Poster: Insights on Communication Range and Capacity Requirements of Automated Vehicles

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***Abstract*-Autonomous/automated vehicles are envisioned to improve traffic safety and efficiency while also reducing environmental impact. While most development has focused on autonomous systems that rely on ego-sensors to make their own decisions, communicating and cooperating with other vehicles and with infrastructure will offer enormous potential. In this paper we look into communication range and capacity requirements of automated vehicles. The results obtained show that fully automated vehicles may eventually require a lower communication range than non-automated vehicles thanks to the reduction in reaction times. In addition, we also analyze the communication capacity required by automated vehicles through an estimation of the vehicle density. Based on existing studies illustrating the increase in road capacity, we derive communication capacity requirements for automated vehicles. Future work will look into application level and link level latency and reliability requirements analysis.**

Keywords—Automated vehicle, connected vehicle, V2X, communication requirements, communication range and capacity

I. INTRODUCTION

Autonomous/automated vehicles are envisioned to improve traffic safety, efficiency and environmental impact. So far most development has focused on autonomous systems that rely on ego-sensors to make their own decisions. Communicating and cooperating with other vehicles and with infrastructure will offer enormous potential. One way of collaborating with other vehicles is to exchange information about what is sensed by each vehicle via their onboard sensors such as cameras, lidars and radars (i.e. cooperative perception or sensing). Another way of collaboration is to cooperate on future maneuvers to avoid conflicts in the path planning in addition to supporting smoother maneuvers (i.e. cooperative driving or maneuvering). In this paper we look into communication range and capacity requirements of automated vehicles considering varying levels of automation. Understanding these requirements and the difference with non-automated vehicles is the first step towards building future communication systems for automated vehicles.

II. COMMUNICATION RANGE REQUIREMENTS

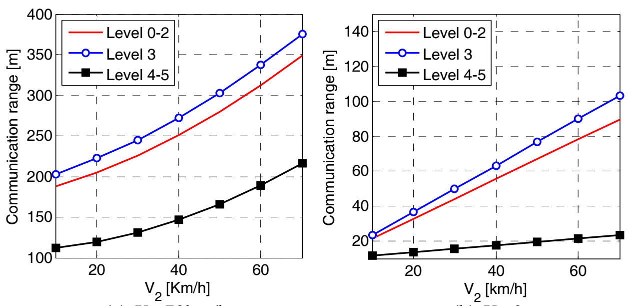
Connected vehicles (automated or not) need to detect with sufficient time all potentially colliding vehicles within certain distance. This distance depends on the time needed to react and avoid any dangerous situation, which in turn depends on factors such as the relative speed, the vehicle braking strength and the reaction time (human and/or machine). An interesting effect on the required communication range can be observed when studying the reaction times at different automation levels. In this paper we adopt the SAE international's levels of driving automation for on-road vehicles. According to SAE, automation level 0 corresponds to no automated vehicles; automation levels 1 and 2 consider partial automation, but require that the driver monitors the driving environment; in automation level 3, the system monitors the driver environment, but the driver will have to respond to a request to intervene; automated levels 4-5 correspond to high-full automation where the driver intervention is not required.

ASV proposed in [1] a set of use cases for connected vehicles and proposed equations to estimate the required communication range. We have extended this study to understand the communication range required for varying automation levels considering their different reaction times. ASV [1] quantifies in 3.7s the time needed by a driver to understand the information provided by the system when an alert is issued, recognize the event, and determine which action to take. ASV also assumes a system delay time of 0.3s and a maximum communication delay of 0.1s considering a packet transmission frequency of 10Hz. That would make the overall reaction time for automation levels 0-2 equal to 4.1s. Automation level 3 requires in addition the driver's switch of attention when a dangerous situation is produced, which can take around 0.7s according to some studies [2]. This would make the overall reaction time for automation level 3 equal to 4.8s. Highly-fully automated vehicles (automation levels 4-5) do not require having the driver in the loop and therefore have the potential to notably reduce the overall reaction time. If we consider that the presentation and reaction time of the driver is reduced to 0.3s of processing time, the overall reaction time required for automation levels 4-5 would be 0.7s. Table I summarizes this example.

