Connected Vehicles Coordination: A Coalitional Game-Theory Approach

Jose Angel Leon Calvo and Rudolf Mathar

Institute for Theoretical Information Technology, RWTH Aachen University Aachen, Germany 52074
Email: {leon, mathar}@ti.rwth-aachen.de

***Abstract*—Collective autonomous vehicles are the next step in Intelligent Transportation Systems (ITS) to optimize the traffic flow and increase road safety. However, the management of collective dense scenarios formed by rapid moving vehicles is not a simple task. Thus, a coordination scheme for connected vehicles is proposed in this paper. The coordination and formation scheme is designed using a joint paradigm. On the one hand, the platoon formation is based on a coalitional game-theory approach. On the other hand, the intra and inter-platoon coordination is controlled using a cooperative communication scheme managing the safety and stability of the platoon. Here we define a utility function-based coalitional game to optimize the traffic flow and manage the platoons. In addition, using the information gathered by the deployed infrastructures, the coalitional game behavior is updated in order to react accordingly to unexpected network events and vehicle actions. The platoon management is coordinated using communication schemes in order to achieve the optimal distance between vehicles and platoons, increasing the traffic flow and stability. In order to validate our theoretical framework, simulations are performed under realistic conditions to determine the positive impact obtained by the proposed cooperative scheme in comparison with different approaches.**

I. Introduction

Autonomous driving is considered to be *the next big thing* in the upcoming years, hence both industry and academia have already turned their eyes to it [1]. It is the key element for the future of Intelligent Transportation Systems (ITS), and hence all efforts are focused on making this technology feasible. Currently, the main progresses in autonomous driving are concentrated in the area of a single-car traveling without considering its cooperation with the rest of vehicles using technologies, such as LIDAR (Light Detection and Ranging) and high resolution maps. Those technologies can possibly be applied in order to avoid collisions while following a predefined route [2]. This approach has shown the potential of autonomous driving, achieving a great success in terms of the number of accidents per kilometer driven [3], including one collision where the Tesla autopilot was exonerated of any fault [4]. Nonetheless, a single autonomous vehicle will not improve the overall traffic flow [5], since it does not take into consideration the rest of the vehicles on the road for more than merely collision avoidance.

In order to add collective adaptation and autonomy to the vehicular network, different communication protocols have been developed in the last years, enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications and improving the efficiency and safety of vehicular networks. At the present time, LTE-V2X, the proposed technology from 3GPP (3rd Generation Partnership Project) in its Release 14 [6], seems like the perfect candidate to be the standard for the next vehicular networks communication scheme considering its advantages. These advantages are, namely, an already deployed communication infrastructure and a robust MAC layer, designed to fulfill the demanding requirements of vehicular communications, in contrast to the non-guaranteed quality of service (QoS) of the IEEE 802.11p technology [7], [8].

The information collected by these communication schemes allows each vehicle to acquire full awareness of the future *intentions* of the rest of vehicles in the network. Hence, it is possible to mimic the human behavior for cooperation [9] without the uncertainty of unknown behaviors. The reason behind mimicking human behavior is that we tend to use the smallest amount of energy or the shortest path, which translated into vehicular terms, means a lower fuel or power consumption and an optimal path to destination [10], [11].

The main goal of the ITS is to optimize the vehicle fuel and energy consumption along with the chosen destination path, while at the same time, increase the traffic safety. Thus a simple question arises, is it possible to simultaneously achieve these goals? Many different approaches for vehicle organization have been considered, but platooning demonstrates the best performance in terms of fuel consumption and path optimization [12], [13]. It has been proven in a previous work [14] that using V2V communication schemes for intra and inter-platooning organization not only improves safety of the vehicles composing it, but also optimizes the traffic flow, i.e., minimizes the distance between vehicles while maintaining the stability of the platoon. However, the merging and managing of platoons is still an open issue under these safety conditions. Most of the previous works in platooning focus on highways or simple scenarios without taking into consideration the traffic flow optimization or the intra-platoon management [15]. In this paper, a game-theory approach is proposed to address these problems related to more complex scenarios, using vehicular communication schemes, both V2V and V2I, in order to optimize the three main aspects aforementioned, i.e., road safety, traffic flow and fuel consumption.

