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Simulation and Experimental Study of 802.11 based Networking for Vehicular Management and Safety

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ABSTRACT

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This project focused on the experimental aspect of short range communication between a moving vehicle and a stationary receiver. The accumulated measurements of signal to noise ratio fit a single line of site model rather well with the implication that the communications channel will function best as the distance between the radios is reduced. However, measurements of both bandwidth and packet loss suggest that when the vehicle passes nearby the stationary receiver at approximately the planned speeds (10 or 20 MPH) that the communication channel throughput is reduced. The present hypothesis for the cause is that the Doppler effect reduces the channel throughput. It is recommended that a representation of the vector velocity as a function of time be compared to the throughput measurements to confirm this hypotheses. Further, this observation of a deviation from a distance based channel model is important in future modeling for inter-vehicle communication as most present models used to combine traffic motion and network throughput do not account for this dominant effect.

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Contents

List of Figures

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Introduction/Problem Statement

This work focuses on the use of wireless networking techniques for their potential impact in providing information for traffic management, control and public safety goals. The premise of this work is based on the reasonable expectation that vehicles in the near future will be equipped with integrated wireless communication and positioning capabilities, enabling vehicle-to-vehicle (v2v) and vehicle-to-roadside (v2r) communications based on the emerging IEEE 802.11a/RA standard.

The potential impact of such new systems on traffic management and traveler information is extremely significant. Wireless vehicular networking will enable a new information infrastructure that can support traffic monitoring for traffic management, as well as contributing to public safety and distribution of traveler information. In the general framework shown in Figure 1, a network is formed by vehicles communicating with other nearby vehicles as well as fixed roadside infrastructure elements. The infrastructure may comprise new roadside DSRC hubs, Wi-Fi enhanced digital cellular networks, or even satellite networks. It is likely that roadside infrastructure is dense close to urban population centers and sparse in rural areas. In either case multi-hop data transfer via cooperating vehicles will be necessary. Such ad-hoc networks are the likely scenario in rural or other areas with low population density where such investment is unlikely due to economic reasons. Such infrastructure-free networks are attractive from a cost viewpoint but the modeling to obtain the performance requirements for such networks does not yet exist. There is a need for a new simulator that bridges the networking and vehicular modeling components and can be readily transferred to the broader research community in vehicular networks. A rational approach to achieve this is to begin with simulators for each sub-area that are individually detailed, and then provide a discrete-event simulation environment that allows transfer of output between them.

This report documents the literature search undertaken in advance of the experimental design in the form of a annotated bibliography. It describes the experimental design and the experiments undertaken. The output of the experiments is analyzed to provide empirical models for the effect of motion on Signal to Noise Ratio (SNR), and packet loss rates.

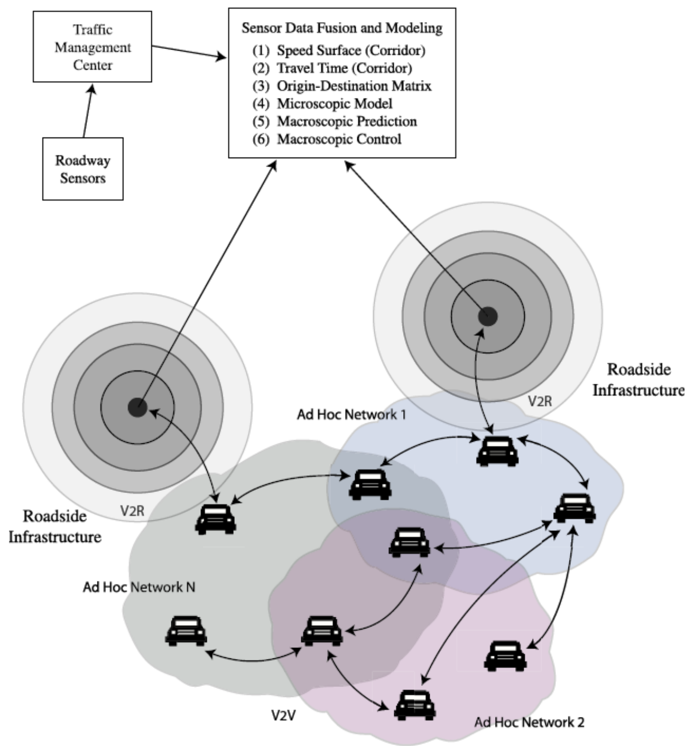

Figure 1 Vehicle to vehicle and vehicle to roadside networks.

Background

We have developed a traffic model that allows for accurate traffic flow predictions based on a micro-simulation approach suitable for "simulator-in-the-loop" ramp control. The basic premise of traffic flow modeling is that the evolution of traffic phenomena can be modeled using the behavior of the driver [1], whether macroscopically or microscopically. Simulators use parameters such as volume, occupancy, and speed to describe instantaneously the traffic state; the primary objective is to use such models to predict future traffic conditions in real-time for use in a ramp control system. In Traffic Management Systems, the traffic flow is measured at specific points on roadways using an inductance loop system. During congested periods the traffic

behaves in a highly non-stationary manner. To model this behavior we enforce a "conservation" principle such that vehicle added to the model stays until it exits the roadway via a ramp or drives the length of the model. In this way, the traffic time series between the locations of existing sensors is reproduced. The literature acknowledges that it is not a trivial task to accurately calculate traffic conditions on the roadway in between the sensors [2]. Our model uses a microscopic simulation of the vehicles on the roadway. Each vehicle propagates down the roadway based on a driver-behavior model. To validate the model against real-world data, speeds and occupancies are calculated at locations in the model where inductance loops are placed on the roadway.

A headway-based, multiple-flow regime framework is used as part of the model update function that moves the vehicles. In order to keep the model simple, each lane is modeled as a FIFO list of cars. The first car in the list is the farthest downstream, and the last car in the list is the one most recently added. By iterating down the list (from first car to the last), the flow of cars downstream is simulated. At each time step, a "snapshot" of the roadway conditions is saved. These conditions are used to calculate the "state" of each car, which is used to determine the acceleration. The three basic state members are: (1) the distance between the current vehicle and the vehicle in front, (2) the difference in velocity between the current vehicle and the vehicle in front of it, and (3) the current velocity of the vehicle. Vehicles are moved serially from the furthest downstream vehicle to the furthest upstream vehicle. For each vehicle, the local occupancy and a new headway are calculated. If the new headway is significantly different from the current headway, the headway is updated and a new set of driver control parameters is generated. The steps used in moving a vehicle are discussed in more detail in [3, 4]. The vehicle motion is based on calculating an optimal acceleration using a modified automatic cruise control framework analogous to that developed in [5].

Once the model reproduces the traffic flow actually measured, it is extended for prediction purposes by quantifying the roadway input and using a Poisson point process model to simulate the demand [5]. A Poisson point process demand model is used to simulate the entrance and exit ramp flow and to drive model prediction by as much as 10 miles and 15 minutes into the future.

As an example of the utility of the model, it is used to simulate large-scale traffic behavior for a situation that could not be tested in real life for safety reasons. The scenario simulated involved all vehicles operating with automated cruise control (ACC), and each vehicle’s state [vehicle speed, vehicle acceleration, vehicle headway, speed relative to surrounding vehicles] was shared among the vehicles via a wireless network. The benefits of wirelessly sharing vehicle state information can be simulated/quantified by using this model.

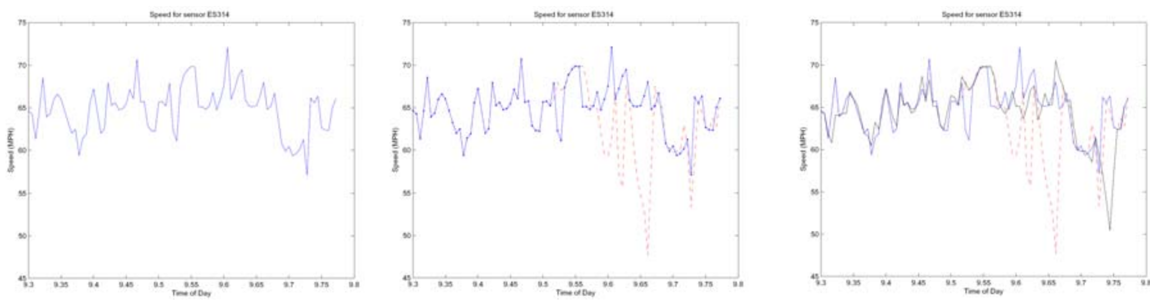

Figure 2 Normal time series at left. Normal plus impaired, middle. Normal, impaired and improved reaction time, right.

To evaluate this scenario, the model is first calibrated for a section of roadway on SR 167 so that it accurately replicates the speed reductions due to congestion. The primary expected change in vehicle behavior as a result of having an appropriately designed wireless network for transport is that the reaction time, typically in the 1- to 2-second range for humans, could be reduced to well below 1 second, and the surrounding vehicle states could be fed directly into the ACC controller to improve control. Figure 2 shows the simulation of a typical traffic time series for the morning at sensor ES-314. At 9:30 AM an impaired vehicle was injected into the flow at that location. The impairment was modeled as a slower desired speed and a larger variability in the speed of that one vehicle. The impaired vehicle affected overall traffic speed, as shown in red in the center in Figure 2, causing a sufficiently large variation in the speed, more than 10 miles per hour, that past research has indicated may be correlated with accidents. At the right of Figure 2 are three time series, the original, the result of the impaired vehicle, and a black line for the traffic speed variation that resulted when the vehicles were given inter-vehicle communication to reduce reaction time. In this last case, variation decreased because of the collaboration between the wirelessly connected vehicles, even though the impaired vehicle was not collaborating. This simulation shows how a properly calibrated micro-simulator can model inter-vehicle communication effects that result in reduced reaction time to accommodate an unsafe or impaired vehicle and reduce the variance of speed, as well as reduce extreme speed changes associated with accidents.

