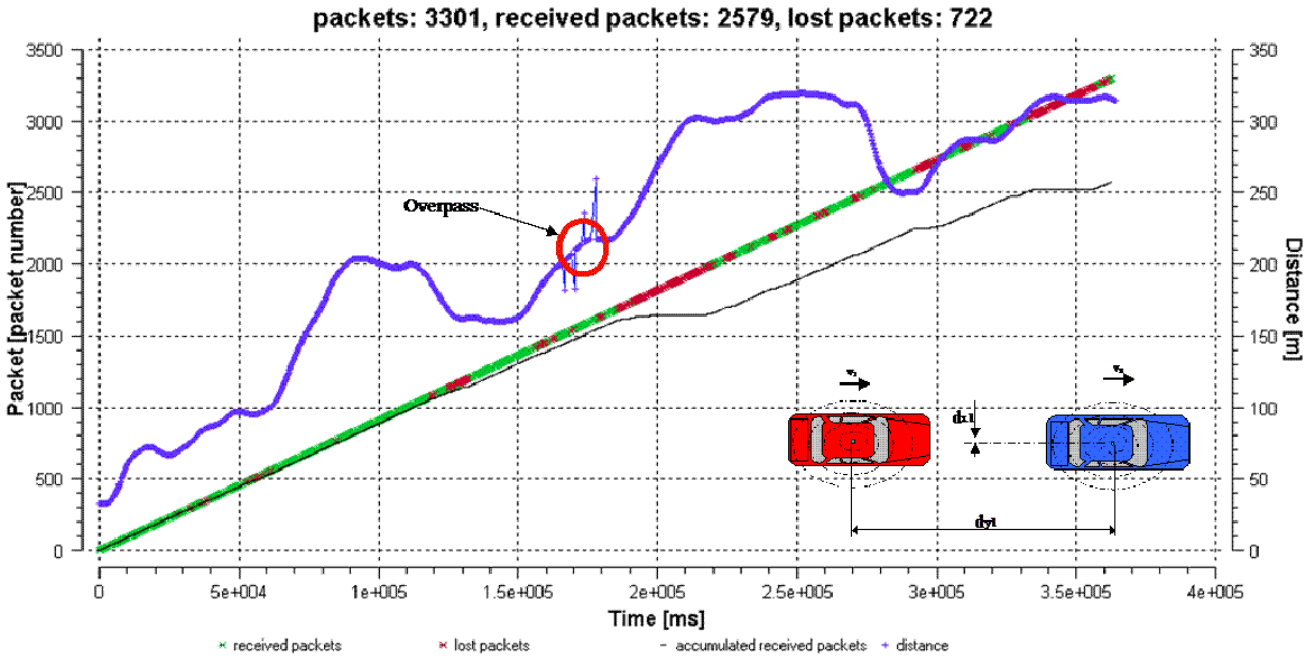
Figure 90. Test Number 2-21 Results

**Test Number 2-21**
**Trace File Name: test2-21-2_070203.trace***
**Date Collected: July 2nd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: Sedan**
**Receiving Vehicle Model/Make: Sedan**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.1**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.20 Test Scenario 2-22

| **Test Scenario** | **2-22** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 75 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 45. Test Scenario 2-22**

Test Comments: The chart shows only the pertinent portion of the test period. Although the overall packet loss for the whole test was over 50 percent, during the pertinent period shown, the packet loss rate was 1.7 percent.

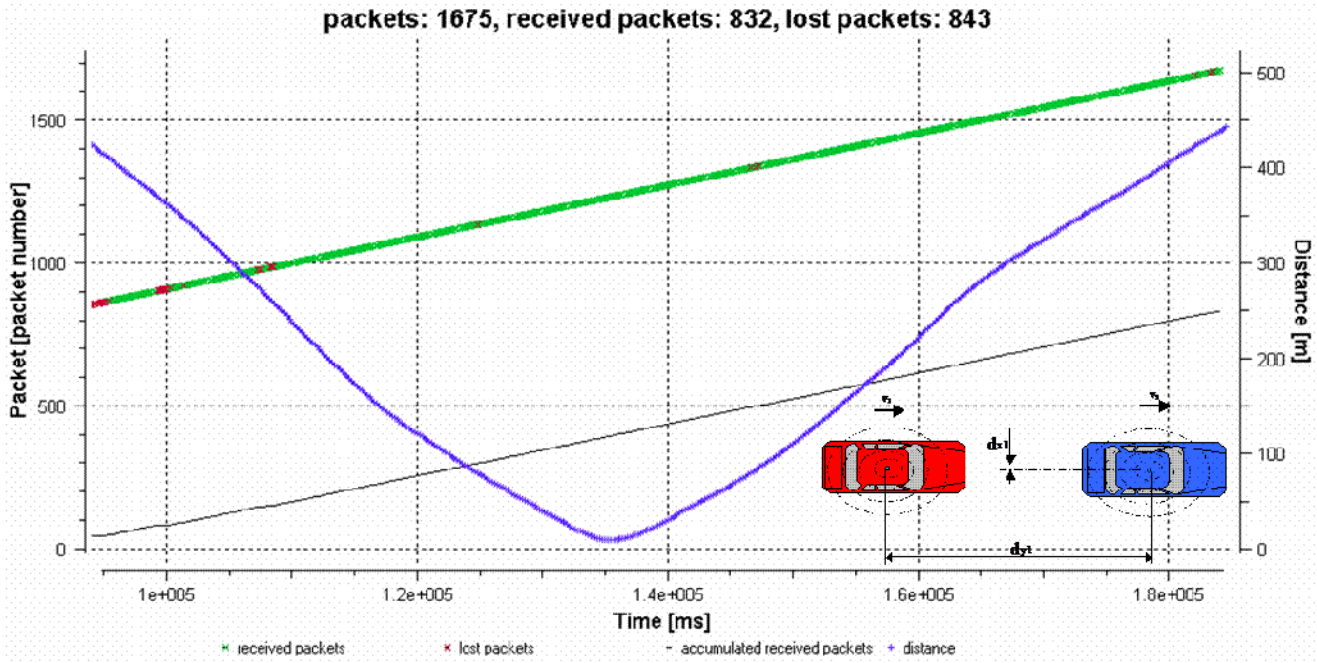
Figure 91. Test Number 2-22 Results

**Test Number 2-22**
**Trace File Name: test2-22_4_071403.trace***
**Date Collected: July 14th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: BMW Series 3**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 5.1.21 Test Scenario 2-23

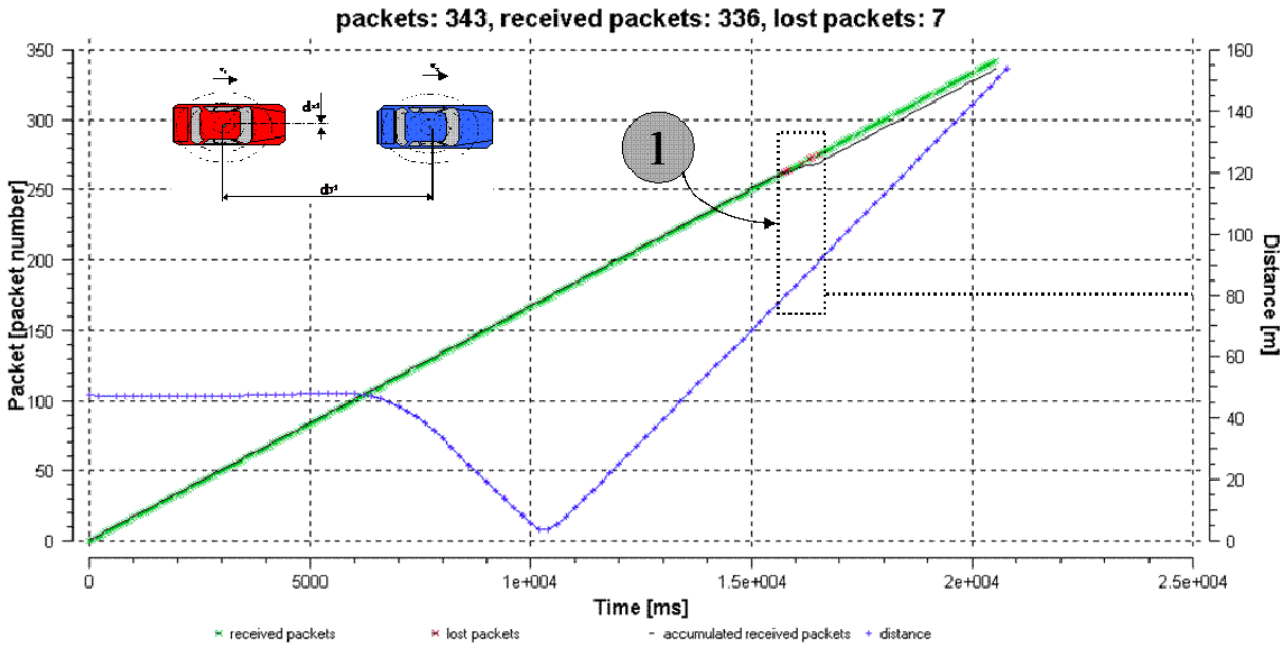
| **Test Scenario** | **2-23** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 30 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 -> 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 46. Test Scenario 2-23**

Test Comments: This test considers a receiving vehicle traveling at 30 mph that passes a sending vehicle braking from 30 to 0 mph. There was a clear line-of-sight for the duration of this test. All of the packets lost in eight of the nine trials occurred at the ~90m range, and this loss can be attributed to multipath that occurred consistently at that general range, as demonstrated in Test 1-20. There were no packets lost at ~90m in Trial 2-23-4 because the vehicles did not reach that separation distance during the course of data collection. Overall, 99 percent of the packets sent during the test were received (3837 out of 3876 packets).

Figure 92. Test Number 2-23 Results

| | | | |
|---|---|---|---|
| Test Number | 2-23 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 071703_2_23_9.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.22 Test Scenario 2-24

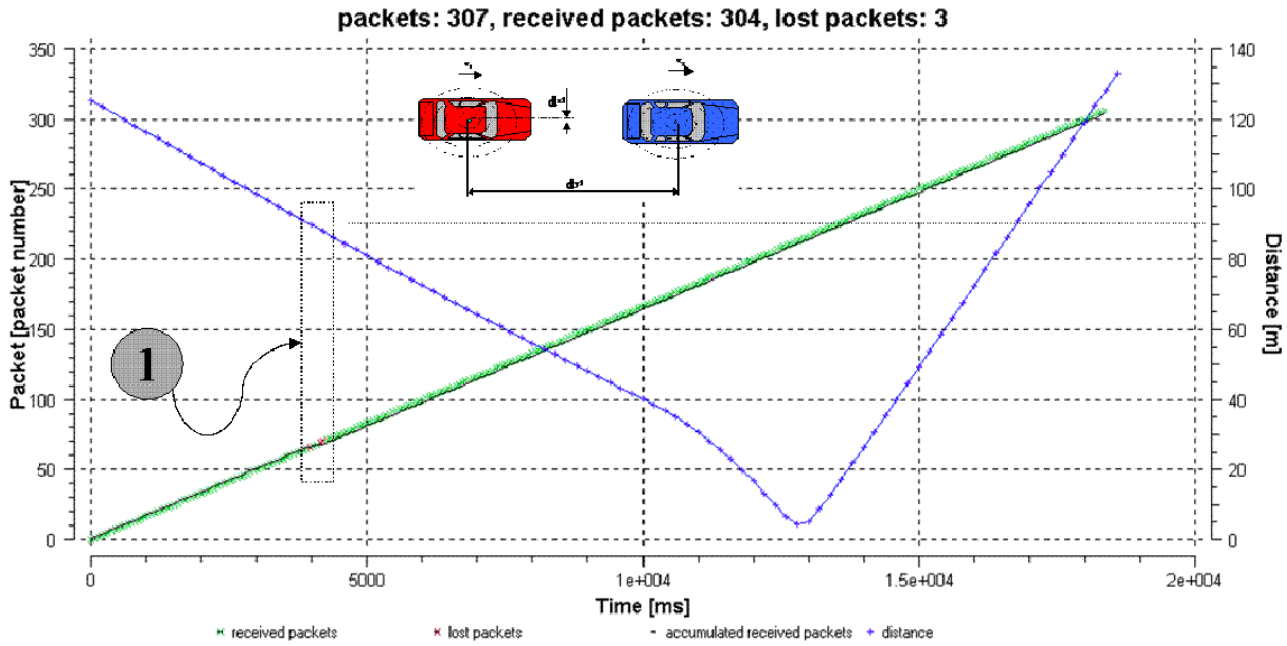
| **Test Scenario** | **2-24** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 -> 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 47. Test Scenario 2-24**

Test Comments: This test considers a receiving vehicle traveling at 50 mph that overtakes and passes a sending vehicle braking from 30 to 0 mph. There was a clear line-of-sight for the duration of this test. A loss of packets (1) took place at a range of ~90m in the 3 trials. This packet loss can be attributed to multipath that occurred consistently at that general range, as demonstrated in Test 1-20. Overall, 99 percent of the packets sent during this test were received (864 out of 873 packets).

Figure 93. Test Number 2-24-1 Results

| | | | |
|---|---|---|---|
| Test Number | 2-24-1 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_24_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.23 Test Scenario 2-25

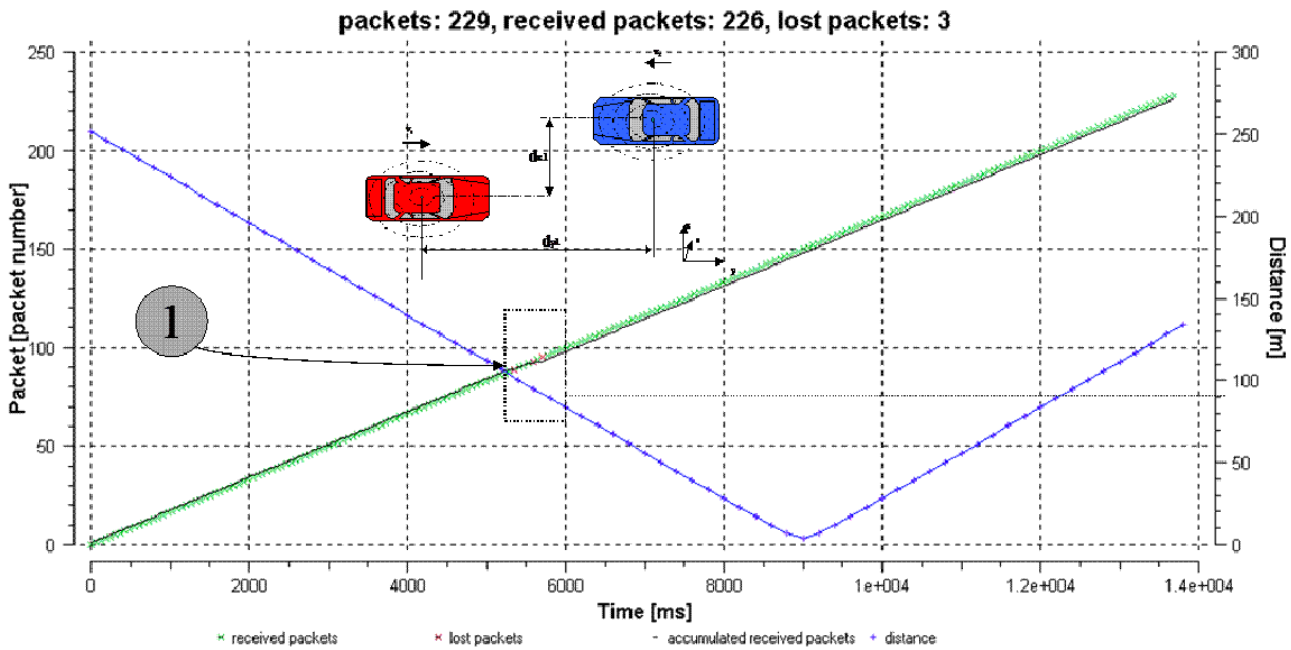
| **Test Scenario** | **2-25** |
|---|---|
| Relevant Applications | Pre-Crash Sensing for Co-op Collision Mitigation |
| Velocity of Receiving Antenna (miles/hour) | 30 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 180 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 48. Test Scenario 2-25**

Test Comments: This test considers a sending vehicle traveling at 30 mph as it approaches and passes a receiving vehicle traveling at the same speed. There was a clear line-of-sight throughout the duration of this test. Of the four trials that were conducted, packets were lost only in Trial 1. The loss of packets (1) took place at the range of ~90m and can be attributed to multipath that commonly occurred at that general range, as demonstrated in Test 1-20. Overall, 99.6 percent of the packets sent during the test were received (793 out of 796 packets).

Figure 94. Test Number 2-25 Results

| | | | |
|---|---|---|---|
| Test Number | 2-25 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_25_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.24 Test Scenario 2-26

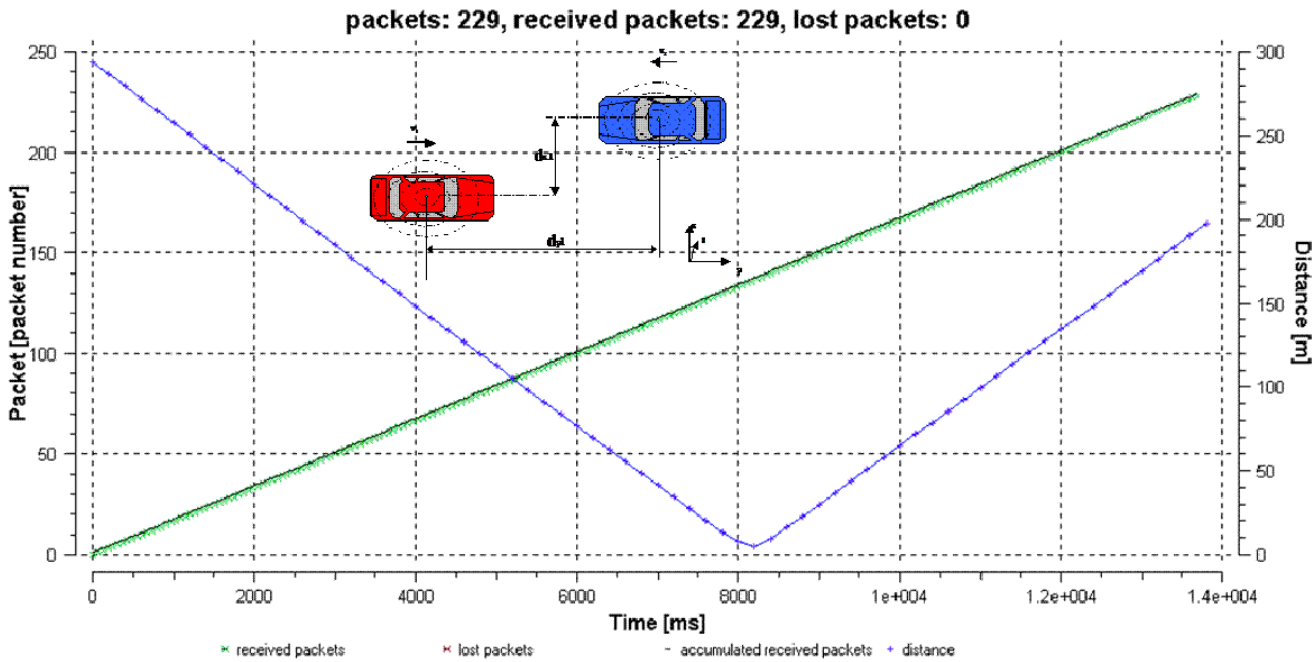
| **Test Scenario** | **2-26** |
|---|---|
| Relevant Applications | Pre-Crash Sensing for Co-op Collision Mitigation |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 180 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 49. Test Scenario 2-26**

Test Comments: This test considers a receiving vehicle traveling at 50 mph that catches up to and passes a sending vehicle traveling at 30 mph. There was a clear line-of-sight for the duration of this test. There were no GPS outages in any of the 4 trials. Overall, 100 percent of the packets sent during the test were received.

