An Advanced Coordination Protocol for Safer and more Efficient Lane Change for Connected and Autonomous Vehicles

Jack Hodgkiss, Soufiene Djahel, Yassine Hadjadj-Aoul

An Advanced Coordination Protocol for Safer and more Efficient Lane Change for Connected and Autonomous Vehicles

Jack Hodgkiss∓, Soufiene Djahel∓, and Yassine Hadjadj-Aoul‡
∓School of Computing, Mathematics and Digital Technologies, Manchester Metropolitan University, UK
‡Univ Rennes, Inria, CNRS, IRISA, France
{jack.hodgkiss@stu.mmu.ac.uk, s.djahel@mmu.ac.uk, yassine.hadjadj-aoul@irisa.fr}

***Abstract*—In this paper we will explore novel ways of utilizing inter-vehicle and vehicle to infrastructure communication technology to achieve a safe and efficient lane change manoeuvre for Connected and Autonomous Vehicles (CAVs). The need for such new protocols is due to the risk that every lane change manoeuvre brings to drivers and passengers lives in addition to its negative impact on congestion level and resulting air pollution, if not performed at the right time and using the appropriate speed. To avoid this risk, we design two new protocols, one is built upon and extends an existing protocol, and it aims to ensure safe and efficient lane change manoeuvre, while the second is an original solution inspired from mutual exclusion concept used in operating systems. This latter complements the former by exclusively granting lane change permission in a way that avoids any risk of collision. Both protocols are being implemented using computer simulation and the results will be reported in a future work.**

***Keywords* – ITS, Smart Cities, Connected and Autonomous Vehicles (CAVs), Road Safety.**

I. Introduction

The continuous evolution of urbanization and the associated increase in the fleet of vehicles make our cities more and more congested. This evolution incites the research community to rethink the current organization and management of services offered to cities inhabitants, such as transport and energy supply and consumption, in particular through a more intensive use of Information and Communication Technologies (ICT).

In the field of transport, Intelligent Transportation Systems (ITS) are certainly one of the most important building blocks to relieve roads (i.e. reducing traffic congestion) and make commuters journeys safer and more pleasant. ITS could be, indeed, used in different ways to optimize vehicles' circulation, such as making traffic light sequence more dynamic, increasing or decreasing the maximum speed in an area or re-routing traffic away from a road incident. ITS could also be very useful in alerting emergency services in the event of an accident, while helping them to arrive as quickly as possible by, for example, controlling traffic lights so that a Green route is created for the emergency vehicle, which will reduce the emergency services response time allowing for an increase in survival rates for all those involved in this event [1].

The introduction of Connected and Autonomous Vehicles (CAVs) technology will certainly be a major step towards making ITS more efficient. In fact, these vehicles could interact faster and in more efficient way with the traffic management system to better control and mitigate traffic congestion, increase road safety and reduce air pollution [2]. They may also coordinate with one another over a communication medium using an agreed protocol to safely and efficiently undertake advanced vehicular manoeuvres.

Vehicle-to-Vehicle (V2V) communication technology is currently being developed by the automotive industry to allow vehicles to communicate with one another through establishing a wireless Ad-Hoc network operating in the 5.9 GHz frequency band. The inclusion of V2V communication in vehicles, more specifically CAVs, will make it possible to go even further in optimizing road traffic not only by reducing journey times but also by improving safety through a local collaboration of vehicles. This paper focuses on such aspect by exploiting the periodic exchange of beacon messages between vehicles as well as between vehicles and the road infrastructure to make lane change, which is considered as one of the major sources of road incidents, a safer and more efficient manoeuvre.

Enhancing lane change manoeuvre safety and efficiency has been the subject of several contributions in the literature. The authors, in [3], proposed an algorithm for advanced driver assistance system (ADAS) that enables autonomous vehicles to calculate not only the lane manoeuvre but also; if it is desired and when it should take place. Although it is efficient, this solution may not meet the needs of all drivers due to safety constraints. In fact, a successful ADAS must be capable of adapting not only to the vehicle but also to the driver behavior, as stated in [4]. Thus, a personalized ADAS is needed to improve the effectiveness and ultimately its widespread use to reduce the collisions rate when performing lane change manoeuvres. To overcome the full customization issue, which makes the lane change manoeuvre a very complex problem given the diversity of drivers and their behaviour, we propose in this paper a novel lane change protocol, underpinned by an original lane change permission management solution, exploiting the collaboration between vehicles as well as the support of the road infrastructure.

