Using Vision-Based Driver Assistance to Augment Vehicular Ad-Hoc Network Communication

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***Abstract*—Using Vehicular Ad-Hoc Network (VANET) communication for a Cooperative Collision Warning System (CCWS) has been explored and has shown promise in improving vehicle safety. However, the performance of such a system under different adoption rates has not been examined in depth. We first examine what effects varying adoption rates will have on a CCWS protocol with a variable broadcast scheme. We then examine the implementation of a VANET alongside a Vision-Based Driver Assistance (VBDA) system that monitors the environment surrounding the vehicle using cameras. We propose an Enhanced CCWS protocol where information from VBDA is included with CCWS related VANET communication to significantly increase its effectiveness under low adoption rates.**

Vehicular-Ad Hoc Network, Vision-Based Driver Assistance, Cooperative Collision Warning System

I. Introduction

In a Vehicular Ad-Hoc Network (VANET)-based Cooperative Collision Warning System (CCWS) each vehicle periodically shares information about itself, primarily its current location and trajectory, with surrounding vehicles. Through these location updates each vehicle can build a model of neighbouring vehicles in the surrounding environment. The concept of a CCWS has been introduced, studied and validated by a number of researchers [1] [2] [3]. However, these studies typically look at the operation of a CCWS with a 100% adoption rate, or in other words 100% of vehicles are equipped for VANET communication. Unfortunately upon adoption of the Wireless Access in Vehicular Environments (WAVE) set of standards in production vehicles there will be a long gap between the initial introduction and nearing 100% adoption.

In addition to VANET communication a Collision Warning System (CWS) utilizing on-board vehicle sensors is another technology of interest for improving safety. We see it in the form of Adaptive Cruise Control (ACC) and Forward Collision Warning Systems (FCWS), for example the Active Cruise Control system found on BMW vehicles. These types of sensors have been extended for use in autonomous vehicles in the DARPA challenges and for Advanced Driver Assistance Systems (ADAS) in the RoadLab project at the University of Western Ontario [4]. In this paper, we describe the use of a Vision-Based Driver Assistance (VBDA) system, which uses cameras and computer vision algorithms, designed as part of the RoadLab project.

In a vehicle capable of both VANET communication and VBDA the information attained from each technology can be merged into a unified model to increase accuracy. This can be taken one step further and information gained from VBDA can be used to enhance VANET communication. In this paper we assume vehicles are either equipped with both VANET and VBDA technologies or have neither. An Enhanced CCWS (ECCWS) protocol is proposed where equipped vehicles append information attained about unequipped vehicles to CCWS location updates. This allows a more complete model of the environment to be built even under low adoption rates.

This paper describes research that has explored the potential for such a system. In a simulation environment both VANET and VBDA technologies are tested alongside one another. Under varying adoption rates between 10% and 100% a CCWS and an ECCWS protocol are tested. The effect of varying adoption rates and the potential for improvement with an ECCWS protocol are examined. To study this we have created a robust simulation environment for realistic vehicular traffic, wireless network communication and computer vision. Multiple open source projects are combined with custom modules to achieve this.

The remainder of the paper is structured as follows. In Section II, we present related work that this research was based on. In Section III, the unified model built from both sources is explained. Following in Section IV, we explain the specifics of the ECCWS protocol. In Section V, we explain the simulation environment. Then, in Section VI, we examine the results of our simulations. Finally, in Section VII, are concluding remarks and future directions for this research.

II. Related Work

The feasibility of a CCWS is analyzed by H. Tan and J. Huang where they examine the technologies necessary to implement such a system effectively [1]. They find implementing a CCWS based on current technologies is feasible and proceed to test out a theoretical CCWS system using two vehicles to produce promising real world results.

Expanding on this work, the frequency of location update broadcasts is examined further by S. Rezaei et al. [2]. In their paper they examine a number of different broadcast schemes under simulation. One such broadcast scheme is periodic communication intervals where location updates are generated on a set interval, from 25ms to 500ms. A second broadcast scheme is variable communication intervals where an error threshold between actual vehicle location and the estimated vehicle location, based on the last location update, must be exceeded before a new location update is broadcast. The paper also introduces a model for Differential Global Position System (DGPS) error which we use in our simulations.