Figure 95. Test Number 2-26 Results

| | | | |
|---|---|---|---|
| Test Number | 2-26 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_26_3.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.25 Test Scenario 2-27

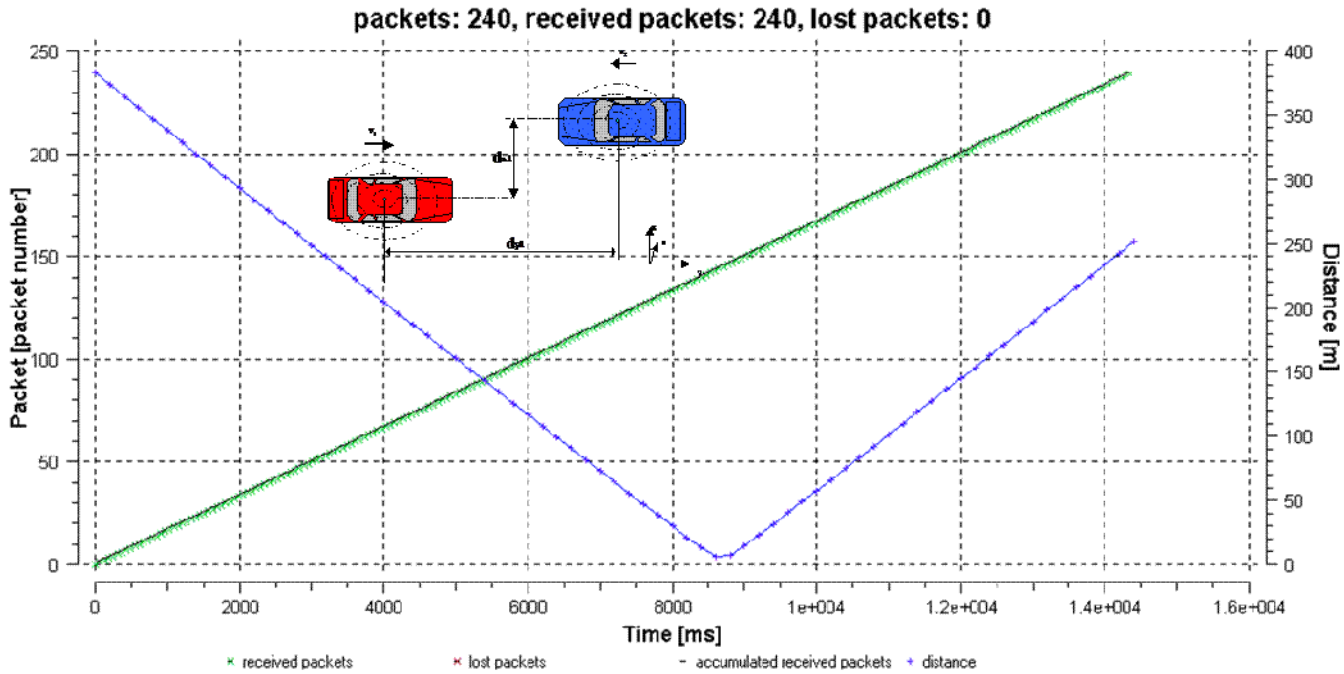
| **Test Scenario** | **2-27** |
|---|---|
| Relevant Applications | Pre-Crash Sensing for Co-op Collision Mitigation |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 50 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 180 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 50. Test Scenario 2-27**

Test Comments: This test considers two vehicles that communicate while approaching and passing each other at 50 mph. There was a clear line-of-sight for the duration of this test. There were no GPS outages in any of the 4 trials. Overall, 100 percent of the packets sent during the test were received.

Figure 96. Test Number 2-27 Results

| | | | |
|---|---|---|---|
| Test Number | 2-27 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_27_4.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.26 Test Scenario 2-28

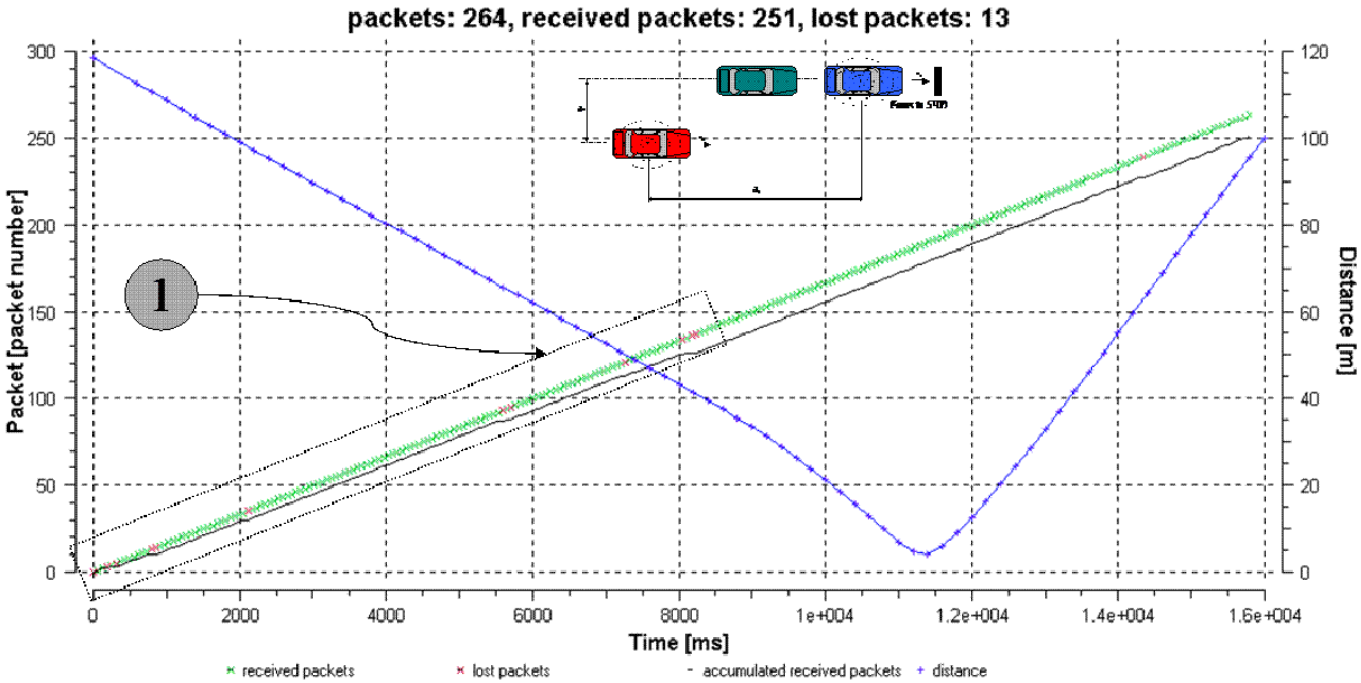
| **Test Scenario** | **2-28** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW) |
| Velocity of Receiving Antenna (miles/hour) | 50 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 -> 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 51. Test Scenario 2-28**

Test Comments: This test considers a receiving vehicle traveling at 50 mph that overtakes and passes an SUV and a sending vehicle as they brake from 30 to 0 mph. The line-of-sight was obstructed by the SUV during the first part of this test, and cleared as the receiving vehicle passes the SUV. Packets were lost in each of the five trials. The packet loss (1) took place at various ranges early in the trials and are likely to be due to the obstructing SUV. Overall, 95 percent of the packets sent during the test were received.

Figure 97. Test Number 2-28-5 Results

| | | | |
|---|---|---|---|
| Test Number | 2-28-5 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 080703_2_28_5.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | August 7th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | GMC Envoy |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.27 Test Scenario 2-29

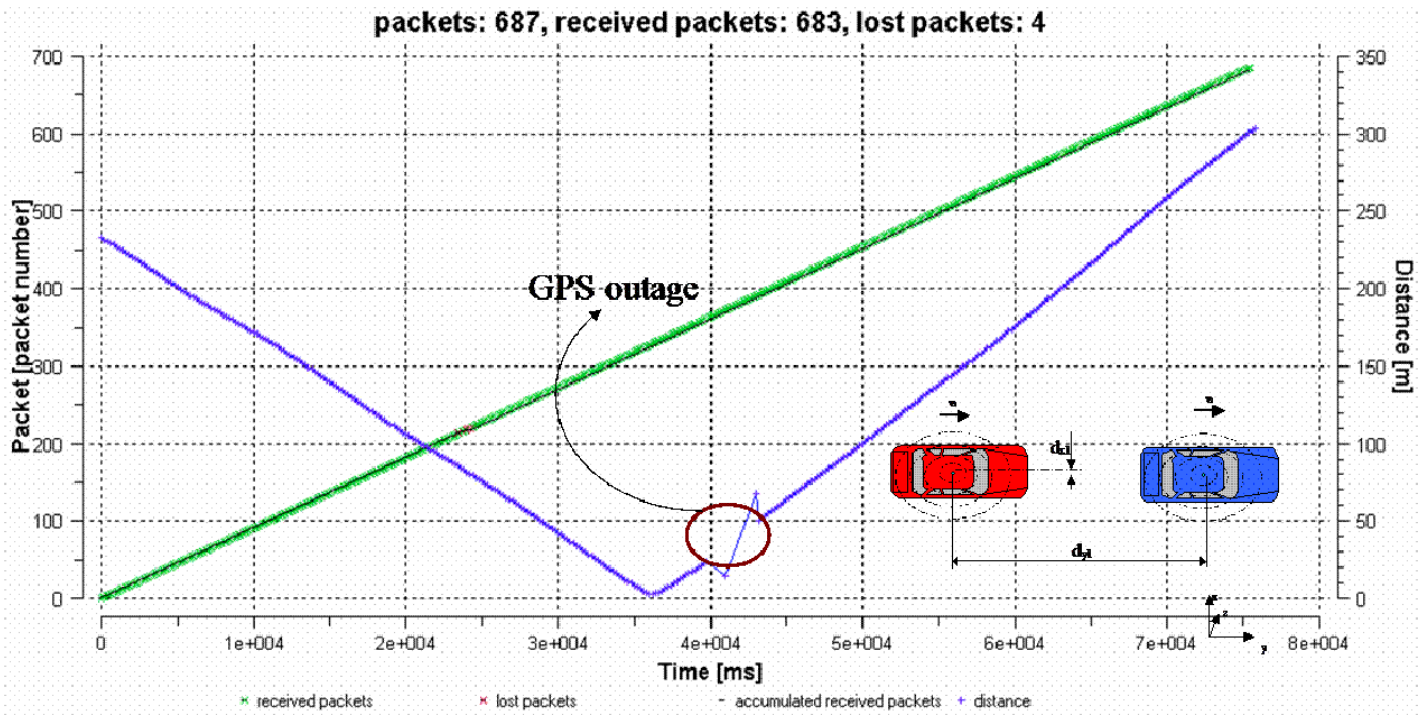
| **Test Scenario** | **2-29** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 40 |
| Distance Between Antennas (meters) | < 300 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 52. Test Scenario 2-29**

Test Comments: There was a clear line-of-sight for the duration of this test between the sending vehicle and the receiving vehicle. Two GPS outages were observed as the vehicles went under a bridge in the test track. There were a few lost packets in all three trials of the test. The reception outage was observed in the same location for all three trials (80-90m) which was proven in Test 1-20 to be a multi-path interference.

Figure 98. Test Number 2-29 Results

| | | | |
|---|---|---|---|
| Test Number | 2-29 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_29_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.28 Test Scenario 2-30

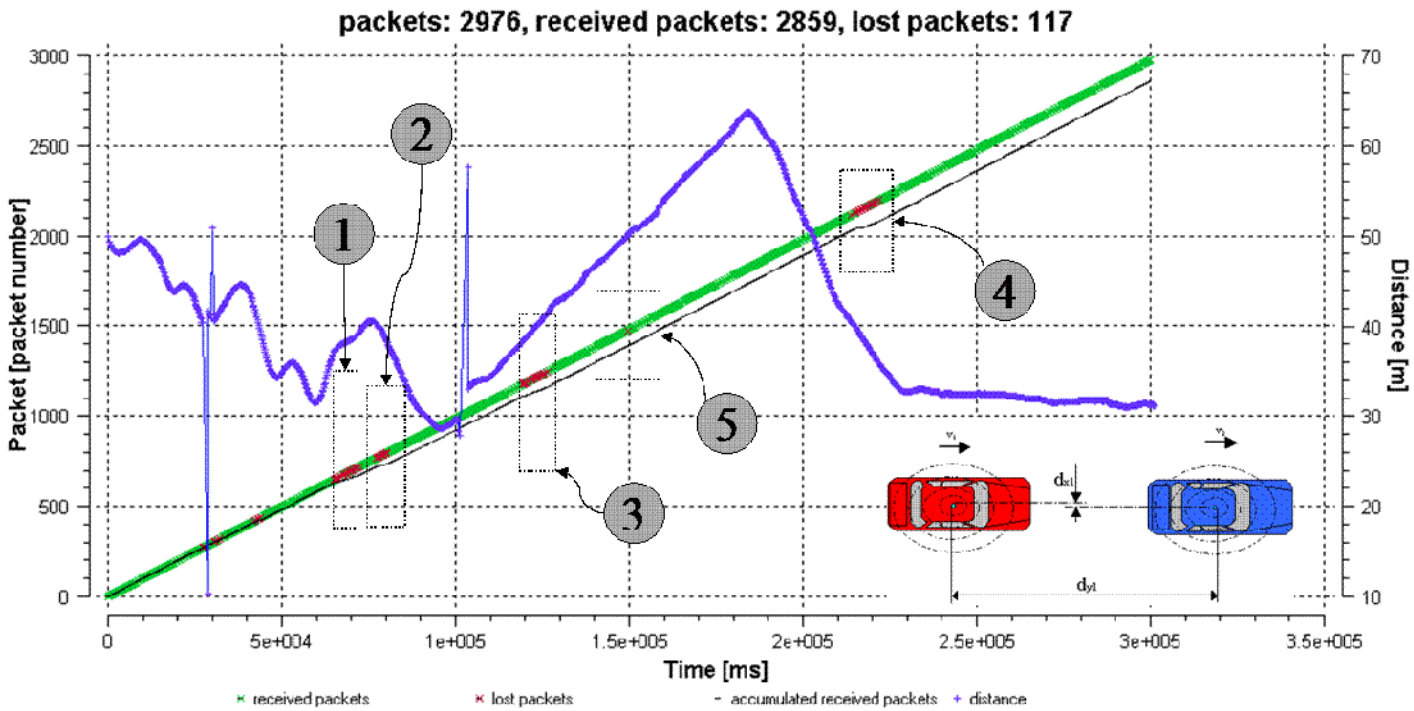
| **Test Scenario** | **2-30** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | < 150 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 53. Test Scenario 2-30**

Test Comments: There was a clear line-of-sight for the duration of this test. Several short partial outages were observed, and an explanation for the outages was not clear at the time of the test. Overall, 96 percent of the packets sent during the test were received.

Figure 99. Test Number 2-30 Results

| | | | |
|---|---|---|---|
| Test Number | 2-30 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 051303_01.trace* | Sending Vehicle Model/Make: | Nissan Altima |
| Date Collected: | May 13th, 2003 | Receiving Vehicle Model/Make: | Lexus GS300 |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.29 Test Scenario 2-31

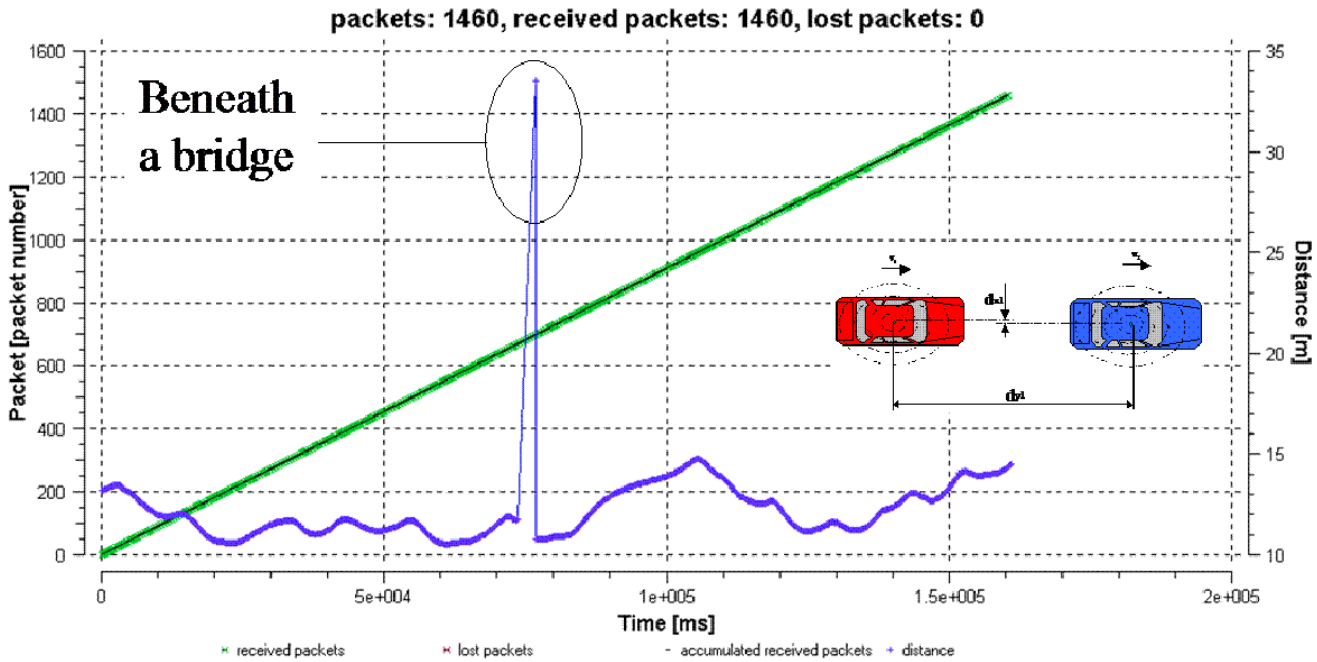
| **Test Scenario** | **2-31** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 15 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 54. Test Scenario 2-31**

Test Comments: This test considers two vehicles traveling at 25 mph in the same direction at close proximity. There was a clear line-of-sight throughout the duration of this test. A GPS outage was observed in the same location for all three trials (while passing underneath a bridge), but no packets were lost. Overall, 100 percent of the packets sent during the test were received.