Similar to human behavior, game-theory approaches face the problem of selfishness in autonomous systems. Therefore, it is required to motivate the autonomous vehicles to cooperate in order to optimize the system. A joint global goal is added to the game-theory framework, so that the autonomous vehicles aim for the optimal decision, not only for themselves, but for the general system. Several studies have been conducted using a game-theory approach in order to implement platooning, specially for trucks. However, the inclusion of communication schemes for the intra-platoon management was not considered, and hence, optimal cooperation schemes based on communication with different vehicles were not achieved [16], [17]. Different studies have considered coalition games from diverse perspectives, such as heuristic approaches [18], Markov chains theory [19] or concepts from the economic world [20]. However, in our work the used model is based on the set theory methods introduced in [21]. Following the principles of the development of autonomous systems [22], we focus on the use of utility-based functions, and the characterization of the cooperation of vehicles.

The remainder of this paper is organized as follows. Section II introduces the system model along with the platoon cooperative communication scheme. Section III shows the main contribution of this paper, where the coalitional game-theory approach is defined using mathematical concepts. In Section IV, a realistic simulation is performed to show the improvements in the network using the concepts previously introduced, followed by the conclusion in Section V.

II. System Model

Let a set of vehicles $\mathcal{N} = \{n_1, \dots, n_N\}$ grouped in $\mathcal{K} = \{k_1, \dots, k_K\}$ platoons under the range of $\mathcal{B} = \{b_1, \dots, b_B\}$ eNodeBs. Each vehicle $n_i \in \mathcal{N}, i = \{1, \dots, N\}$ belongs simultaneously to only one platoon $k_u \in \mathcal{K}, u = \{1, \dots, K\}$, and each platoon is individually connected to a unique $b_z \in \mathcal{B}, z = \{1, \dots, B\}$ eNodeB. The vehicles are equipped with two different types of on-board equipment, i.e., short-range sensors in order to sense the environment and the surrounding vehicles, and communication devices which enable the V2V and V2I communication schemes. The communication protocol is based on the recently proposed LTE-V2X standard, included in the LTE Release 14. Following the standard proposed by LTE-V2X, the radio resources are allocated using a semi-persistent scheduling (SPS). Each vehicle has resources reserved persistently until it abandons the infrastructure coverage, and the retransmissions or event-based transmissions are dynamically allocated. In the present proposed system model, the infrastructure (eNodeB) works as a scheduler for the SPS, i.e., the radio resources are allocated based on the information gathered by the infrastructure, exploiting its high communication range.

In order to obtain an optimal traffic flow, the vehicles are organized in platoons[1]. This is the most efficient way regarding the number of vehicles per lane/hour, due to the smaller gap between vehicles [23]. It has been confirmed in [14] that due to the addition of a V2V communication scheme, the traffic

[1]the terms platoon and coalition are interchangeable during the entire paper.

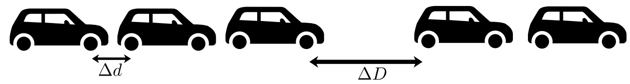

Fig. 1: Optimal Platoon Formation

flow rate can be optimized while the stability of the platoon is not affected. The required intra-platoon distance for vehicles driving at a speed $v_{n_i}[mT]$ at time mT is $\Delta D = 0.1\mathrm{s}{\cdot}v_{n_i}[mT]$ and the inter-platoon distance is $\Delta D = 1\mathrm{s} \cdot v_{n_i}[mT]$ to insure stability and safety, as shown in Fig. 1. The update interval is given by the value $mT, m \in \mathbb{N}$, defined as the adaptation time. Therefore, if the vehicles are traveling in an urban environment at $50\ \mathrm{km\,h^{-1}}$, the distance between consecutive vehicles in a platoon is approximately $1.5\ \mathrm{m}$, and the distance between two consecutive platoons is $15\ \mathrm{m}$. It is noteworthy that these values are obtained under the assumption of a perfect mechanical response and no sensor failure. Moreover, the information within the platoon is shared using a V2V protocol as follows

$$v_{n_i}[mT] = v_{n_i}[(m-1)T] + a_{n_i}[(m-1)T] \cdot T \tag{1}$$

$$v_{n_{i+1}}[mT] = v_{n_{i+1}}[(m-1)T] + a_{n_{i+1}}[(m-1)T] \cdot T \tag{2}$$

$$\begin{aligned} S_{n_i}[mT] = {} & S_{n_i}[(m-1)T] \\ & + (v_{n_{i+1}}[(m-1)T] - v_{n_i}[(m-1)T]) \cdot T \\ & + 0.5 \cdot T^2 (a_{n_{i+1}}[(m-1)T] - a_{n_i}[(m-1)T]) \end{aligned} \tag{3}$$

