Design and simulation evaluation of cooperative adaptive cruise control for a platoon of vehicles

Alexandru Tiganasu, Corneliu Lazar, *Member*, *IEEE*, Constantin F. Caruntu
Department of Automatic Control and Applied Informatics
"Gheorghe Asachi" Technical University of Iasi, Romania
tiganasu.alexandru@ac.tuiasi.ro, clazar@ac.tuiasi.ro, caruntuc@ac.tuiasi.ro

Abstract—**The semnificative growth of the number of vehicles around the world can conduct to a condensation of the highway traffic. Therefore, the research to find optimal solutions for a higher vehicle flow on highways in a shorter time and with less accidents is ongoing. The organization of vehicles in platoons represents an appropriate method for increasing the roads' capacities. This type of organization permits the decreasing of the distances between vehicles using an electronic coupling made by suitable devices. This functionality allows the simultaneous acceleration or deceleration of all vehicles in the platoon. Moreover, the intelligent vehicles are capable to automatically join or leave the platoon. Another advantage of this system is the decreasing of the fuel consumption and implicitly of the pollution. In this paper, a design approach for cooperative adaptive cruise control (CACC) of vehicle platooning is presented together with a performance evaluation through simulations. The proposed CACC system is based only on the communication with the directly preceding vehicle and consists of a cruise control system for the leader vehicle and a combination of feedback and feed-forward control systems for the followers. An ACC feedback controller is used to keep the desired inter-vehicle distance and a feed-forward one to reduce the effect of measurable disturbances.**

Keywords — cooperative adaptive cruise control design; inter-vehicle communications; distance-headway; time-headway; vehicle platooning.

I. INTRODUCTION

In the automotive field there are many classifications of the existing or future technologies. One of these is made by the Society of Automotive Engineers (SAE), in which they start from level 0 (no-automation) to level 5 (full automation). The conventional cruise control (CCC) system allows the driver to maintain a certain speed automatically. The research in this domain for the vehicle control technology led to the development of the adaptive cruise control (ACC) system that allows a vehicle to drive behind another vehicle at a certain distance [1].

Cooperative Adaptive Cruise Control (CACC) is an advanced version of the ACC system through which the vehicles from the platoon have the possibility to transmit information between each other using a wireless network, termed vehicular ad-hoc network (VANET). The vehicles receive information about the speed of the vehicle in front of them. It belongs to the automation level 2 defined by SAE. This enhancement of the ACC tries to increase this system's efficiency because the vehicles will accelerate or decelerate by anticipation compared to the vehicle in front to obtain fewer distance errors and to avoid the eventual collisions, considering also a safety distance.

The ACC is intended to be, firstly, a comfort system and afterwards a safety system, and therefore a relatively large inter-vehicle distance has to be adopted. When this distance is decreased to a small value of only several meters the increasing of the traffic throughput is expected. Considering the heavy duty vehicles, a significant reduction of the drag force will appear, which leads to the decrease of fuel consumption. To be able to maintain the string stability of the platoon, the ACC system needs an extension, i.e., adding inter-vehicle communications. CACC functionality is not yet commercially available even if there are a lot of advantages brought by it. There are so many things that need to be considered in a real implementation on a platoon of vehicles whereas is hard to obtain a very efficient and safe system considering the disadvantages and the configuration problems of a wireless network [2].

The main blocks that build a CACC system can be classified into the next three functions: communication between vehicles and road infrastructure that must create a link for vehicles to transmit real-time information between them; CACC interfaces for helping the drivers to properly react to the CACC functioning depending on certain driving conditions; control strategies in vehicles must deal with the computation of appropriate actions to maintain safe CACC operations [1].