TABLE I. EXAMPLE OF REACTION TIMES FOR VARYING AUTOMATION LEVELS

	Level 0-2	Level 3	Level 4-5
Driver's shift of attention [s]	-	0.7	-
Presentation and reaction time [s]	3.7	3.7	0.3
System delay [s]	0.3	0.3	0.3
Communication delay [s]	0.1	0.1	0.1
Overal reaction time [s]	**4.1**	**4.8**	**0.7**

The overall reaction time has a direct impact on the communication range required. Fig. 1 plots the communication range that would be required by a connected vehicle with different automation levels for two of the use cases defined in [1] for intersection collision avoidance. The results show that the communication range required can be notably reduced for highly-fully automated vehicles. However, automated vehicles operating in level 3 may require a higher communication range than conventional vehicles due to the need for the driver to shift her/his attention.



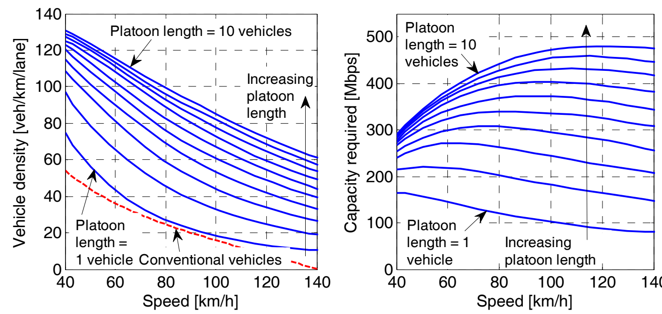
(a) V_1=70km/h (b) V_1=0

Fig. 1. Communication range required for different use cases considering the overall reaction times of Table I and a deceleration of 2m/s^2 [1]. Use case (a) considers 2 vehicles approaching an intersection at speeds V_1 and V_2, and both decelerate to avoid the accident. Use case (b) considers that vehicle 1 is stopped at an intersection (V_1=0) and needs to detect vehicle 2.

III. Communication Capacity Requirements

The communication capacity required by automated vehicles will not only depend on the amount of information that each vehicle will need to transmit and its communication range, but also on the traffic density. Automated vehicles have the potential to enable a better utilization of roadway space [3][4] because they are expected to better sense and anticipate other vehicles' actions, including acceleration/deceleration decisions than human drivers. The capacity benefits are expected to be higher when automated vehicle technologies are combined with connected vehicle technologies; in that case automated vehicles will be able to be grouped in platoons with reduced inter-vehicle spacing. Derived from the capacity estimations of [3], Fig. 2a shows an estimate of the average vehicle density for different vehicle speeds and varying platoon lengths. The figure also shows an estimate of the traffic density of conventional vehicles using the well-known Van Aerde model [5] and considering a maximum capacity of 2200 vehicles [3] (achieved at 50km/h), a maximum speed of 140km/h, and a maximum density of 200 vehicles (traffic jam). As it can be observed, the traffic density increases with automated vehicles compared to conventional vehicles, especially when considering platoons. Moreover, the increase of the platoon length augments the average traffic density. While higher density levels are observed for lower speeds, higher increments are produced at higher speeds compared with single-vehicle platoons and conventional vehicles.

Fig. 2b depicts an estimate of the communication capacity that would be required by automated vehicles for the cooperative perception process. The results obtained consider the traffic density levels of Fig. 2a and that each automated vehicle transmits 2.5Mbps of data for limited automated platooning [6]. The communication capacity required has been estimated as the amount of information that each automated vehicle would need to receive from its neighboring vehicles within certain communication range that depends on the speed as $CR=10\cdot v_r$ [6], where v_r is the maximum relative speed in the scenario. As it can be observed, fulfilling the capacity requirements for cooperative perception would require a high bandwidth under the proposed conditions. The communication capacity required for conventional (non automated) vehicles considering 400B packets at 10Hz and the density levels of Fig. 2a would be around 1.6Mbps.



(a) Vehicle density (b) Communication capacity

Fig. 2. Average vehicle density and communication capacity as a function of the vehicle speed for different platoon lengths. Results for automated vehicles derived from [3]. Communication capacity considering a highway of 4 lanes and that each automated vehicle transmits 2.5Mbps.

IV. Conclusions

In this paper we analyze the communication range requirements of varying levels of automated vehicles. The results obtained show that fully automated vehicles may eventually require a lower communication range than non-automated vehicles thanks to the reduction in reaction times. However, intermediate levels of automation could require higher communication ranges because they might require the driver's shift of attention which might add to the total reaction time. In addition, we also analyze the communication capacity required by automated vehicles through an estimation of the vehicle density. Based on existing studies illustrating the increase in road capacity, we derive communication capacity requirements for automated vehicles. Future work will look into application level and link level latency and reliability requirements analysis.

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