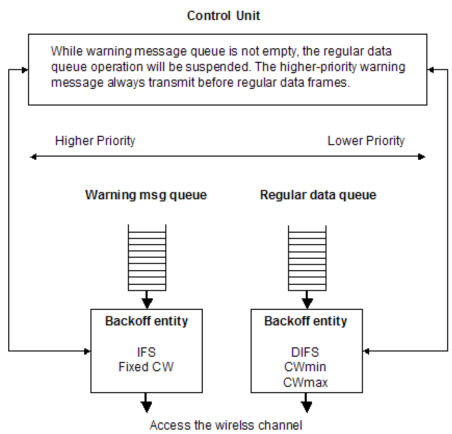

Figure 3 Alternative channel access paradigm.

In past wireless work, by co-investigator Roy, there are preliminary results on collaborative collision avoidance (CCA) using a simple scenario for illustration, a linear platoon moving with constant velocity. A schematic of a CCA protocol is shown in Figure 3 where a separate queue, along with its own backoff entity, for delivering an Emergency Warning Message (EWM) has been added to the standard 802.11 Distributed Contention Function (DCF) multiple access protocol. Whenever the EWM queue is not empty, regular data queue operation is suspended so that EWM has priority. A vehicle will keep contending for the channel to relay the EWM until it receives an EWM broadcast with same event ID from any succeeding vehicle, implying that the message has propagated down the platoon to at least one vehicle behind the reference vehicle. It will then stop trying to relay EWM. Unlike regular operation of DCF for data, we propose that no explicit ACK is required for EWM. The receipt of EWM from a subsequent car in the platoon serves as an implicit ACK. This simple but novel mechanism contributes to protocol efficiency in various ways. It controls the ACK explosion problem while reducing the number of active nodes contending for channel access at each stage. The EWM propagates from the lead vehicle down the platoon in a multi-hop manner. Each relay iteration is based on DCF-based channel contention among all 'active nodes' leading to a winner. Then, all nodes in front of the winner become inactive, and those behind the winner within a transmission range become active upon receiving EWM.

When an emergency is detected, the lead car starts to decelerate and simultaneously releases an Emergency Warning Message (EWM) to the platoon that contains the sender's location, the event's location, and an event ID. Cars receiving EWM can instruct drivers whether to decelerate or not according to their current location and velocity. In our simplified study, we assume that all vehicles upon receiving the message (1) start to decelerate after a fixed human-reaction time and (2) attempt to access the channel so as to relay the broadcast EWM to cars behind them. Thus, EWM is relayed through multiple hops to the final car in the platoon.

In this report the experimental portion of a simulation and experiment framework is described. The closest experimental work is reported in [6] and uses 802.11b and directional antenna at the AP. Netperf was used and the throughput rate was set at two seconds. The measurements are done over a large area and with access point placed at elevated positions. In [6] they assert that the “conventional wisdom on the topic ranges from claims that the Doppler shift will kill the 802.11b signal at any speed, to people who engage in “wardriving”—the practice of locating open WiFi access points by driving around with a tool such as Kismet.”

Research Objectives

To provide experiment data for a model that allows questions like how far from a AP and at what speeds can data be reliably exchanged.

An experimental basis for modeling how much data can be exchanged in a passing.

Experiments

Previous experimental work by Singh and Bambos do not include the temporal aspects of the data transfer, and does identify which components of the channel models are dominant in the various scenarios. In this work experiments were done to establish the range effects, and the Doppler effects as a function of vehicle speed. This was done in a series of experiments using a stationary access point simulating a DSRC roadside installation and a vehicle traveling at a variety of speeds. Experimental measurements include measuring the signal to noise ration (SNR), bandwidth, packet loss and position (GPS) as a function of time. Speed is calculated by smoothing repeated GPS fixes and differentiating that time series.

The baseline experiments are done in the University of Washington E-1 parking lot which provides a relatively flat and relatively straight roadway, and allows for passing the stationary access point near the middle of the transverse of the parking lot. An image of the parking lot and a schematic representation of the vehicle path is shown in Figure 5. The stationary access point is located just above the middle of Figure 5 along the east bounding roadway and at the eastern end of the row of trees in the image. Since the parking lot is not completely flat the access point is mounted ten feet above the parking lot surface to guarantee a line of site path between the vehicle and the access point during the entire drive along the east bounding roadway.

The hardware used for the experiments consists of: (1) A stationary access point connected to a laptop and auxiliary power (a vehicle battery with inverter) to act as the DSRC base station, see Figure 4, and (2) A mobile laptop with a Proxim PCMCIA network card with an externally mounted 6db gain antenna as well as a USB externally mounted GPS receiver, see Figure 4**.**

The software used for the experiments consisted of Netstumbler and the Iperf client installed on the mobile computer and the Iperf server installed on the stationary computer. Netstumbler1 is an application that records the Media Access Control ID (MACID) of all of the Wifi access points heard by the local Wifi card as well as time, signal to noise ratio and GPS location. Iperf2 is a Microsoft Windows based application that measures throughput, bandwidth, jitter and packet loss between two networked computers for both the TCP and UDP protocols each second. For the experiments UDP throughput as UDP does not perform rebroadcast and 1450 is the Maximum Transmission Unit for the Wifi packets

The experiments consist of:
(1) Establish location of access point: Place GPS receiver on vehicle near access point. Record data for 10 minutes to establish the stationary baseline.

With the settings:

Access Point Computer: 192.168.1.2

Iperf server is run with the command:

Iperf -s -l 1450 -t 28800 -i 1 -u | tee "Iperf_output_`date '+%Y%m%d%H%M%S'`.txt"

Mobile Computer: 192.168.1.3

GPS is initialized in the mobile Computer.
Netstumbler is run on the mobile.

Iperf client is run on the mobile computer

Iperf -c 192.168.1.2 -u -l1450 -t600

(2) A set of passing tests with the vehicle driver attempting to maintain a controlled speed of 5, 10, 20, 30 mph while driving back and forth the length of the parking lot for duration of 10 minutes.

Several measurement campaigns where undertaken; however, due to "bugs" in the Netstumbler's recording of GPS data only the 5/14/2008 measurement set was successful and is reported on here.

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[1] http://www.Netstumbler.com/
[2] http://Iperf.sourceforge.net/

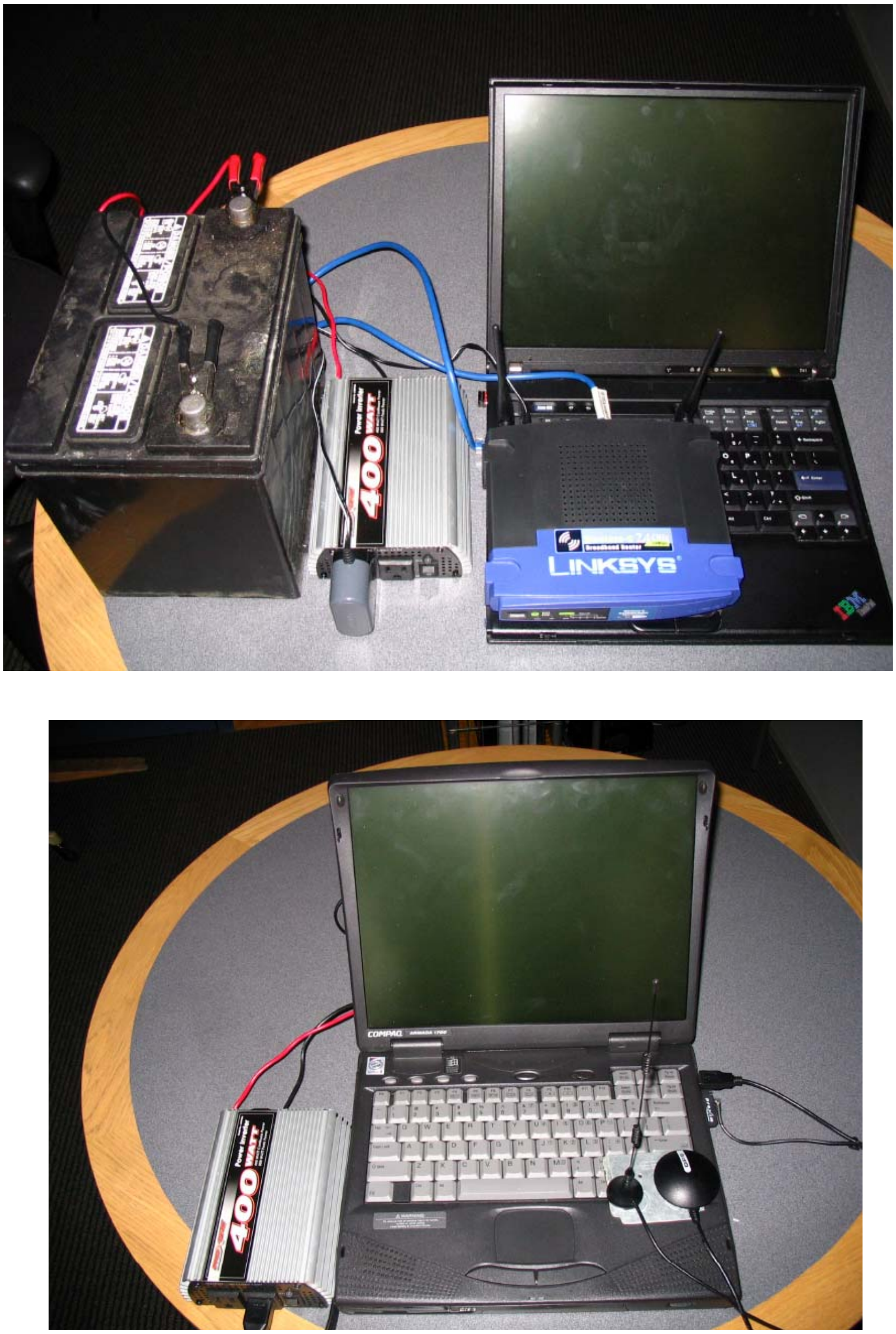


Figure 4 Experimental hardware, stationary transceiver at top and mobile transceiver at bottom

Figure 5 UW E-1 Parking lot location of experiments.

Analysis

The analysis of the 5/14/2008 measurement is the focus of this section. The first portion of the experiments uses the equipment and software to establish base lines for the location of the stationary access point and the static errors in location, packet loss.