The goals that are targeted by the automatic speed control are the following: safety and traffic flow dynamics improvements, the increasing of the highway capacity adopting smaller inter-vehicle distances, the reduction of the pollution and the energy saving through aerodynamic drafting and improvement of driver's comfort. A CACC system that is optimized to keep a constant inter-vehicle distance is not likely to maximize fuel efficiency when frequent speed changes are required. The vehicles equipped with autonomous control systems react on the road only using the information that is obtained by their sensing devices (radar or camera), while vehicles that have cooperative control systems add to the data collected from sensors the information received from the vehicle to vehicle (V2V) communication system. When V2V communication exists in the platoon, the information

Acknowledgement: The work of A. Tiganasu and C. F. Caruntu was supported by a grant of the Romanian National Authority for Scientific Research and Inovation, CNCS-UEFISCDI, project number PN-II-RU-TE-2014-4-0970.

about the leader is received firstly by the second vehicle and after that when the third vehicle senses its reaction, the data is transmitted to it and elaborates the actions that are needed to be performed. Thus, all information is transmitted along the string to the last vehicle in the platoon [3].

The traditional traffic management systems are built as centralized infrastructures equipped with video cameras and sensors which collect data about the traffic state and use it to elaborate the proper decisions. The implementation of such a system is very expensive and its processing capacity and information transfer are extremely important. The transfer rates should be very high with small delays and fewer errors which can be propagated in the network. The maintenance of the devices that build this communication system is made periodically. In the communication field, the wireless networks have evolved very fast, which made possible the building of a new decentralized architecture based on inter-vehicle communications. In this case, the infrastructure is excluded, the system being composed only from the vehicles themselves [4].

In the literature there are many papers dealing with ACC systems and more recently with CACC. For example, in [5] a Model Predictive Control (MPC) design of a centralized ACC system is presented. In that paper, it is proven that this method assures the string stability of the vehicle platoon. The proposed controller is chosen to guarantee the integration of the system constraints to reduce the effects of the delays and data loss from the network. The algorithm was simulated using a LTE/EPC Network Simulator LENA. Another proposal of a CACC system implementation is represented by the approach of the authors in [6]. In this work, a heterogeneous platoon of vehicles is considered for the formulation of the control problem, which consists of the tracking of the inter-vehicle distance, velocity and acceleration. For this purpose a decentralized longitudinal tracking control law is proposed. The feed-forward terms contain information about the platoon leader and the nearest preceding vehicle and the feedback items store the states of host vehicles. In [7], a CACC system which consists of two controllers is presented. The first one is used to manage the approaching maneuver to the preceding vehicle and the second one to control the tracking after the vehicle joins the platoon. The system was implemented on four Infiniti M56s vehicles and the authors made research and experiments on them.

This paper focuses on the design of a CACC system for a platoon of vehicles that can be used within the current traffic infrastructure. Only the communication with the directly preceding vehicle is considered. This kind of structure is called semi-autonomous ACC [8], with the advantage that if communications do not work, standard ACC functionality will be available. The main control objective for a platoon vehicle is to follow the preceding vehicle at a desired distance that depends on the vehicle velocity. The velocity dependent spacing policy relates the desired inter-vehicle distance with time-headway. The platoon leader is assumed to follow a desired time-varying reference velocity by means of a CC system. The other vehicles of the platoon use radar devices to measure the distances between them and the vehicle in front of them, which are used in standard feedback ACC controllers. The velocity of the preceding vehicle is available via wireless communication and is used by a feed-forward controller. The delay in the communicated signal is taken into account in simulations. The main contribution of this paper is a CACC design approach that considers all of the above suppositions.

The paper is organized as follows. In section II the longitudinal vehicle motion model is defined. Section III is dedicated to the design of the control algorithms. In section IV the simulation results are presented and the paper ends with the conclusions in section V.

II. Longitudinal Vehicle Motion Model

The traction force desired for the vehicle displacement can be obtained using a lookup table and applying the proper acceleration angle or the appropriate fuel injection rate. It is assumed that the tires friction force does not represent a limitation factor. Thus, it is supposed that the traction force can be directly manipulated.

Considering the previous statements, the longitudinal vehicle motion equation is given by [9]:

$$m\frac{dv}{dt} = F_x - mg\sin\theta - fmg\cos\theta - 0.5\rho AC_d\left(v+v_w\right)^2, \quad (1)$$

where m is the vehicle mass, F_x is the traction force, g is the gravitational acceleration, θ is the road slope, f is the rolling resistance coefficient, ρ is the air density, A is the vehicle frontal area, C_d is the drag coefficient, v is the vehicle velocity and v_w is the wind speed.