Figure 100. Test Number 2-31 Results

| | | | |
|---|---|---|---|
| Test Number | 2-31 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_31_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 24th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.30 Test Scenario 2-32

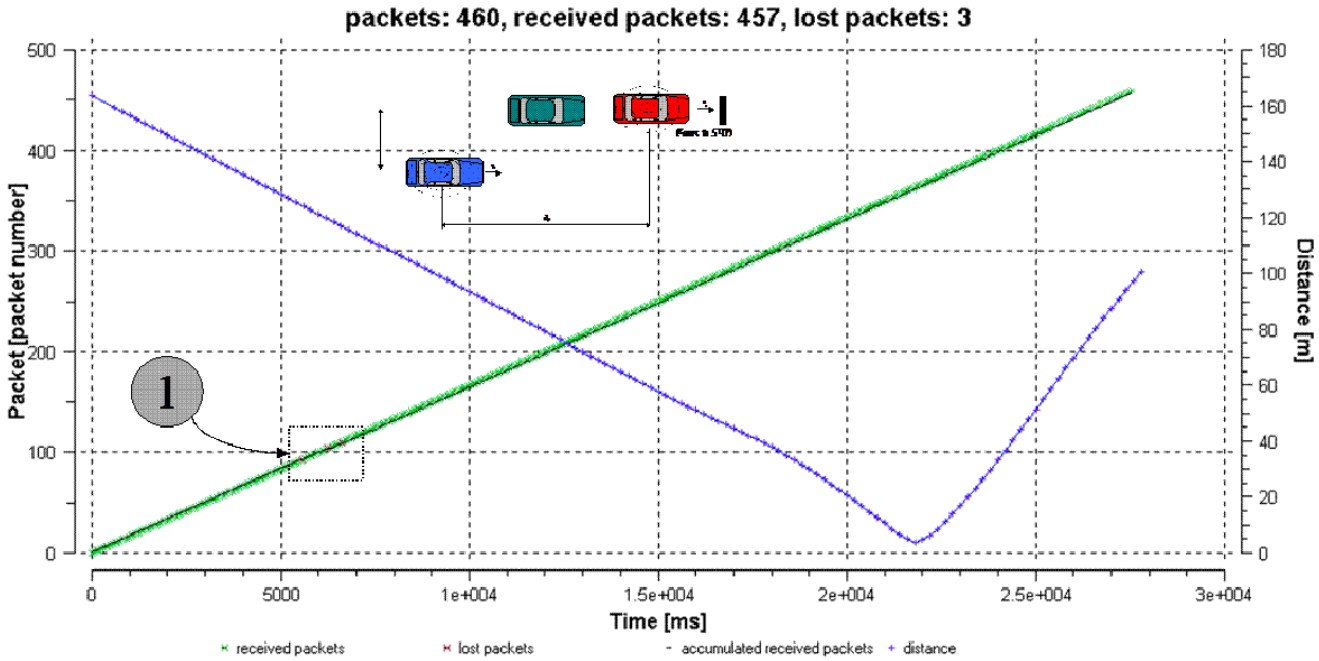
| **Test Scenario** | **2-32** |
|---|---|
| Relevant Applications | Pre-Crash Sensing for Co-op Collision Mitigation<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 30 -> 0 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 50 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 50 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 55. Test Scenario 2-32**

Test Comments: This test considers a sending vehicle traveling at 50 mph that overtakes and passes a receiving vehicle and an SUV that brake from 30 to 0 mph. The line-of-sight was obstructed by the SUV during the first part of this test, and clear after the receiving vehicle passes the sending vehicle. The 3 lost packets highlighted in (1) of Trial 2 took place at a range of ~40 and is probably due to the obstructing SUV, although the loss of packets at that range was not repeated in Trials 1 and 3. There was a lost packet in Trial 1 at a range of ~90m. The packet loss at this range happened in other tests and is likely due to multipath, as shown in Test 1-20. Overall, 99.7 percent of the packets sent during the test were received.

Figure 101. Test Number 2-32-2 Results

| | | | |
|---|---|---|---|
| Test Number | 2-32-2 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 080703_2_32_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | August 7th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | Jim Bauer | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | GMC Envoy |
| Software Level Used: | Version 2.3 | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 5.1.31 Test Scenario 2-33

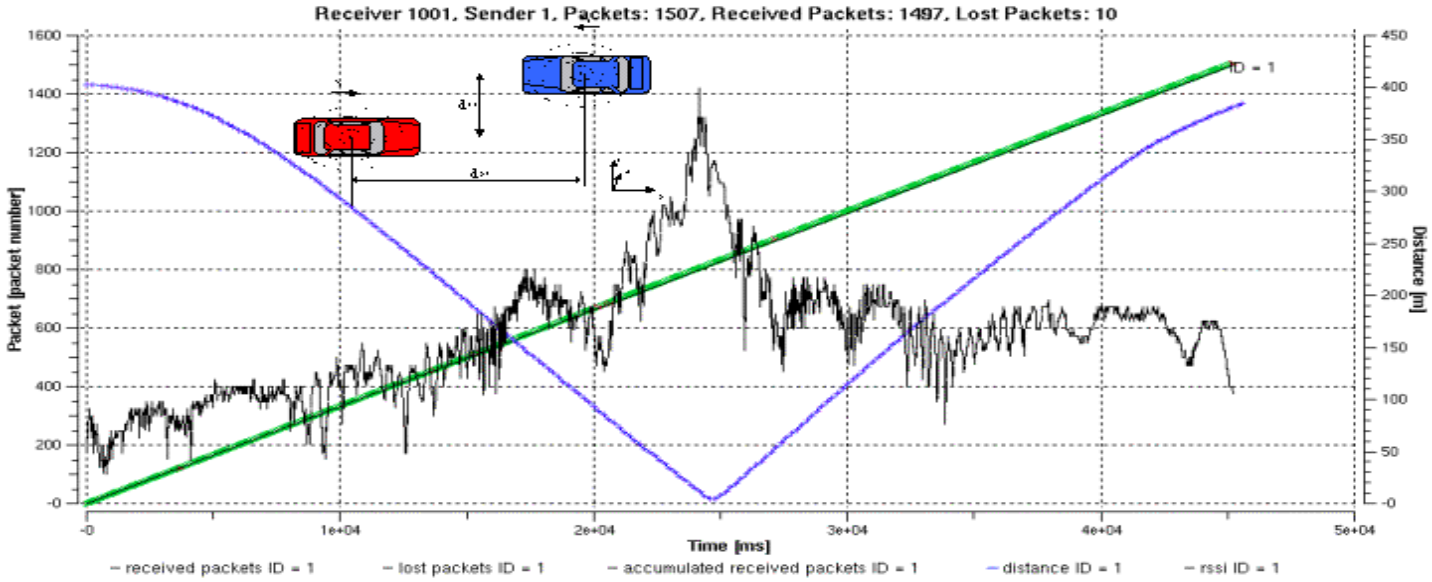
| **Test Scenario** | **2-33** |
|---|---|
| Relevant Applications | Pre-Crash Sensing for Co-op Collision Mitigation |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | < 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 180 |
| Update Rate (milliseconds) | 20 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Test Track |
| Traffic Conditions | N/A |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 56. Test Scenario 2-33**

Test Comments: This test considers a receiving vehicle traveling at ~25 mph that approaches and passes a sending vehicle traveling at ~25 mph in the opposite direction. While this test was essentially conducted before (scenario 2-26), it was repeated in this context at an update rate of 20ms to be consistent with the safety requirements of Task 3. In this particular test, there was a reasonably clear line-of-sight, however there was a significant amount of clutter in the form of parked cars and trees along the side of the route. There were no more than a few packets lost in any of the runs, and they may have merely been due to the roadside clutter.

**Figure 102. Test Number 3-33 Results**

| | | | |
|---|---|---|---|
| Test Number | **2-33** | Ambient Weather Conditions: | **Light Rain** |
| Trace File Name: | **Test_2_33_*.*** | Sending Vehicle Model/Make: | **Camry** |
| Date Collected: | **March 30, 2004** | Receiving Vehicle Model/Make: | **Taurus** |
| Files Resident With Whom: | **Jim McBride** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **N/A** |
| Software Level Used: | **V3.0 – B3** | VSC Obstacle Vehicle #2 Model/Make: | **N/A** |



# 6 Stationary Vehicle Communications

## 6.1 Test Scenarios

### 6.1.1 Test Scenario 3-1

| **Test Scenario** | **3-1** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 10 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 57. Test Scenario 3-1**

Test Comments: Two vehicles separated by ~20m. There was a clear line-of-sight and no packets were lost. Even though the vehicles were standing still, there was a distance variance of 0.5m (19.65m to 19.15m) in the GPS readings.

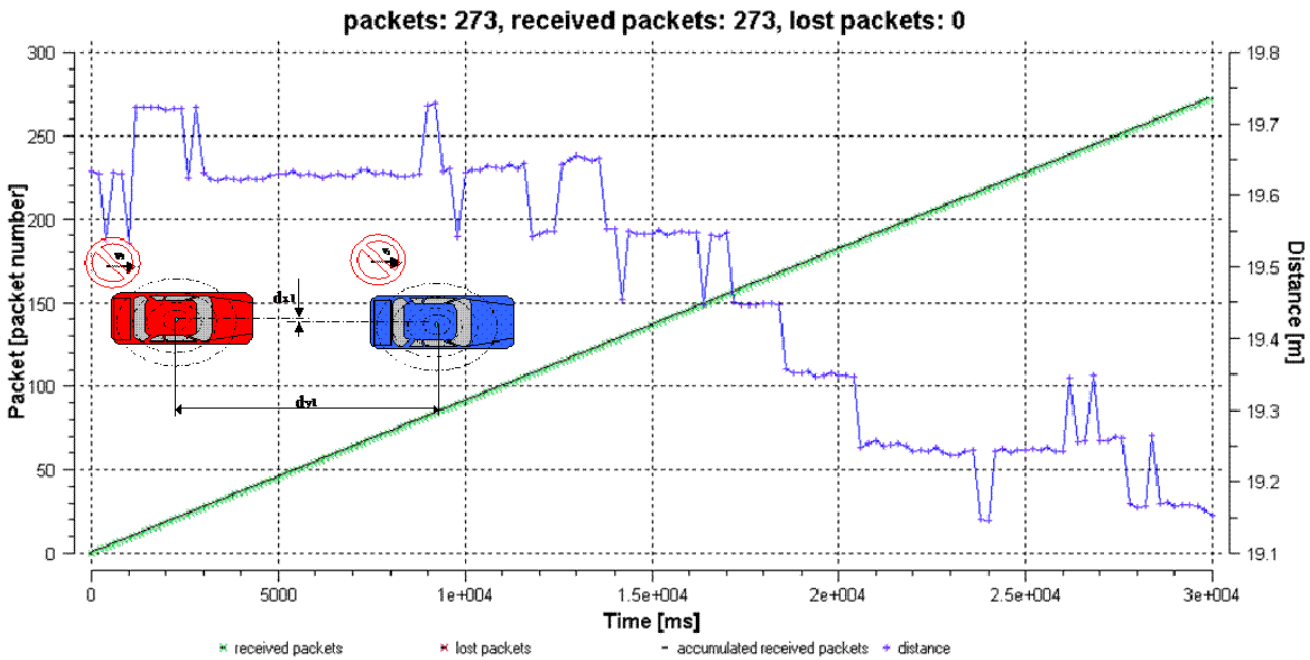
Figure 103. Test Number 3-1 Results

**Test Number 3-1**
**Trace File Name: test3-1_1_072503.trace***
**Date Collected: July 25th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.2 Test Scenario 3-2

| **Test Scenario** | **3-2** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 50 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 58. Test Scenario 3-2**

Test Comments: Two vehicles separated by ~46m. There was a clear line-of-sight and no packets were lost. Even though the vehicles were standing still, there was a distance variance of 0.8m (46.5m to 45.7m) in the GPS readings.

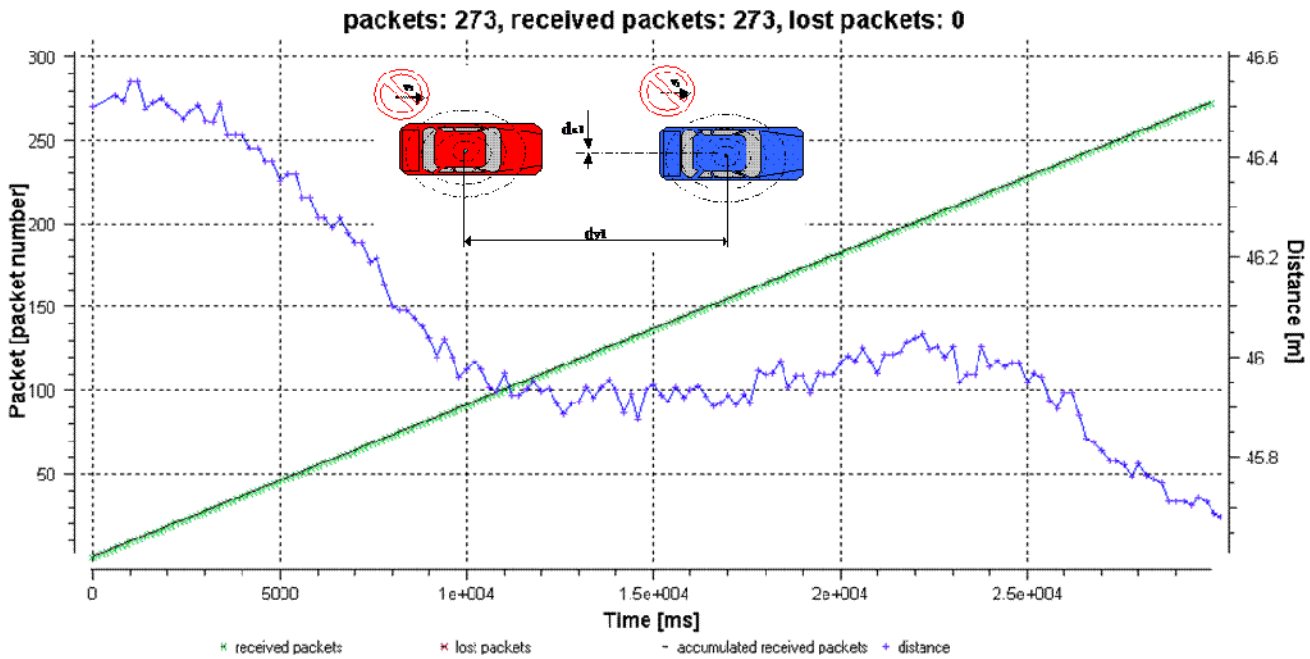
Figure 104. Test Number 3-2 Results

**Test Number 3-2**
**Trace File Name: test3-2_2_072503.trace***
**Date Collected: July 25th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.3 Test Scenario 3-3

| **Test Scenario** | **3-3** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 150 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 59. Test Scenario 3-3**

Test Comments: Two vehicles separated by ~148m. There was a clear line-of-sight and no packets were lost. Even though the vehicles were standing still, there was a distance variance of 1.7m (147.1m to 148.8m) in the GPS readings.

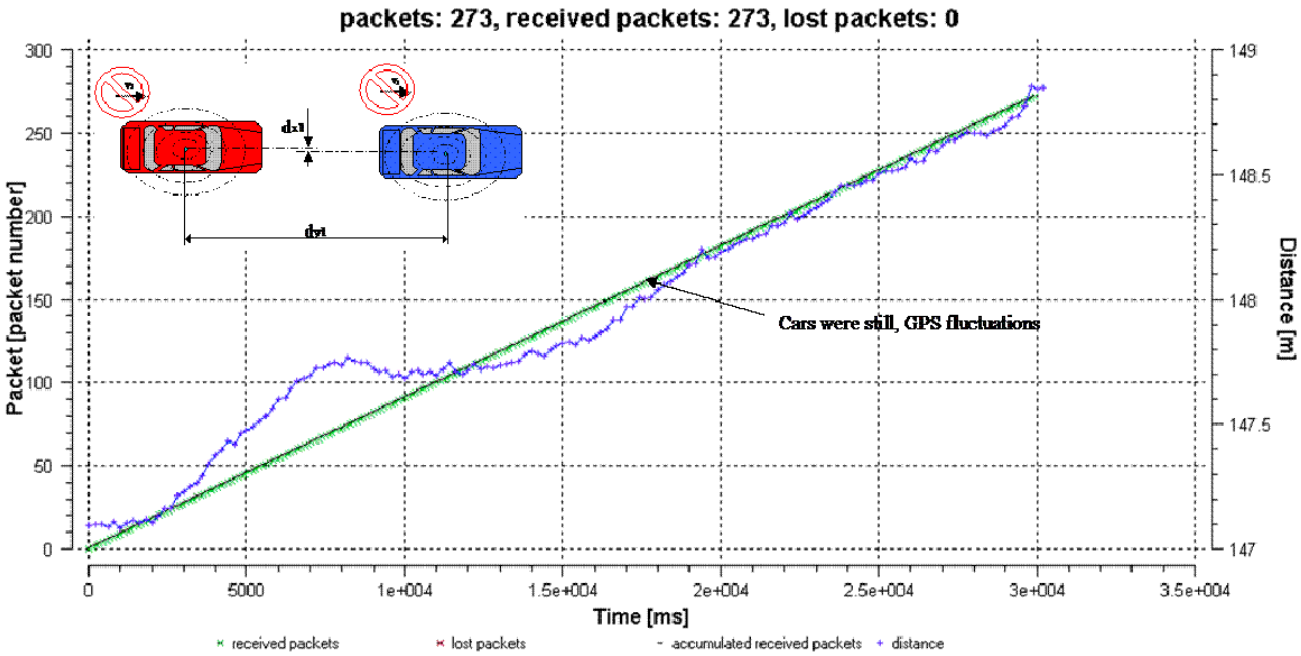
Figure 105. Test Number 3-3 Results

**Test Number 3-3**
**Trace File Name: test3-3_2_072503.trace***
**Date Collected: July 25th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.4 Test Scenario 3-4

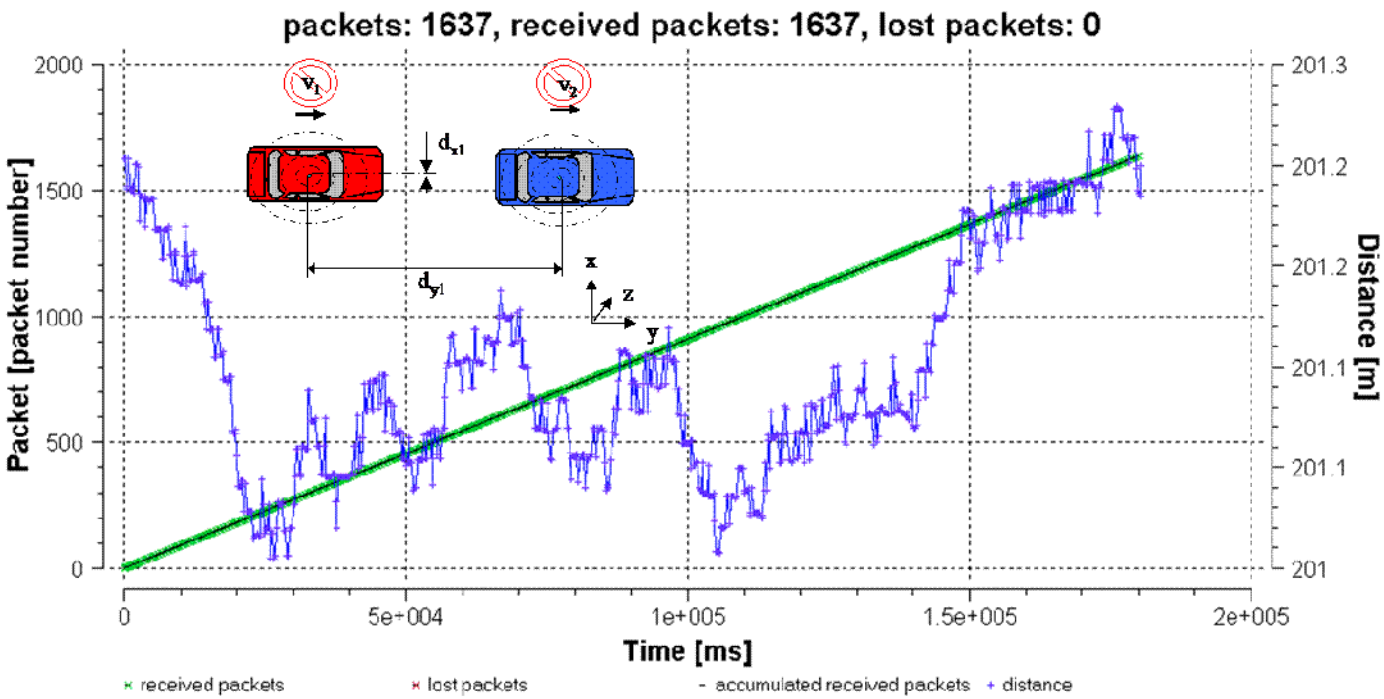
| **Test Scenario** | **3-4** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 200 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 60. Test Scenario 3-4**

Test Comments: In this test, the RSU (GMC Envoy) sends messages (200 bytes) every 100 msec. Both vehicles are stationary and about 200 m apart. Both units are constantly in a clear line-of-sight. The communication link was very reliable since in all trials of this test, no packets were dropped.

