Analyzing the Impact of a lossy communication link on various position estimation techniques for Crash Warning Algorithm

Rajib Dey
Department of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida, USA
rajib@cs.ucf.edu

***Abstract*—With the increase of Internet usage in Vehicles and recent rapid developments in the field of Semi-Autonomous/Autonomous vehicles have brought in some ground breaking changes in the Transportation System. Vehicles are now capable of creating a communication medium between themselves to form Cooperative vehicular communication system of many kinds which provides better traffic safety and management. These systems heavily rely on a stable communication network which should provide dynamic connectivity between vehicles to vehicles (V2V) or between vehicles to infrastructure units (V2I). In a cooperative vehicle safety (CVS) system, vehicles broadcast data packets that contain their speed, acceleration, position etc over a shared wireless network. This allows other vehicles on the road to track them with precision and predict a possible crash in future. In this paper, three different vehicle tracking (position estimation) techniques have been implemented. These methods have been analyzed side by side in the face of increasing Packet Error Rate ranging from 0% to 90% for three different Rate of Transmission.**

***Index Terms* – Packet Error, Cyber-Physical system, Vehicle safety, V2V, Collision detection, Kalman Filter, Cooperative collision avoidance.**

I. Introduction

Self-Driving vehicle technologies are going through a major overhaul in recent few years. Recent developments in sensing technologies and use of the Internet for many vehicle operations are making vehicles more intelligent than their predecessors ever were. They can interact with other vehicles, the traffic system and what not. Among many other things, these systems heavily rely on robust communication facility without which the vehicles can not create a complete map of all the vehicles around them. This handicap prevents the vehicles from taking a proper decision, which can easily create dangerous situations. Real-time communication between vehicles over dedicated short range communication (DSRC) channels can prevent that. A Vehicular Ad-Hoc Network (VANET) whose primary function is Broadcasting messages is used for providing communication between neighboring vehicles and between vehicles and neighboring infrastructure. For different environments and operating conditions for V2V and V2I communications, the IEEE 802.11p communications technology has been tested in [1]. On top of that, to improve road safety, A Vehicular Collision Warning Communication (VCWC) protocol was designed and implemented [3].

It is evident that a robust communication system is of paramount importance to facilitate a proper environment for these self-driving vehicles to prosper. In real-world scenario, achieving such communication system that can guarantee near 0% Packet Error Rate is next to impossible. To counter this fact, we need to design the whole self-driving vehicle system in such a way that it should be capable of handling high Packet Error Rate (PER) by the use of estimator models which should be able to predict the data that was lost in transmission with a safe accuracy rate [2]. In V2V network, One of the primary components that need to be monitored rigorously is Packet Error Ratio (PER) [1]. The PER is the probability that a packet reaches unsuccessfully from one vehicle to another.

In this paper, we will present an analysis of a Crash warning Algorithm named CAMP Linear crash warning algorithm using different position estimation techniques. The CAMP linear crash warning algorithm along with the position estimation techniques have been implemented and their performances are analyzed while changing the PER from 0% to 90% to see how well these different position estimation techniques perform with the change in packet losses.

The paper is arranged in the following format - System description, System Implementation, Performance evaluation and Conclusion.

II. System Description

Consider a scenario where there are two vehicles moving along a single lane of a road. The vehicle in front is called the Leading Vehicle(LV) and the car behind that is called the Following vehicle (FV). If suddenly LV slows down or stops then the Forward Collision Warning (FCW) system should be able to generate an alert for the FV as shown in Figure 1.

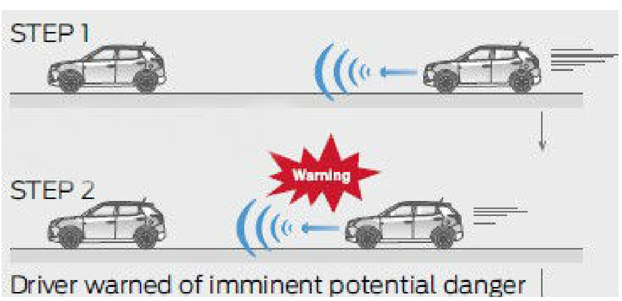

Fig. 1. Forward Collision Warning [5]

The overall communication model that is used in this paper is shown in Figure 2.

The data from the lead vehicle, XLV is broadcasted over the network with a particular rate R. The network has a Packet Error Rate (PER). So, XLV will have some lost packets (XLV with loss), which is now sent to an Estimator to recover the lost packets by estimating it. The estimator might follow different estimator technique to improve its performance. The following vehicle receives the data from the estimator. We put this data in the