The equation (1) can be linearized considering a nominal operation condition, when $dv/dt = 0$. At equilibrium, equation (1) can be solved for [9]:

$$F_{x0} = mg\sin\theta_0 + fmg\cos\theta_0 + 0.5\rho AC_d\left(v_0+v_w\right)^2. \quad (2)$$

Linearizing the equation (1) in relation to the specified operation state using Taylor series the next relation is obtained:

$$\tau\dot{v}' + v' = K(u+w), \quad (3)$$

where the incremental or disturbed variables together with the model parameters are defined as follows:

$$\begin{aligned} &v = v_0 + v';\ F_x = F_{x0} + u;\ \theta = \theta_0 + \theta', \\ &w = mg\left(f\sin\theta_0 - \cos\theta_0\right)\theta', \\ &\tau = \left(m/\left(\rho C_d A\left(v_0+v_w\right)\right)\right), \\ &K = \left(1/\left(\rho C_d A\left(v_0+v_w\right)\right)\right). \end{aligned} \quad (4)$$

The vehicle model represented in Fig. 1 was built based on the linearized equations and it can be expressed as a transfer function:

$$G_v(s) = \frac{K}{\tau s+1}. \quad (5)$$

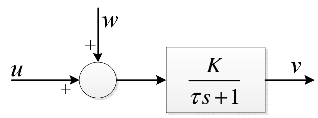

Fig. 1. The block diagram of the linearized longitudinal vehicle dynamics

III. CACC Design Aproach

A. Control problem formulation

A platoon of vehicles is considered as illustrated in Fig. 2. The main control objective is to follow the preceding vehicle at a desired distance:

$$d_i^{ref} = r_i + h_{d,i} v_i, \tag{6}$$

where r_i is the desired distance at standstill, $h_{d,i}$ is the so-called desired time-headway, and v_i is the velocity of vehicle i. The time-headway is the time it takes for vehicle i to reach the current position of its preceding vehicle i–1 when continuing to drive with a constant velocity.

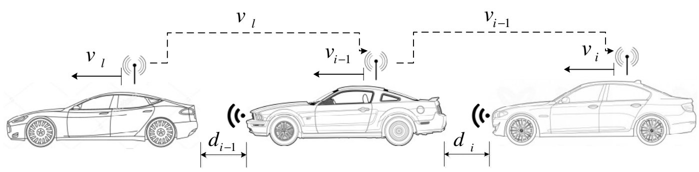

Fig. 2. Vehicle platooning with the CACC system

The available measurements for a vehicle i in the platoon are the distance d_i between vehicles i-1 and i obtained with a radar device and the velocity $v_{i\text{-}1}$ of the preceding vehicle accessible via wireless communication. Considering the main control objective and the available measurements, a CACC structure was developed and is represented in Fig. 3 for the three vehicles illustrated in Fig. 2.