Stationary Measurements

The measurements of latitude and longitude over a ten minute period are used to establish a mean location for the stationary access point and an expected variation in range estimates from that location. The individual latitude and longitude measurements are transformed into Washington State plane north coordinates using a Lambert Conical projection to provide a Cartesian coordinate system to measure ranges. Once transformed the position of the stationary access point is estimated using the mean values on the assumption that the GPS errors are randomly distributed (x = 1279206, y = 243279). To test this assertion of stationary of the GPS measurements the range of each measurement

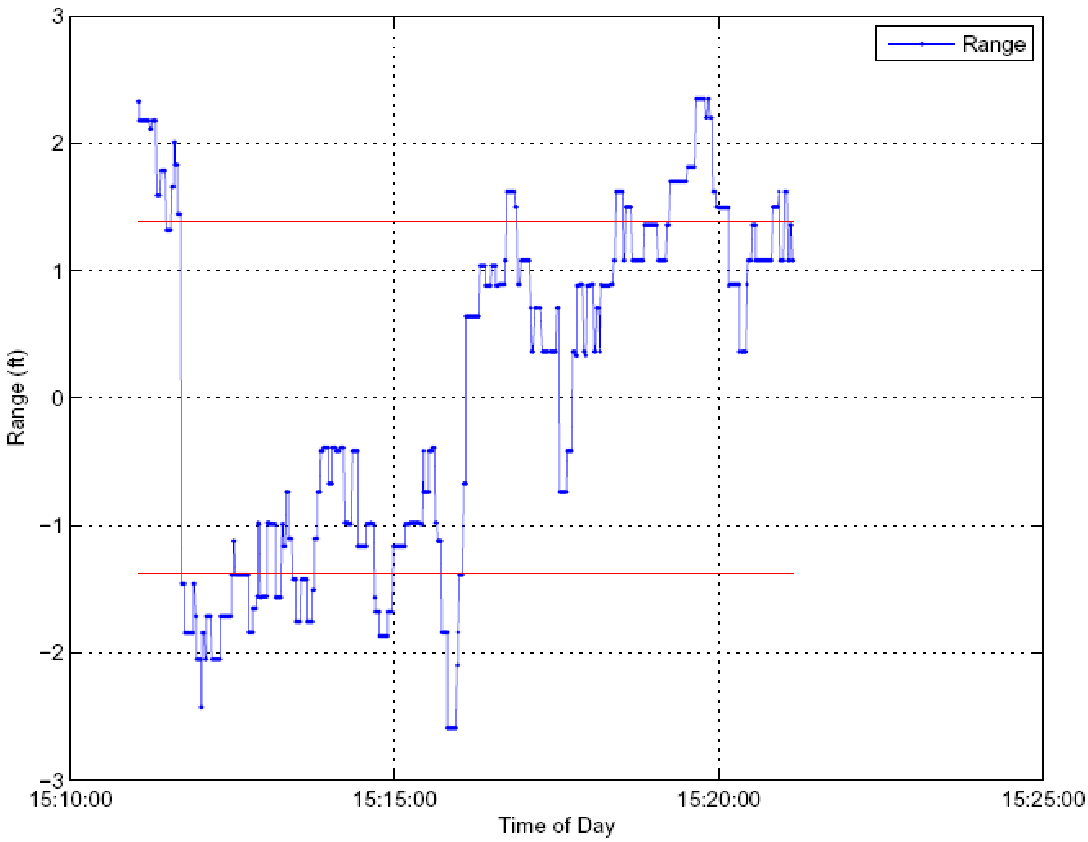


Figure 6 Deviation in range from mean value.

from the mean value for the receiver position is shown in Figure 6. The figure shows that the range errors are on the order of one foot but has a bimodal temporal distribution. The

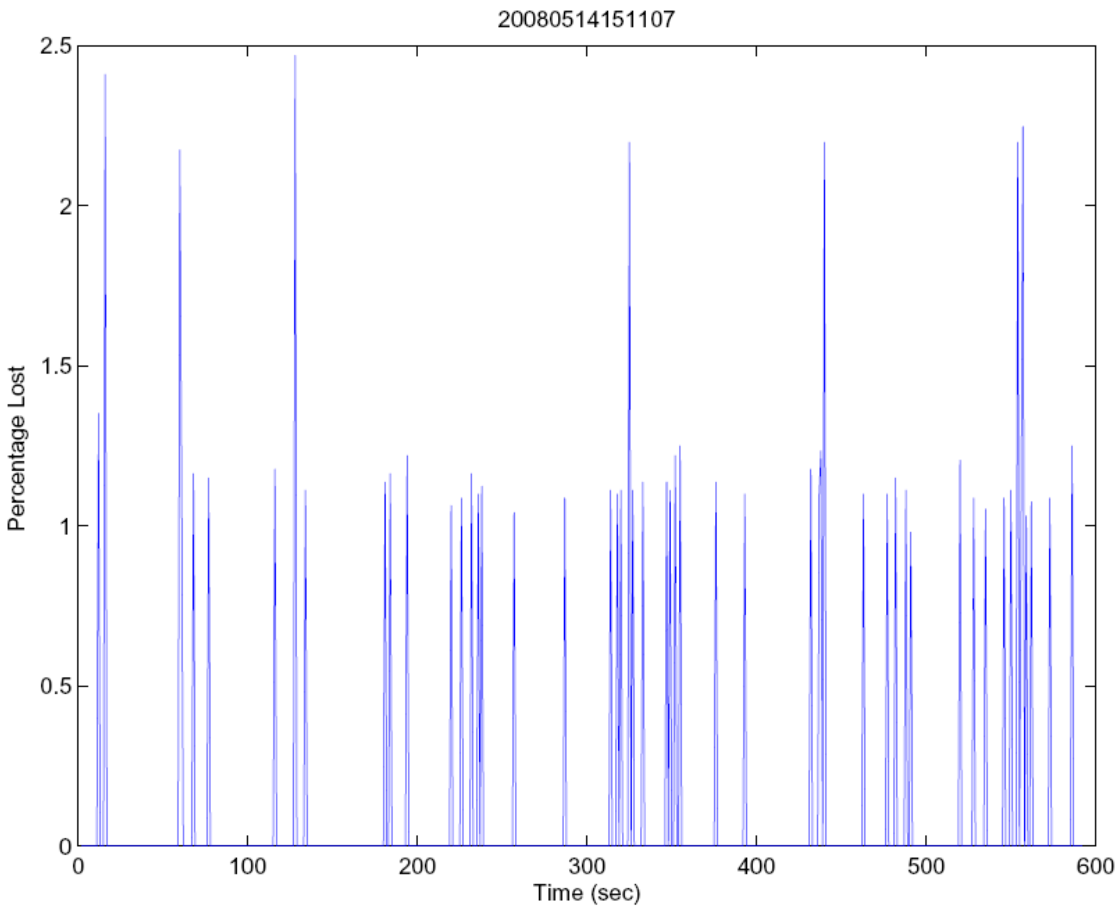


Figure 7 Percentage of lost datagram for the static measurement.

hypothesis for this deviation from a random distribution in time is that the GPS receiver changed the set of four of satellites it was using to estimate position during the measurement period; however, since the deviation, the standard deviation is shown in red in the figure, is on the order of one foot the position is deemed as sufficiently accurate for the work presented here. The percentage of lost data grams for this stationary measurement is shown in Figure 7. A very small packet loss rate is observed for this stationary data.

Dynamic Measurements

The next phase of the experiments created two data sets, one where the driver was instructed to try to maintain 10 MPH and a second where the driver was instructed to maintain 20 MPH. For the purposes of presentation in this manuscript the data sets are referred to a "10MPH" and "20MPH;" however, in reality, the driver cannot maintain the requested speed especially while reversing directions at the terminus of the route.

The position tracks as a function of time are shown in Figure 8. These positions are converted to range measurements using the Euclidean (or L2) norm. For display purposes the zero point for the

Y axis of the range measurement is set to the Y value of the fixed receiver site. The range measurements as a function of time are found in

Figure 9. As the vehicles are traveling different average speeds it is clear that during the same 10 minute duration the 10MPH measurement set covers more cyclic trips in the parking lot.

The vehicles are clearly not traveling at a constant speed throughout the tests and so to examine the effect of speed on the communications process the vehicle instantaneous speed needs to be estimated from the sequence of positions in time. It is noteworthy that the position measurements while appearing smooth on the multi-minute time scale of the previous figures are actually quite variable on a second by second basis, as the measurements are made every second. To make a smooth speed estimate from the position data the frequency content of the time series was considered. To identify the frequency content the magnitude of the amplitude spectrum (the multiple of the time series fast Fourier transform (FFT) and it's complex conjugate) is estimated, and the results are shown in Figure 10. The large peak is as a result of the periodic nature of the drive between the end points in the parking lot. In order to reduce the high frequency component of the position time series the data is filtered at four time the frequency of the large peak in the spectrum. Once this is done in the frequency domain the data is inverse transformed in to the time domain and a simple two point difference is used to estimate the speed as a smooth function of time as shown in Figure 11.

The signal to noise ratio is measured using the Netstumbler software. The signal-to – noise-ratio (SNR) is plotted with the range in FIG. It is noteworthy that the SNR is highest near the stationary station and lower as the distance increases, and this is repeated with each passing of the stationary receiver. Both the 10MPH and 20MPH data have similar features. In pervious work a free space model was used with the cumulative data for all passes to provide a quantitative model for the signal loss as a function of distance.

Initially a two path propagation model was under consideration for this set of measurements. However, after the data was collected and fit with both the single and two path models it was determined that the single path model was a better match to the data. The model for signal strength as a function of range is based on a single path free space propagation model (sometimes called the Friis transmission equation[7, 8])

$$\frac{P_R}{P_T} = G_R G_T \left(\frac{\lambda}{4\pi d} \right)^2$$

where is the power available at the receiving antenna and is the power supplied to the source antenna; is the receiver antenna gain and is the transmitter antenna gain; is the carrier wavelength; is the transmitter-receiver distance.