The best broadcast scheme is found to be a variable communication interval with repetition within 50ms. A similar broadcast scheme is again selected by C. Huang et al. for further testing [3]. Our simulations confirm that this is an excellent broadcast scheme for CCWS communication and as such our CCWS protocol is based on it.

The VBDA system is based on the RoadLab project[4]. Vehicles are instrumented with 10 cameras arranged in stereo pairs monitoring the world surrounding the vehicle. To improve vision performance looking forwards there are two pairs of cameras monitoring that direction. The layout of the cameras and range they provide useful information for is shown in Figure 1. The images provided by these cameras are analyzed in real time to identify vehicles and objects surrounding the instrumented vehicle at a rate of 30Hz or higher. The results produced for each object identified include a distance to the object and 2D bounding box drawn over the object in 3D space.

Information from both VANET communication and VBDA is integrated into a unified model [5]. While RoadLab relies on VBDA the results from a RADAR or LIDAR based driver assistance system could be used instead as all three are fundamentally based on line of sight.

Finally, our simulation environment is based on work done by C. Sommer et al. in linking the discrete event simulator OMNeT++ and traffic simulator Simulation of Urban Mobility (SUMO) [6]. Both simulators are linked together for realistic wireless network and node mobility simulation.

III. Unified Model

In order to use information from both VANET communication and VBDA, we first create a unified model. We will often have location estimates for neighbouring vehicles from both sources with varying amounts of error. These position estimates should be linked when they are both in reference to the same vehicle.

Through the CCWS, location estimates consist of vehicle position, heading and size. This provides us with a good

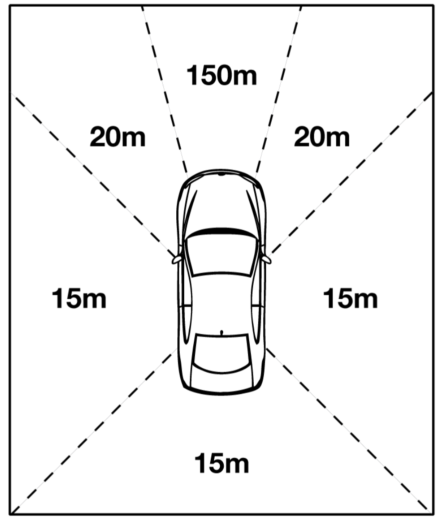

Figure 1. Range and layout of RoadLab cameras

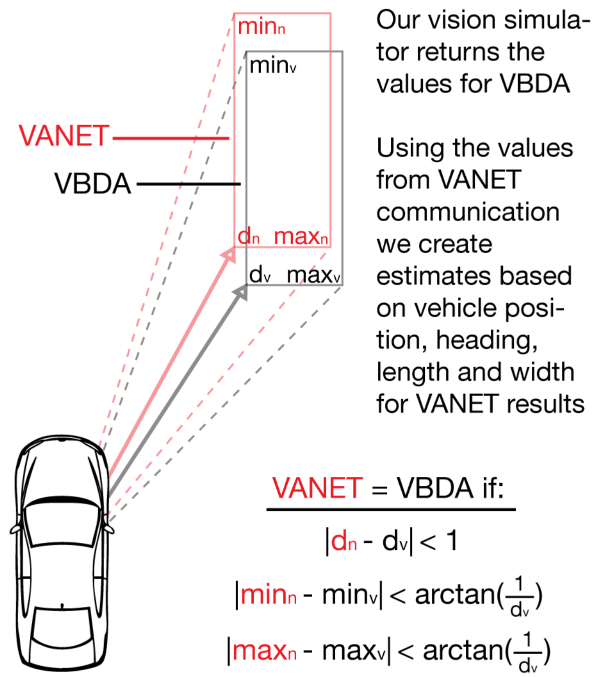

Figure 2. Unified model demonstrated

estimate of the space occupied by the vehicle however the actual vehicle location may be inaccurate due to communication errors. Through VBDA we only receive a distance to the vehicle along with a 2D bounding box. This does not provide us with the physical space occupied by the vehicle however the information we attain should be very accurate

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due to the frequency of VBDA updates. In our simulations we assume no measurable error in VBDA results.