$$\begin{aligned} a_{n_i}[mT] = f_{control}(& v_{n_i}[mT], S_{n_i}[mT], a_{n_{i+1}}[mT], \\ & v_{n_{i+1}}[mT], S_{min}, T_g, T) \end{aligned} \tag{4}$$

where T is defined by the LTE standard as 100 ms, and $v_{n_i}[mT]$ and $a_{n_i}[mT]$ are the velocity and acceleration of the corresponding vehicle, respectively. Moreover, $S_{n_i}[mT]$ is defined as the inter-vehicular gap between two successive vehicles. Eq. 4 shows the input parameters in order to adjust the acceleration, $a_{n_i}[mT]$, for vehicle n_i, regarding the status of the preceding car, and T_g is the time gap between vehicles. It is noteworthy, that these values are obtained using the short-range sensors installed in the vehicles.

In the model described in [14], the first vehicle of the platoon is considered as the platoon leader and scheduler. All the vehicles in the platoon drive using a car-following model and the pace is marked by the preceding car. However, in the current proposed model, the infrastructure plays the role of scheduler and not the platoon leader as in [14]. Using the infrastructures in order to regulate the network has several advantages, such as extending the electronic horizon due to its higher altitude, in addition to the exchange of information between infrastructures enabling optimal traffic routing. Grouping vehicles in platoons is the optimal formation not only for the traffic flow rate, but also for the fuel or energy consumption of the vehicles, specially in the case of heavy trucks [13]. In our system model, it is assumed that every autonomous vehicle has a predefined initial position and final destination known by the infrastructure. Hence with the layout of the road network preloaded in the infrastructure, it is possible to predict the position of each vehicle n_i at every time. Therefore, the network can be defined by a set of links $\mathcal{L}$ where $(j,l) \in \mathcal{L}$ is the link between the node j and the node l. Moreover, the density of vehicles for each link, $\lambda_{j,l}$, can be predicted and updated accordingly using the information gathered by the infrastructures.

III. Coalitional Game-Theory Approach

From the previous section, we conclude that forming platoons is the most efficient way to organize the vehicle network. Accordingly, we define our *problem statement:* a coalitional game-theory approach is defined considering the particular properties of our scenario, i.e., physical restrictions, communication among vehicles and fast changing environment, while forming coalitions to optimize the traffic flow. In general, maximizing the individual utility function for each vehicle independently does not provide a global optimization, since the payoff of each player is dependent of the joint actions of the rest of players. Thus the game can be defined as non-transferable utility (NTU) [24], where the value of a coalition is not longer a single value, but a set of utility function vectors, $v(k_u) \in \mathbb{R}^K$, depending on the actions of the rest of players. Under these assumptions, a dynamic coalition formation game is defined

Definition 1: **Dynamic Coalition Formation Game**

1) Finite set of players $\mathcal{N}$ forming $\mathcal{K} = \{k_1, \ldots, k_K\}$ coalitions such that for any collection of disjoint coalitions $\mathcal{N} = \bigcup_{u=1}^{K} k_u$.
2) Creating coalitions may benefit the players involved, but there are also costs of forming a coalition, hence forming grand coalitions is usually not the optimal decision.
3) Finite set of potential actions $\mathcal{C}$ for each player limited by the road network.
4) The game is defined as dynamic since the actions of the players may bring changes in the strength of the players and to the coalition formation.

The game is defined using the triplet $(\mathcal{N}, \nu, \mathcal{K})$ where the value of a coalition K_u is denominated as $\nu(k_u)$. Since we are using a formation game, i.e., the network structure and costs to form coalitions play a major role, the value for each coalition has the *restriction property* [25], and hence, the value $\nu(k_u)$ has to be calculated in two steps: i) Consider the set of coalitions $\mathcal{K}$ independent of each other and calculate the value of each one (using the canonical definition) as

$$\nu(k_u) = \sum_{n_i \in k_u} \phi_{n_i}(\nu) \tag{5}$$

where ϕ_{n_i} is the payoff given to the player n_i belonging to the coalition K_u by the Shapley value ϕ which is defined as

$$\phi_{n_i}(\nu) = \sum_{k_u \subseteq \mathcal{N} \setminus \{n_i\}} \frac{K!(N-K-1)!}{N!} [\nu(k_u \cup \{n_i\}) - \nu(k_u)] \tag{6}$$

where K and N are defined as the cardinal of the coalition k_u and the set of players $\mathcal{N}$, respectively. Moreover, in the second step ii) the resulting value of the game $v(k_u)$ is the $1 \times K$ vector of payoff functions constructed by combining all the restricted game values $(k_u, \nu|k_u)$.