The vehicle is traveling on the roadway

$$x(t) = x_0 + v(t)t + \frac{1}{2}a(t)t^2$$

where d_0 is along the roadway. The minimum distance between the station and the roadway is d_0 located at . This distance between receiver and transmitter is

$$d(t) = \sqrt{(x(t) - x^{'})^2 + d_0^2}$$

$$R_{ij}(t) = C_{ij}\left(\frac{\lambda}{4\pi\sqrt{(x(t)-x^{'})^2 + d_0^2}}\right)^2$$

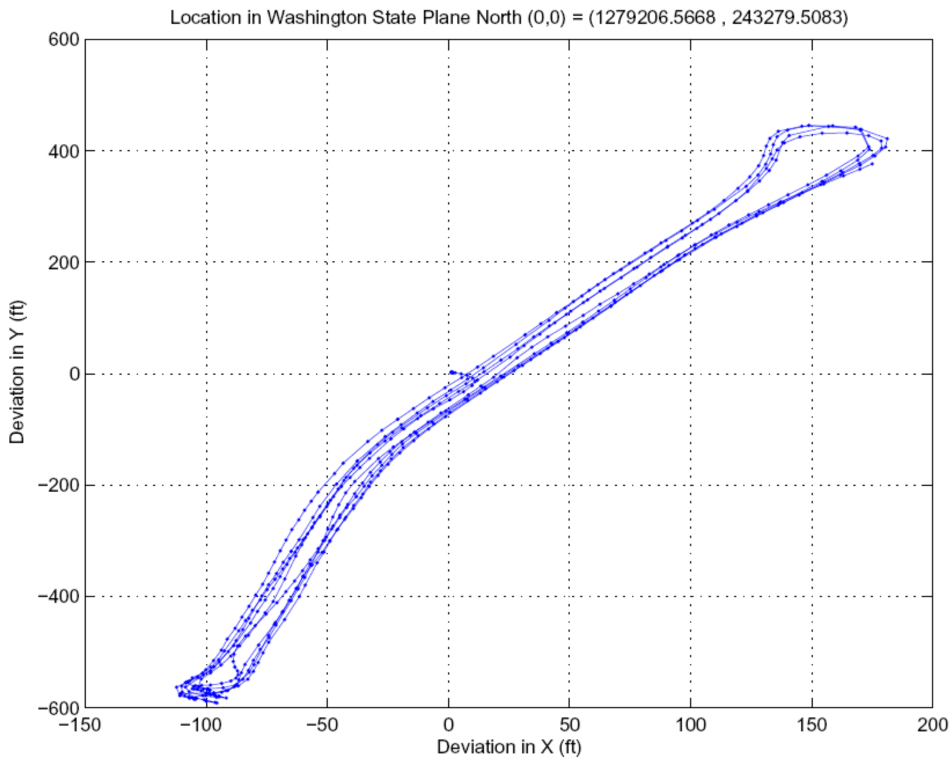
where R_{ij} is the power ratio for the i^{th} station for the j^{th} receiver and $C_i j$ are the combined constants for the i^{th} station for the j^{th} receiver. The fitted model and the range verses SNR are shown in Figure 13.

The bandwidth and packet loss statistics are measured using the Iperf software package. In order to compare the range, speed and SNR with the bandwidth and packet loss rate the measurements need to be aligned in time and placed on the same time base. Both the stationary and mobile units use Network Time Protocol to synchronize the clocks on the computers. Since the Iperf and Netstumbler applications are started by hand, introducing small errors on the order of a second or two, the starting time for these two data sets is aligned by shifting the data in time. The sampling rate for the Netstumbler software is slightly faster that that of Iperf, so linear interpolation is used to align all the data with the Iperf sample times. Once the alignment and interpolation is done the data sets can be compared.

The bandwidth as a function of time and compared to the range measurement can be see in Figure 14 where the 10 MPH data set is at the top and the 20 MPH data set at the bottom. Since the peed is larger in the bottom set the number of repetitions of the vehicle passing the stationary receiver is also larger. The notable aspect of the two figures is that in both figures the bandwidth seems to be reduced as the vehicle approaches the stationary receiver placed at the $Y = 0$ location. The previous signal to noise model development, and past work, might lead one to believe that the high signal to noise ratio near the stationary receiver would provide a good communications channel nearby the stationary antenna, this result indicates that that assumption is not true for these measurements.

Bandwidth as a function of time and compared to estimated speed is shown Figure 15. Once again the decrease in bandwidth is not associated with the slowing taking place when the vehicle reverses direction at a large distance, instead the bandwidth is reduced at higher speed and when the vehicle is nearby the stationary receiver.

The packet loss is represented by the percentage of packets lost in each one second measurement using Iperf. Figure 16 shows the percent packet loss compared to the range estimate. Once again the packet loss seems more correlated with the passing of the stationary receiver than with greater range. Figure 17 shows the percent packet loss compared to the speed estimate. The packet loss is correlated to higher speed and occurs when the vehicle is nearby the stationary receiver.



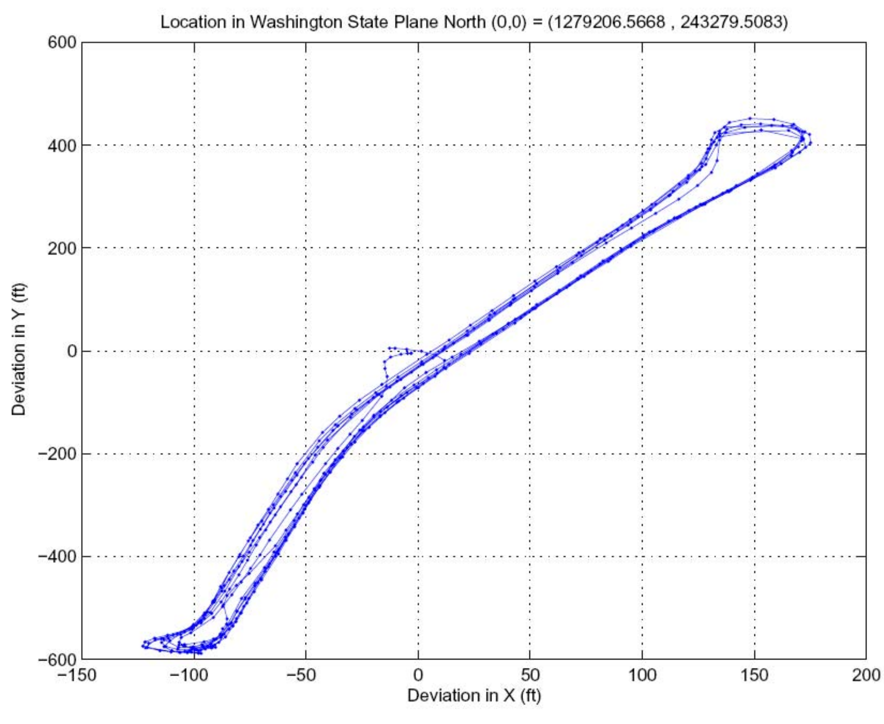


Figure 8 State Plane projection of GPS data from moving vehicle, 10MPH case at top, and 20MPH case at bottom.

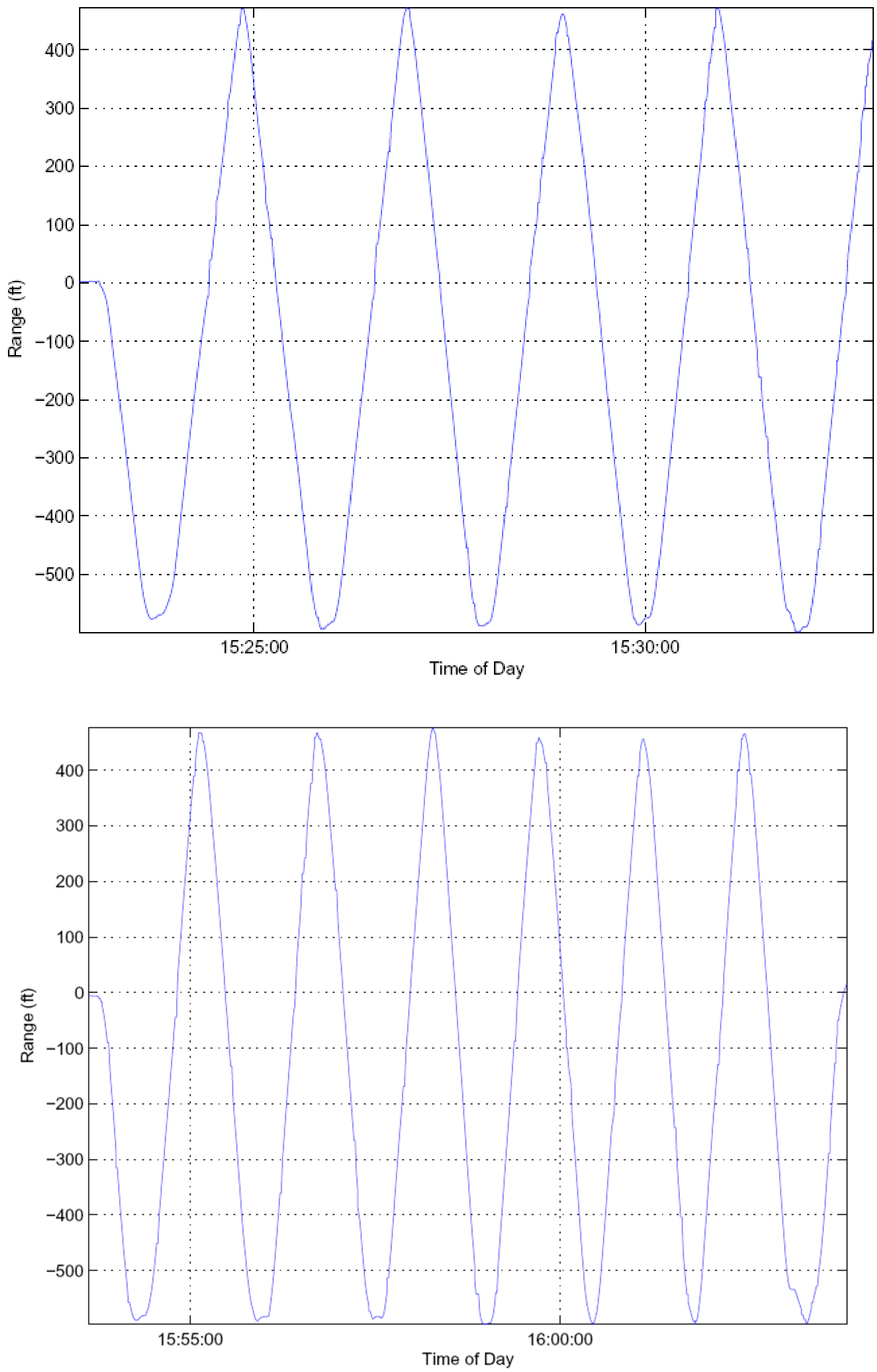


Figure 9 Range estimates for 10MPH at top and 20MPH at bottom.