In order to combine the two estimates we take the information attained from our CCWS and draw a 2D bounding box where we believe the vehicle is and calculate the distance to the vehicle. We compare this result for each CCWS estimate with each of our VBDA results in order to determine which VANET estimates and VBDA results are closely matched. The simulations we will describe in Section V are performed in 2D so instead of calculating a 2D bounding box in 3D space we calculate the minimum and maximum angle the object would occupy in the cameras' field of view as described in Figure 2.

For each potential match of a VBDA result and VANET estimate we compare the distance to both. A maximum difference in distance of 1m is allowed for a match to be made. If less than 1m of difference in distance exists we compare both angles. A difference in angle equivalent to a maximum of 1m at the distance the vehicle is away from us or $\arctan(\frac{1}{d})$ is allowed. This is to ensure the difference in angle scales along with distance to the vehicle.

If more than one vehicle exists that matches these parameters the one with smallest combined difference in distance and angles is chosen as a match. We record all matches along with the number of errors made. We also record any vehicles that go unmatched but could potentially be matched.

IV. ECCWS

Our regular CCWS protocol involves broadcasting the vehicle location, trajectory, current time and information on the vehicle, such as vehicle dimensions, with a variable communication interval. The variable communication interval works as follows. When a location update packet is broadcast the vehicle position and trajectory are saved. Every 10ms the difference between the current vehicle position, from DGPS, and the estimated vehicle location, based on the last vehicle position update, are compared. If the error between the actual vehicle location and estimated vehicle location is greater than our error threshold of 0.5m then a new location update packet is broadcast. In addition we repeat each broadcast a second time within 50ms. These location updates allow other vehicles to estimate the space our vehicle is currently occupying along with where it will be in the next few seconds. The CCWS protocol only broadcasts information for the vehicle itself.

Our ECCWS protocol appends information to each location update for unequipped nearby vehicles. Since a large portion of our CCWS packets are made up of physical, MAC and network layer headers along with message security features, adding information on nearby vehicles will be more efficient than broadcasting additional packets.

If we have identified a vehicle using VBDA and have not received any VANET communication from it, based on our unified model identifying the vehicle, we will mark the vehicle as being unequipped. We will append the information of up to the four closest unequipped vehicles to our own location updates. By doing this we share information that vehicles outside of visual range could not possibly receive with VBDA alone and give them a more complete picture of the environment.

The size of our CCWS application layers packets is 242 bytes including a 54 byte signature and 128 byte certificate [7]. For each appended vehicle the packet size is increased by 40 bytes to include all relevant information. If extra information for four other vehicles is included, the application layer packet increases in size by only 66% providing us with an efficient way to increase the amount of information shared between vehicles. For our ECCWS protocol location updates are broadcast at the same time as the regular CCWS protocol, only the extra information is appended and the packet size is increased accordingly.

V. Simulation

Using our simulation environment we test both the CCWS and ECCWS protocols. Network simulation is done using OMNeT++ using the MiXiM framework. Our CCWS application layer is implemented as a custom module. The WAVE Short Message Protocol (WSMP) is implemented for the network layer. An existing 802.11b MAC layer is adapted with appropriate timing parameters for 802.11p. Finally, a Packet Error Rate (PER) model developed by S. Cocorada for Orthogonal Frequency Division Multiplexing (OFDM) broadcasts is used to decide if incoming packets are accepted or rejected [8].

We transmit our messages with a bitrate of 6Mbps and transmission power of 35.4dBm on IEEE 802.11p channel 178 or the Control Channel (CCH). We model path loss with a path loss coefficient of 3.0 and shadowing with a mean signal attenuation of 0dB and standard deviation of 4dB [9].

The Vehicles in Network Simulation (VEINS) project is used to link OMNeT++ with SUMO. This controls node movement inside a provided road network. We test our CCWS and ECCWS protocols on three different road networks, a Manhattan grid type network with roads running in a grid pattern, a city network based on downtown London, Canada and a highway network based on Highway 401, Canada.

Finally, our vision simulation is implemented as a custom module in OMNeT++. Each vehicle is modeled as a 2D rectangle. Every 100ms we update our vision algorithm and for each vehicle create a list of visible neighbouring vehicles. We determine if a vehicle is visible by calculating what percentage of it is occluded. If less than 50% of the vehicle is occluded it is determined to be visible. It is assumed that we cannot see through any vehicles and anything behind them is occluded.

The simulations are each 120 seconds in length and statistics are recorded throughout the entire simulation runtime.

