An Implementation of Adaptive Content Control for Cooperative Automated Vehicles

Nitish A. Gupta
Department of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816, USA
nitish.gupta@knights.ucf.edu

***Abstract*—The decision-making of automated or autonomous vehicles heavily rely on the information they receive from their environment. Within each vehicle, various sensors are used to make local decisions. However for an extended view of its environment and to make prior decisions, these vehicles communicate their sensor data with other vehicles. For optimum utilization of the communication channel, an adaptive content control technique with probabilistic inclusion of data based on the distance between vehicles is implemented and analyzed in this paper.**

I. Introduction

Automated vehicles use Odometry information along with Radar, Lidar or Stereo cameras for localizing themselves on the road. This is followed by many other sensor data such as GPS and ultrasonic for correction of position estimate. However using only local sensory data limits the global perception of vehicle when it comes to planning long-distance trajectories or alternate paths. The range of vehicle's perception can be expanded when they communicate their local sensory information with other vehicles by using short-range wireless communication. Each vehicle can combine all of its sensing modalities into a map which can contain information such as heading, speed and location. This map after some processing can then be communicated to other vehicles. Along with this map, the vehicle may also include map data received from other vehicles and then transmit this over a communication network. In this way, vehicles can augment all of the maps received from neighboring vehicles to achieve an expanded view of its surrounding, which isn't possible when only local sensing is used. This exchange of local information results in drastic improvement in performance of certain high-level applications such as long-distance trajectory planning and crash avoidance in automated or autonomous vehicles.

For communication among automated vehicles, Dedicated short-range communication (DSRC) protocol is used. However the throughput and channel utilization of DSRC decreases with high load and congestion. This could be due to increase in several parameters such as vehicle density, transmission power or range, transmission rate or packet size. In order to improve performance of the channel, several rate and range control techniques have been studied. However [1] presents a adaptive content control strategy which is a general and scalable framework to address this problem. We will study, implement and analyze the performance of this scheme throughout this paper. Section 2 provides a thorough Literature review along with problem statement and then describes an scalable architecture for cooperative automated vehicles. Section 3 and 4 describes the methodology and performance analysis of content control strategy.

II. Literature Review

A. System Description

The autonomous vehicles use Lidar, radar, stereo cameras and GPS to create a three-dimensional map of its surrounding. These maps give a great deal of information for autonomous driving of a car. Moreover applications such as lane-keeping, adaptive cruise control, collision avoidance and automated parking can be achieved by using only locally generated maps, as these applications only depend on local perception of the vehicle. However, an intelligent vehicle should be able to predict the perception which has not been encountered yet or is outside the reach of locally available sensors, well ahead in time. This includes high-level applications such as advance traffic or congestion prediction, long-distance trajectory planning or collision avoidance. The solution to this problem is that the vehicle should exchange their map information with other vehicles in order to expand their field of view. Each car receives a condensed map which is then merged with its own map from local sensors to generate an updated map of its environment. This updated map is then again transmitted to other nodes within the range of the current node. In this way all vehicles can extend their maps beyond the immediate perception which can be used by higher-layer applications for prior and efficient decision-making.

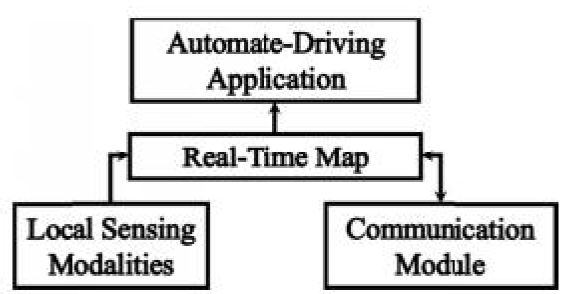

Fig. 1. System Model

The main problem arises when the size of the map to be exchanged is large or the vehicle density on the road is high. This is because the amount of information to be shared increases which results in loss of packets and thus reduces efficiency of the channel. As [2] suggests, channel busy ratio (CBR) is an excellent performance measure parameter for channel utilization. CBR increases with offered load or transmission range as shown in Figure 2. The acceptable range of CBR values is between 0.4 and 0.8, with 0.68 being the ideal value. When CBR is below 0.4, the channel remains under-utilized and when it increases above 0.8, packet loss increases. Thus beyond the specified range of CBR, the channel utilization is not efficient and the map-update packet loss is higher. In the following sections, a content-aware congestion control technique is explained which helps in maintaining the CBR value around 0.68 hence resulting in close to maximum channel utilization.