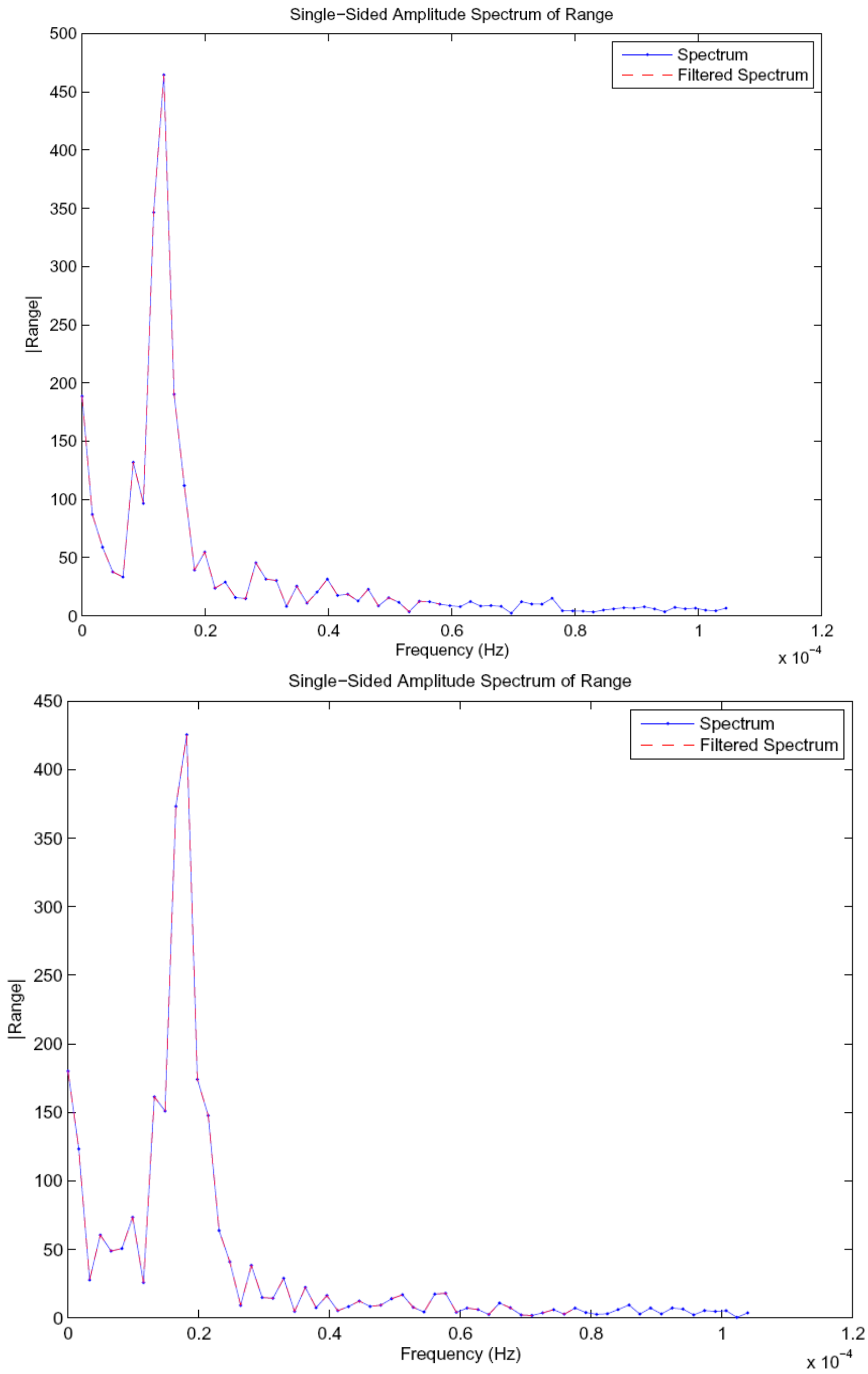


Figure 10 Amplitude Spectrum of Range Variation, 10MPH at top, 20 MPH at bottom.

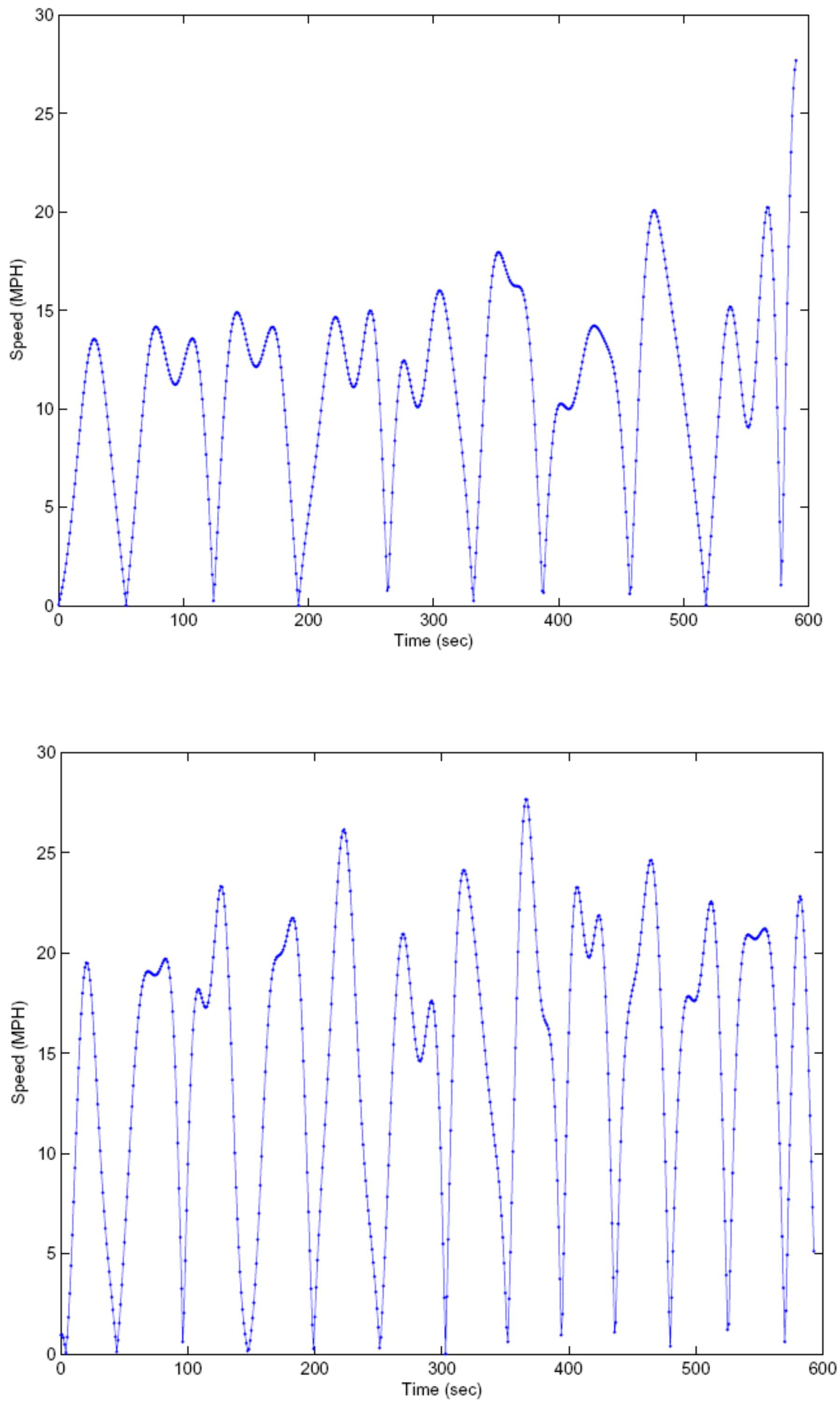


Figure 11 Speed estimate as a function of time, 10MPH top, 20 MPH bottom.