Using the proposed scheme, we analyzed the dynamic coalition formation game from bottom to top by means of three different utility functions; individual, coalitional and global as shown in Fig. 2. The first level is the individual utility function $\nu(n_i)$ for a player $n_i \in \mathcal{N}$ which considers the local environment, i.e., its own state vector, and the information shared by the infrastructure. The next level corresponds to the coalitional utility function which motivates the creation of coalitions. This function defines the trade-off between the maximization of the individual utility function and the coalitional utility function of the network. Finally, the global utility function where the players are not individuals, but the coalitions are created by several of them.

A. Individual Utility Function

In order to formalize the dynamic coalitional game framework, each vehicle $n_i \in \mathcal{N}$ has an individual utility function as follows

$$\nu_{n_i}[x, mT] = d_{n_i}[x, mT] + \tau_{n_i}[x, mT] + \xi_{n_i}[x, mT] \tag{7}$$

where d_{n_i} is the distance from the actual position of the player to destination, τ_{n_i} is the travel time from the vehicle position to destination and ξ is a congestion tax created in order to stimulate the creation of coalitions. In this case, $\tau_{n_i}[x, mT]$ is linearly related to the density of vehicles. The congestion tax variable for a given position x, $\xi_{n_i}[x, mT] = \tau_{n_i}[x, mT] \cdot f_{n_i}[q, mT]$ where q is the number of vehicles using the road at the same time. The congestion tax form can be justified by the idea that in a road with more vehicles, it is more likely to create platoons (which are the optimal way of traveling). However, to avoid a high congestion in a single road path, the variable $\tau_{n_i}[x, mT]$ is included which penalizes a low speed in the given path. Using both considerations, we achieve that the platoons are created with a high probability without congesting the network.

B. Coalitional Utility Function

The main goal of our approach is to create coalitions denoted as $\mathcal{K}$ where the total payoff of this particular organization is greater than other possible set of coalitions $\mathcal{S}$, i.e., $v(\mathcal{K}) > v(\mathcal{S})$. Therefore, in order to motivate the vehicles to join a coalition, and consequently, obtain an optimal management of the traffic, the following concept must be fulfilled:

$$\nu(k_u) \geq \sum_{i=1}^{\hat{N}} \nu(n_i^{k_u}) \tag{8}$$

this concept follows the *Pareto order* which states that a player $n_i^{k_u} \in \mathcal{N}$ belonging to a platoon k_u will prefer to join the coalition k_u if at least one player belonging to k_u improves its utility function without hurting any of the other players.