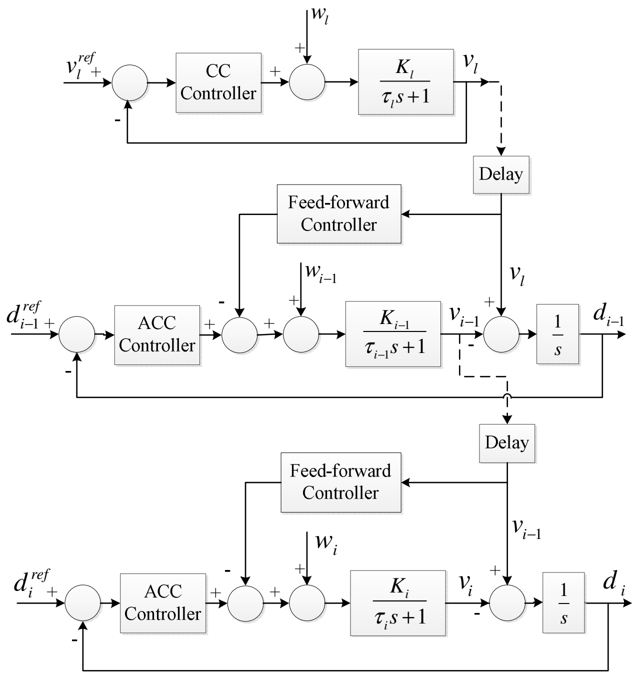

Fig. 3. The CACC structure for vehicle platooning

The platoon leader is assumed to follow a given time-varying reference velocity v_l^{ref} by means of a cruise control system. Each follower vehicle denoted with i in Fig. 2 and 3 has as measurements the radar output data, which represents the distance d_i towards the preceding vehicle, and the velocity $v_{i\text{-}1}$ of the preceding vehicle obtained via a wireless communication system. Having in view the main control objective to follow the preceding vehicle at a desired distance d_i^{ref} and considering the velocity $v_{i\text{-}1}$ as a measurable disturbance, for each follower vehicle a combined control structure with a feedback ACC controller and a feed-forward controller was adopted. The CACC structure for a platoon of vehicles is designed taking into account the above assumptions and is detailed in what follows.

B. CC System Design for Leader Vehicle

The difficulties of the CC system design appear due to the uncertainty introduced by the vehicle mass variation, and the external diturbances occurred because of the road condition. For the CC system a PI controller that was designed based on the vehicle model (5) and using a pole allocation method was adopted. Considering a PI controller with the parallel form:

$$G_{cc}(s) = K_P + K_I / s \tag{7}$$

and the vehicle model (5), the closed loop transfer function is derived as follows:

$$G_{0cc}(s) = \frac{\dfrac{K_l K_I}{\tau_l}\left(\dfrac{K_P}{K_I}s+1\right)}{s^2 + \dfrac{K_l K_P + 1}{\tau_l}s + \dfrac{K_l K_I}{\tau_l}}. \tag{8}$$

The PI controller introduces a zero to the closed-loop transfer function that increases the control system overshoot. The zero introduced by the PI controller can be compensated by introducing a zero-cancellation block in the feed-forward path as in Fig. 4, which has the following transfer function:

$$G_{zc}(s) = \frac{1}{\dfrac{K_P}{K_I}s+1}. \tag{9}$$

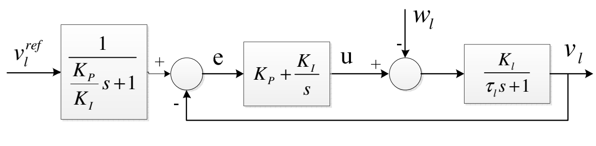

Fig. 4. The closed-loop system with PI controller and zero-cancellation block in feed-forward

The closed-loop transfer function with the zero-cancellation block in feed-forward is now equivalent with a standard second order system. Using this equivalence, the proportional and integral gains of the PI controller can be therefore calculated as:

$$\begin{aligned} K_P &= (2\zeta\omega_n\tau_l - 1)/K_l, \\ K_I &= \tau_l\omega_n^2 / K_l, \end{aligned} \tag{10}$$

where ζ and ω_n are the damping factor and the natural frequency of the second order system. Usually, the second order system parameters are determined from the imposed performances as overshoot and settling time.

C. *Control system design for the Follower Vehicles*

The control system of each follower vehicle has two controllers: a feedback one for keeping the desired distances between vehicles and a feed-forward one to compensate the effect of the measurable disturbance. The desired distance is maintained by an ACC controller. Considering the possibility of wireless communication fail, the ACC controller must have a double integral of the error because it is assumed that the preceding vehicle velocity that acts as a disturbance can be modeled as a ramp-type signal input. As a result, the controlled vehicle can follow the preceding vehicle even when large acceleration and deceleration events appear. The need for a double integrator has made impossible the use of a PID controller. Considering this, a state based control algorithm with double integrator was used for the ACC controller.

The state plant model of vehicle *i* for the ACC controller is obtained using the transfer function (5) and adding a double integrator and it results as:

$$\begin{aligned} \dot{x}_1 &= -x_2 + v_{i-1}, \\ \dot{x}_2 &= -(1/\tau_i)x_2 + (K_i/\tau_i)(u + w_i), \\ \dot{x}_3 &= d_i^{ref} - d_i, \\ \dot{x}_4 &= x_3, \end{aligned} \tag{11}$$

where $x_1 = d_i$, $x_2 = v_i$, x_3 is the integral of control error and x_4 the double integral of error. The state based controller yields:

$$u = -F_1x_1 - F_2x_2 - F_3x_3 - F_4x_4 = f^T x, \tag{12}$$

where $f^T = -\begin{bmatrix} F_1 & F_2 & F_3 & F_4 \end{bmatrix}$ and $x = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \end{bmatrix}^T$.