The remainder of the paper is organized as follows. Section II gives an overview on lane change manoeuvre and outline its main safety requirements. In Section III, we describe in detail

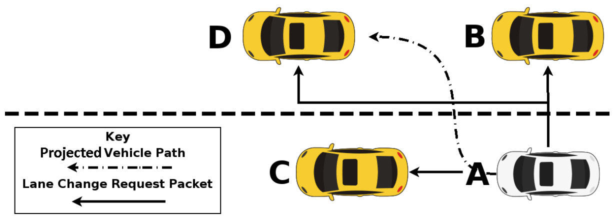

Fig. 1. The first stage in a lane change manoeuvre

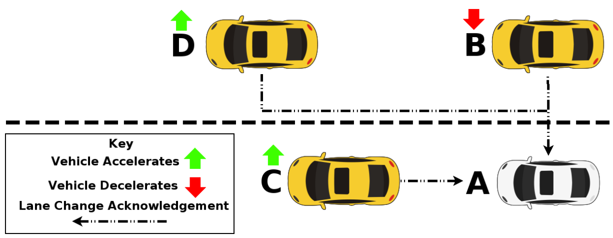

Fig. 2. The second stage in a lane change manoeuvre

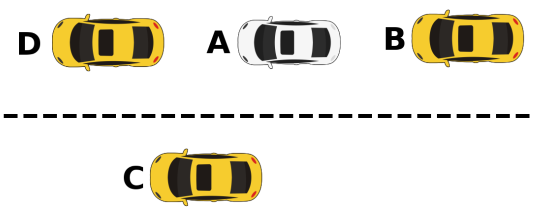

Fig. 3. The final stage in a lane change manoeuvre

the key idea and operations of our two proposed protocols. In Section IV, we conclude the paper and present our future work plan.

II. Lane change manoeuvre

In this Section, we will briefly present the different steps involved in a lane change manoeuvre as well as the main requirements for undertaking it in a safe manner.

A. An overview

Fig. 1 illustrates the first stage within the lane change manoeuvre, where vehicle *A* intends to move to the lane at its right. Before it can do this there must be a sufficient gap between its target position and the vehicles surrounding that area. To create this gap the vehicle *A* can broadcast its intention to change lane using IEEE802.11p beacon messages, as defined in the Wireless Access in Vehicular Environments (WAVE) Standard [5], to nearby vehicles.

Fig. 2 shows the second stage in the lane change manoeuvre, where vehicles; *B*, *C* and *D* respond to vehicle *A*'s request to change lane acknowledging its reception and confirming their willingness to cooperate with it to make this manoeuvre safe and efficient. Such cooperation includes adjusting their position based on vehicle *A*'s current position and its projected position in the target lane, by accelerating or decelerating, if needed.

The final stage within the lane change manoeuvre is depicted in Fig. 3, where vehicle *A* has successfully changed its position to move to the target lane between vehicles *B* and *D*.

B. Safe lane change requirements

For any lane change procedure to be safe and efficient it must meet a number of requirements. The first requirement would be that all vehicles involved in a lane change (e.g., vehicles A, B, C and D shown in Figures 1, 2 and 3,) should follow the driving policies precisely such as not exceeding the speed limit enforced within the area and using indicators to alert nearby human drivers and pedestrians of their intention to change lane. Moreover, any dangerous lane change manoeuvres to be undertaken by two vehicles in close proximity should be avoided/postponed till it is safe to do so. Another requirement would be that vehicles in the target lane should cooperate by creating an adequate gap by either accelerating or decelerating until the available space is sufficient and guarantees the safety distance. Finally, this lane change procedure should minimize the negative impact on traffic by performing this manoeuvre as fast as possible without risking human lives in addition to avoiding halting the traffic flow in the target lane or the vehicle's current lane.