Figure 106. Test Number 3-4 Results

| | | | |
|---|---|---|---|
| Test Number | 3-4 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 081403_3_4_2.trace* | Sending Vehicle Model/Make: | GMC Envoy |
| Date Collected: | August 14, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | F. Ahmed-Zaid | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.5 Test Scenario 3-5

| **Test Scenario** | **3-5** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 250 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 61. Test Scenario 3-5**

Test Comments: Two vehicles separated by ~210m. There was a clear line-of-sight and no packets were lost. One of the vehicles moved twice during the test and it's shown in the plot.

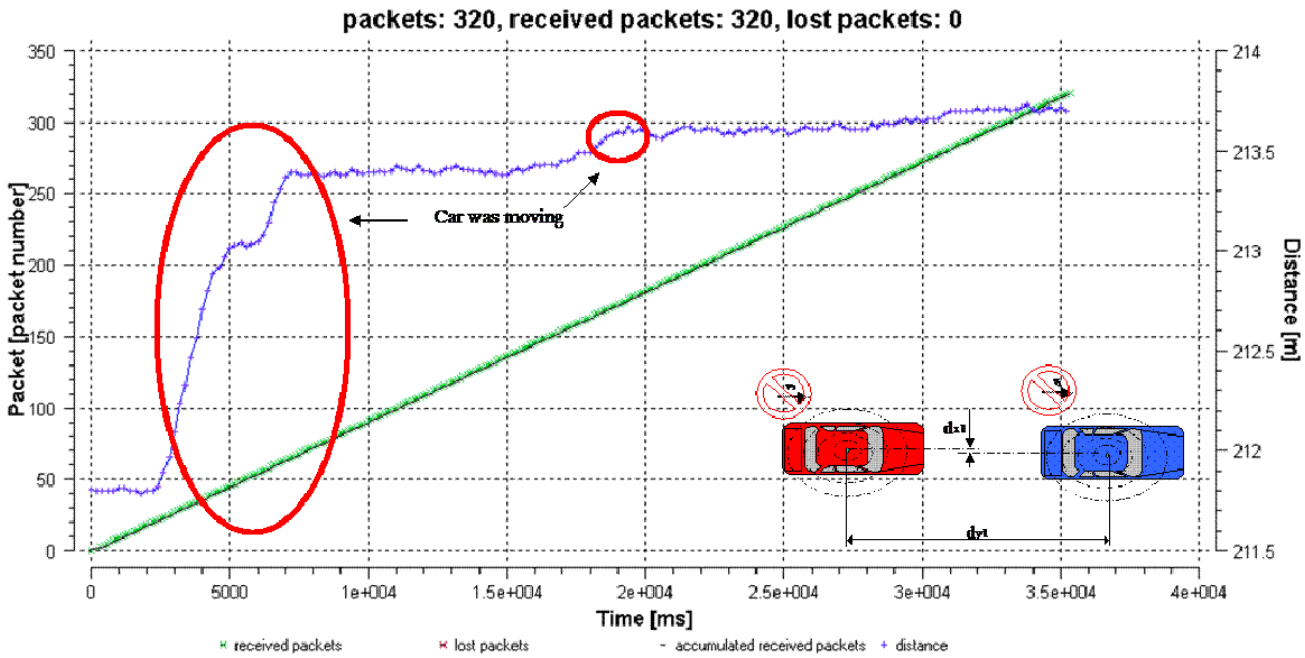
Figure 107. Test Number 3-5 Results

**Test Number: 3-5**
**Trace File Name: test3-5_1_072803.trace***
**Date Collected: July 28rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.6 Test Scenario 3-6

| **Test Scenario** | **3-6** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 300 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 62. Test Scenario 3-6**

Test Comments: There wasn't a clear line-of-sight at the beginning (~350m) and it caused some packet loss. Once the vehicles were in line-of-sight (~300m) no packets were lost.

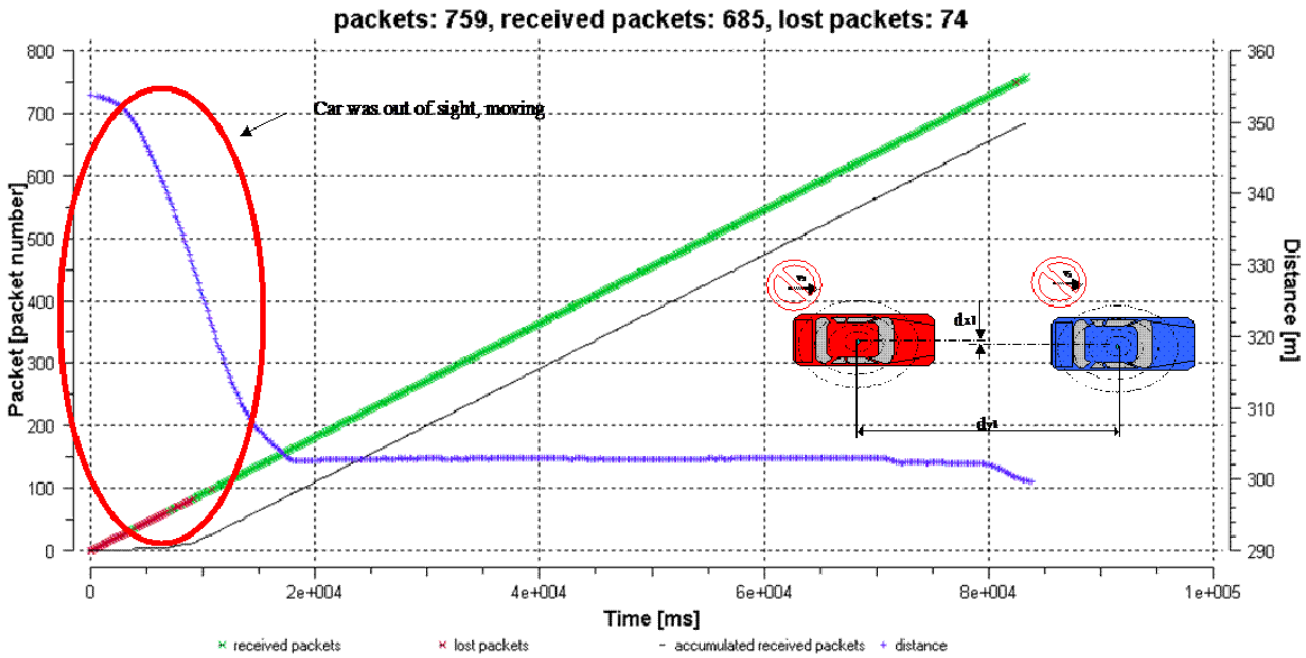
Figure 108. Test Number 3-6 Results

**Test Number: 3-6**
**Trace File Name: test3-6_1_072803.trace***
**Date Collected: July 28rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.7 Test Scenario 3-7

| | |
|---|---|
| Test Scenario | 3-7 |
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 10 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 50 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 63. Test Scenario 3-7**

Test Comments: Two vehicles separated by ~10m. There was a clear line-of-sight and no packets were lost. Even though the vehicles were standing still, there was a distance variance of ~2m. The sender used half power (50mW) and the average RSSI shown in the trace file but not in the graph was 34/60.

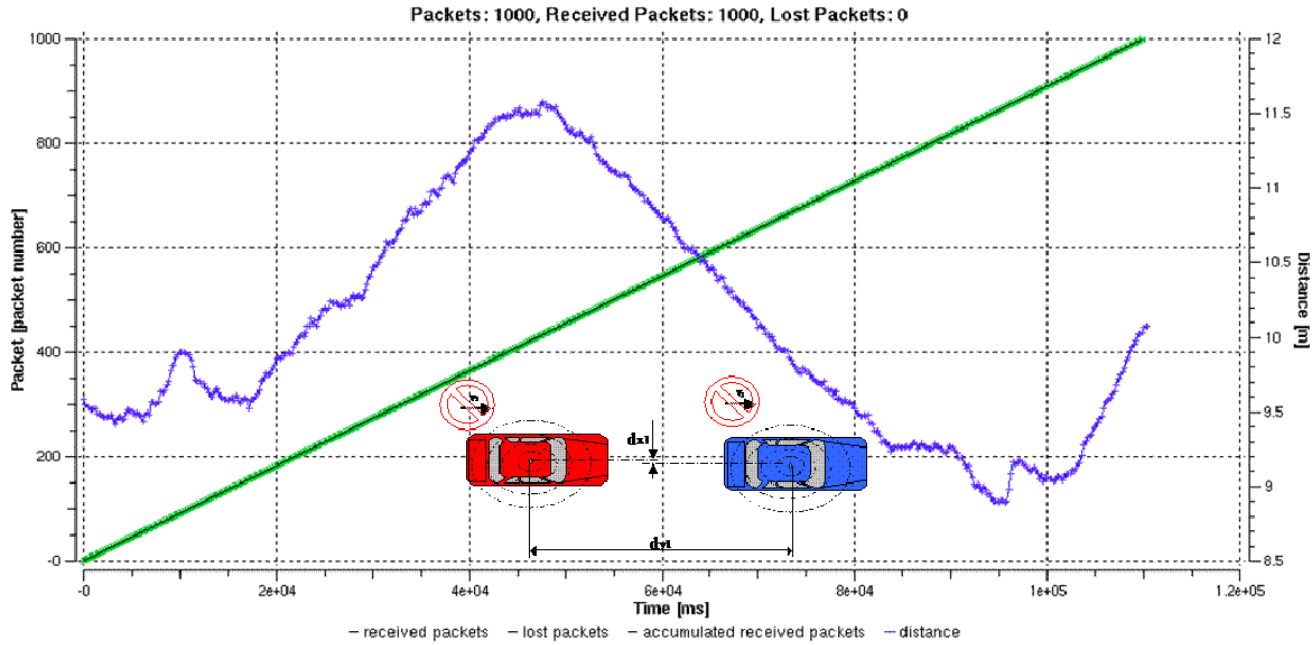
Figure 109. Test Number 3-7 Results

**Test Number: 3-7**
**Trace File Name: test_3-7_1_2003-08-20.***
**Date Collected: August 20th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat W8**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.5**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.8 Test Scenario 3-8

| **Test Scenario** | **3-8** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 50 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | None |

**Table 64. Test Scenario 3-8**

Test Comments: Two vehicles separated by ~100m. There was a clear line-of-sight and 11 packets got lost. Typically there is no packet loss in the setting with full transmission power (please refer to test 3-3 for comparison). Even though the vehicles were standing still, there was a distance variance of ~3m. The sender used half power (50mW) to transmit and the average RSSI shown in the trace file but not in the graph was 9/60.

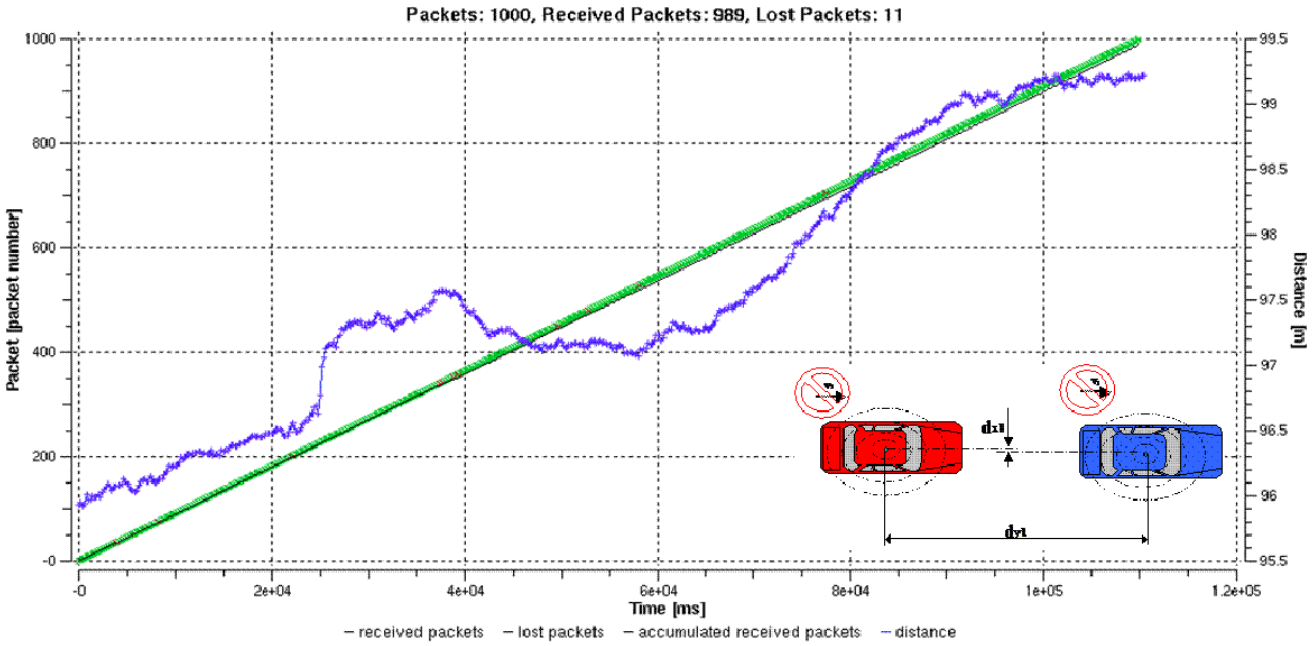
Figure 110. Test Number 3-8 Results

**Test Number: 3-8**
**Trace File Name: test_3-8_1_2003-08-20.***
**Date Collected: August 20th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat W8**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.5**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.9 Test Scenario 3-9

| **Test Scenario** | **3-9** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 10 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 65. Test Scenario 3-9**

Test Comments: Sending and receiving vehicles were separated by ~10m. A blocking vehicle (an SUV) was in between but no packets were lost during the test. The distance based on GPS data fluctuated from ~9m to ~10m.

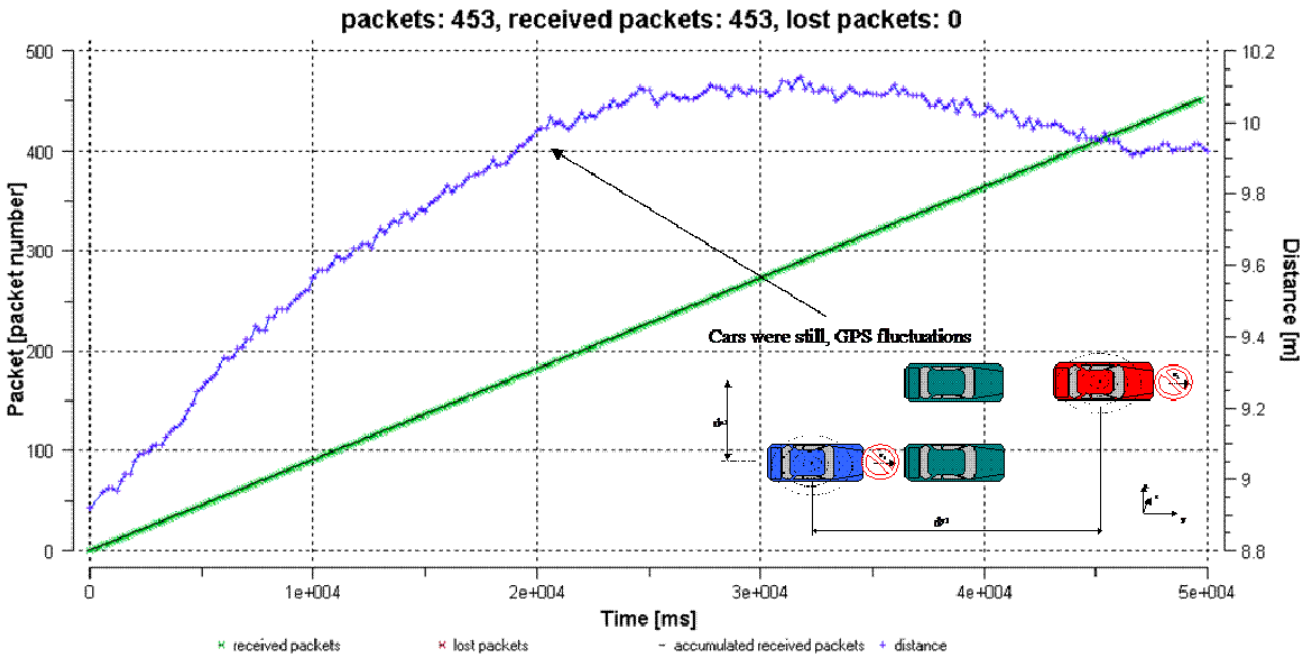
Figure 111. Test Number 3-9 Results

**Test Number: 3-9**
**Trace File Name: test3-9_1_072803.trace***
**Date Collected: July 28rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: Jeep SUV**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.10 Test Scenario 3-10

| **Test Scenario** | **3-10** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Parking Lot |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 66. Test Scenario 3-10**

Test Comments: Sending and receiving vehicles were separated by ~76m. A blocking vehicle (an SUV) was in between but no packets were lost during the test. The distance based on GPS data fluctuated from ~74m to ~77m.

