Economized Sensor Data Processing with Vehicle Platooning

Henry Hexmoor, Kailash Yelasani

***Abstract*—**We present vehicular platooning as a special case of *crowd-sensing framework* where sharing sensory information among a crowd is used for their collective benefit. After offering an abstract policy that governs processes involving a vehicular platoon, we review several common scenarios and components surrounding vehicular platooning. We then present a simulated prototype that illustrates efficiency of road usage and vehicle travel time derived from platooning. We have argued that one of the paramount benefits of platooning that is overlooked elsewhere, is the substantial computational savings (i.e., economizing benefits) in acquisition and processing of sensory data among vehicles sharing the road. The most capable vehicle can share data gathered from its sensors with nearby vehicles grouped into a platoon.

***Keywords*—**Cloud network, collaboration, Internet of Things, social network.

I. Introduction

MOBILE crowd-sensing is an emerging discipline that capitalizes sensing capabilities of mobile nodes that are capable of forming a communication network [1]. We are experiencing the dawn of vehicles as mobile sensing platforms that are networked. Among vehicles, roadside traffic units and infrastructure, and pedestrians, as needed communication clouds may form permanent or as-needed, transient communication networks as well as impromptu, transient social networks [2]-[4]. Such impromptu networks form the small world of internet of things. Rules and policies will be the preferred tools used in managing such ad hoc communication clouds and social networks facilitating sharing of information resources during driving.

An emerging technology is to allow vehicles to form a group (i.e. a platoon) where a leader vehicle (i.e. the network cluster-head) sets pace and driving lead for the remainder of the vehicles [5]. In a platoon, follower vehicles may conserve deployment of their sensory capabilities by reduced usage and reliance on their sensors. Instead, they may take instruction and driving cues from their lead vehicle. By and large, platooning increases road safety, reduces energy consumption, lowers vehicle emission rates, and it provides for driving convenience for the follower vehicle occupants. Of focal interest for us is circumscribing, gathering and processing large volumes of sensory data among a set of vehicles sharing the road. Platooning is largely intended for the coming age of driverless vehicles. However, manually driving vehicles or a mix of driverless and manual vehicles will also experience the full spectrum of platooning benefits. We will not further elaborate the myriad of desirable platooning properties such as platoon spacing, string stability, and issues that arise from interaction among multiple platoons.

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In this paper, we highlight increased efficiency for road usage and vehicle travel time that is derived from vehicles that share their sensors after they platoon. In Section II, we briefly sketch platoon formation issues codified into policies. Section III reviews categories of vehicle automation and available sensors. In Section IV, we outline the rudimentary components of modern platoons and common scenarios encountered, while the benefits of platooning are visited in Section V. Section VI offers a description of a platooning prototype that heralds a way to quantify basic platooning efficiency, and we end the paper with concluding remarks in Section VII.

II. Platooning Policy

A platoon encompasses a communication network as well as a social network that is initiated possibly by one vehicle. A vehicle that may detect the presence of other vehicles sharing a road segment with it driving in the same direction with similar driving characteristics (e.g. sharing a common speed and similar vehicle communicating and driving capabilities) for a specified window of time (e.g. 10 seconds), may propose formation of a platoon with them. Vehicles within communication range may respond to the platoon proposal. Once the proposer confirms the platooning requirements, it may announce the initiation of a platoon once it secures agreements. Henceforth, a platoon is established and will remain until either the original proposer disbands it due to changes in the driving conditions or platoon members have abandoned the platoon. A platoon may also time out and dissolve if the proposer had specified a temporal *lifespan*. The proposer may become the *leader* or a *follower* of its own suggested platoon. Leader election is a topic that is well covered elsewhere [6]. Putting this into a codified policy can be in the form of a vector composed of four attributes: <lifespan, structure, rule order, platoon-master>. The *structure* attribute specifies the scope of affected vehicles. Permissions or restrictions for exchange among vehicles form the third attribute called *rule order*, see [2]. The fourth attribute identifies a platoon-master, i.e. the vehicle that originally proposed formation of the platoon. At any given time and on any road segment, there can be many platoons independently formed in parallel. However, each vehicle is allowed to exclusively join a single platoon. Policies will manage ad hoc platoons. In vehicular settings, policies for an accident application or a weather incident would supersede platooning in order for emergency intervention of driving patterns. The platooning policy for social network exchanges may constrain myriad facets of social interconnectedness among its vehicles but this will be explored in future work.