III. Proposed protocols

Although a number of works have been proposed in the literature, which use inter-vehicles coordination to safely undertake a lane change or other manoeuvres, such as [4], [6] and [7], their performance is still limited in terms of either the achieved efficiency or safety level. Therefore, we present in this Section our two complementary protocols aiming to overcome the above limitations.

A. How to acquire a Lane change permission?

Here, we propose an original protocol to efficiently manage the lane change permission requests sent by vehicles intending to move a new lane. In this protocol the ability to change lane (towards a specific lane in case of a road with more than two lanes in each direction) within a given road segment is considered as a shared resource, similar to threads competing to read/write a shared data in operating systems where mutual exclusion is required, among all vehicles moving in the same direction. Therefore, the autonomous vehicles will act as if the ability to change lane is a resource shared throughout the vehicular network and once one vehicle, e.g., A, has its ownership no other vehicle in its close proximity can attempt a lane change manoeuvre until the ownership is released by A after completing its manoeuvre.

If the ability to change lane is currently held by another vehicle then all other vehicles must wait until it has been released back to the network. The vehicles will gain access to the resource of changing lane by forming a list operating on the first in first out (FIFO) principle in order to ensure no vehicle gets stuck waiting to have access.

This protocol has been proposed as it is believed to improve safety of lane change manoeuvres as it would ensure that within close-proximity no two vehicles may change lane simultaneously as this may result in a collision. There exists a number of challenges that must be solved before implementing this protocol. Firstly, this protocol requires that close-proximity is accurately defined since the resource is shared

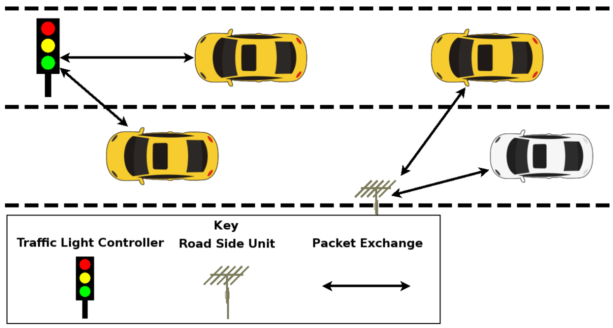

Fig. 4. Illustration of the exchange between Traffic Light Controllers (TLC)/Road Side Units (RSU) and autonomous vehicles to check the state of the lane change capability (locked or available)

among nearby vehicles. Secondly, a robust mechanism that efficiently manages the shared resource (i.e. the capability of changing lane) and enforces its rules among all vehicles is required.

One way to define the scope of close-proximity is to consider the following conditions that should be met. Two vehicles, A and B, are in close-proximity if they are; (i) moving in the same direction, (ii) within communication range of each other, (iii) located either in the same lane or in two adjacent lanes, and (IV) using other on-board sensors such as LIDAR. Once these conditions are met, the rules of our proposed protocol need to be enforced to prevent any vehicle from changing lane without owning of this capability (i.e., permission to change lane) as this may lead to fatal consequences. To this end, we propose to split the road into a set of segments on which individual vehicles may request and acquire ownership of lane change capability. This would be implemented by creating a structure managed by either the Traffic Light Controller (TLC) or the Road Side Unit (RSU) that holds “road segment id”, “lock value” and “vehicle id”. This structure would allow all vehicles within the network to look-up a given road segment to determine if they are capable of taking ownership of the lane change capability or have to enter some blocked state waiting until the resource is released by the current owner. The TLC and RSU shall be used to store the state of a given road segment and relay this information to vehicles checking if they can change lane in addition to other vehicles confirming that a given vehicle can change lane, as illustrated in Fig. 4. Algorithm 2 describes how lane change requests are handled in this protocol.

Fig. 5 illustrates two possible scenarios where a road segment has more than two lanes in each direction. In this case, we distinguish two situations where a lane change manoeuvre undertaken by more than one vehicle can take place simultaneously. Vehicles ‘A’ and ‘C’ may change their current lane and move to lanes 3 and 1, respectively, as even though they are departing from the same lane they are targeting two different lanes, which significantly reduces the risk of a collision. However, vehicle ‘B’ may not undertake a lance change at this moment as it may collide with Vehicle ‘A’ if they both attempt this manoeuvre simultaneously.