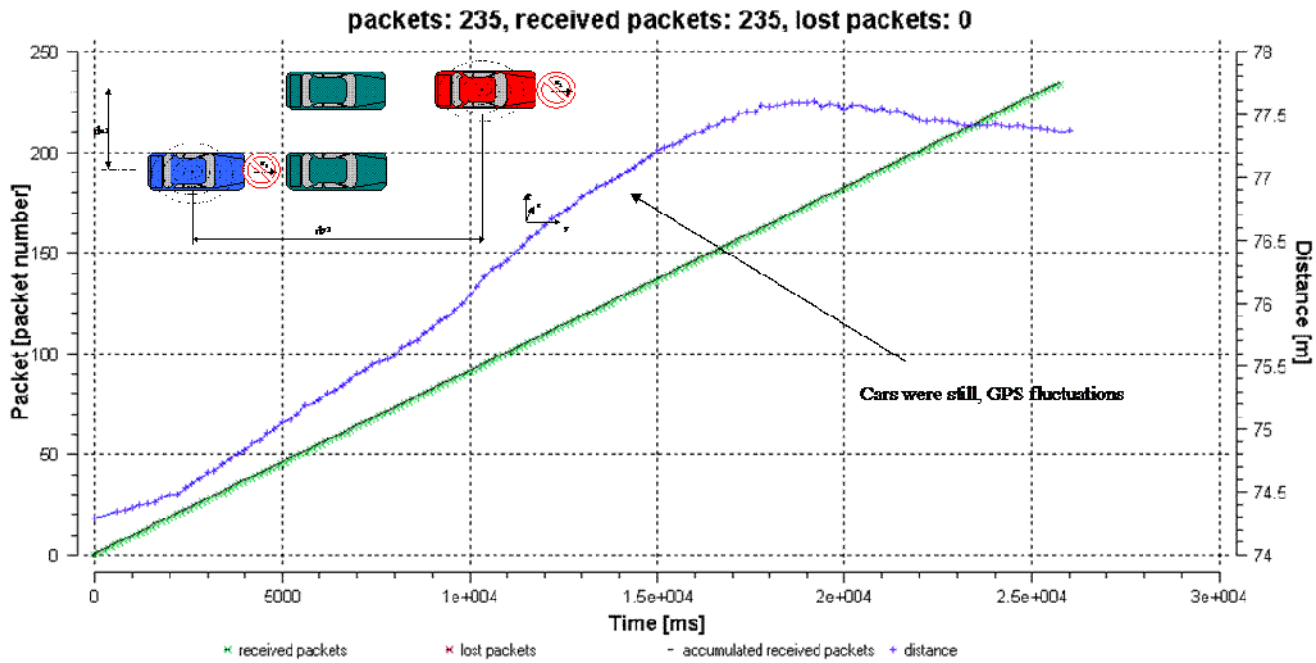
Figure 112. Test Number 3-10 Results

**Test Number: 3-10**
**Trace File Name: test3-10_1_072803.trace***
**Date Collected: July 28rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW 330**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: Jeep SUV**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.1.11 Test Scenario 3-11

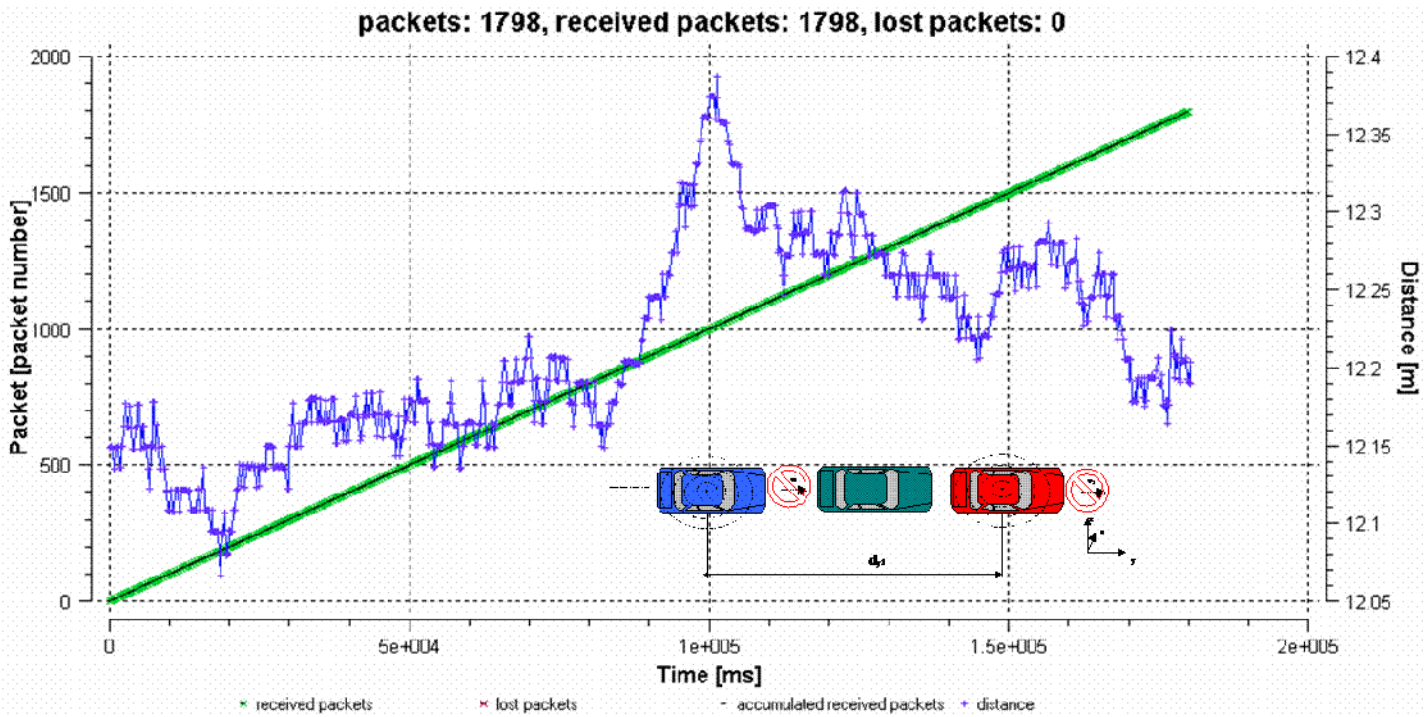
| **Test Scenario** | **3-11** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 10 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 67. Test Scenario 3-11**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Chevy Suburban SUV. There was no loss of reception due to the SUV interception. No packets were lost in all trials of this test.

Figure 113. Test Number 3-11 Results

| | | | |
|---|---|---|---|
| Test Number | 3-11 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_11_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Chevy Suburban |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.12 Test Scenario 3-12

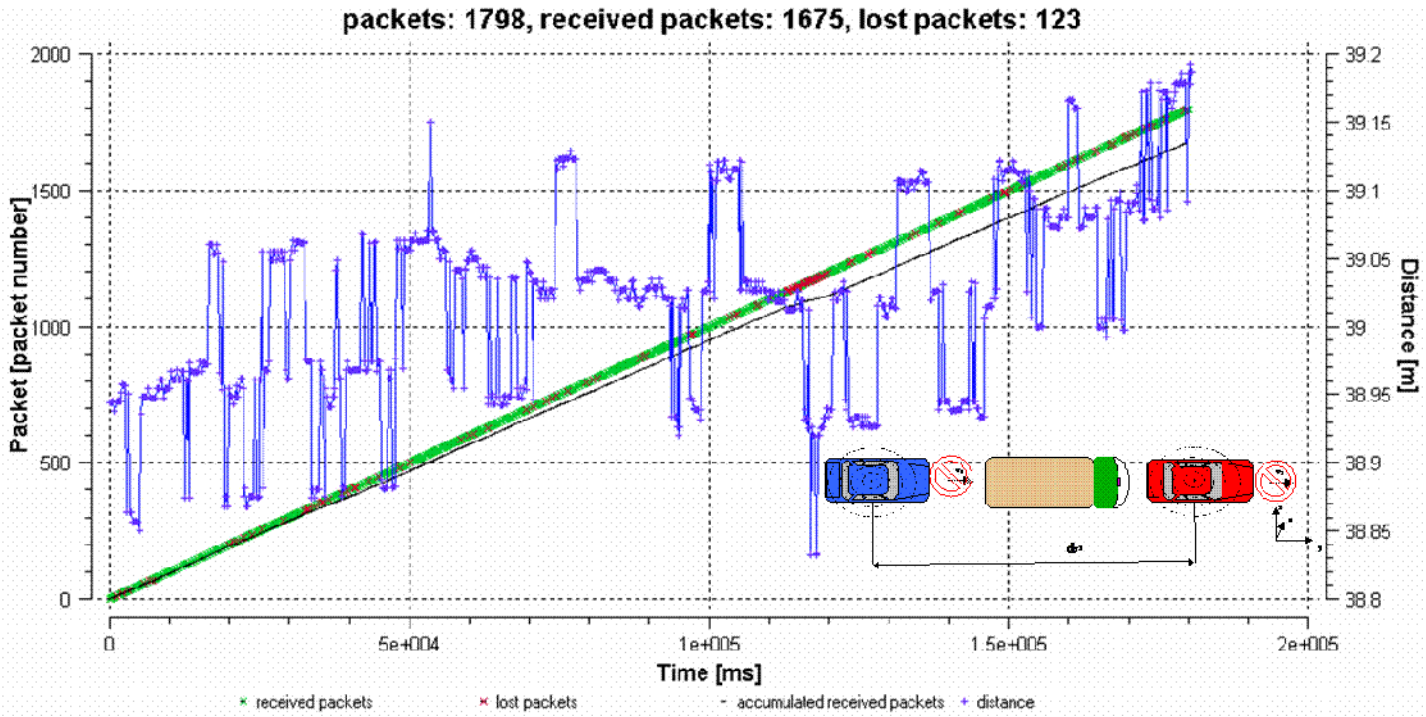
| **Test Scenario** | **3-12** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 40 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 68. Test Scenario 3-12**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Large Truck. There were frequent losses of reception due to the large truck interception. The packet loss of less than 10 percent was found in all trials of this test.

Figure 114. Test Number 3-12 Results

| | | | |
|---|---|---|---|
| Test Number | 3-12 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_12_4.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.13 Test Scenario 3-13

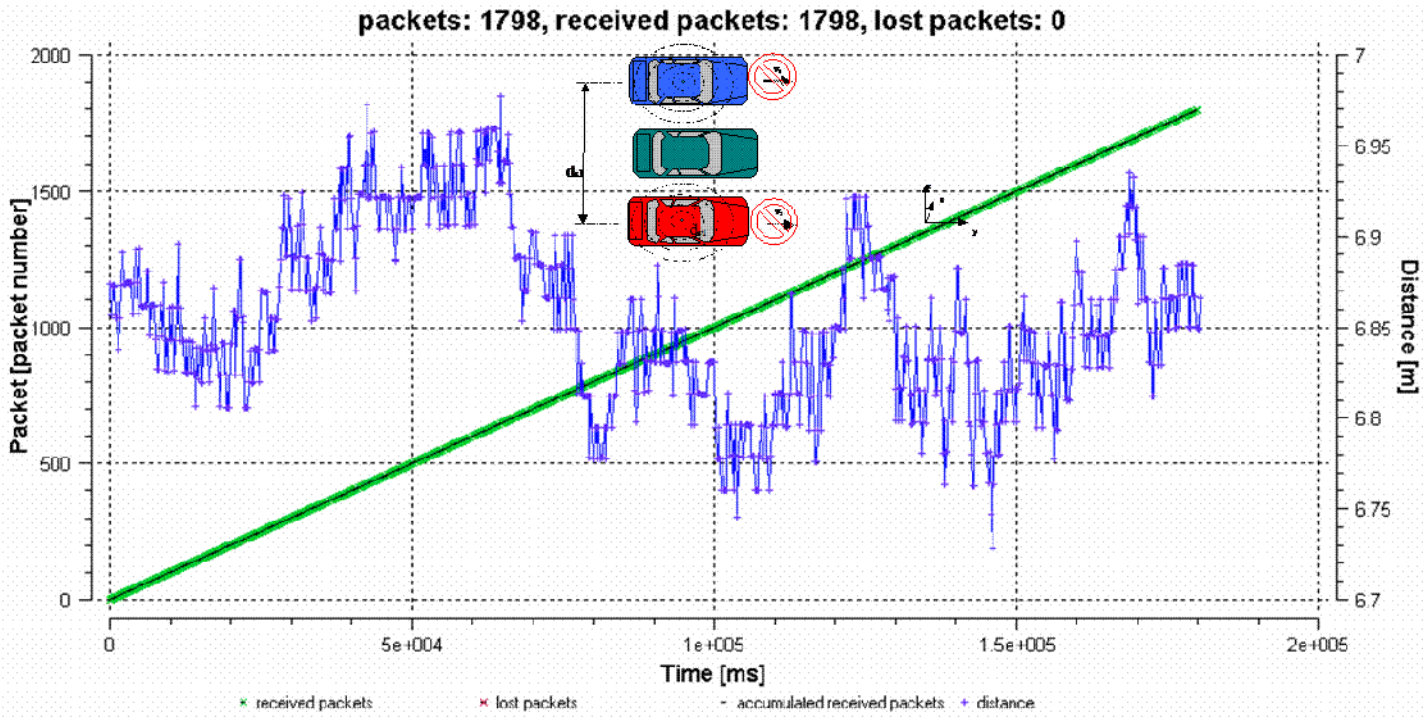
| **Test Scenario** | **3-13** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 0 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 69. Test Scenario 3-13**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Chevy Suburban SUV. There was no loss of reception due to the SUV interception. No packets were lost in all trials of this test.

Figure 115. Test Number 3-13 Results

| | | | |
|---|---|---|---|
| Test Number | 3-13 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_13_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Chevy Suburban |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.14 Test Scenario 3-14

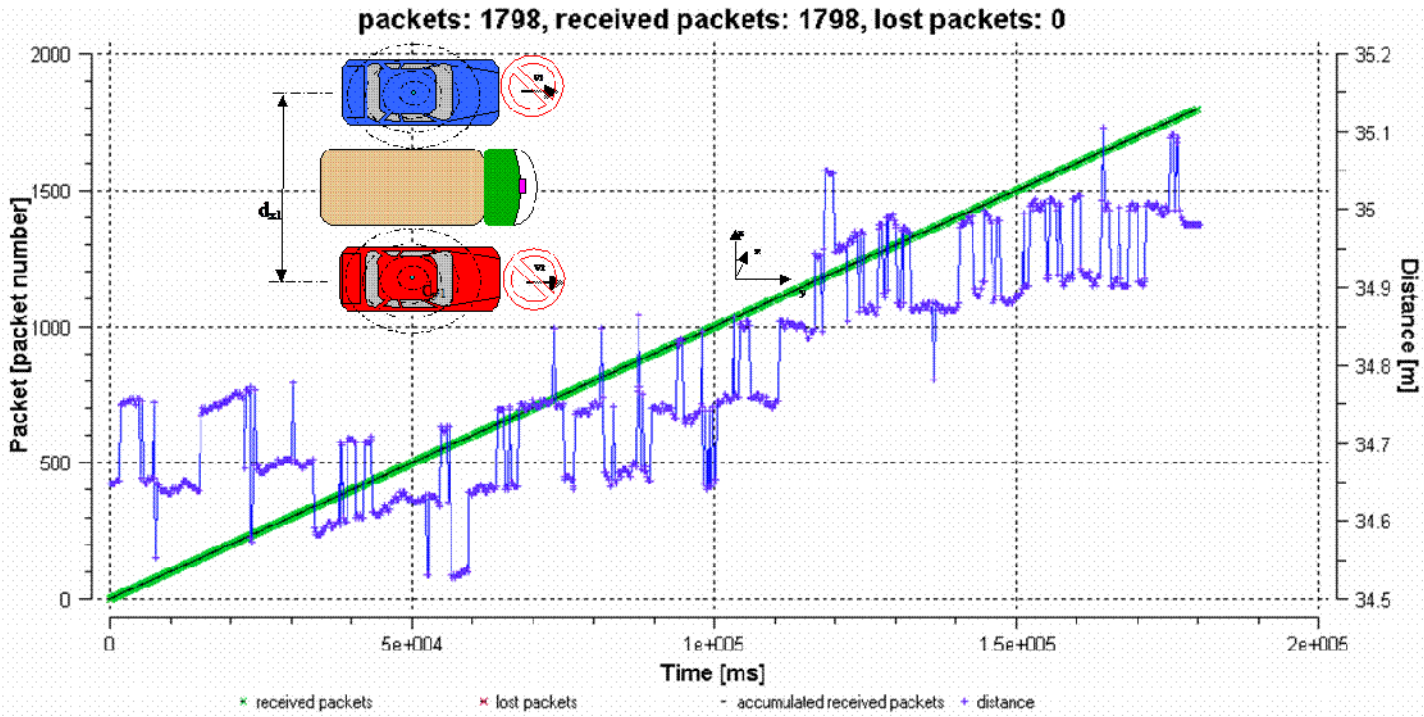
| **Test Scenario** | **3-14** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 0 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 70. Test Scenario 3-14**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Large Truck. There was no loss of reception due to the large truck interception. The phenomenon of no packet loss was found in several trials of this test.

Figure 116. Test Number 3-14 Results

| | | | |
|---|---|---|---|
| Test Number | 3-14 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_14_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.15 Test Scenario 3-15

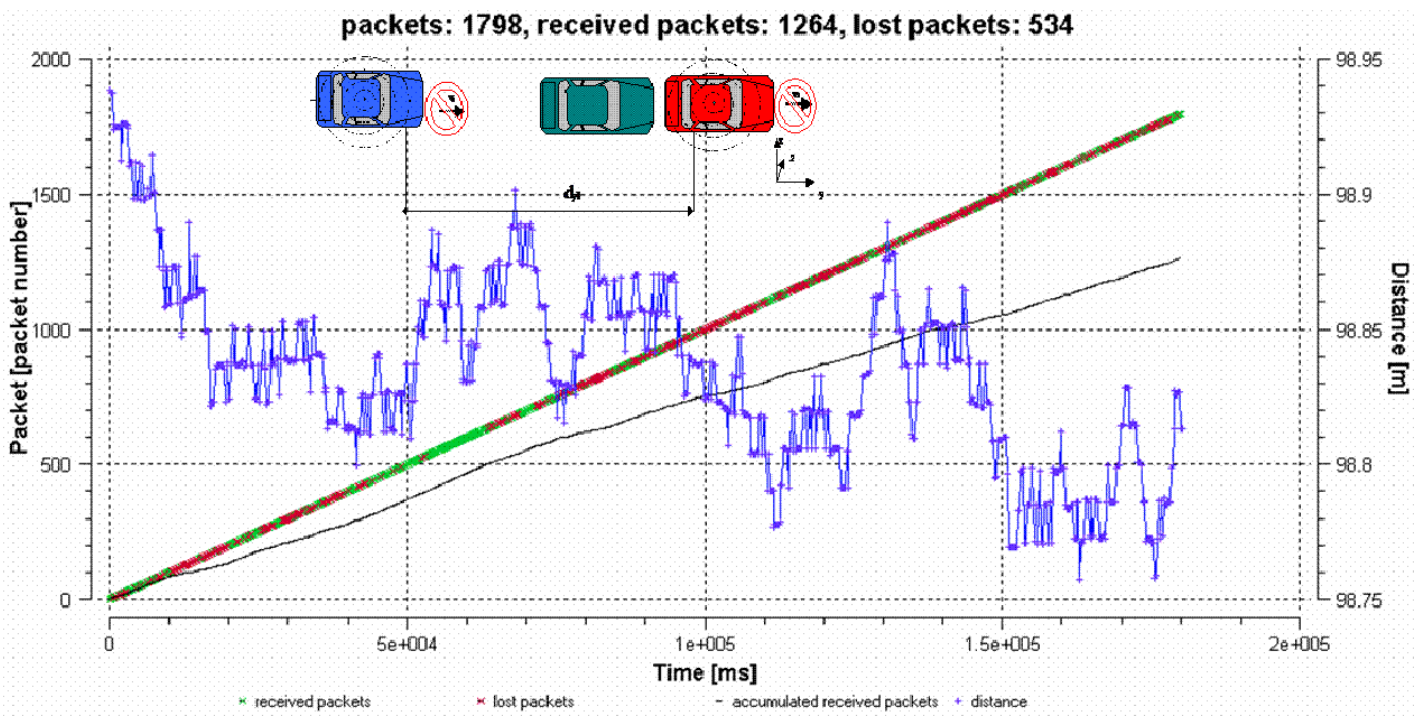
| **Test Scenario** | **3-15** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 71. Test Scenario 3-15**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Chevy Suburban SUV. There was significant loss of reception due to the SUV interception. The most significant packet loss was observed when the SUV was close to the front vehicle (receiver).