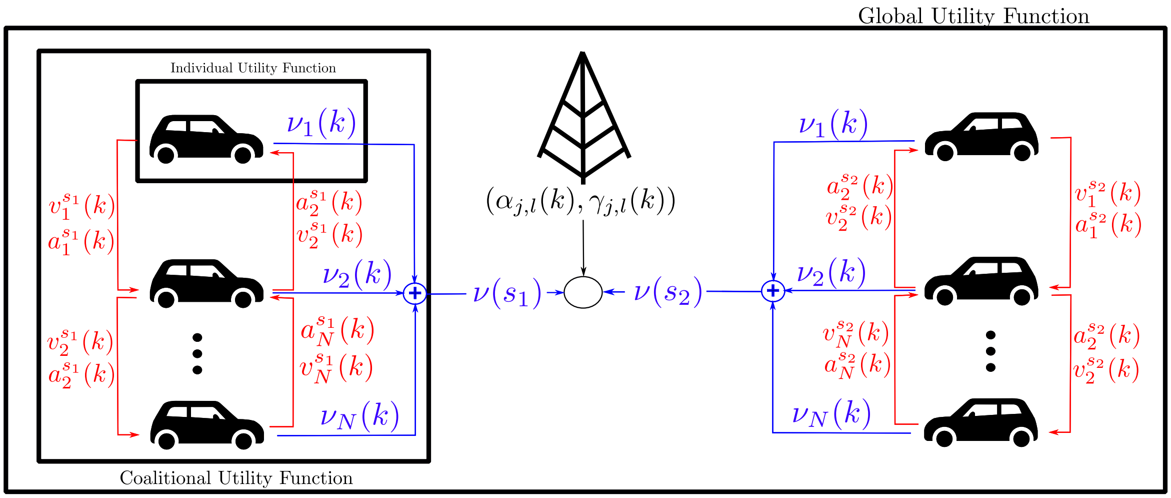

Fig. 2: Dynamic Coalition Formation Game Overview

Hence, if Eq. 8 is fulfilled no individual vehicle would have the incentive to abandon the coalition since the individual utility function outside a coalition is always smaller, or at best equal, compared to the coalitional utility function. Therefore, the optimization problem for the coalitional utility function is defined as follows

$$\underset{\substack{d_{n_i}[x,mT],\tau_{n_i}[x,mT],\\ \xi_{n_i}[x,mT]}}{\text{minimize}} \quad \nu(k_u) = \sum_{i=1}^{\hat{N}} \hat{\nu}(n_i) \tag{9a}$$

$$\text{s.t.} \quad \hat{\nu}_{n_i}[x,mT] = \hat{d}_{n_i}[x,mT] + \hat{\tau}_{n_i}[x,mT] + \hat{\xi}_{n_i}[x,mT] \tag{9b}$$

The value $\hat{\nu}(n_i)$ is defined using the optimal values for the coalition k_u which satisfies Eq. 8 and fulfills the condition $\nu(\mathcal{K}) > \nu(\mathcal{S})$, however, they do not need to be the optimal for the individual payoff function $\nu(n_i)$. It is important to mention that the coalitional utility function, $\nu(k_u)$ denoted in Eq. 9a, should be fair for each vehicle $n_i \in k_u$, i.e., no vehicle should be left starving which in game-theory is denoted as $\hat{\nu}(n_i) \to \infty$. In order to update the cost parameters $d_{n_i}[x,mT], \tau_{n_i}[x,mT], \xi_{n_i}[x,mT]$, the infrastructure requires the following information:

- State vector for each vehicle $n_i \in \mathcal{N}$ $\vec{SV}_{n_i}[mT] := (p_{n_i}[mT], v_{n_i}[mT], h_{n_i}[mT])$.
- Initial and desired final position $(f_0^{n_i}, f_f^{n_i})$ for each vehicle n_i
- Road network information and cost coefficients $\beta_{j,l}[mT]$, $\gamma_{j,l}[mT]$ for each path.

Moreover, each individual vehicle in this scenario is also able to take evasive and safety decisions on its own and without the assistance of the infrastructure, as a way to improve the safety against disconnections, following the principles of implicit coordination [26].

C. Global Utility Function

Once the coalitions are formed and the coalitional function is maximized, we proceed in a way where the global utility function is enhanced by the centralized architecture. In practice, due to the communication limitations, in both range and reliability, the number of members for each platoon is limited. In order to obtain an optimal system where all the different coalitions help to maximize the general utility function, the cost coefficients $\beta_{j,l}[mT]$ and $\gamma_{j,l}[mT]$ are estimated using the infrastructure. These parameters provide external information to the players in order to adjust their payoff function. The chosen coefficient will be the one maximizing the general utility function, even if it is not optimal for the individual or coalition utility function. The use of an infrastructure contributes to add global perception to the system, along with the distributed perception of each individual vehicle.

IV. Simulation Results

In oder to validate the theoretical framework introduced in the previous sections, a realistic simulation is implemented. The simulation is performed considering a road network as depicted in Fig. 3, and its equivalent in graph form as shown in Fig. 4. The graph-form network is formed by the nodes (roadway points), and the weights of the edges connecting these nodes. The vehicles are generated using a Poisson distribution, and the initial and final node of each vehicle are chosen randomly from the entire set of nodes. The communication scheme parameters for the simulation are shown in Table I.