Algorithm 1: Handling Lane Change Cooperation Requests sent by neighboring vehicles

Data: $\mathrm{R_{lanes}}$: Set of lanes used throughout the current request (i.e., the current lane of the requester vehicle and its target lane); $\mathrm{C_{lane}}$: Current lane of the vehicle processing the request (i.e. the receiver vehicle); LRT: (Last Request Time) refers to the amount of time passed since the last request within the network was processed; $\mathrm{Threshold}$: the amount of time required to pass before another lane change can take place (for safety reasons)

```
if (C_lane ∈ R_lanes) then
    if ((CurrentTime - LRT) < Threshold) then
        Reject lane change request and ask the requester
          to retry after Threshold + LRT
    else
        if (Lane Change Permission was granted by
          TLC/RSU) then
            Process Lane Change request and cooperate
        else
            Ignore this request as it is not valid
        end
    end
else
    Ignore lane change request
end
```

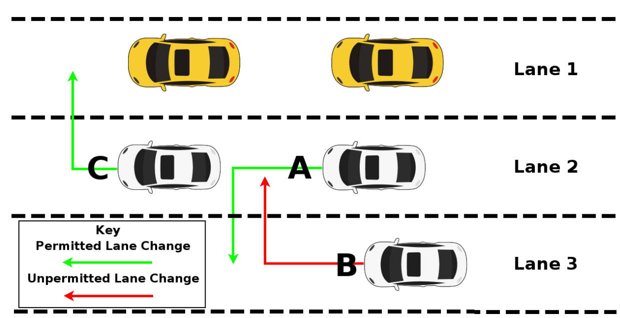

Fig. 5. Illustration of two lane change scenarios: permitted (vehicle A and C) and forbidden (vehicle A and B)

B. ILACH+

Once the capability of changing lane is acquired by a vehicle it then executes ILACH+. This protocol is an extension and improvement of the Intelligent Lane CHange assistant (ILACH) protocol proposed in [8]. Before presenting the main features of ILACH+ we will first briefly describe the key working principle of ILACH.

ILACH was developed to assist drivers in safely changing lanes to prevent fatal collisions on highways. It employs inter-vehicle communication capabilities to periodically collect data about neighbor vehicles for awareness purposes. Such data ranges from location, speed, direction and destination information. Each vehicle running ILACH uses this data to determine the distance between itself and its projected new location within the target lane known as D_{switch}, the time needed for the vehicle to reach this location in the target lane known as

T_{switch}, and the distance between the position in the target lane the vehicle is aiming for and the first vehicle within that lane known as D_{gab}. These values are used by ILACH protocol to determine if it should recommend an immediate lane change to the driver (or autonomous vehicle), or change the speed of the vehicle to allow the vehicle blocking/preventing the lane change to pass.

In ILACH+, we propose to improve ILACH by enabling collaboration between vehicles to achieve high safety and efficiency level when changing lanes. This means that instead of just recommending whether to change lane or not, as in ILACH, ILACH+ assists the vehicle to make lane change happen while respecting all safety and efficiency requirements. This is done by adding a new feature to ILACH whereby the vehicle intending to change its current lane can request and receive assistance from the nearby vehicles in both lanes (its current lane and its target lane). The vehicles in the target lane make appropriate adjustments to their speed to create an adequate gap for the requester vehicle while the vehicle in front of it, for example, accelerates to let it adjust its speed to move to the target lane. This feature has been proposed as it is not always possible for the vehicle intending to change lane to adjust its speed due to traffic density level within its current lane and the lack of collaboration between vehicles.