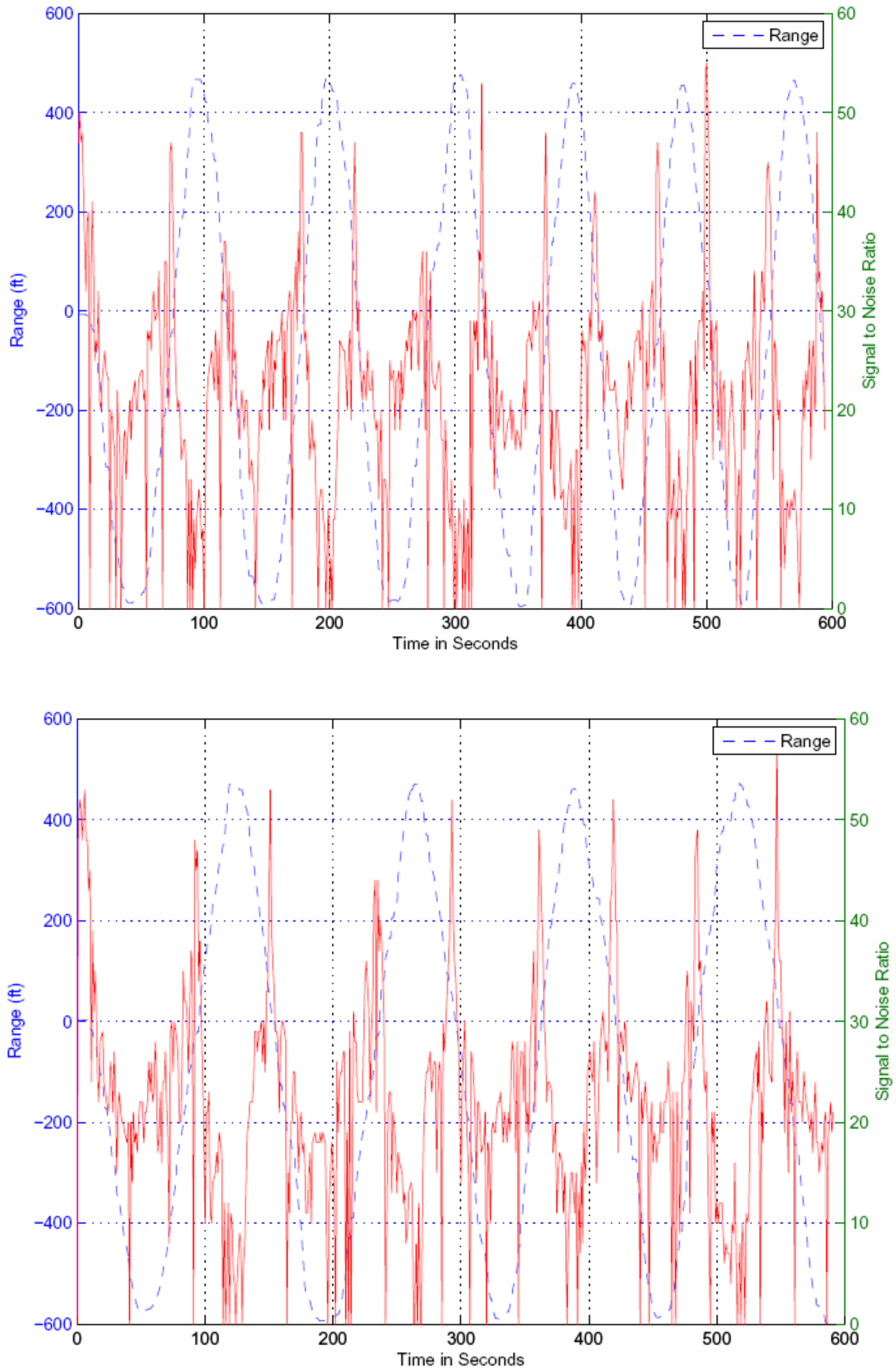


Figure 12 Range in dashed line, SNR in solid line. 10MPH data set at top and 20 MPH at bottom.

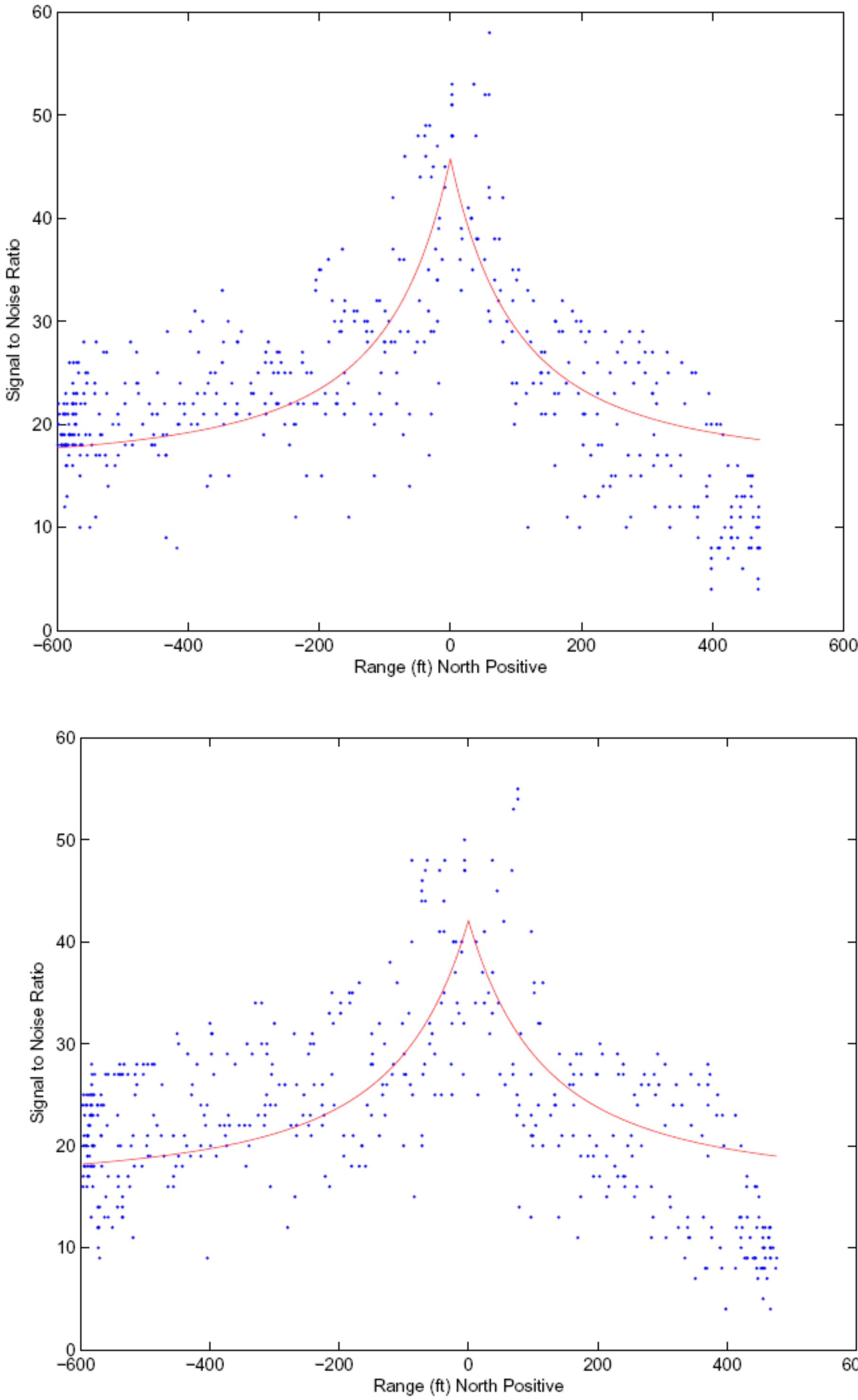


Figure 13 Range vs Signal to Noise Ratio and free space radiation fitted model, solid line. 10MPH data set at top and 20 MPH at bottom.

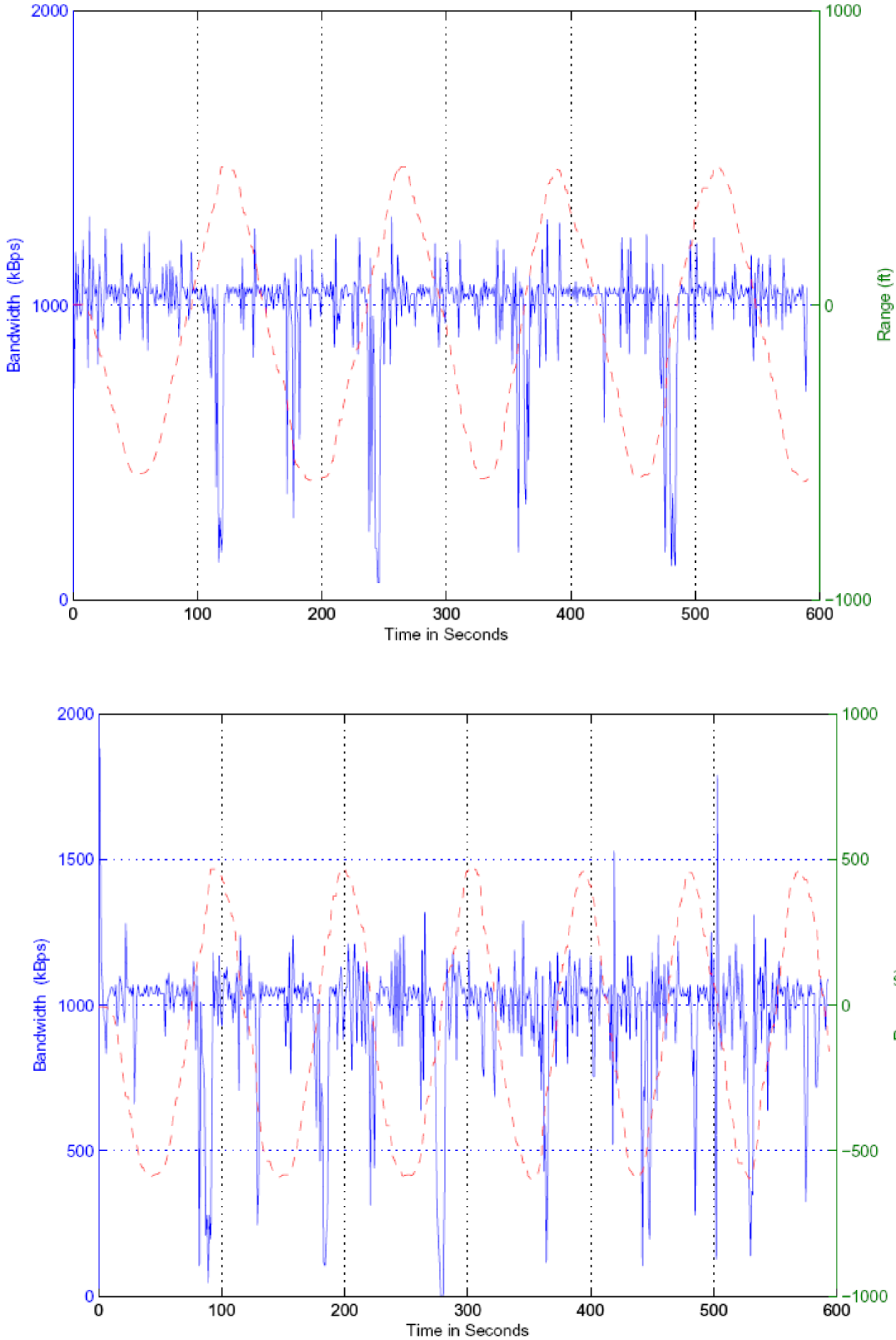


Figure 14 Bandwidth in Kbps and range in feet, dashed line. 10MPH data set at top and 20 MPH at bottom.