Adding the feed-forward controller G_{ff} for rejecting the measurable disturbance, the control structure from Fig. 5 for a follower vehicle results.

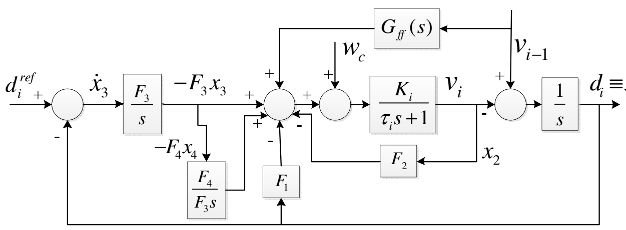

Fig. 5. The control system structure for a follower vehicle

The feed-forward controller is designed to reduce the effect of the measurable disturbances yielding [10]:

$$G_{ff}(s) = G_p^{-1}(s). \tag{13}$$

The ideal feed-forward controller is determined by taking the inverse of the vehicle dynamics (5), but this inverse is not realizable and an approximation has to be used. Thus, the inverse of the transfer function (5) can be approximated with:

$$G_p^{-1}(s) \cong \frac{1 + s\tau_i}{K_i\left(1 + s\tau_i / N\right)}, \tag{14}$$

where *N* gives the frequency range where inversion is valid.

The state feedback gain matrix of the ACC controller (12) can be computed using Ackermann's formula. The state model (11) of the vehicle *i* is considered and written in the form:

$$\begin{aligned} \dot{x} &= Ax + bu + Dw^T, \\ y &= c^T x, \end{aligned} \tag{15}$$

with the matrices/vectors:

$$A = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & -1/\tau_i & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, b = \begin{bmatrix} 0 \\ K_i/\tau_i \\ 0 \\ 0 \end{bmatrix}, D = \begin{bmatrix} 1 & 0 \\ 0 & K_i/\tau_i \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \tag{16}$$

$$c^T = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}, w^T = \begin{bmatrix} v_{i-1} & w_i \end{bmatrix}.$$

Using Ackermann's formula, the following state feedback gain matrix is obtained:

$$f^T = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix} R^{-1} P_c(A), \tag{17}$$

where $R = \begin{bmatrix} b & Ab & A^2b & A^3b \end{bmatrix}$ is the controllability matrix and $P_c(s) = \left(s^2 + 2\zeta\omega_n s + \omega_n^2\right)\left(s + 4\omega_n\right)^2$ is the characteristic polynomial of the closed-loop system built based on the desired performances. For example, by imposing the overshoot and the settling time, the damping factor ζ and the natural frequency ω_n can be obtained.

The CACC structure from Fig. 5 uses V2V communication in order to obtain the information about the velocity of the preceding vehicle considered as measurable disturbances that are rejected by the feed-forward controller. Usually, the communications between vehicles is done at every 100 ms. From this reason, in the control system a delay appears, whose maximum value will be 100 ms.

IV. Simulation Results

The proposed design approach of the CACC system for vehicle platooning was evaluated through simulation using the MATLAB/Simulink software environment. In Fig. 6, a platoon of five vehicles, with one leader and four followers, is illustrated. For the simulation, the following values for the parameters from equation (1) are used:

$$\begin{aligned} &g = 9.81\ m/s,\ v_0 = 25\ m/s,\ \theta_0 = 5,\ m = 1000\ \text{kg}, \\ &\rho = 1.202\ kg/m^3, A = 1.5\ m^2, C_d = 0.5, \\ &f = 0.015,\ v_w = 2\ m/s. \end{aligned}$$

The lead vehicle control structure is implemented with the cruise control structure presented in Fig. 4, as it is shown in Fig. 7. The PI controller's design is done with the pole allocation method, resulting the tuning parameters K_P = 9695.7, K_I = 29160. Fig. 8 illustrates the control system of the follower vehicles built with the feedback-feedforward control structure from Fig. 3. The ACC algorithm consists of a state-feedback controller with four states, two of them being introduced with integrator blocks applied on the distance error

(Fig. 5). The controller is designed using the pole placement design technique, resulting f^T = [-3010000 90000 38680000 184390000]. The feed-forward controller was designed using (13) and (14). The values of the tuning parameters for PI and ACC controllers are so high because the actuators are missing from the control structure. The actuators would have the role of amplifying the signals provided by the controllers and to generate the traction force. In the simplified diagram used in this paper the traction force is directly given by the controllers.