III. Levels of Vehicle Automation

Vehicular automation is commonly divided into five levels outlined next:

Level 0: Driver only: the human driver controls everything independently, steering, throttle, brakes, etc.

Level 1: Assisted driving: assistance systems will help during vehicle operation (e.g., cruise control and adaptive cruise control).

Level 2: Partial automation: the operator must monitor the system at all times. At least one system, such as cruise control and lane centering is fully automated.

Level 3: Conditional automation: the operator monitors the system and can intervene when necessary. Safety-critical functions, under certain circumstances, are shifted to the vehicle.

Level 4: High automation: there is no need for monitoring the driver. Vehicles are designed to operate safety-critical functions and monitor road conditions for the entire trip. The functions do not encompass all driving scenarios and are limited.

Level 5: Full automation: driver-free driving.

There are no human inputs in this mode.

Fig. 1 depicts a vehicle with all possible sensors on it that are at different locations of the vehicle.

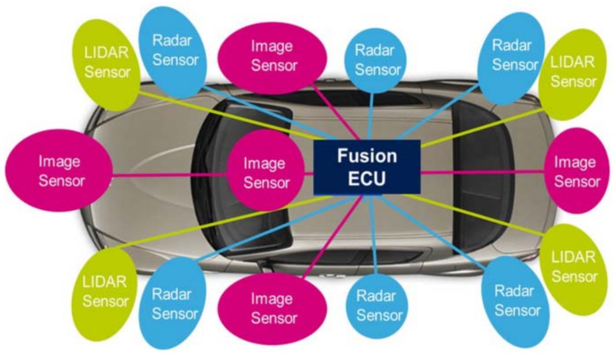

Fig. 1 Common Sensors in a Modern Vehicle

We will next briefly describe common sensor types.

Ultrasonic Sensors: Ultrasonic sensors are the sensors that emit high freqncy, and short sound pulses at regular intervals. These pulses propagate in the air at the velocity of sound. If they strike an object, then they are reflected as echo signals to the sensor, which itself determines the distance to the target based on the time-span between emitting the signal and receiving the echo. Ultrasonic sensors are suitable for target distances from 20 mm to 10 m. Vehicles use sensors to detect the obstacles in their immediate vicinity- be it vehicles, pedestrians or obstacles. They play an important role in automated parking. Distance is computed based on time of flight “t” as refer to (1)-(3).

$$d = \frac{1}{2} c\, t \quad (1)$$

$$C = C_0 + 0.6\, T \quad (2)$$

$$C_0 = 331 \text{ m/s} \quad (3)$$

C_0= speed of sound. *T*- Temperature in Celsius degrees.

Cameras: Cameras are very efficient at the classification of texture interpretation. Several cameras generate images of vehicle’s surroundings, imitating human eyesight. Rear and 360° cameras support the driver with a better representation of the environment outside the vehicle. Rear and 360° video systems usually have a centralized architecture. A central control unit processes the raw data of four to six cameras. The range varies between zero and 120 meters. These vision systems use predefined algorithms to automatically detect objects, classify them, and calculate the distance from them. These cameras can identify pedestrians and cyclists, motor vehicles, side strips, bridge abutments, and road margins. The algorithms are also used to detect traffic signs and signals. Risks of failure include Weather limitations such as fog, rain or low sun.

Radar: Radar stand for Radio Detection and Ranging, which means the detection and localization of objects using radio waves. The radar emits a radio signal (green) which is scattered in all directions (blue). The “time-of-flight” t for the signal, back to the radar gives the distance referred in (4).

$$D = C.t/2 \quad (4)$$

Radar range varies between zero and 250 meters. If the object moves, the frequency of the scattered wave changes. A doppler radar measures the shift in frequency and computes the speed (in addition to distance). Vehicles use two types of radar: Short Range Radar (SRR) and Long-Range Radar (LRR). Radars are used in blind spot detection, lane-change assistance, collision warning or collision avoidance, park assist, cross-traffic monitoring, brake assist, emergency braking, and automatic distance control.

LIDAR: LIDAR stands for Light Detection And Ranging and is a laser-based system. LIDAR sensors scan the environment with non-visible laser beam. The low intensity, non-harmful beam visualizes the distance between the vehicle and an object. LiDAR is capable of scanning over 100 meters in all directions, giving it the ability to generate an intricate 3D map of its surroundings.