Figure 117. Test Number 3-15 Results

| | | | |
|---|---|---|---|
| Test Number | 3-15 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_15_1_trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Chevy Suburban |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.16 Test Scenario 3-16

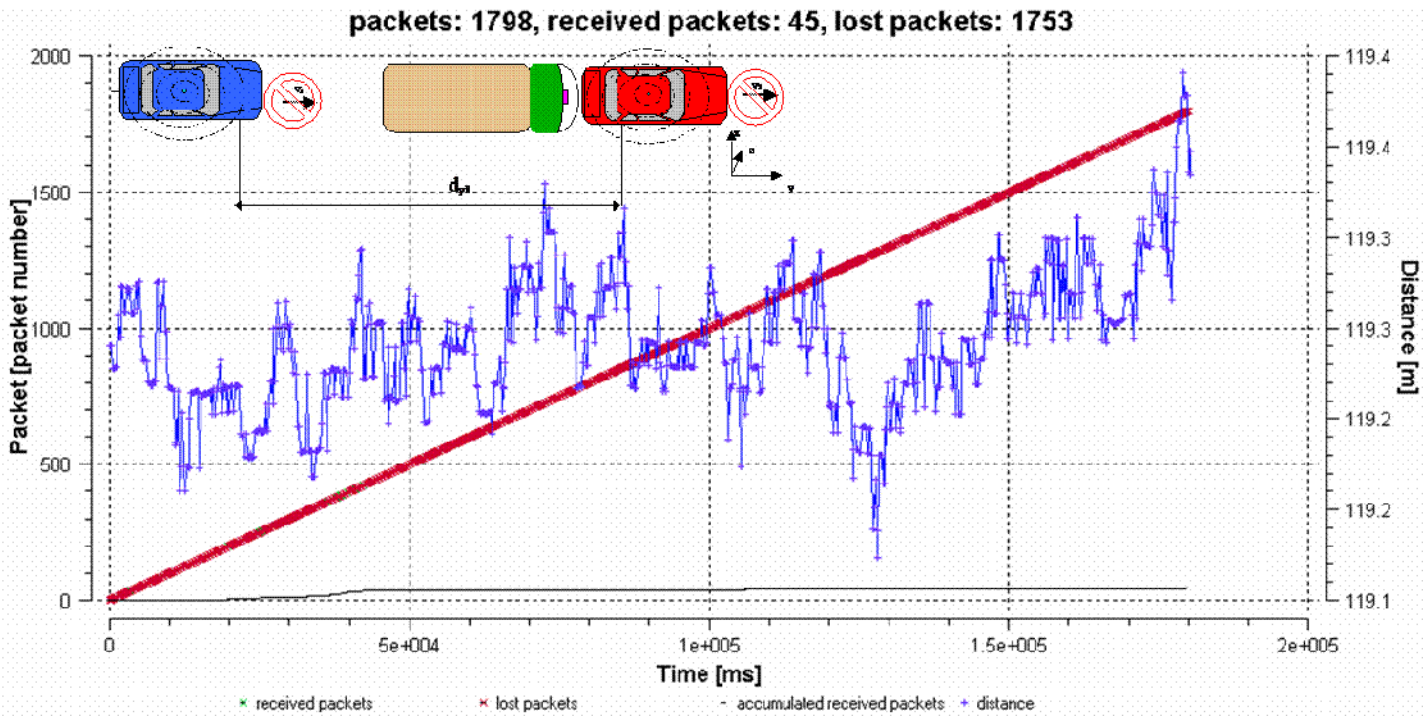
| **Test Scenario** | **3-16** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 0 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | Truck |

**Table 72. Test Scenario 3-16**

Test Comments: This test was done in MS Windows. The intercepting vehicle was a Large Truck. There were very few packets that were received and the loss of reception due to the large truck interception was severe. The phenomenon of increased packet loss was found in all trials of this test and particularly when the truck was close to the front vehicle (receiver).

Figure 118. Test Number 3-16 Results

| | | | |
|---|---|---|---|
| Test Number | 3-16 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_3_16_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.1.17 Test Scenario 3-17

| **Test Scenario** | **3-17** |
|---|---|
| Relevant Applications | Traffic Signal Violation Warning<br>Left-Turn Assistant<br>Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | < 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Test Track |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

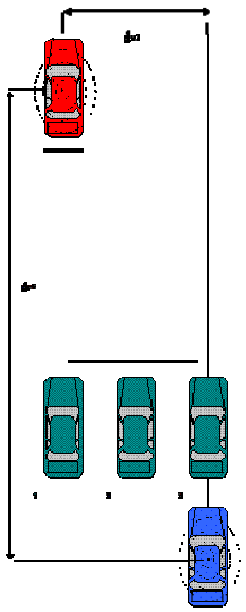
**Table 73. Test Scenario 3-17**

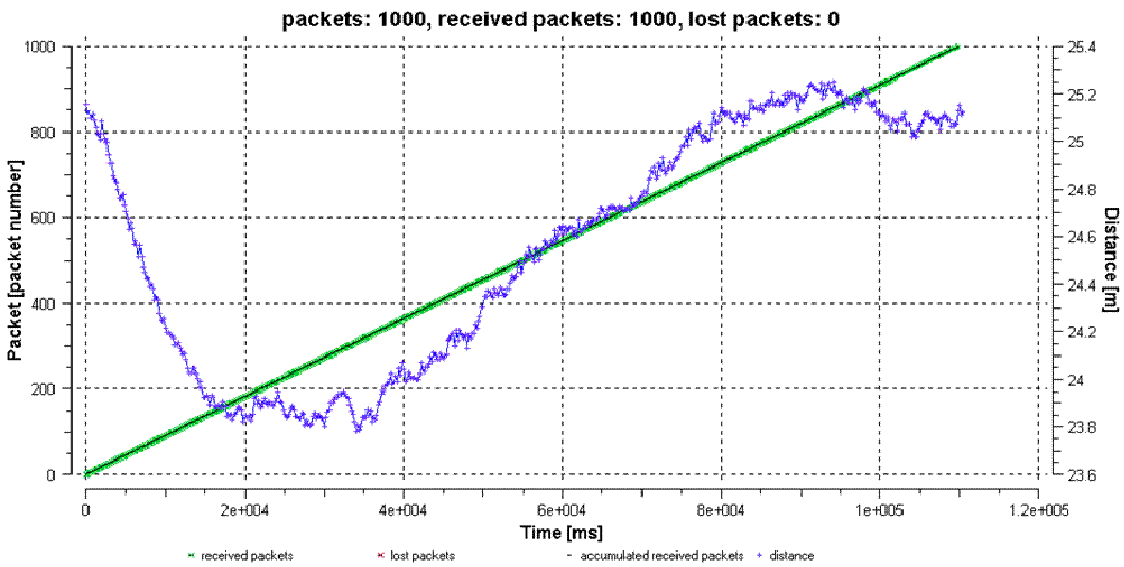
Test Comments: This test considers the effect of three side-by-side SUVs parked between a stationary sending and receiving vehicle. In Trial 1, the sender and receiver vehicles were positioned ~25m apart, and the obstacle vehicle was separated from the sender vehicle in the dy1 direction by ~5m. The line-of-sight was obstructed by Obstacle Vehicle #2. Overall, 100 percent of the packets sent during the test were received. Tests 1-27 and 1-28 were run to check this vehicle configuration under dynamic conditions.

Figure 73. Test Number 3-17-1 Results

| | |
|---|---|
| Test Number: | 3-17-1 |
| Trace File Name: | 082703_2_19_1_SUV.trace* |
| Date Collected: | August 27th, 2003 |
| Files Resident With: | Jim Bauer |
| Operating System Used: | Linux |
| Software Level Used: | Version 2.3 |

| | |
|---|---|
| Ambient Weather Conditions: | Mostly Sunny |
| Sending Vehicle Model/Make: | Toyota Prius |
| Receiving Vehicle Model/Make: | Lexus GS300 |
| Antenna Type Used: | Standard |
| Obstacle Vehicle #1 Model/Make: | Toyota Sequoia |
| Obstacle Vehicle #2 Model/Make: | Toyota Sequoia |
| Obstacle Vehicle #3 Model/Make: | Toyota Highlander |





## 6.2 Multiple Senders Communications

### 6.2.1 Test Scenario 4-1

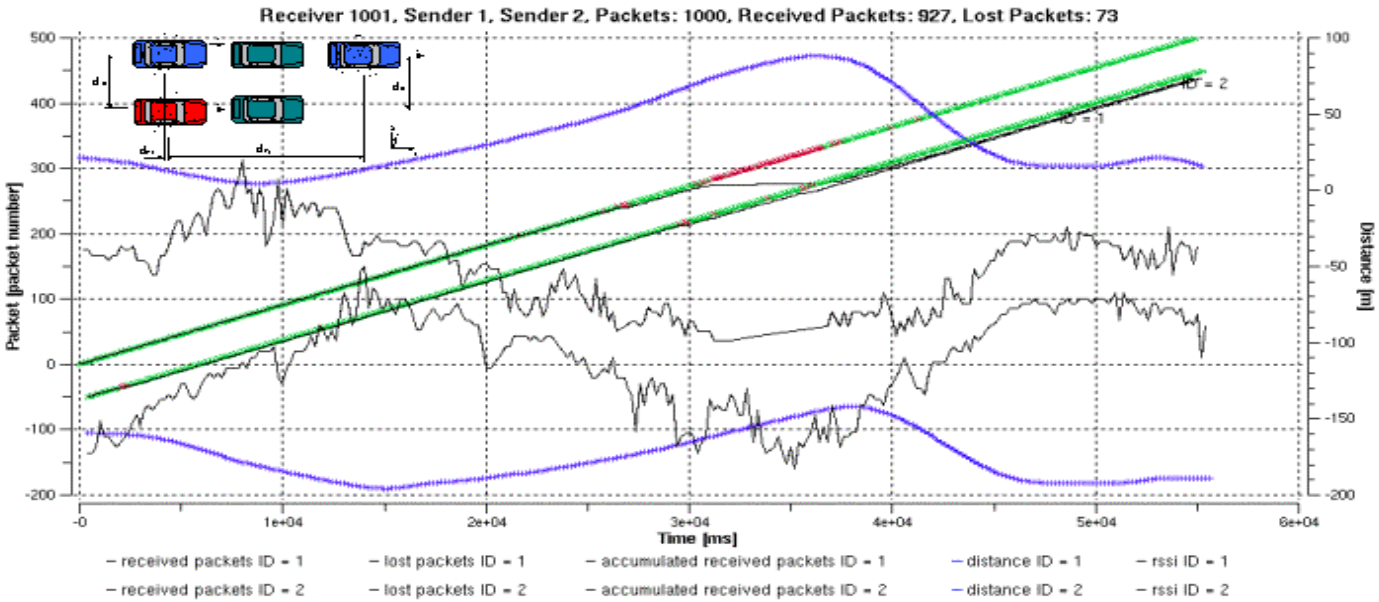
| **Test Scenario** | **4-1** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 30 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 74. Test Scenario 4-1**

Test Comments: Offset used for the graph is 20 (packets), 200 (distance), and 200 (RSSI). The test was done on arterial road with light traffic. The sending vehicles were moving approximately 40 mph and the receiver at 30 mph. The frequency used for this test was at 5.8GHz. There was no blocking vehicle between the 2 senders. However, there were some vehicles on the road blocking the receiver from the sender causing packet drops. The top number of packets, distance and RSSI correspond to sender 1.

**Figure 119. Test Number 4-1 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-1** | Ambient Weather Conditions: | **Cloudy** |
| Trace File Name: | **test_4_1_8_2_*.*** | Sending Vehicle Model/Make: | **BMW 330, VW Passat** |
| Date Collected: | **March 26, 2004** | Receiving Vehicle Model/Make: | **Mercedes M class** |
| Files Resident With Whom: | **C. Lee** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **N/A** |
| Software Level Used: | **v3.0.4** | VSC Obstacle Vehicle #2 Model/Make: | **N/A** |



### 6.2.2 Test Scenario 4-2

| **Test Scenario** | **4-2** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 65 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 75. Test Scenario 4-2**

Test Comments: Receiver constant speed of about 60mph, Senders slow pass at 65 mph, one-lane offset, up to and over 100m between the front sender (sender 1) and the receiver, 5.8 GHz, 100 percent power, nominal 600 packet duration. Occasionally, non-test vehicles entered the test pattern and blocked some packets. Offset values used for the plot: 0 (packets), 0 (distance), and 0 (RSSI).

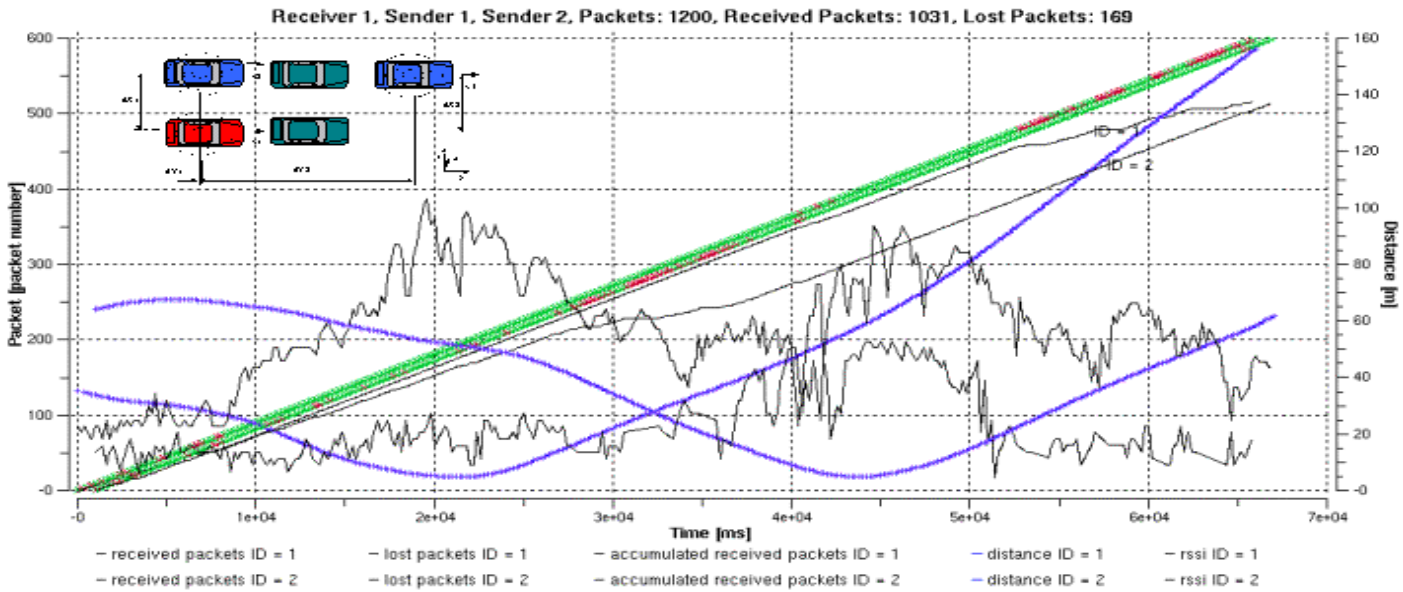
**Figure 120. Test Number 4-2 Results**

Test Number **4-2**
Trace File Name: **test_4-2_2_*.***
Date Collected: **March 22nd, 2004**
Files Resident With Whom: **Gordon Peredo**

Ambient Weather Conditions: **Sunny**
Sending Vehicle Model/Make: **BMW 330, VW Passat**
Receiving Vehicle Model/Make: **Chrysler Pacifica**
Antenna Type Used: **Standard**

Operating System Used: **Linux**
Software Level Used: **v3.0.4**

VSC Obstacle Vehicle #1 Model/Make: **N/A**
VSC Obstacle Vehicle #2 Model/Make: **N/A**



### 6.2.3 Test Scenario 4-3

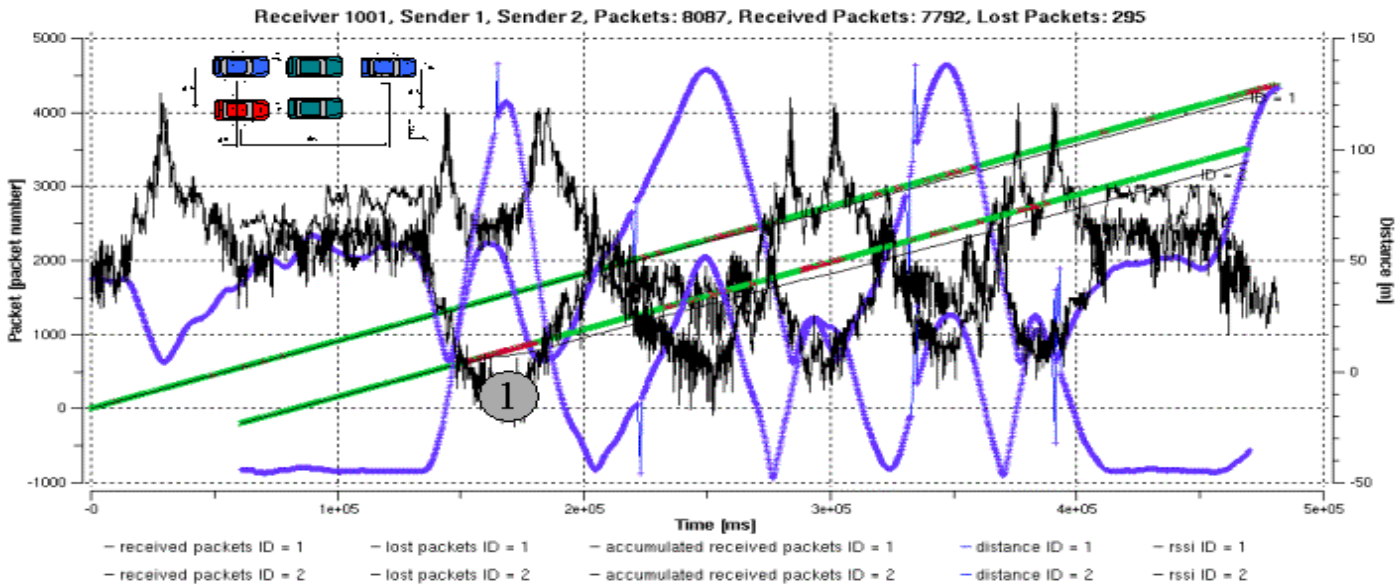
| **Test Scenario** | **4-3** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 65 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 76. Test Scenario 4-3**

Test Comments: The test was conducted at highway speeds varying from the prescribed 60/65 mph to 75 mph with occasional obstacle vehicles outside the intended test vehicles. Overall, 96 percent of the packets sent during the test were received. The majority of the lost of packets (encircled by 1) was caused by an obstacle 18-wheeler in close proximity (under 25m). Offset values used for the plot was 200 (packets), 50 (distance), and 500 (RSSI). The sinusoidal nature of the distance curves during the middle of the test graph represents multiple repetitions of test 4-3 (the senders pass the receiver going approximately 5mph faster). This test was conducted at 5.32GHz.