In the block diagram from Fig. 6 there are two possibilities to set the reference distance. The first is represented by a constant value (distance-headway) d_i^{ref} = 4m introduced with a Step block and the second one (time-headway) is computed according to equation (6) depending on the velocity of each vehicle and a predefined distance value r_i = 1m. The time headway, $h_{d,i}$, is set to 0.1s. The data is sampled at a rate of T_s = 0.01s.

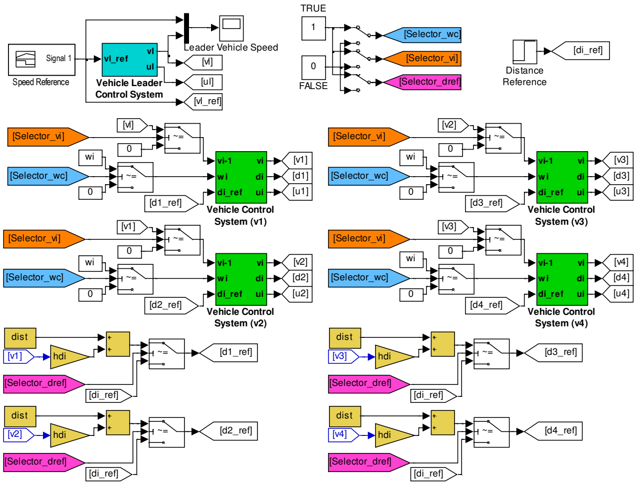

Fig. 6. The Simulink representation of the vehicle platoon

The follower vehicles shall respond to their predecessors' actions faster than the leader responds to the automatic adaptation of its speed. So the response time set for the other vehicles is significantly smaller than the one established for the platoon leader.

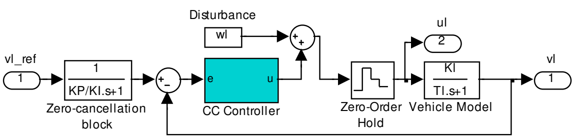

Fig. 7. The Simulink structure of the leader vehicle control system

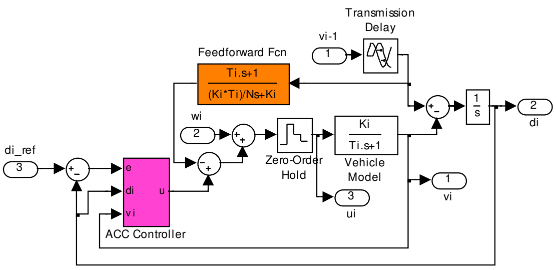

Fig. 8. The Simulink scheme of the control system for follower vehicles

All the vehicles from the considered platoon are identical. The speed signals of every vehicle from the platoon are shown in Fig. 9. It can be observed that each control system acts as it is expected such that the vehicles are able to maintain their velocities depending on the speeds of their predecessors. In Fig. 10, the distances between vehicles after a speed-dependent reference is applied on the control systems' inputs are represented. It can be seen that in this case the distances waveforms follow the speed profile introduced as reference for the leader. The standstill distance is considered equal to 1 meter. When the vehicle velocity is increasing, the distance between a vehicle and its predecessor is growing also. This proportional characteristic is applied also when the speed is decreasing.