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The average number of vehicles in the Manhattan grid, London and highway road networks is approximately 640, 720 and 1100 vehicles respectively. The adoption rates of 10%, 25%, 50%, 75%, 90% and 100% are tested on each road network once with our regular CCWS protocol and once with our ECCWS protocol. The results are recorded and analyzed afterwards.

VI. RESULTS

We execute our simulation once for all three road networks, under six different adoption levels with both CCWS schemes for a total of 36 executions. Every 100ms during the simulation we record statistics for each vehicle on VBDA, VANET communication and the unified model. Additionally, for each CCWS position estimate we record the error between the estimated position and the actual vehicle position. Finally, we record statistics on packets sent, received and error rates. For each statistic collected the mean and standard deviations are calculated both on a per vehicle and overall basis.

Our unified model, despite being quite simplistic, performs well. There are two types of unified model errors. First, matches-missed, which is a vehicle tracked by both CCWS and VBDA but incorrectly assumed to be two separate vehicles. Second, match-errors, which are matches made between two separate vehicles, one tracked by CCWS and and one tracked by VBDA, that are incorrectly assumed to be the same vehicle. In general both matches-missed and match-errors are below 0.5% of all possible matches or all matches made respectively. In the highway road network, matches-missed is slightly higher at approximately 1%. With the higher speeds present on a highway compared to city driving there is the potential for a larger error between actual vehicle location and estimate vehicle location. This would explain the higher matches-missed on the highway network. Using our unified model we implement a ECCWS.

From Figure 3, we can see the number of vehicles tracked by the CCWS and VBDA in our unified model increases in a linear fashion as the adoption rate rises. This is expected since the number of vehicles within communication range will increase linearly. The number of vehicles tracked by the ECCWS and VBDA is very promising though. This initially increases quite rapidly until we reach approximately 50% adoption. At this point the number of vehicles tracked is approximately the same as the number tracked at 100% adoption. The result levels off and is stable from 50% to 100%.

This result shows that by 50% adoption our ECCWS protocol can track essentially all vehicles that the CCWS protocol would be able to at 100% adoption. Additionally, by 25% adoption, the ECCWS protocol can track the same number of vehicles as the CCWS protocol at 75% adoption. This presents a strong case for an ECCWS in extending the reach of VANET communication during its initial stages.