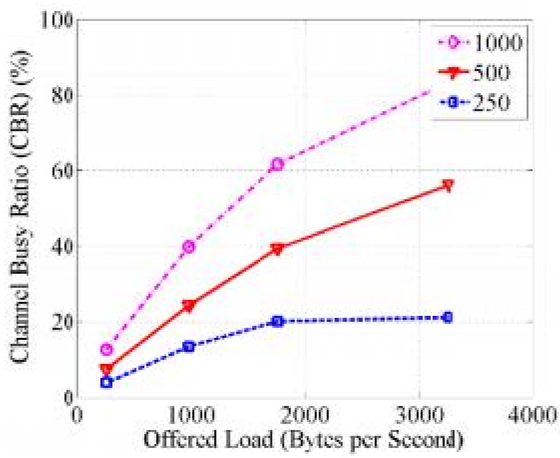

Fig. 2. CBR versus average offered load at 125 vehicles/Km

B. Architecture

The communication framework for active cooperative vehicle safety can be divided into several modules as shown in Figure 3. A multi-resolution local map is created by combining data from three local sensing modalities along with the vehicle's previous map knowledge and the processed map data received from other vehicles within the communication range. Depending on the map resolution requirement from higher-layer applications and also the computational and storage capabilities, the resolution of this map can be controlled.

The Multi-Resolution Data-Processing Module (MRDP) generates the Cooperative Situational Awareness Messages (CSAM) to be transmitted through communication module to other vehicles and also extracts information from the received CSAMs from other vehicles. The message broadcast from MRDP in the communication channel is based on network performance, map content and request from other vehicles. This architecture provides a robust distributed framework which can adapt to the network conditions. The MRDP module processes and extracts important information from the received CSAM and provides this extracted information to the Map-update module. In this way the range of multi-resolution maps can be extended significantly.

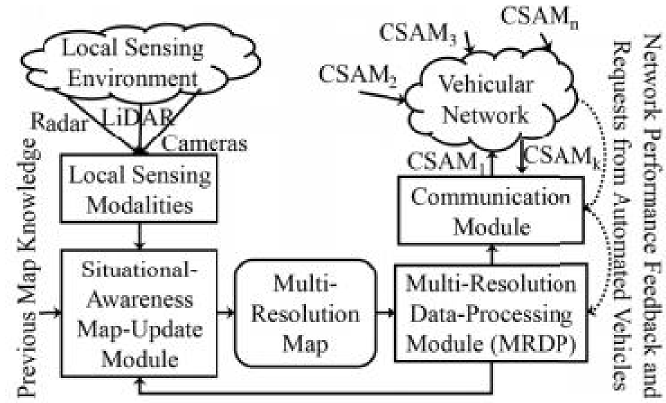

Fig. 3. Communication framework

Based on the condition of communication channel, the MRDP module can control the generation of CSAM messages in three different schemes, namely, rate control scheme, content control scheme and range or transmission power control scheme. In case of rate control scheme, the transmission power is kept fixed, but the rate at which maps are broadcasted adapts to the conditions of communication channel. Similarly in range control scheme, the broadcast rate is kept constant while only altering the transmission power, thus when the load on the channel is less, packets travel a larger distance and vice versa. In the content control based strategy, the content and thus the length of the messages to be transmitted is according to the channel congestion. Hence higher multi-resolution maps (information from more vehicles) are transmitted when channel is less congested.

Ideally these schemes should be implemented in combination to achieve the optimum point where all three strategies perform efficiently. However in this paper, we will restrict our implementation to adaptive content control scheme for cooperative vehicle safety. We will later compare this strategy with the case where no control scheme is used.

III. Implementation

In adaptive content control strategy, the size and content of the message is controlled based on the load on the network while the broadcast rate and power is fixed. The size of each message is chosen in accordance to the current load on the channel and the content is selected in a probabilistic manner such that the information from closer nodes is included with higher probability. In the following two subsections, we will discuss both length and content control technique in more detail.

A. Message Length Control

Optimum utilization of channel is when maximum number of map updates can be delivered to as many vehicles as possible. From [2] it is clear that Information dissemination rate or IDR considers both the amount of information delivered successfully and the number of receivers. IDR is itself a function of CBR which can be sensed directly from a node. Hence maintaining CBR value within the operational range (ideally 0.68) ensures near optimal channel utilization.