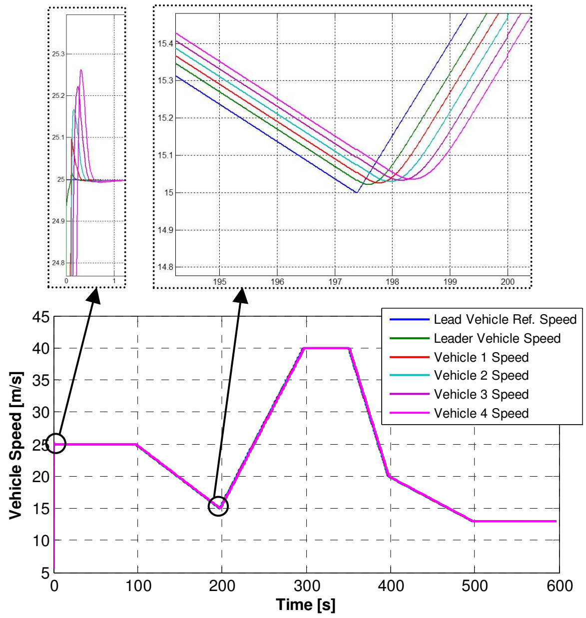

Fig. 9. The speeds for all vehicles in the platoon

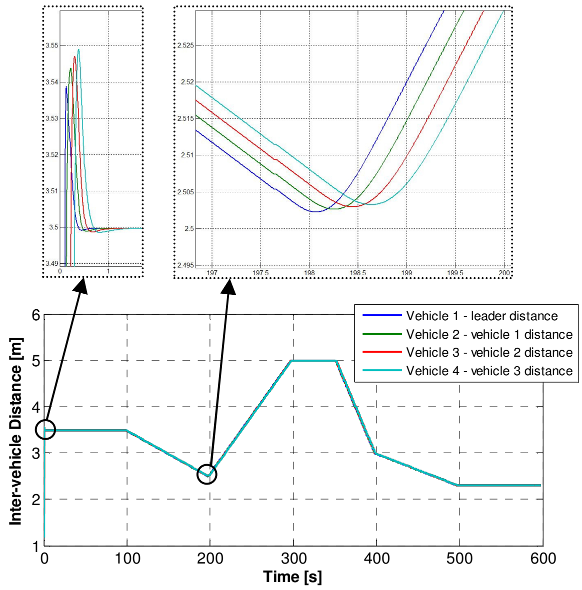

Fig. 10. The distances between vehicles with speed-dependent reference

Fig. 11 illustrates the inter-vehicle distances obtained when the reference is set as a constant value. The desired distance, in this case, is equal to 4 meters and is shown that a constant distance is maintained by every vehicle independent of its speed.

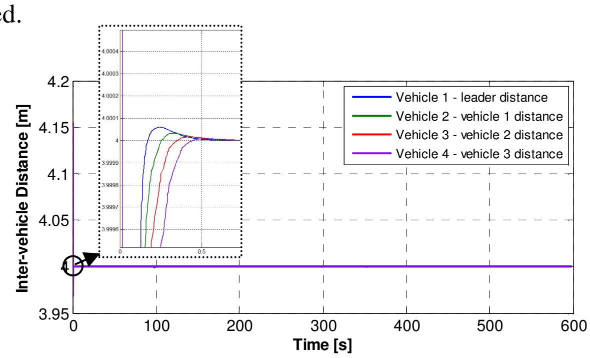

Fig. 11. The distances between vehicles with constant reference

Through the responses from Fig. 10 it is proven that each vehicle from the designed platoon is able to accordingly adapt its speed to keep a safety distance between it and its predecessor. This is needed in the real traffic on highways to avoid collisions with the vehicle in front because, as the speed gets higher, the braking distance increases. The case of the distance-headway, shown in Fig. 11, is presented for a theoretical purpose to prove that the vehicles can maintain also a constant inter-vehicle distance. The effects of the disturbances introduced by the wireless network and by the vehicle dynamics are compensated. Other factors that can affect the behavior of the CACC systems are the wind velocity (v_w) and the road slope (θ). For the designed platoon, the obtained responses are the same as in Fig. 9 and Fig. 10 after some random values were considered for the measurable factors previously mentioned.

In Fig. 12, the traction forces computed by the CC controller and CACC systems are presented. The traction force values are proportional with the vehicle speeds illustrated in Fig. 9. Depending on the acceleration or deceleration case the force is increasing or is decreasing. When a constant speed value is needed to be maintained the traction force is constant.