It should still default to rely on the vehicle with the desire to change lane to adjust its speed whenever possible without requiring further assistance, if the traffic conditions in both lanes permit. However, if traffic conditions are not in its favor then it should request assistance from the appropriate vehicles, using inter-vehicle communication, which in turn will make some adjustments to their speed by either accelerating or decelerating and then alerting the requester vehicle about the changes made so that it can initiate the lane change manoeuvre. Another benefit that ILACH+ brings is that it also notifies the surrounding vehicles of a vehicle's intention to change lane so that any receiver vehicle would postpone its lane change, if it desires to move to the same target lane, to prevent any possibility of collision or slowing down other vehicles[1]. By including this feature surrounding autonomous vehicles may anticipate the vehicle's manoeuvre and prepare for this scheduled event, leading to higher efficiency and safety level. The main operations of ILACH+ are summarized in the Algorithm 1.

Algorithm 2: ILACH+ main operations

Data: V_i: the vehicle intending to change its current lane; $V_i \cdot S$: current speed of vehicle i; $Lane_1$: the current lane of V_i; $Lane_2$: the lane that V_i intends to move to (i.e., target lane); V_j: the first vehicle on $Lane_2$; N_{Loc}: the expected location of V_i on $Lane_2$; D_{gab}: the distance between V_j and N_{Loc}; T_{gab}: the required time for V_j to reach N_{Loc}; D_{switch}: the distance between V_i and N_{Loc}; T_{switch}: the required time for V_i to reach N_{Loc} in the case that it accelerates

1 **if** ($\dfrac{D_{\text{gab}}}{T_{\text{switch}}} < V_j \cdot S$) **then**
2   V_i is recommended to move to $Lane_2$
3 **else**
4   **if** *(V_i has the ability to adjust its own speed due to low traffic density)* **then**
5   **if** *($T_{\text{switch}} 2 < T_{\text{gab}}$)* **then**
6   V_i is recommended to move to $Lane_2$ and accelerate
7   **else**
8   V_i should decrease its speed until V_j passes it; GoTo line 1
9   **end**
10   **else**
11   V_i requests that V_j creates an adequate gap; GoTo line 1
12   **end**
13 **end**

IV. Conclusion

This paper introduced two novel complementary protocols that leverage vehicular communication to enable Connected and Autonomous Vehicles (CAVs) to perform lane change manoeuvre at the highest safety and efficiency level. The first protocol grants exclusive permission for lane change to a single vehicle within a given range and requires central management of lane change capability by the smart road infrastructure in place such as Traffic Light Controllers and Road Side Units. The second protocol, dubbed ILACH+, extends and improves an existing work by introducing the cooperation between nearby vehicles during a lane change manoeuvre. We believe that both protocols can significantly enhance safety and efficiency of lane change manoeuvre for CAVs. As a future work, we are implementing both protocols using computer simulation to test their performance under varying scenarios.

[1] Here, we assume that the penetration rate of vehicles compliant with our proposed protocols is not 100%.

References

[1] S. Djahel et al. Adaptive traffic management for secure and efficient emergency services in smart cities. In *2013 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)*, pages 340–343, March 2013.

[2] S. Djahel et al. A communications-oriented perspective on traffic management systems for smart cities: Challenges and innovative approaches. *IEEE Communications Surveys Tutorials*, 17(1):125–151, Firstquarter 2015.

[3] J. Nilsson et al. If, when, and how to perform lane change maneuvers on highways. *IEEE Intelligent Transportation Systems Magazine*, 8(4):68–78, winter 2016.

[4] V. A. Butakov and P. Ioannou. Personalized driver/vehicle lane change models for adas. *IEEE Transactions on Vehicular Technology*, 64(10):4422–4431, Oct 2015.

[5] Ieee standard for wireless access in vehicular environments (wave) – multi-channel operation. *IEEE Std 1609.4-2016 (Revision of IEEE Std 1609.4-2010)*, pages 1–94, March 2016.

[6] M. Bashiri and C. H. Fleming. A platoon-based intersection management system for autonomous vehicles. pages 667–672, June 2017.

[7] A. Petrillo et al. A collaborative control strategy for platoons of autonomous vehicles in the presence of message falsification attacks. pages 110–115, June 2017.

[8] M. B. Younes and A. Boukerche. A vehicular network based intelligent lane change assistance protocol for highways. In *2017 IEEE International Conference on Communications (ICC)*, pages 1–6, May 2017.