The length of the message should adapt itself based on the sensed CBR value. Thus whenever the CBR exceeds the specified limit, the length of the message should decrease and similarly when it falls below the limit, more information can be included in the message. This gives us a gradient descent based relation as,

$$L_{OPT}^{t+1} = L_{OPT}^{t} + \eta \text{ x } (CBR^{*} - CBR^{t})$$

CBR* specifies the optimum CBR value i.e. 0.68, CBR(t) and L(opt)t is the CBR value sensed and the length of message respectively at time t. (n) a controllable gain factor and L(opt)t is the length of message at time t+1. The length of message must be bounded between Lmin and Lmax at all times. Lmin is the minimum length of message required to be sent even when the CBR value increases beyond its limit. Similarly Lmax is the maximum length of message that could be sent given a lower CBR value. Lmax can be easily calculated given the Rate and frequency of transmission.

B. Distance-dependent Content Control

Each Multi-resolution map gives a great deal of information about speed, heading, location, orientation and so on. Automated vehicle use this information to update their own maps to serve the higher-layer applications. Once the length of the message to be transmitted is calculated, the next step is to fill this message with most relevant information. This inclusion of information can be done directly without any control. However, this may result in inclusion of information which is not as relevant as the information which couldn't be included due to length limitation. This not only results in wastage of channel bandwidth but also fails to provide most relevant information to the higher-layer applications. Therefore a content control technique has to be used in order to make sure that most relevant information is included first.

In [1], a distance-dependent content control technique has been discussed. The idea is to first include the messages from the vehicles which are closer than other. Since the data from closer nodes is most accurate and relevant, this provides a higher overall efficiency in decision-making by application layer. Based on the distance, a message can be included mainly in two ways, probabilistically or deterministically. In this paper we will only focus on probabilistic inclusion.

Every node in the network keeps a pool of messages it received from other nodes. After message length calculation, the node first includes its own information. Now for the remaining message length, it picks a message from the received message pool, if the distance of the node from which this message has been received is below a fixed distance r0, it is included with probability 1. However, if the distance of the node is larger the r0, this message is included with the probability which monotonically decreases with distance from the transmitter node.

$$Pr(ObjectReported) = \begin{cases} 1 & \text{if } r \leq r_0 \\ \lambda exp(-\lambda r), & \text{if } r > r_0 \end{cases}$$

where $\lambda = \frac{1}{r_0} \ln \frac{1}{|1 - r_0|}$

In a communication channel, the reliability of the information from closer objects is higher than from the farther objects. Thus inclusion of the most accurate information results in efficient performance of applications in higher-layer.

IV. Numerical Evaluation

This section shows results of adaptive content control strategy implementation in a broadcast medium in the NS-3 simulator. The map-update frequency f is assumed to be fixed at 5 Hz. The parameter r_0 used for probabilistic content control is fixed at 100 meters. For length control scheme, the reference CBR* value is 68%. Figure 4 shows a comparison of real-time CBR value sensed by the communication module with and without content control strategy. It can be seen that when the content control strategy is used, the message length adapts itself such that the CBR value always oscillates around 68%.

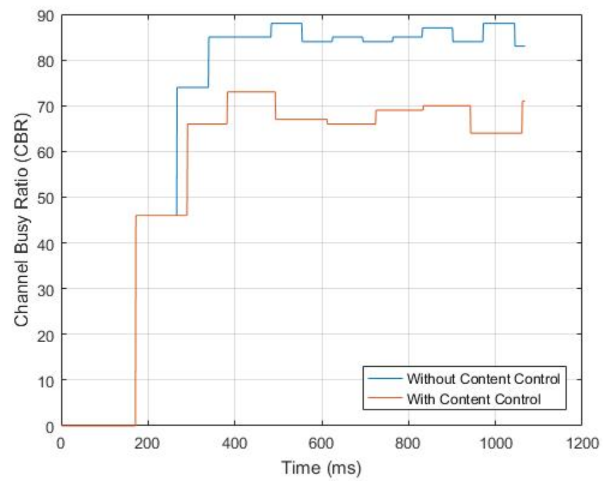

Fig. 4. Channel Busy Ratio versus Time

Figure 5 to 7 shows Packet error rate (PER) verses distance for 25, 125 and 250 vehicles/Km on a 4 Km road. It can be seen that the PER value for the content-control scheme is much lower than that without any control scheme.