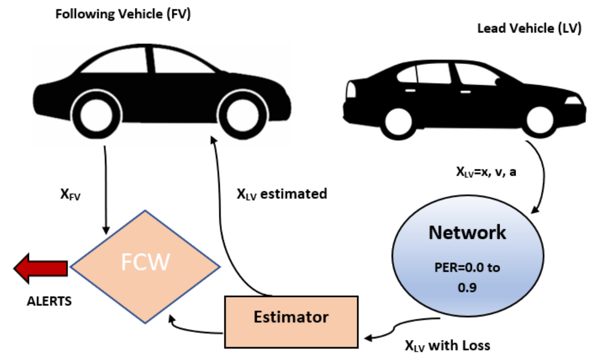

Fig. 2. Overall Communication Model

FCW and compare it with the data of the following vehicle. Various algorithms such as CAMPLinear, neural net based algorithms, SVM etc can be used by The forward collision warning system (FCW) to create the warning range and generate the alerts. The filter used in the estimator to estimate the data lost is very important for the generation of alerts by the FCW. Here, we used the CAMPLinear algorithm for the warning range and generating alerts for the FCW. This paper implements 3 different filtering techniques and analyzes their performance over a lossy network. They are:

1) Constant Speed Model
2) Constant Acceleration Model and
3) Kalman Filter Model

For the constant speed model, we assume that the speed of the vehicle remains the same as the last received packet. On the other hand, for the constant acceleration model, we assume that the acceleration of the vehicle remains the same as the last received packet. For the Kalman filter model, we constantly estimate and update the data iteratively. The Kalman filter is described briefly later in this paper.

A. *CAMPLinear Algorithm*

In this paper, the forward collision warning system is implemented using the CAMPLinear Algorithm. We are provided with a dataset that contains some near-crash situations and we used it to design the algorithm. The algorithm is designed in such a way that a warning is generated only if it is absolutely necessary. The algorithm updates the warning range continuously as the speed, acceleration and position changes between two vehicles. A warning is generated when the distance between FV and LV becomes less than the warning range. How we can come up with this warning range is discussed in literature [4].

B. Kalman Filter

Kalman filter is also known as linear quadratic estimation (LQE). A series of measurements which can also contain noise and various types of errors (in our case it is the Packet loss over a communication link) is used in this algorithm. Kalman Filter produces estimates of unknown variables that are more accurate most of the time than those estimates which were generated using a single measurement. This algorithm works in 2 steps:

1) Prediction
2) Correction

In the prediction step, it produces estimates for the state. In the correction step, the estimation is checked with the measurements from the observation model and is corrected using a weighted average. For this correction, more weight is given to the estimates with higher certainty. This helps to minimize the error covariance of the process. This recursive process is shown in Figure 3.

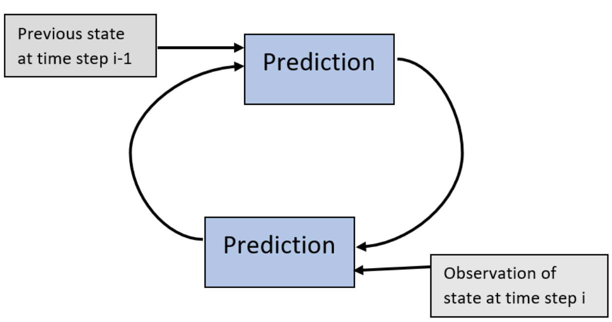

Fig. 3. The Kalman Filter Model

III. System Implementation

We were provided with the data of 100 vehicles from the Virginia Tech database. Using that, the whole system is implemented in MATLAB and the result is analyzed later using excel sheet. The trajectories for FV and LV is simulated. The given data has trajectories of 800+ scenarios which includes some near crash scenario. Here in this project, we have the data for the Lead Vehicle(LV), which consists of speed vLV, position xLV and acceleration aLV. Data for the following vehicle(FV), xFV, aFV and vFV is simulated. For a particular scenario, we hard-coded the Rate of transmission and Packet Error Rate (PER). For each varying Rate and PER, we calculated and compared the accuracy of each position estimation techniques.

Three different position estimation techniques mentioned in II have been implemented with proper warning range so that the alerts are generated when expected. By training the dataset, the ground truth has been established.

IV. Performance Evaluation

Using MATLAB we generated Mean accuracy (compared to the original value that we assumed are lost) for each position estimation techniques for varying Rate of transmission and PER. Then using Microsoft Excel we plotted the PER VS Mean accuracy graph for all the position estimation techniques for different Rate of transmission.

We changed the Packet Error Rate (PER) from 0% to 90% with an increase of 10% per step. For each Position Estimation Techniques we calculated the Mean Accuracy for Each of the 100 vehicle data, then we calculated the Average Mean Accuracy from all of those mean accuracies. This calculation follows the following simple mathematical process:

$$TotalMeanAccuracy = \sum_{n=1}^{100} MeanAccuracy$$

Then simply,

$$AverageMeanAccuracy = \frac{TotalMeanAccuracy}{100}$$

This process is repeated for all position estimation technique for varying PER (0% to 90%) and for varying Rate of Transmission (2Hz, 5Hz and 10 Hz).

Figure 4 shows the Mean Accuracy data for varying PER values for all three position estimation techniques where Rate of Transmission is fixed at

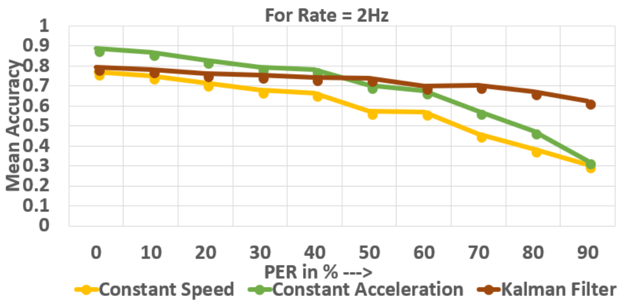

Fig. 4.