TABLE I: Simulation Parameters

Parameter	**Value**
Frequency	5.9 GHz
Transmission Power	23 dBm
Max. Vehicle Speed	50 $\mathrm{km\,h^{-1}}$
Number of vehicles	40

For the simulation parameters, the values presented in Table I were considered to be the standard values used in vehicular communications. In order to obtain a realistic simulation, we have also taken into consideration the limitations of the road network and the communication scheme as analyzed in

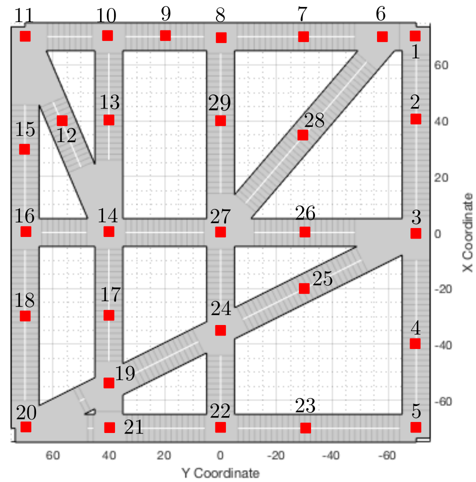

Fig. 3: Roadmap for the simulation example.

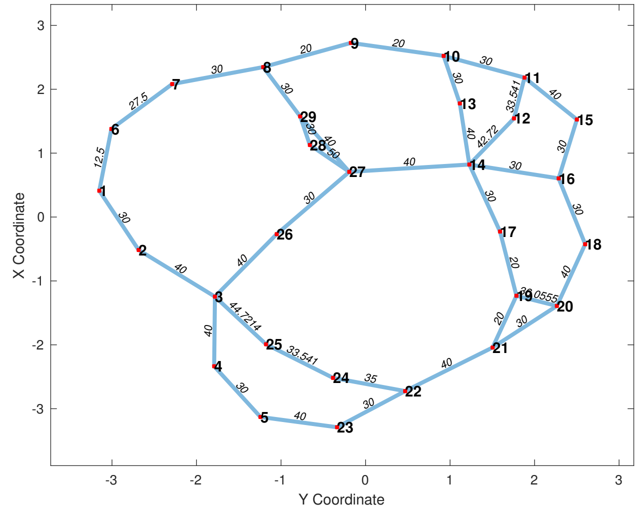

Fig. 4: Graph form of the network including the weights for each edge.

Section II. The proposed model is compared with two different approaches. The first one is the simplest routing algorithm, based on the shortest path, with no incentives to create platoons, and no inter-vehicular communication to optimize the traffic flow. The second approach is published in [17]., which includes an incentive for a certain number of trucks in order to form platoons. This scheme has no centralized architecture, and additionally, does not optimize the traffic flow by means of minimizing the inter-vehicular distance. The goal of our game-theoretical approach is to motivate the creation of platoons, hence we aim to route most of the vehicles by the same routes to motive the creation of coalitions, nevertheless avoiding extreme congestion. Additionally, the second goal is to minimize the time to destination of the vehicles, i.e., use the platoon formations and the global perception to detect the fastest routes for the particular vehicles. Therefore, the first parameter to analyze is the load per path, and additionally compare it with the other two approaches as shown in Fig. 5.

TABLE II: Statistical Analysis for the load per path.

	Mean	**Std. Dev. (SD)**
No Incentive Scheme	31.7724	8.3413
Truck Incentive Scheme [17]	28.5292	10.8876
Proposed Incentive Scheme	25.8265	10.3222

The simulation results show a lower mean load per path (see Table II) in our scheme compared to the other two, which results in a minimization of the overall network costs. Moreover, in comparison with the no incentive scheme, the standard deviation is higher indicating the incentive to drive in some paths over others in order to create platoons. Regarding the scheme proposed in [17], the mean load per path is higher than in our case, due to the lack of an inter-platoon optimization scheme, and that not every vehicle has the equipment to form coalitions. Moreover, the statistical analysis, in Table II, shows the improvement in network costs obtained by means of the infrastructure.

The second parameter under consideration is the mean travel time to destination for the vehicles as shown in Fig. 6. The goal of this parameter is evident, minimize the average time to destination for the vehicles. The statistical analysis shown in Table III presents that our proposed scheme outperforms both the no incentive scheme and the one proposed in [17]. It is noteworthy to mention that our scheme achieves the best results not only in average time travel to destination, but also with the smallest standard deviation which is the indicator of a fair game, i.e., no vehicle is left starving. Furthermore, this parameter shows that introducing incentives in the network, in order to form platoons, improves the overall network performance in terms of average time to destination.