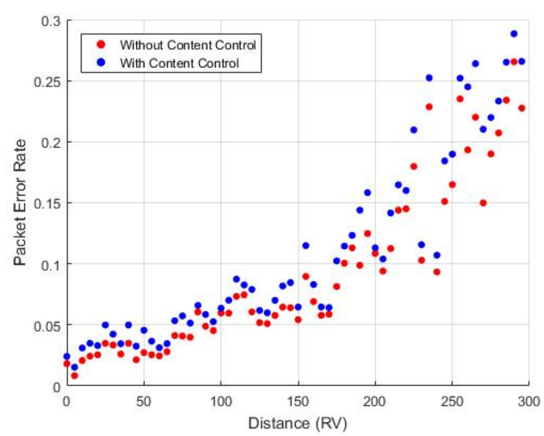

Fig. 5. PER versus Distance for density 25 vehicles/Km

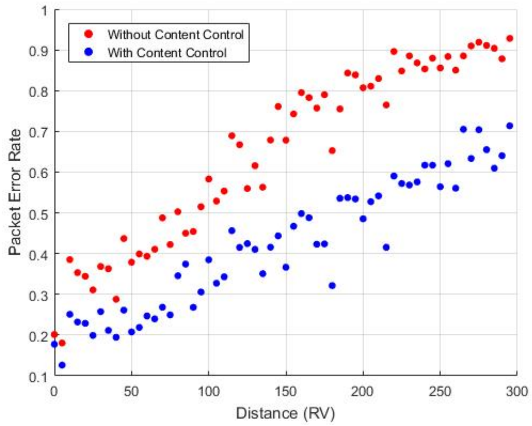

Fig. 6. PER versus Distance for density 125 vehicles/Km

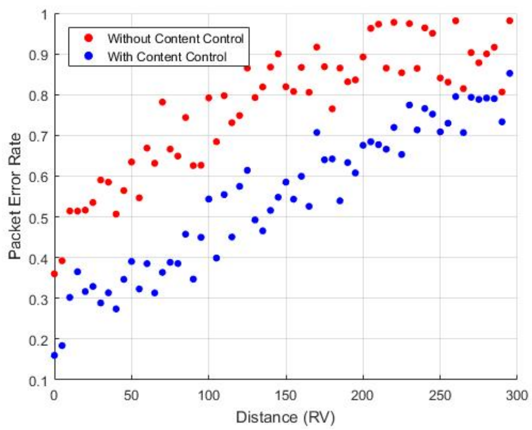

Fig. 7. PER versus Distance for density 250 vehicles/Km

V. Conclusion

This paper presented an implementation and performance analysis of a scalable communication framework in cooperative automated vehicles. For active safety and planning of vehicles, this framework uses a multi-resolution map from local sensors and then exchanged this map in order to expand their field of view which wouldn't be possible with the local map. This exchange of this information was based on an adaptive content control scheme. This scheme controls both the length and content of a message to be transmitted or shared with other vehicles. Although transmission rate and range control schemes have been studied to a great extent, content-control scheme provides a larger range of adaptation based on channel congestion. In addition, this scheme reduces the loss and latency of information transmission in a communication channel. In future, even better scalable framework can be studied, where different control techniques could be combined and implemented to achieve a best region of operation for optimal channel utilization in cooperative automated vehicles.

References

[1] M. Fanaei, A. Tahmasbi-Sarvestani, Y. P. Fallah, G. Bansal, M. C. Valenti, J. B. Kenney, *Adaptive Content Control for Communication amongst Cooperative Automated Vehicles*, In Wireless Vehicular Communications (WiVeC), 2014 IEEE 6th International Symposium on (pp. 1-7). IEEE.

[2] Y.P. Fallah, C.L. Huang, R. Sengupta, and H. Krishnan, *Analysis of informaiton dissemination in vehicular ad-hoc networks of cooperative vehicle safety systems*, IEEE Trans. on Vehicular Technology, vol. 60, no. 1, pp. 233247, January 2011.

[3] Y.P. Fallah, C.L. Huang, R. Sengupta, and H. Krishnan, *Congestion control based on channel occupancy in vehicular broadcast networks*, IEEE Vehicular Technology Conference (VTC-Fall), September 2010.