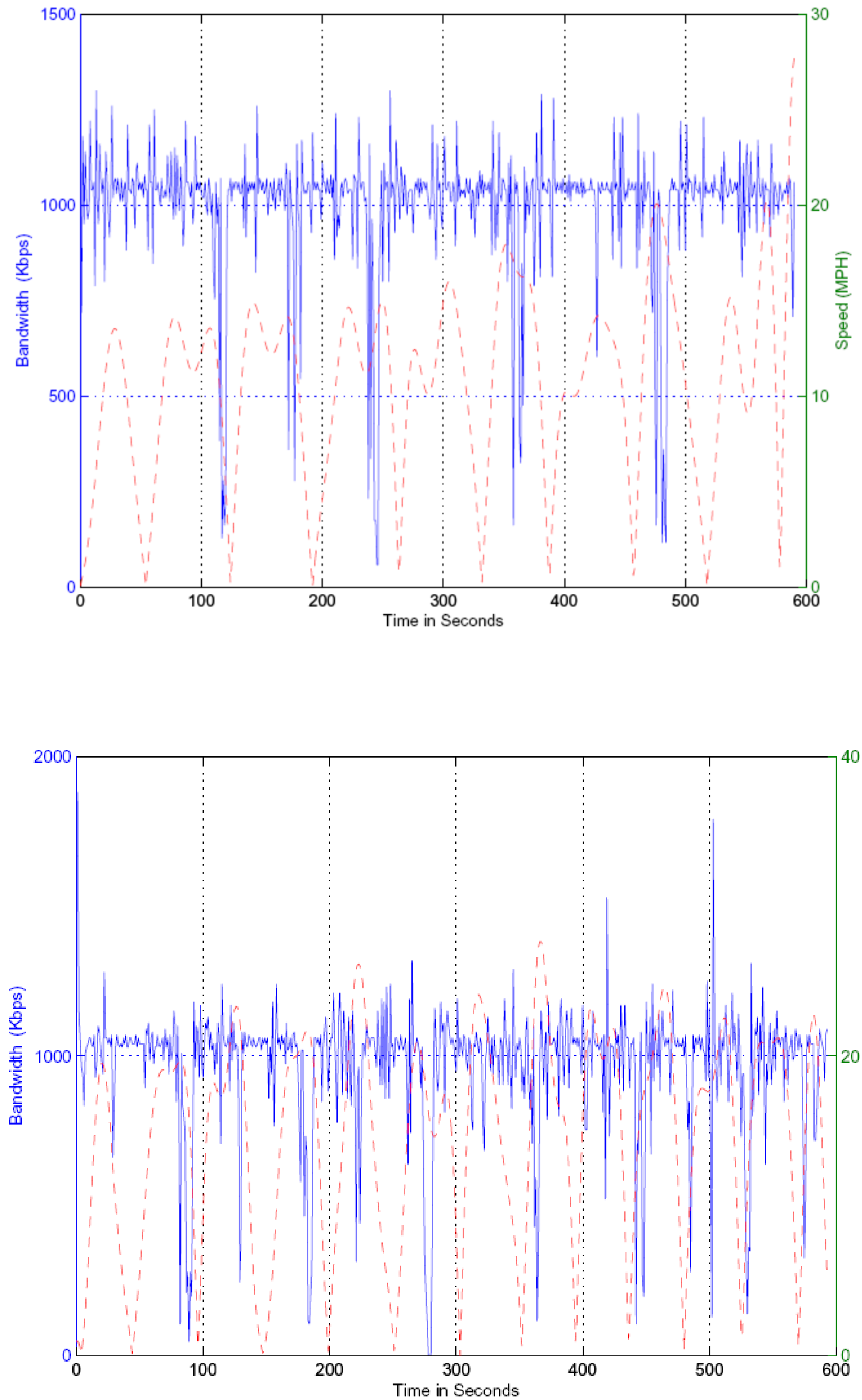


Figure 15 Bandwidth and estimated speed as a function of time., 10MPH data set at top and 20 MPH at bottom.

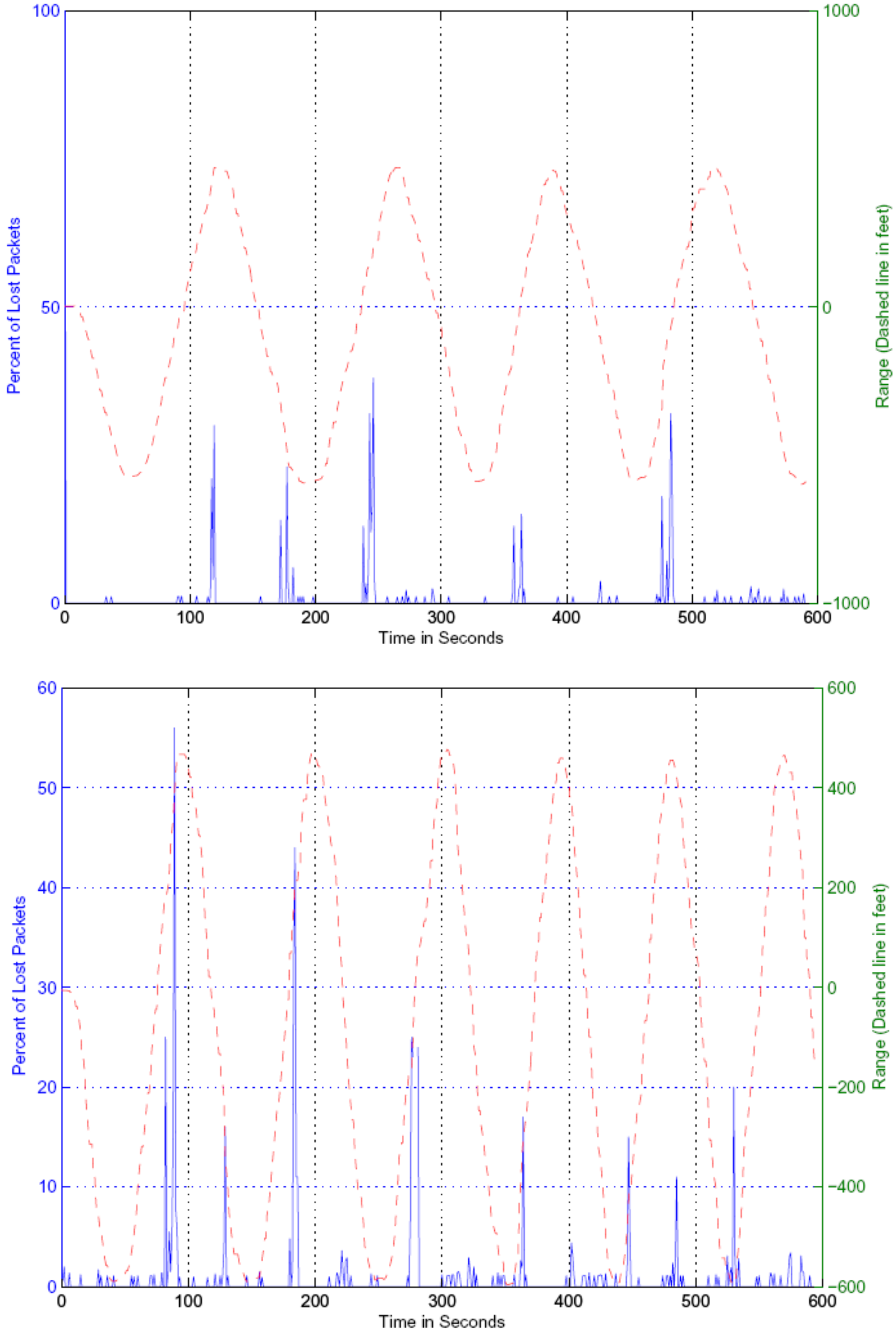


Figure 16 Percentage of lost packets and range (dashed line) in feet, 10MPH at top and 20 MPH at bottom.