2Hz. We can tell that for low PER the constant acceleration model works the best. But with increasing PER, its efficiency goes down. While with increasing PER, the efficiency of Kalman Filter does not change that much. Here constant speed model has the lowest efficiency for all the PER values.

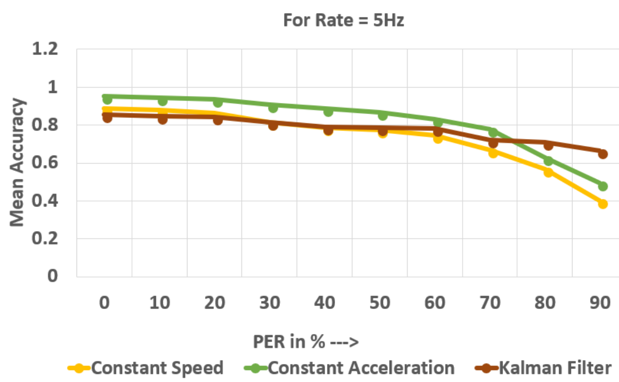

Fig. 5.

Figure 5 shows the Mean Accuracy data for varying PER values where Rate of Transmission is fixed at 5Hz, for all three position estimation techniques. Similar to the previous figure, We can conclude that, Kalman filter works best with a PER greater than 75%. For low PER the constant acceleration model works the best. But with increasing PER, its efficiency goes down. Again, for all the PER values greater than 25%, constant speed model has the lowest efficiency .

At Figure 6 the Rate of Transmission is fixed at 10Hz. It shows the Mean Accuracy data for varying PER values for all three position estimation techniques. We can infer that, the constant acceleration model works very well for this rate of transmission except when the PER is greater than 85%. When

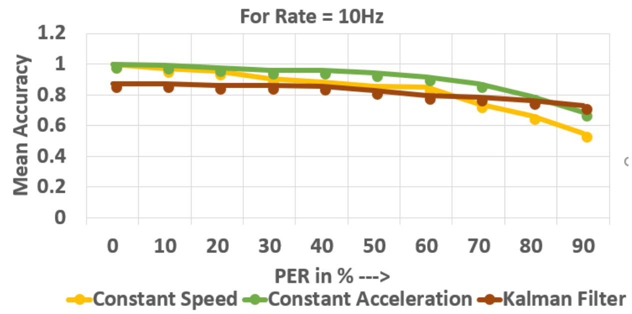

Fig. 6.

PER is greater than 85% the Kalman filter works the best. In this case, Constant speed model has the lowest efficiency only after PER crosses65% mark. Before that, it works better than Kalman Filter but (most of the time) worse than Constant Acceleration.

V. Conclusion

In the field of autonomous to semi-autonomous vehicles, vehicular communication plays a vital if not the most important role. Any lapse in this network can potentially cause a fatal crash and cause huge financial loss.

In this paper Project, we were provided with data of 100 cars from the Virginia Tech Database. Using MATLAB, we implemented Forward Collision warning algorithm for varying Packet Error rate values. This needs different position estimation techniques to estimate the data that was lost due to (simulated) packet loss. The techniques implemented here are Constant Speed model, Constant acceleration Model and Kalman Filter. Using these techniques, we compared the estimated values with the actual values and calculated the Mean Accuracy. We did this process for varying PER and Packet Transmission values.

We observed that, for low PER, constant acceleration gives us the most efficient estimation. While we face a high Packet error rate, the famous Kalman Filter works the best. In conclusion, researchers can use this paper to help them build a robust vehicular network in future. Depending on the PER values they are facing, they can refer back to this paper to know which position estimation techniques would be best suited for their particular network.

ACKNOWLEDGEMENT

The empirical analysis carried out in this paper is heavily based on Dr. Yaser P. Fallahs research paper [1]. This paper is presented in partial fulfillment for the course EEE 6712 - Modeling & Analysis of Networked Systems: A Cyber Physical Systems Perspective.

REFERENCES

[1] Yaser P. Fallah, Masoumeh K. Khandani, *Analysis of the Coupling of Communication Network and Safety Application in Cooperative Collision Warning Systems.* ICCPS, 2015.

[2] Hoffmann, E. R., Mortimer R. G, *Drivers' estimates of time to collision. Accident Analysis & Prevention* NHTSA 1994.

[3] Xue Yang, Jie Liu, Feng Zhao, Nitin H. Vaidya, *"A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning"* Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004

[4] M. Sepulcre, J. Gozalvez, J. Hernandez, *Cooperative vehicle-to-vehicle active safety testing under challenging conditions.* Elsevier, October 2012

[5] Safety Features for the New Ssangyong Tivoli G.B. 2017 http://www.ssangyonggb.co.uk/new/ssangyong/tivoli/safety