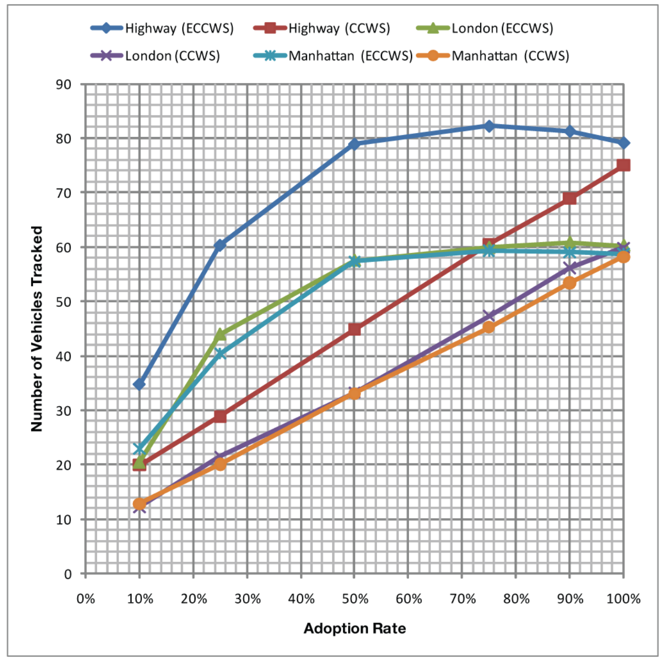

Figure 3. Number of vehicles tracked at various adoption rates

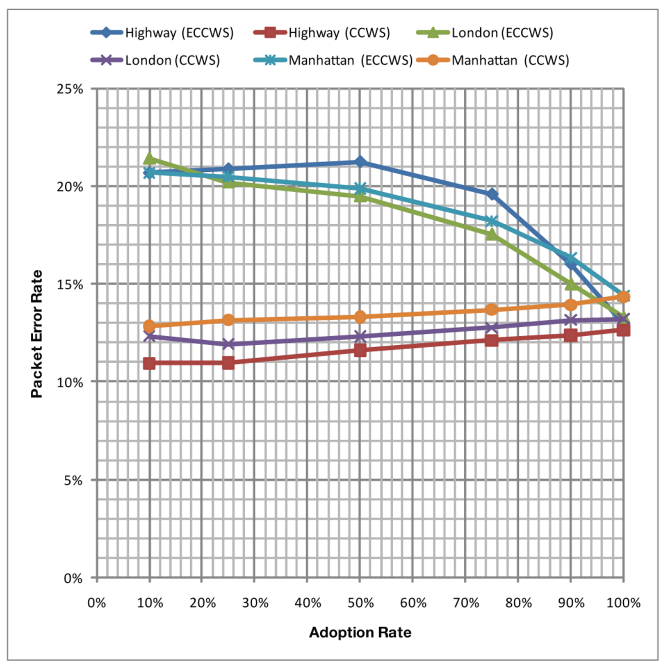

Figure 4. PER at various adoption rates

Furthermore, we can look at the PER for these simulations under different conditions in Figure 4. As expected the PER for the CCWS increases slightly as adoption rate increases. This is the result of increased number of transmissions and related interference causing lost packets. The packet error

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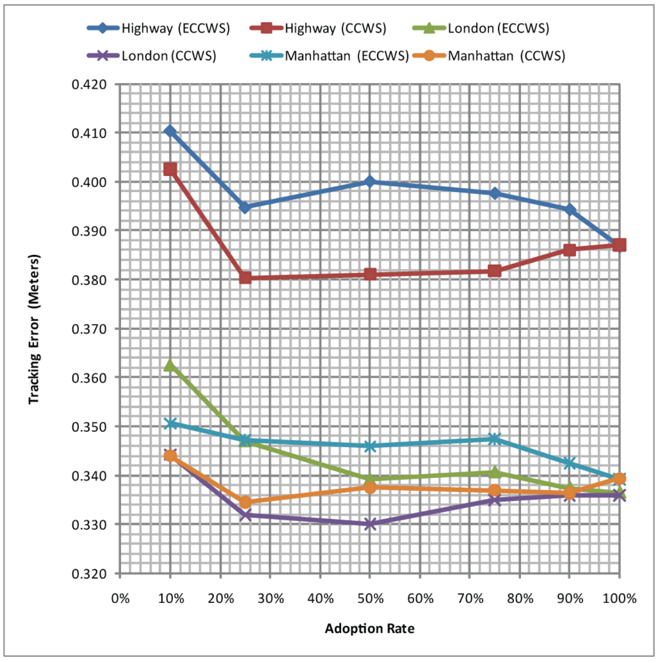

Figure 5. VANET CCWS tracking error at various adoption rates

rate for the ECCWS is higher for low adoption rates and levels off under 100% adoption at approximately equal to the CCWS protocol. Since under lower adoption rates we have larger packets, leading to more bit errors and therefore more packet errors, this result is to be expected. The PER for both protocols at 100% adoption converges as there are few vehicles visible but not tracked by our CCWSS. Therefore no additional information is appended to our location updates and the packet size remains unchanged between CCWS and ECCWS protocols.

However, PER does not necessarily give us an indication of CCWS performance. We calculate the mean tracking error for each system for each simulation in Figure 5. Under low adoption rates, the ECCWS does have a slightly higher mean tracking error than the CCWS, however it only 2-3cm higher at most. This difference is smaller than the mean DGPS error [2] and well under the 0.5m accuracy requirement for accurate position of a vehicle within a lane [1]. Despite the increase in PER the ECCWS performs well under all adoption rates tested.

VII. Conclusion and Future Works

Overall, these results show that an ECCWS protocol with additional information from VBDA shows great potential for improving system performance under low adoption rates. Of course, VBDA or any similar sensor based driver assistance system also presents additional benefits in terms of accuracy, latency and security under all adoption rates. As such, the implementation of both VBDA and VANET communication together and the use of an ECCWS protocol shows great potential.

In future work we plan to improve the simulation environment by extending it into 3D space and adding obstruction information for vision and radio shadowing. Furthermore, by examining how to use our unified model to improve vehicle safety and what information is necessary we can better quantify the benefits of an ECCWS.

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