Flag	Vehicle Id	Vehicle Position	Vehicle Level	Sensor Limit	Status

Fig. 2 LV Control Message

IV. A Platooning Prototype and Common Cases

For the creation of platoons, we define a leader vehicle control message that is composed of the following five fields: Flag, Vehicle_id, Vehicle_position, Vehicle_speed, and Status fields (see Fig. 2). The status of a vehicle is one of the three possible values: leader vehicle (LV), follower vehicle (FV), or no platoon. The Flag field is 2-bit long and identifies four types of control messages—the beacon message (00), the LV_Join message (01), the LV_Confirm message (10), and the LV_Leave message (11):

Beacon message (00). This is sent by LV to deliver its sensing information to its neighboring vehicles.

LV_Join message (01). This is sent y LV to the follower vehicles to request joining the platoon and following its messages as the leader.

LV_Confirm message (10). This is sent by LV to follower vehicles confirming their position in platoon and asking them to turn off (or to turn down) their vehicle sensors and follow LV messages.

LV_Leave message (11). This is sent to the following vehicles, when leader wants to leave the platoon. Once following vehicles receive this message, they turn on their own vehicle sensors and use them. A few common cases are discussed next.

A. Case One: Normal Platoon formation

When vehicles intend to create or join a platoon, they broadcast beacon messages periodically so that nearby vehicles can rapidly react to highly dynamic traffic environments. Initial status of a vehicle is *no-platoon status*. Each vehicle computes its position based on beacon messages, a vehicle with level 4 or above sends out an LV_Join message to its following vehicles within its sensor range. Level 4 is the minimum qualification requirement to be a leader. A vehicle without adequate sensor capabilities will not be qualified to be a leader guiding other vehicles in a platoon. In Fig. 3, all vehicles (V_1 to V_9) will accept the follow request irrespective of their own levels as potential to be a lead vehicle. All vehicles in sensory range of the lead vehicle will accept the request. Once the leader vehicle (V_i) receives a positive reply for its LV_Join message from all vehicles following it, (V_i) will transmit the LV_Confirm message. The LV_Confirm message adds all the following vehicles into the platoon with Leader (V_i) and commands all the following vehicles to turn off their sensors and stop using them until further commanded. This continues until (V_i) sends an LV_Leave message. If a platoon follower wishes to exit the platoon, it sends out an exit request to the leader, which then commands the vehicles in platoon accordingly. Next, the vehicle changes lane and takes the appropriate exit. Once the vehicle takes the exit, the remaining vehicles re-arrange their positions in the platoon.

B. Case Two: Multiple Platoon with Multiple Leaders

In Fig. 4, V_i and V_j are two vehicles with level 4 or level 5 and V_j is not in the sensor range or V_i. In this case, each platoon runs independently without any involvement. A platoon led by V_i commands vehicles V_1 to V_5 and a platoon lead by V_j commands vehicles V_6 to V_9