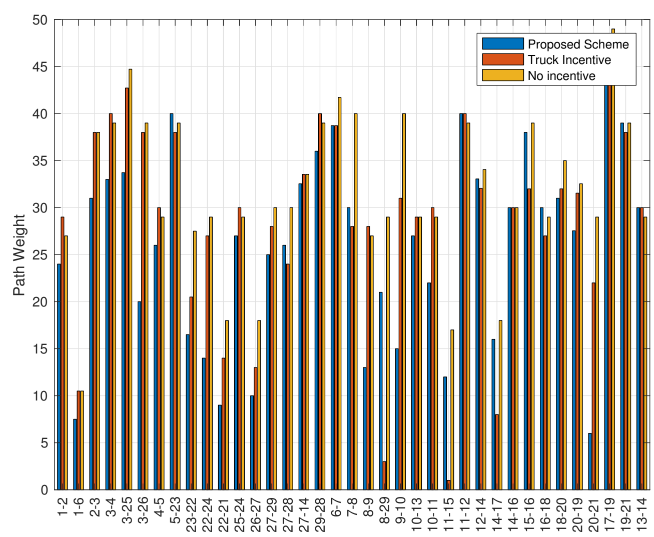

Fig. 5: Load for each path comparing the three schemes.

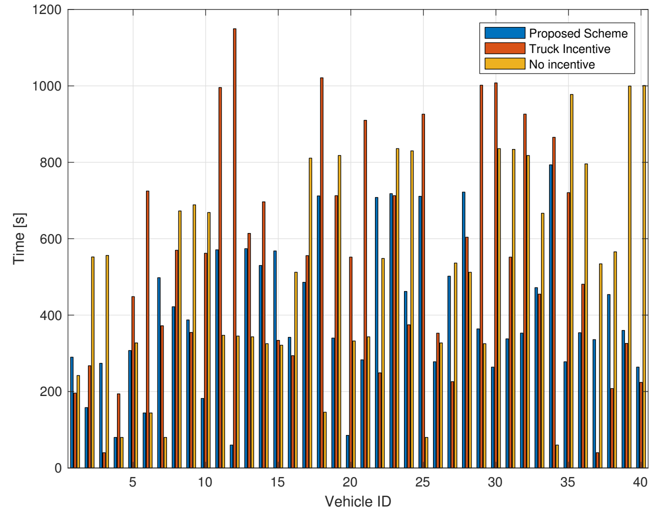

Fig. 6: Travel time to destination for each vehicle comparing the three schemes.

TABLE III: Statistical Analysis for trip time to destination

	Mean [s]	Std. Dev. (SD)
No Incentive Scheme	60.3190	32.2963
Truck Incentive Scheme [17]	54.5467	29.7141
Proposed Incentive Scheme	40.0651	19.0869

V. Conclusion

In this paper, we propose a coalitional game-theory approach designed to offer incite the formation of platoons under realistic communication constraints. Once the platoons are created, the management and safety conditions are handled by V2V and V2I communication schemes. It has been demonstrated that the best way to optimize the traffic flow and safety is prioritizing the creation of platoons, which are optimized under a global coalitional game. The overall performance of the network is improved in terms of traffic efficiency and network load, although it may go to the detriment of individual utility functions. The main contribution of this work is to establish a theoretical framework which incites the creation of platoons, and consequently increase the safety and traffic throughput, while showing an improved network performance.

References

[1] S. Hassler, "Self-driving cars and trucks are on the move [spectral lines]," *IEEE Spectrum*, vol. 54, no. 1, pp. 6–6, January 2017.

[2] Mobileye. (2015) Collision avoidance system. protecting your fleet and improving your bottom line. [Online]. Available: http://www.mobileye.com

[3] Google Inc., "Google self-driving car project," 2016.

[4] U.S Department of Transportation. National Highway Traffic Safety Administration, "The automatic emergency braking (aeb) or autopilot systems may not function as designed, increasing the risk of a crash," 2016.

[5] R. Hult, G. R. Campos, E. Steinmetz, L. Hammarstrand, P. Falcone, and H. Wymeersch, "Coordination of cooperative autonomous vehicles: Toward safer and more efficient road transportation," *IEEE Signal Processing Magazine*, vol. 33, no. 6, pp. 74–84, Nov 2016.

[6] 3GPP, "3rd generation partnership project: technical specification group radio access network:study on LTE-based V2X services (release 14)," 2016.