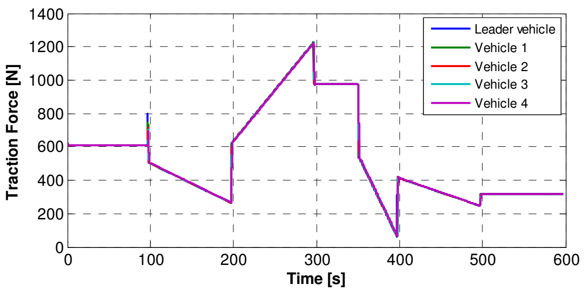

Fig. 12. The traction forces of each vehicle in the platoon

V. Conclusions

In this paper, the design and simulation of a vehicle platoon with a cooperative adaptive cruise control system was presented. The platoon contains a leader that is controlled via a classic CC system because in this case the speed reference is manually set by the driver. The other vehicles use a combination of feedback and feed-forward control. This allows the vehicles to keep a certain distance between them and their predecessors using an ACC feedback controller, the actual distance being measured with a radar sensor. To make the platoon more stable and more compact, inter-vehicle communications were introduced, and a feed-forward controller to reduce the effect of the measurable disturbance. A wireless network is responsible to transmit the velocities from one vehicle to the vehicle behind it. All the design parameters of the controllers were computed to obtain very fast responses and to compensate the disturbances' effects. In the considered platoon the disturbances were introduced by the VANET's transmission and reception delays and by the vehicle's dynamics.

Moreover, in the designed simulation tests the reference for the distance was a speed-dependent value or a constant value independent of the velocity. The obtained responses illustrate that the behavior of the vehicles in their motion in a platoon is the desired one, i.e. the speeds and the inter-vehicle distances follow the desired values.

References

[1] Dey K. C., Yan L., Wang X., Wang Y., Shen H., Chowdhury M., Yu L., Qiu C., and Soundararaj V., "A Review of Communication, Driver Characteristics and Controls Aspects of Cooperative Adaptive Cruise Control (CACC)", IEEE Transactions On Intelligent Transportation Systems, 2015, vol. 17, no. 2, pp. 491-509.

[2] Naus G., Vugts R., Ploeg J., Molengraft R. V., and Steinbuch M., "Towards On-The-Road Implementation Of Cooperative Adaptive Cruise Control", 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services, Stockholm, Sweden, 2009.

[3] Shladover S. E., Nowakowski C., Lu X.-Y., and Ferlis R., "Cooperative Adaptive Cruise Control (CACC) Definitions And Operating Concepts", 94th TRB Annual Conference, Washington D. C., USA, 2015.

[4] Meraihi R., Senouci S.-M., Meddour D.-E., and Jerbi M., „Wireless Ad Hoc and Sensor Networks", „Chapter 12 - Vehicle-to-Vehicle Communications: Applications and Perspectives", 2008, pp. 315-339.

[5] Mazzola M., and Schaaf G., „Modeling and Control Design of a Centralized Adaptive Cruise Control System", International Journal of Computer, Electrical, Automation, Control and Information Engineering, Vol. 8, No. 7, 2014, pp. 1142-1146.

[6] Han S.-Y., Chen Chen Y.-H., Wang L., and Abraham A., „Decentralized Longitudinal Tracking Control for Cooperative Adaptive Cruise Control Systems in a Platoon", IEEE International Conference on Systems, Man, and Cybernetics, 2013, Manchester, United Kingdom, pp. 2013-2017.

[7] Milanés V., Shladover S. E., Spring J., Nowakowski C., Kawazoe H., and Nakamura M., "Cooperative Adaptive Cruise Control in Real Traffic Situations", IEEE Transactions on Intelligent Transportation Systems, 2014, 15, pp. 296-305.

[8] Rajamani R. and Zhu C., "Semi-autonomous Adaptive Cruise Control systems", IEEE Transactions on Vehicular Technology, vol. 51, no. 5, pp. 1186-1192, September 2002.

[9] Ulsoy A. G., Peng H., and Çakmakc M., "Automotive Control Systems", Cambridge University Press, USA, 2012.

[10] Astrom K. J., and Hagglund T., "Advanced PID Control", ISA - Instrumentation, Systems, and Automation Society, USA, 2006.