**Figure 121. Test Number 4-3 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-3 and 4-5** | Ambient Weather Conditions: | **Mostly Sunny** |
| Trace File Name: | **test_4_3_2_*.*** | Sending Vehicle Model/Make: | **M45 & Camry** |
| Date Collected: | **March 2nd, 2004** | Receiving Vehicle Model/Make: | **Lexus GS300** |
| Files Resident With Whom: | **Steve Tengler** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **Infiniti Q45** |
| Software Level Used: | **v3.0-B2 (27-Feb-04)** | VSC Obstacle Vehicle #2 Model/Make: | **Ford Explorer** |



### 6.2.4 Test Scenario 4-4

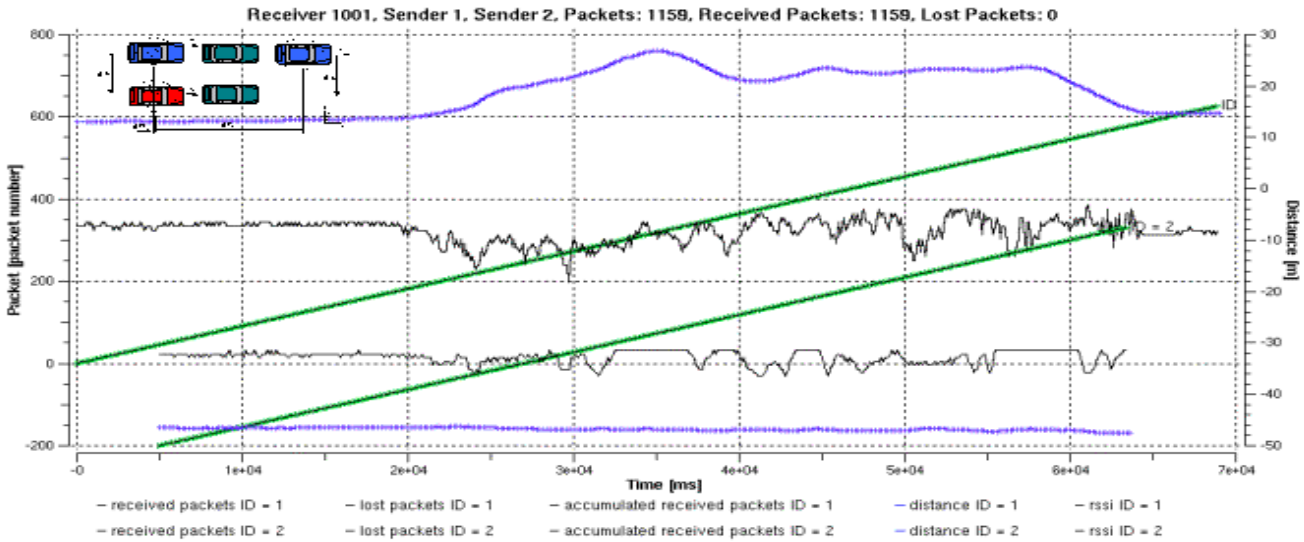
| **Test Scenario** | **4-4** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | <20 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV/sedan |

**Table 77. Test Scenario 4-4**

Test Comments: The test was conducted at arterial speeds close to 25 mph. The tight formation maintained a distance less than 20 m between Sender1 and Receiver, and Sender2 was one lane to the left of the Receiver. Two obstructing vehicles were sustained during the test. Overall, over 99 percent of the packets sent during all three trials of the test were received. The obstructing vehicles did not cause any significant loss of reception from Sender1. The Sender 2 values are offset from the Sender 1 values by 200 packets, 50 meters, and 500 RSSI. This test was conducted at 5.32GHz.

**Figure 122. Test Number 4-4 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-4** | Ambient Weather Conditions: | **Mostly Sunny** |
| Trace File Name: | **test_4_4_2_*.*** | Sending Vehicle Model/Make: | **M45 & Q45** |
| Date Collected: | **March 2nd, 2004** | Receiving Vehicle Model/Make: | **Buick LeSabre** |
| Files Resident With Whom: | **H. Krishnan** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **Toyota Camry** |
| Software Level Used: | **v3.0-B3** | VSC Obstacle Vehicle #2 Model/Make: | **Ford Explorer** |



### 6.2.5 Test Scenario 4-5

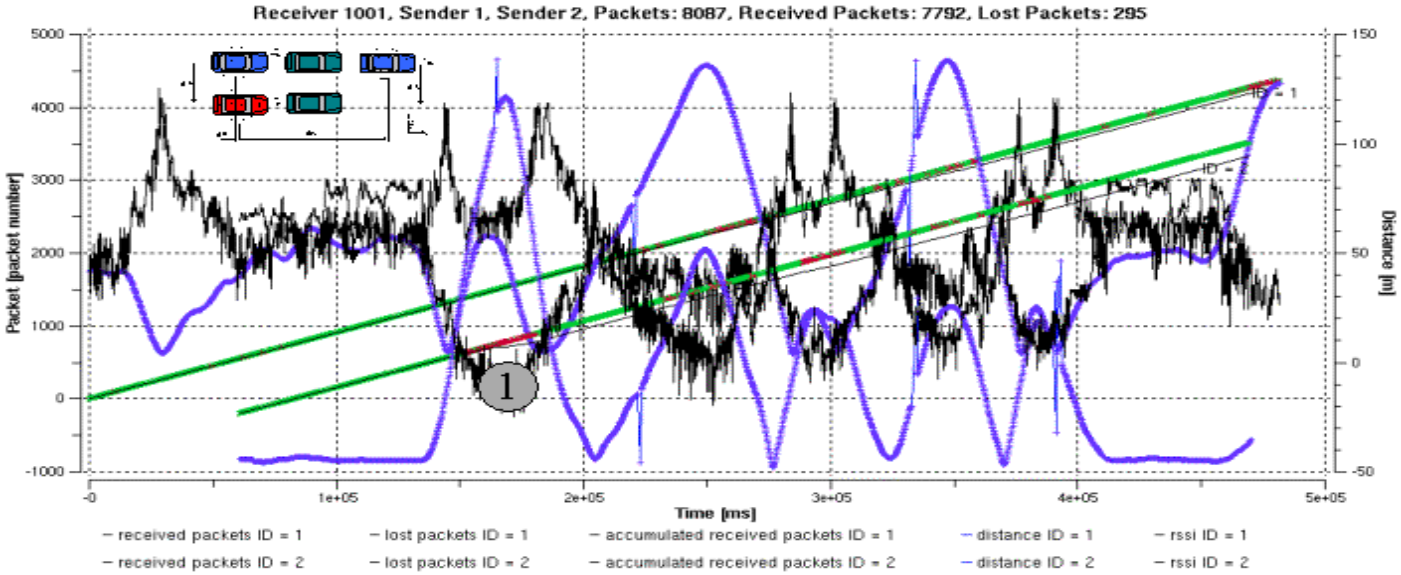
| **Test Scenario** | **4-5** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV/Sedan |

**Table 78. Test Scenario 3-14**

Test Comments: The test was conducted at highway speeds varying from the prescribed 60/65 mph to 75 mph with occasional obstacle vehicles outside the intended test vehicles. Overall, 96 percent of the packets sent during the test were received. The majority of the lost of packets (encircled by 1) was caused by an obstacle 18-wheeler in close proximity (under 25m). Offset values used for the plot was 200 (packets), 50 (distance), and 500 (RSSI). The ends of the graph demonstrate repetitions of test 4-5. This test was conducted at 5.32GHz.

**Figure 123. Test number 4-5 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-3 and 4-5** | Ambient Weather Conditions: | **Mostly Sunny** |
| Trace File Name: | **test_4_3_2_*.*** | Sending Vehicle Model/Make: | **M45 & Camry** |
| Date Collected: | **March 2nd, 2004** | Receiving Vehicle Model/Make: | **Lexus GS300** |
| Files Resident With Whom: | **Steve Tengler** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **Infiniti Q45** |
| Software Level Used: | **v3.0-B2 (27-Feb-04)** | VSC Obstacle Vehicle #2 Model/Make: | **Ford Explorer** |



### 6.2.6 Test Scenario 4-6

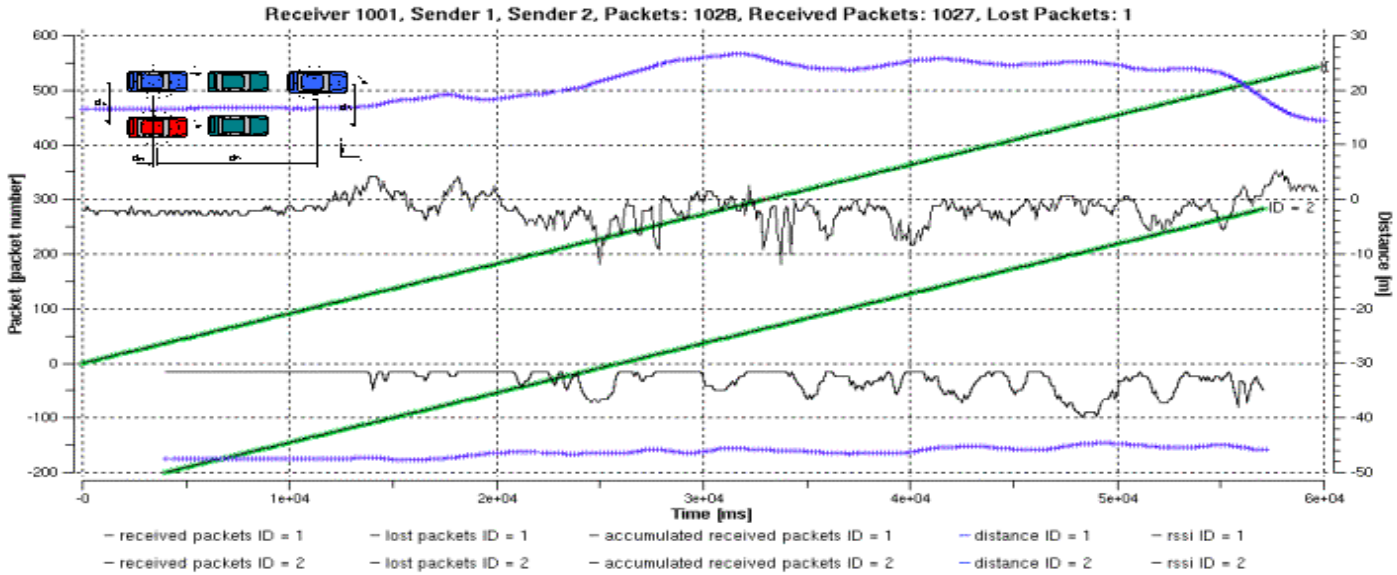
| **Test Scenario** | **4-6** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 25 |
| Distance Between Antennas (meters) | <20 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV/Sedan |

**Table 79. Test Scenario 4-6**

Test Comments: The test was conducted at arterial speeds close to 25 mph with occasional obstacle vehicles outside the intended test vehicles. The Sender 2 values are offset from the Sender 1 values by 200 packets, 50 meters, and 500 RSSI. Overall, over 99 percent of the packets sent during the test were received. No more than one packet was lost out of the thousand packets that were sent during each of the three trials. This test was conducted at 5.32GHz.

**Figure 124. Test Number 4-6 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-6** | Ambient Weather Conditions: | **Mostly Sunny** |
| Trace File Name: | **test_4_6_5_*.*** | Sending Vehicle Model/Make: | **M45 & Q45** |
| Date Collected: | **March 2nd, 2004** | Receiving Vehicle Model/Make: | **Buick LeSabre** |
| Files Resident With Whom: | **Jim Bauer** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **Ford Explorer** |
| Software Level Used: | **v3.0-B3** | VSC Obstacle Vehicle #2 Model/Make: | **Toyota Camry** |



### 6.2.7 Test Scenario 4-7

| **Test Scenario** | **4-7** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 80. Test Scenario 4-7**

Test Comments: Test conditions: constant speed of about 60mph, one lane offset, approximately 100m between the front sender (sender 1) and the receiver, 5.8 GHz, 100 percent power, nominal 1000 packet duration. Traffic surrounding the vehicles was moderate. Almost all packets from sender 2 were received, but many packets from sender 1 were lost.

Offsets:

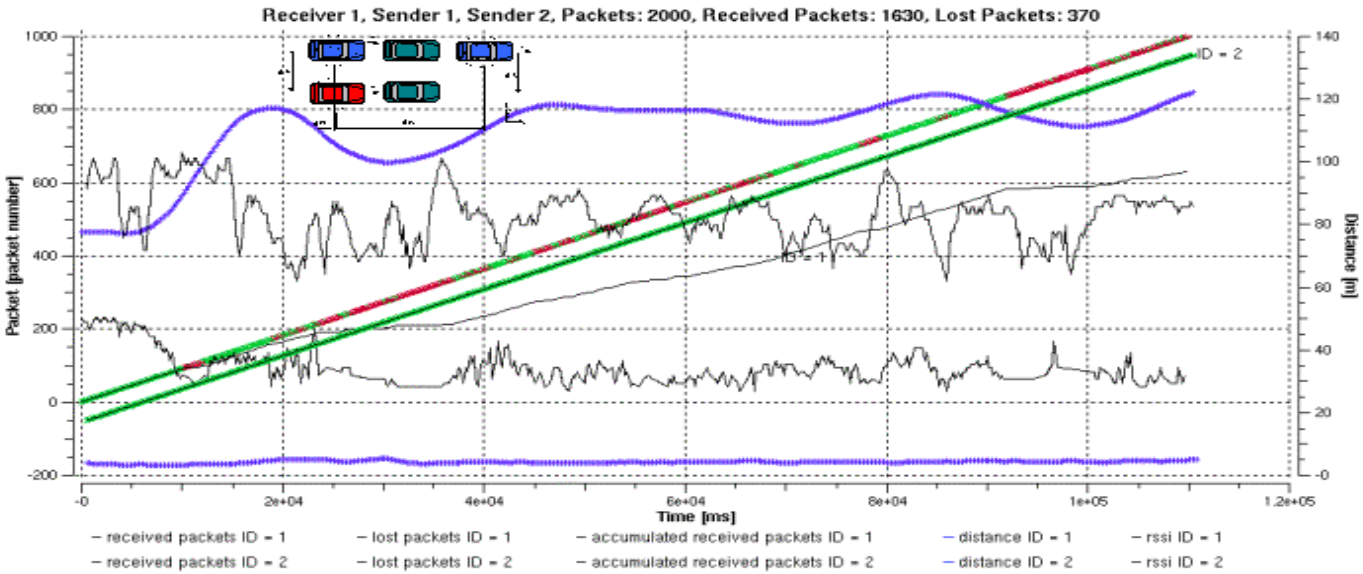
50 packets (on left y-axis); sender 1 packets on top in the diagram

200 meters (on right y-axis); sender 1 distance on top in the diagram

0 RSSI; 0 to 1000 packets corresponds to 0 to 60 RSSI; sender 2 RSSI on top in the diagram

**Figure 125. Test Number 4-7 Results**

| | | | |
|---|---|---|---|
| Test Number | **4-7** | Ambient Weather Conditions: | **Sunny** |
| Trace File Name: | **test_4_7_3_*.*** | Sending Vehicle Model/Make: | **BMW 330, VW Passat** |
| Date Collected: | **March 22, 2004** | Receiving Vehicle Model/Make: | **Chrysler Pacifica** |
| Files Resident With Whom: | **E. Clark** | Antenna Type Used: | **Standard** |
| Operating System Used: | **Linux** | VSC Obstacle Vehicle #1 Model/Make: | **VW Touareg** |
| Software Level Used: | **v3.0.4** | VSC Obstacle Vehicle #2 Model/Make: | **BMW X3** |



### 6.2.8 Test Scenario 4-8

| **Test Scenario** | **4-8** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 60 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 81. Test Scenario 4-8**

Test Comments: Test conditions: constant speed of about 60mph, two-lane offset, approximately 100m between the front sender (sender 1) and the receiver, 5.8 GHz, 100 percent power, nominal 1000 packet duration. Virtually all packets from sender 2 were received, but many packets from sender 1 were lost. Additional (blocking) vehicles occasionally passed between the two lanes of test vehicles.