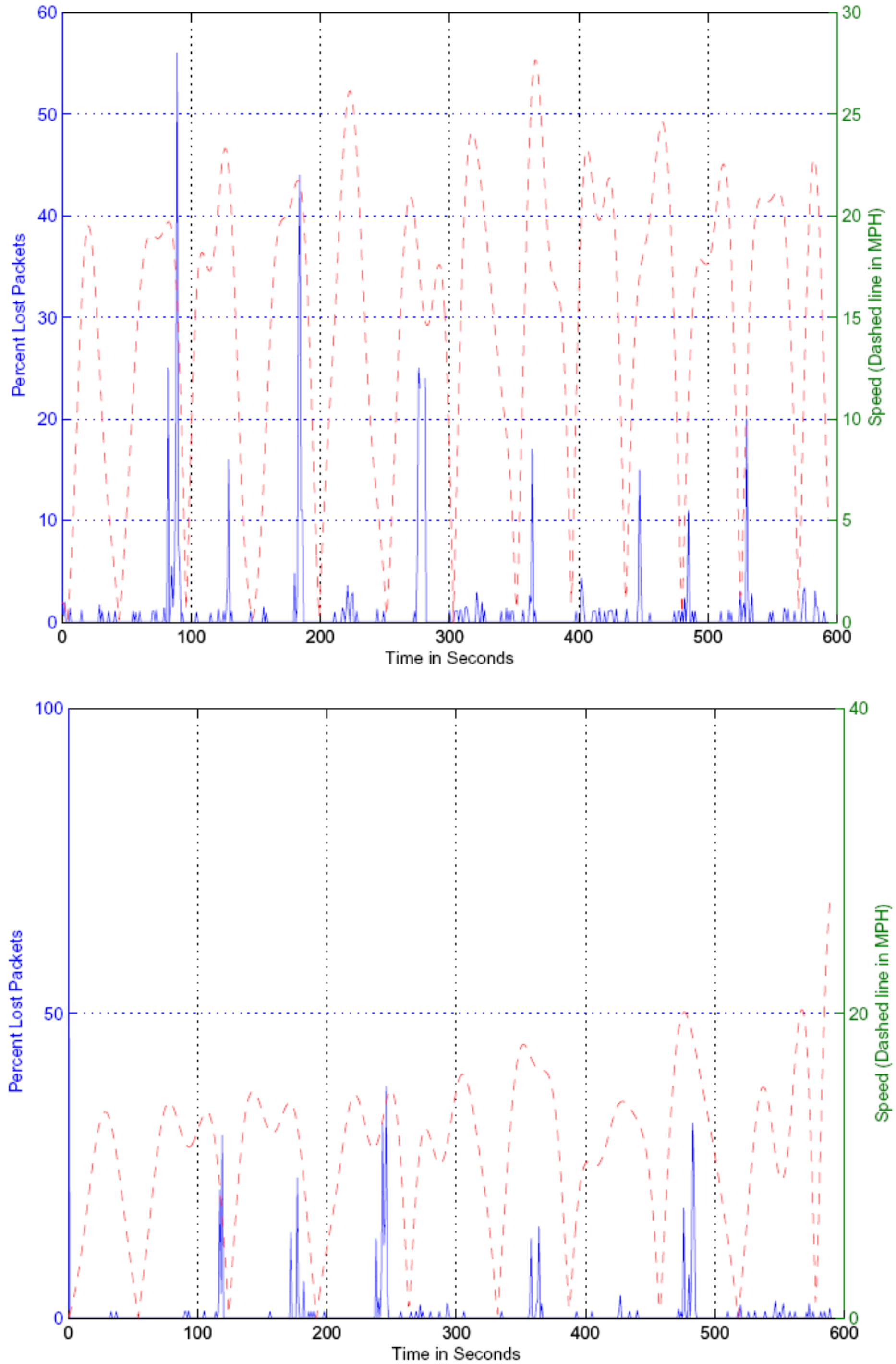


Figure 17 Percentage packet loss and estimated speed (dashed line) as a function of time., 10 MPH at top and 20MPH at bottom.

Conclusions and Recommendations

This project focused on the experimental aspect of short range communication between a moving vehicle and a stationary receiver. The accumulated measurements of signal to noise ratio fit a single line of site model rather well with the implication that the communications channel will function best as the distance between the radios is reduced. However, measurements of both bandwidth and packet loss suggest that when the vehicle passes nearby the stationary receiver at approximately the planned speeds (10 or 20 MPH) that the communication channel throughput is reduced. The present hypothesis for the cause is that the Doppler effect reduces the channel throughput. It is recommended that a representation of the vector velocity as a function of time be compared to the throughput measurements to confirm this hypotheses. Further, this observation of a deviation from a distance based channel model is important in future modeling for inter-vehicle communication as most present models used to combine traffic motion and network throughput do not account for this dominant effect.

Annotated Bibliography

In reference [9] to test 802.11b Mobility, and using NS-2 incorporating Doppler shift to estimate throughput verses speed, throughput verses distance lead to the conclusions: "1 Mbps and 2 Mbps channel data rates may be well suited to use in a high mobile environment, while the 5.5 Mbps and 11 Mbps channel data rates may not be appropriate for this environment."
"The tests were performed using a single AP and a wireless laptop, located in a car driving alongside the tracks. The laptop would gather throughout information as well as GPS location data in order to correlate location, velocity and throughput."

[10] "presents measurement results on two critical aspects encountered in deploying and provisioning PWLANs: (a) typical traffic statistics, and (b) application-level throughput performance. Traffic statistics and coverage/throughput models are studied with data measured from real-world PWLANs in the summer of 2003. The traffic measurement campaign involved over 14,400 minutes of PWLAN traffic and 15,983,748 packets measured at two Schlotzsky's restaurants. The throughput measurement campaign included measurements at 33 locations in and around three Schlotzsky's restaurants, with a total of 792 different throughput and signal-to-noise ratio (SNR) measurements (throughout this paper, SNR denotes the perceived SNR by PWLAN clients)."

[11] "presents a novel cooperative-vehicle-position-estimation algorithm which can achieve a higher accuracy and more reliability than the existing global-positioning-system-based positioning solutions by making use of intervehicle-distance measurements taken by a radio-ranging technique. Our algorithm uses signal-strength based intervehicle-distance measurements, vehicle kinematics, and road maps to estimate the relative positions of vehicles in a cluster."

In [12] the authors "record the strengths of the signals received by a client from multiple access points at different locations in the building. This information is then used to build a system which, given a sample of signal strength information, will determine the location at which the sample was recorded."

In [13] a "computationally efficient yet accurate enough error modeling approach used in our MAC layer simulator" and further concludes "the two ray path loss model is more suitable for LOS cases."

$$P_r = \frac{P_t}{(4\pi)^2\left(\frac{d}{\lambda}\right)^{\gamma}}\left[1+\eta^2+2\eta\cos\left(\frac{4\pi h^2}{d\lambda}\right)\right]$$

“The Ricean distribution can be used for modeling the small-scale fading envelope of the received signal with the Ricean parameter K defining the ratio between the directly received.”

[14] describes a program “GPSIperf “ that “combines measurements of Transmission Control Protocol (TCP) throughput with Global Positioning System (GPS) coordinates to give users a map of wireless bandwidth for outdoor environments where a wireless infrastructure has been deployed.”

[15] uses a LOS two path model to develop “A method to develop a commercial channel emulator model for a doubly selective vehicle-to-vehicle wireless channel is presented.”

[16] describes three sinarios:
Sub-urban: The suburban scenario corresponds to vehicular
speeds limits of around 40 miles per hour and drivingenvironments with a few building structures and roadside tree plantations. The vehicles stop at traffic lights but not frequently.
Urban: The urban scenario has speed limits of 25 miles
per hour amidst roadside building constructions. The traffic scenario is the typical rush hour urban traffic, with vehicles often stopping at traffic lights and in jams.
Freeway: The freeway as a open environment with scarce roadside vegetation and driving speed limit of 65 miles per hour. There can be vehicles traveling between and along the communication test vehicles.

And uses 20, 90 second tests, that include GPS, and UDP Netperf to consider Adhoc routing by measuring, throughput, lost packets, SNR and GPS

[17] uses UDPpackets with netperf to measure throughput, uses GPS for positional information and makes SNR measurements from the network card once per second. The results are presented in averaged form. The framework is that of two vehicles following and crossing.

[18] “presents narrow-band measurements of the mobile vehicle-to-vehicle propagation channel at 5.9 GHz, under realistic suburban driving conditions in Pittsburgh, Pennsylvania. Our system includes Differential Global Positioning system (DGPS) receivers, thereby enabling dynamic measurements of how large-scale path loss, Doppler spectrum, and coherence time depend on vehicle location and separation. A Nakagami distribution is used for describing the fading statistics. The Speed-Separation diagram is introduced as a new tool for analyzing and understanding the vehicle-to-vehicle propagation environment. We show that this diagram can be used to model and predict channel Doppler spread and coherence time using vehicle speed and separation.”

[19] considers the questions:
"i) what is the probability of reception of a broadcast message by another car depending on its distance to the sender, ***ii)*** how to give priority access and an improved reception rate for important warnings, e.g., sent out in an emergency situation, and ***iii)*** how are the above two results affected by signal strength fluctuations caused by radio channel fading?

And asserts
"We quantify via simulation the probability of reception for the two-ray-ground propagation model as well as for the Nakagami distribution in saturated environments. By making use of some IEEE 802.11e EDCA mechanisms for priority access, we do not only quantify how channel access times can be reduced but also demonstrate how improved reception rates can be achieved. Our results show that the mechanisms for priority access are successful under the two-way-ground model. However, with a non-deterministic radio propagation model like Nakagami's distribution the benefit is still obvious but the general level of probability of reception is much smaller compared to two-ray-ground model. The results indicate that -- particularly for safety-critical and sensor network type of applications -- the proper design of repetition or multi-hop retransmission strategies represents an important aspect of future work for robustness and network stability of vehicular ad hoc networks."

In [20] statistical channel models based on BER performance are presented for a frequency- and time-selective vehicle-to-vehicle wireless communications link in an expressway environment in Atlanta, Georgia, where both vehicles traveled in the same direction. The models are developed from measurements taken using the direct sequence spread spectrum (DSSS) technique at 2.45 GHz. A collection of tapped delay line models, referred to as a "partitioned" model in the paper, is developed to attempt to capture the extremes of BER performance of the recorded channel. Overall and partition models are compared to the recorded channel in terms of the BER statistics obtained when the channels are inserted in a dedicated short range radio (DSRC) standard simulation system. The quality of the match between synthesized and recorded channel BER statistics is analyzed with respect to type of modulation (fixed or adaptive), the frame length, and the length of the interval over which the BER was calculated.

[21] captures the current state of the art of 802.11-based multiple access protocols and highlights open research issues.

Reference [22] analyzes the causes of packet loss in a 38-node urban multi-hop 802.11b network. The patterns and causes of loss are important in the design of routing and error correction protocols, as well as in network planning. The paper makes the following observations. The distribution of inter-node loss rates is relatively uniform over the whole range of loss rates; there is no clear threshold separating "in range" and "out of range." Most links have relatively stable loss rates from one second to the next, though a small minority have very bursty losses at that time scale. Signal-to-noise ratio and distance have little predictive value for loss rate. The large number of links with intermediate loss rates is probably due to multi-path fading rather than attenuation or interference.

In [23] it is asserted, “Our measurements have shown that the coverage obtained from a single access point is much larger than expected. providing more than ten seconds connectivity even at speeds of 180 km/h. Using several access points to extend the reach of a connectivity island turns out to be more difficult and requires a larger distance between the access points or different parameterization than would be used for stationary users. We have also seen that the connectivity is - expectedly -poor at the edges of a connectivity island (entry and exit phase). with a negative impact on packet loss and transmission delay. but that over a distance of more than.200 meters network performance is excellent. We have managed to transmit a maximum of 9 Mbytes of data in a single pass through a connectivity island with a single access point which confirms the principal suitability of WLAN for Drive-thru networking.”

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