[7] R. Blasco, H. Do, S. Shalmashi, S. Sorrentino, Y. Zang, "3GPP LTE Enhancements for V2V and Comparison to IEEE 802.11p," in *11th ITS European Congress, no. EU-SP0264*, 2016, pp. 6–9.

[8] A. Vinel, "3GPP LTE Versus IEEE 802.11p/WAVE: Which Technology is Able to Support Cooperative Vehicular Safety Applications?" *IEEE Wireless Communications Letters*, vol. 1, no. 2, pp. 125–128, April 2012.

[9] A. Turnwald, D. Althoff, D. Wollherr, and M. Buss, "Understanding human avoidance behavior: Interaction-aware decision making based on game theory," *International Journal of Social Robotics*, vol. 8, no. 2, pp. 331–351, 2016.

[10] R. McNeill Alexander, "Energetics and optimization of human walking and running: The 2000 raymond pearl memorial lecture," *American Journal of Human Biology*, vol. 14, no. 5, pp. 641–648, 2002.

[11] S. Bitgood and S. Dukes, "Not another step! economy of movement and pedestrian choice point behavior in shopping malls," *Environment and Behavior*, vol. 38, no. 3, pp. 394–405, 2006.

[12] N. Lyamin, Q. Deng, and A. Vinel, "Study of the platooning fuel efficiency under ETSI ITS-G5 communications," in *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, Nov 2016, pp. 551–556.

[13] K. Y. Liang, J. Mrtensson, and K. H. Johansson, "Heavy-duty vehicle platoon formation for fuel efficiency," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 4, pp. 1051–1061, April 2016.

[14] C. Zhang, Y. Zang, J. A. L. Calvo, and R. Mathar, "A novel v2v assisted platooning system: Control scheme and mac layer designs," in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Montreal, QC, Canada, Oct. 2017.

[15] J. Rios-Torres and A. A. Malikopoulos, "A survey on the coordination of connected and automated vehicles at intersections and merging at highway on-ramps," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 5, pp. 1066–1077, May 2017.

[16] F. Farokhi and K. H. Johansson, "A game-theoretic framework for studying truck platooning incentives," in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, Oct 2013, pp. 1253–1260.

[17] A. Gattami, A. A. Alam, K. H. Johansson, and C. J. Tomlin, "Establishing safety for heavy duty vehicle platooning: A game theoretical approach," *IFAC Proceedings Volumes*, vol. 44, no. 1, pp. 3818 – 3823, 2011, 18th IFAC World Congress.

[18] T. Sandholm, K. Larson, M. Andersson, O. Shehory, and F. Tohm, "Coalition structure generation with worst case guarantees," *Artificial Intelligence*, vol. 111, no. 1, pp. 209 – 238, 1999.

[19] D. Ray, *A game-theoretic perspective on coalition formation*. Oxford University Press, 2007.

[20] T. Arnold and U. Schwalbe, "Dynamic coalition formation and the core," *Journal of Economic Behavior & Organization*, vol. 49, no. 3, pp. 363 – 380, 2002.

[21] K. R. Apt and A. Witzel, "A generic approach to coalition formation," *International Game Theory Review*, vol. 11, no. 03, pp. 347–367, 2009.

[22] M. Hölzl, N. Koch, M. Puviani, M. Wirsing, and F. Zambonelli, "The ensemble development life cycle and best practices for collective autonomic systems," in *Software Engineering for Collective Autonomic Systems*. Springer, 2015, pp. 325–354.

[23] B. Van Arem, C. J. Van Driel, and R. Visser, "The impact of cooperative adaptive cruise control on traffic-flow characteristics," *IEEE Transactions on Intelligent Transportation Systems*, vol. 7, no. 4, pp. 429–436, 2006.

[24] R. J. Aumann and B. Peleg, "Von neumann-morgenstern solutions to cooperative games without side payments," *Bull. Amer. Math. Soc.*, vol. 66, no. 3, pp. 173–179, 05 1960.

[25] R. J. Aumann and J. H. Dreze, "Cooperative games with coalition structures," *International Journal of Game Theory*, vol. 3, no. 4, pp. 217–237, Dec 1974.

[26] A. Espinosa, J. Lerch, R. Kraut, E. Salas, S. M. Fiore, and J. A. C. bowers (editors, "Explicit vs. implicit coordination mechanisms and task dependencies: One size does not fit all," 2002.