Offsets:

0 packets (on left y-axis); sender 2 on top in the diagram

0 meters (on right y-axis); sender 1 on top in the diagram

0 RSSI; 0 to 1000 packets corresponds to 0 to 60 RSSI; sender 2 RSSI on top in the diagram

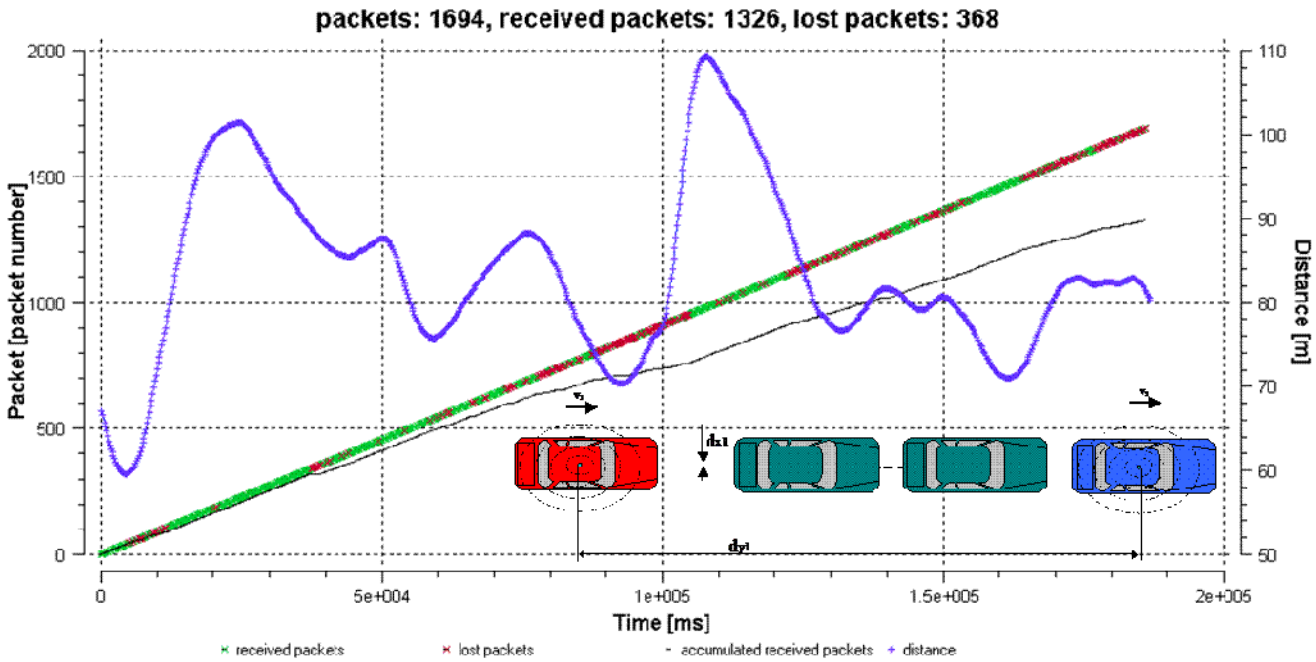
Figure 126. Test Number 4-8 Results

**Test Number 2-11**
**Trace File Name: test2-11_3_080603.trace***
**Date Collected: August 6th, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: BMW Series 3**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: BMW X5**
**VSC Obstacle Vehicle #2 Model/Make: Mercedes M-class**



### 6.2.9 Test Scenario 4-9

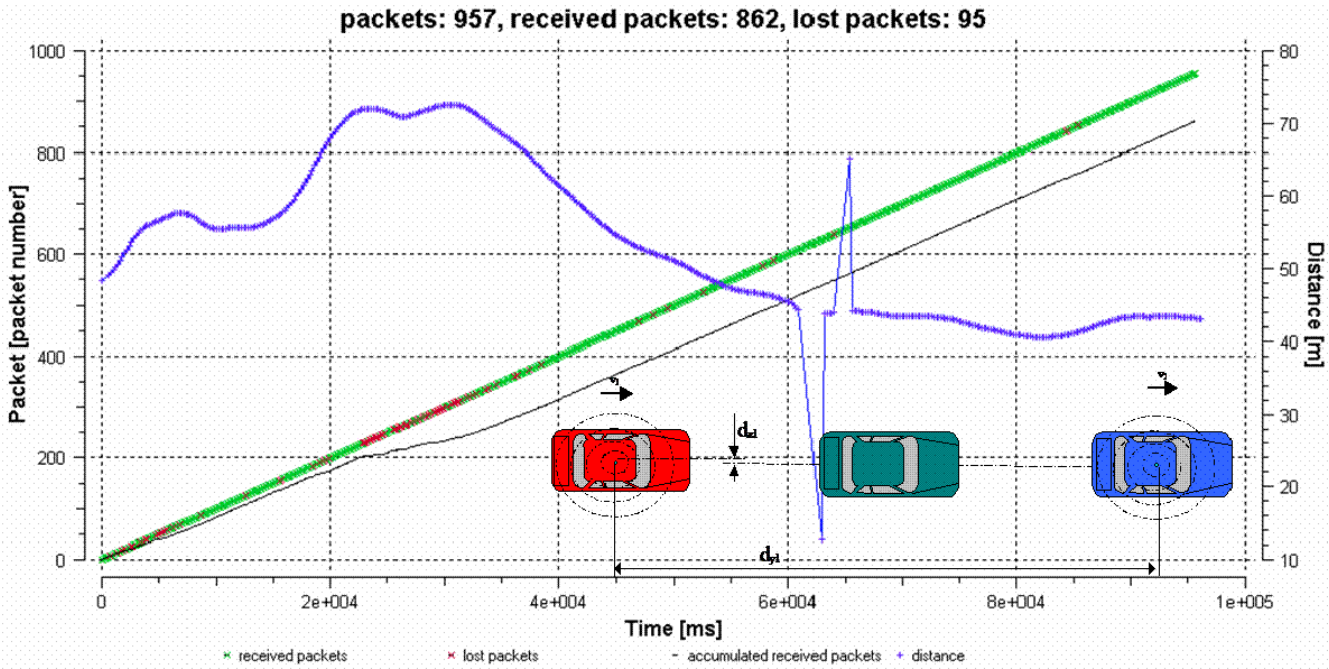
| **Test Scenario** | **4-9** |
|---|---|
| Relevant Applications | Emergency Electronic Brake Light<br>Pre-Crash Sensing for Co-op Collision Mitigation<br><br>Co-op Forward Collision Warning (FCW)<br>Lane Change Warning |
| Velocity of Receiving Antenna (miles/hour) | 60 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 8 |
| Velocity of Sending Antenna (miles/hour) | 0 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | 0 |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 400 |
| Path Obstructions | None |
| Vehicle Obstructions | Sustained |
| Road Class | Highway |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | SUV |

**Table 82. Test Scenario 4-9**

Test Comments: Receiver constant speed of about 60mph, Senders slow pass at 65 mph, two-lane offset, up to and over 100m between the front sender (sender 1) and the receiver, 5.8 GHz, 100 percent power, nominal 600 packet duration. Severe packet loss due to large truck passing between test vehicles and blocking senders' line-of-sight to receiver. Occasional line-of-sight blockage by obstructing SUVs. Offset values used for the plot was 0 (packets), 0 (distance), and 0 (RSSI).

Figure 127. Test Number 4-9 Results

| | | | |
|---|---|---|---|
| Test Number | 2-12 | Ambient Weather Conditions: | Mostly Sunny |
| Trace File Name: | 060503_2_12_2.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | June 5th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | H. Krishnan | Antenna Type Used: | Standard |
| Operating System Used: | Windows XP | VSC Obstacle Vehicle #1 Model/Make: | Large Truck |
| Software Level Used: | 2.4a beta (27-Feb-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.2.10 Test Scenario 4-10

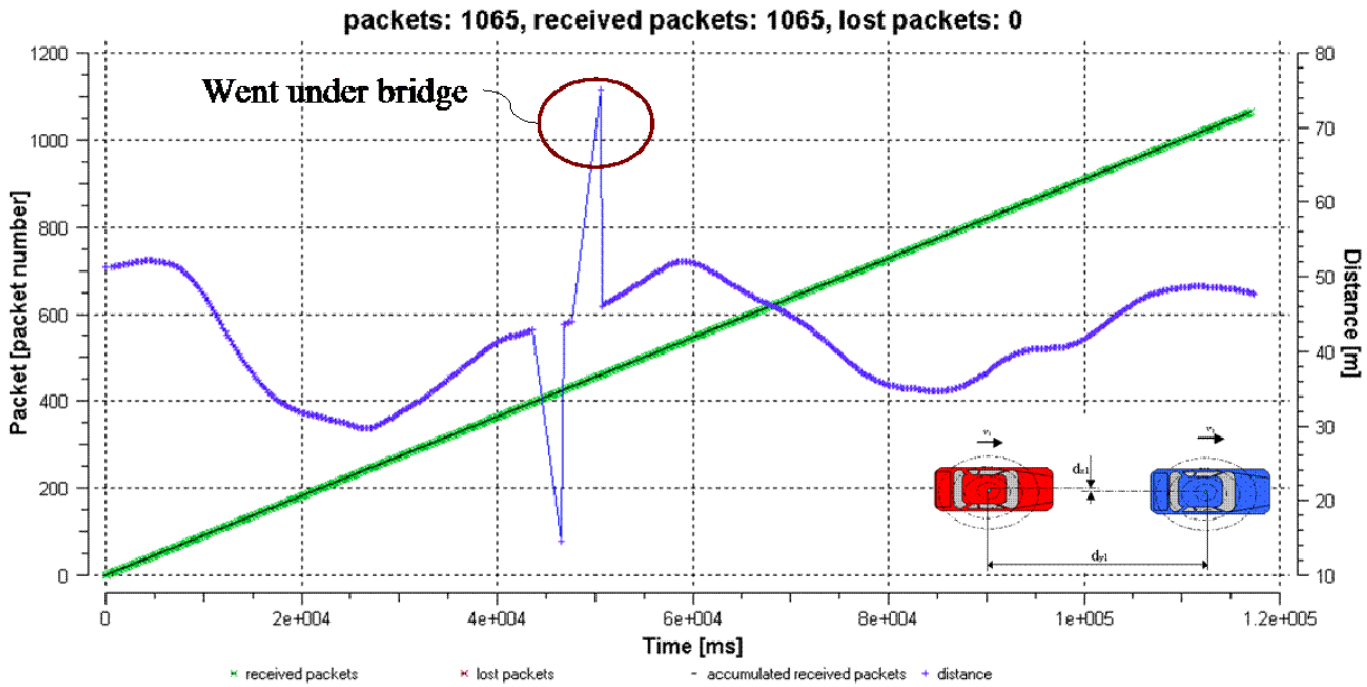
| **Test Scenario** | **4-10** |
|---|---|
| Relevant Applications | Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 83. Test Scenario 4-10**

Test Comments: This test was conducted at 5.32GHz. This test was conducted on an arterial road at speeds close to 25 mph. The distance between (stationary) Sender 1 and the Receiver was ~10m. The test demonstrates that having 2 senders in an intersection-type scenario has no adverse effect on packet reception. (Note that the data curves are offset for clarity, with a shift of 200 packets, 50 meters, and 500 RSSI units between each.) Sender 1 began transmission significantly prior to Sender 2 so that the receiver could verify packet reception. Only a few packets were lost during any of the multiple runs for this scenario; primarily near the endpoints where Sender 2 was often out of sight. A couple additional packets were lost during the actual drive-by portion, but it should be further noted that there was significant roadside clutter in the form of trees and parked cars, which may have partially contributed to this.

Figure 128. Test Number 4-10 Results

| | | | |
|---|---|---|---|
| Test Number | 2-13 | Ambient Weather Conditions: | Sunny |
| Trace File Name: | 072403_2_13_1.trace* | Sending Vehicle Model/Make: | Buick LeSabre |
| Date Collected: | July 17th, 2003 | Receiving Vehicle Model/Make: | Buick LeSabre |
| Files Resident With Whom: | S. Tengler | Antenna Type Used: | Standard |
| Operating System Used: | Linux | VSC Obstacle Vehicle #1 Model/Make: | N/A |
| Software Level Used: | V2.3 (8-July-03) | VSC Obstacle Vehicle #2 Model/Make: | N/A |



### 6.2.11 Test Scenario 4-11

| **Test Scenario** | **4-11** |
|---|---|
| Relevant Applications | Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 50 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 25 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 300 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

**Table 84. Test Scenario 4-11**

Test Comments: The test was conducted at arterial speeds close to 25 mph. The distance between stationary Sender3 and Receiver was about 10m, and Sender1 and Sender2 were one lane apart. Overall, over 99 percent of the packets sent during all three trials of the test were received. The test shows that having 3 senders in an intersection type scenario has no effect on packet loss of reception. The Sender 2 values are offset from the Sender 1 values by 200 packets, 50 meters, and 500 RSSI. The Sender 3 values are offset from the Sender 2 values by 200 packets, 50 meters, and 500 RSSI. This test was conducted at 5.32GHz.

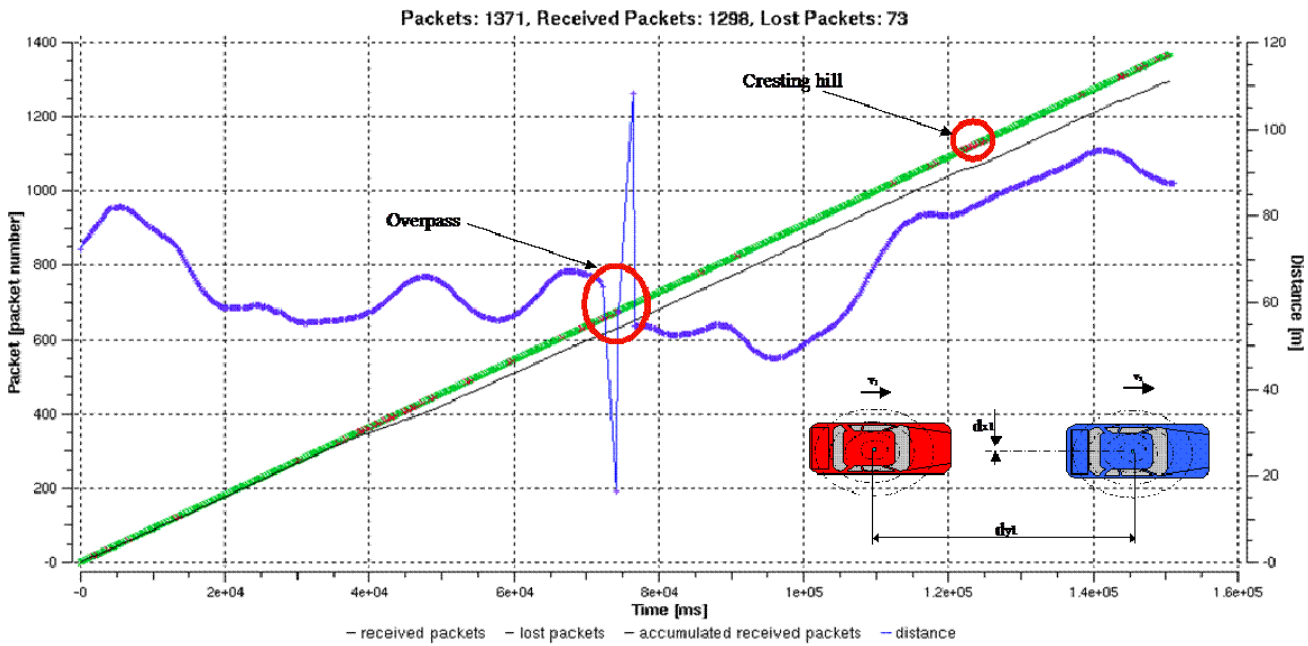
Figure 129. Test Number 4-11 Results

**Test Number 2-14**
**Trace File Name: test2-14_3_072303.trace***
**Date Collected: July 23rd, 2003**
**Files Resident With Whom: Chu-Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: VW Passat**
**Receiving Vehicle Model/Make: BMW Series 3**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: N/A**
**VSC Obstacle Vehicle #2 Model/Make: N/A**



### 6.2.12 Test Scenario 4-12

| **Test Scenario** | **4-12** |
|---|---|
| Relevant Applications | Stop Sign Movement Assistant |
| Velocity of Receiving Antenna (miles/hour) | 0 |
| Distance Between Antennas (meters) | 100 |
| Lateral Offset to Broadcast Antenna (meters) | 4 |
| Velocity of Sending Antenna (miles/hour) | 45 |
| Angle Between Vehicle 1 & Vehicle 2 (degrees) | N/A |
| Update Rate (milliseconds) | 100 |
| Transmitter Power Level (%) | 100 |
| Packet Size (bytes) | 200 |
| Path Obstructions | None |
| Vehicle Obstructions | None |
| Road Class | Arterial |
| Traffic Conditions | Light |
| Other Effects | None |
| Vehicle-Class of Cut-In Vehicle | N/A |

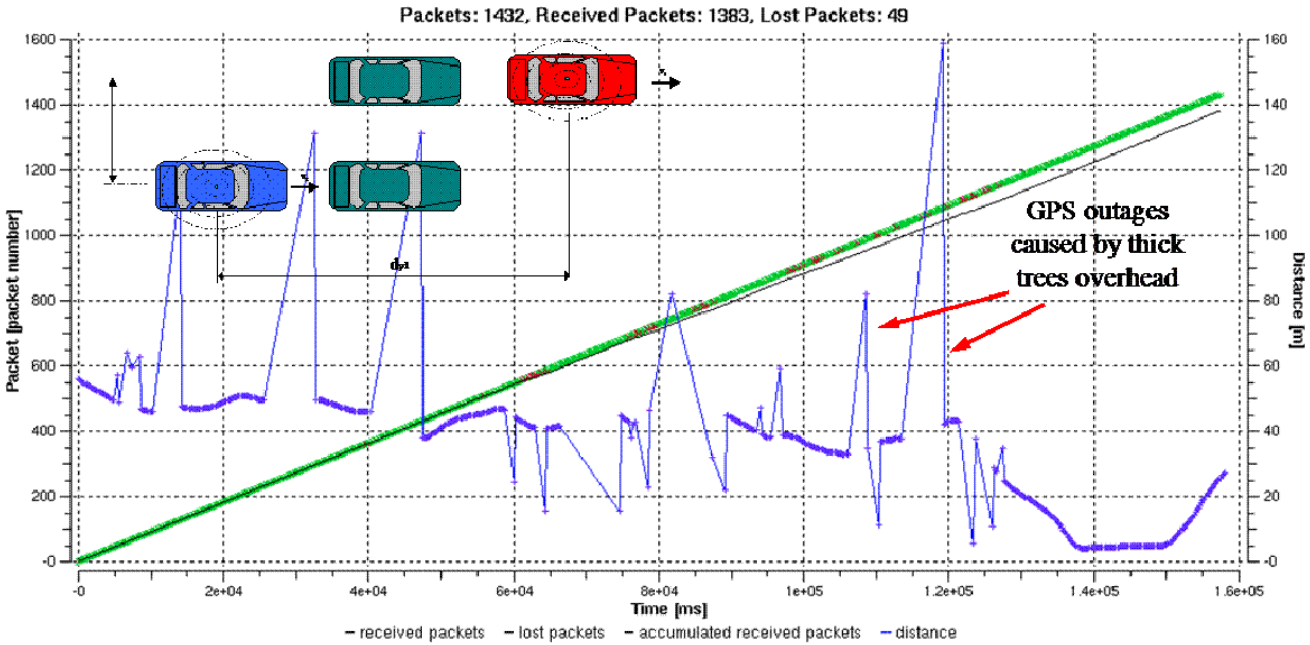
**Table 85. Test Scenario 4-12**

Test Comments: This test was conducted at highway speeds close to 50 mph. The distance between (stationary) Sender 3 and the Receiver was ~10m, and Sender 1 and Sender 2 were one lane apart. The test demonstrates that having 3 senders in an intersection-type scenario has no adverse effect on packet reception. (Note that the data curves are offset for clarity, with a shift of 200 packets, 50 meters, and 500 RSSI units between each.) Senders 1 and 2 were initially stationary for a significant period of time while waiting for unexpected traffic to clear from the test zone. Also, Sender 2 began well beyond the line-of-sight to the Receiver. Aside from this, very few packets were lost during the actual drive by. It should be further noted that there was significant roadside clutter in the form of trees and parked cars, which may have partially contributed to the few lost packets. This test was conducted at 5.32GHz.

Figure 130. Test Number 4-12 Results

**Test Number: 2-15**
**Trace File Name: test2-15_3_072303.trace***
**Date Collected: July 23rd, 2003**
**Files Resident With Whom: Chu Hee Lee**

**Ambient Weather Conditions: Sunny**
**Sending Vehicle Model/Make: BMW Series 3**
**Receiving Vehicle Model/Make: VW Passat**
**Antenna Type Used: Standard**

**Operating System Used: Linux**
**Software Level Used: 2.3**

**VSC Obstacle Vehicle #1 Model/Make: Audi A4 Quattro**
**VSC Obstacle Vehicle #2 Model/Make: N/A**