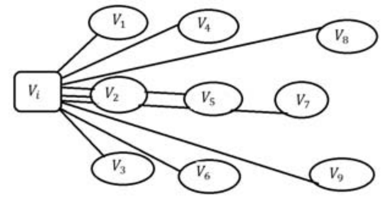

Fig. 3 Case 1: Platoon formation

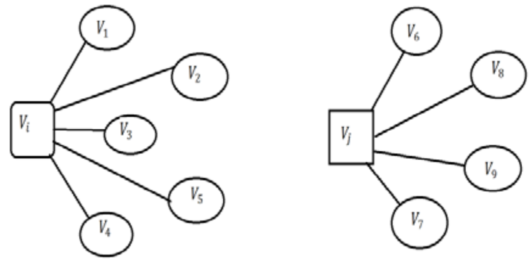

Fig. 4 Case 2: Platoon formation

C. Case Three: Cooperative Leader Platoon

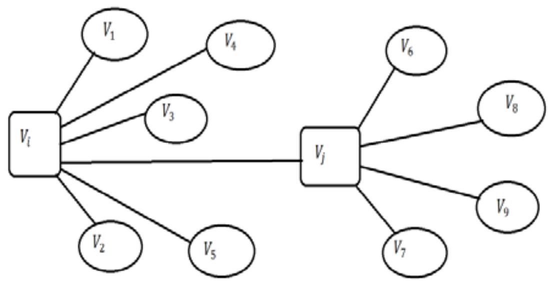

Fig. 5 Case 3 Cooperative Leader Platoon

In the situation depicted in Fig. 5, vehicle V_j is already a platoon leader and vehicles V_6 to V_9 are following it. When V_j receives the follow request from , V_j communicates with V_i saying j is leading a platoon with n vehicles. After V_i Analyzes the data and determines whether its sensor ranges can sense all vehicles in the platoon led by V_j. If all the vehicles in platoon V_j are in sensory range of the vehicle V_i, all vehicles V_1 *to* V_5, V_j , V_7, V_8, and V_9 will join the platoon with leader V_i. In the case V_i is unable to sense all the vehicles in the platoon led by V_j, it commands V_j to remain the leader of its own platoon as well as follower of it. This means V_j will be a follower of V_i and will act accordingly to commands of V_j, at the same time will sense the sensors for its following vehicles and acts as leader to them. This is so because, if a vehicle in the platoon lead by V_i may take the exit and move out of the platoon and if V_i can accommodate all the vehicles in V_j platoon they can form a single platoon.

D. Case Four: Vehicles Taking an Exit

When a vehicle in a platoon wants to take an exit on the highway and moves out of the platoon, it sends an exit request to the corresponding leader. Fig. 6 shows a platoon where vehicle "V_4" wants to take the exit. The leader commands the vehicles in the platoon accordingly so that remaining vehicles in platoon change their positions and assist the vehicle taking the exit to change lanes and move out of the platoon.

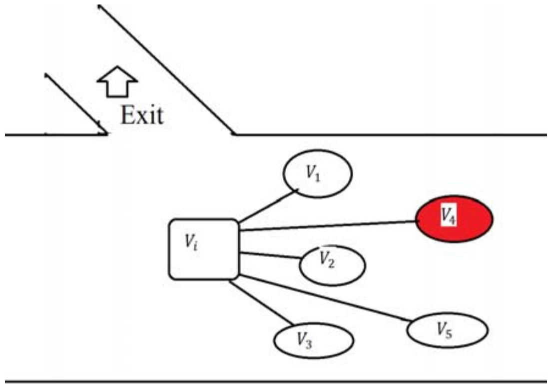

Fig. 6 Case 4: Platoon vehicle exit

E. Case Five: Vehicles Joining the Highway

When a vehicle wants to enter the highway, and is entering through an entry ramp, it sends out beacon messages to vehicles within its sensory range on the highway. As shown in Fig. 7, this information is transferred to leaders from the following vehicles if leaders are not in sensor range or a joining vehicle. In this situation, leader V_i, checks whether it can accommodate another vehicle joining its platoon, else ignores the beacon message. Leader V_j, checks the level of the joining vehicle. If it is at the same level of the leader, it may ask the joining vehicle to be a follower or become a leader. If it is of greater level than the leader, it asks the entering vehicle to be a leader and lead the platoon. If it is at a level that is lower than the leader it joins the platoon as a follower.

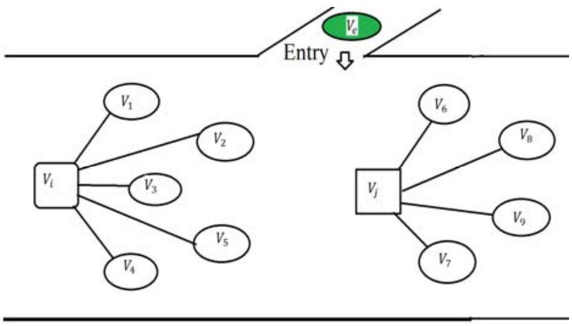

Fig. 7 Case 5: Platoon vehicle entry

V. Benefits of Platoon Formation

In a normal highway situation, each vehicle relies on its sensors to detect neighbor vehicles and obstacles on the road. It examines the data from sensors, processes the data, and performs corresponding actions for efficient and safe driving without much concern to emission or best road utilization. There are large amounts of data being processed and forwarded. Chiefly, each vehicle collects the same data set and forwards it. When one vehicle can read the data for 100 meters around it, why should this data not be shared? This is preferred to all vehicles redundantly gleaning the same data. Hence, the benefit for platooning with sensor data sharing is self-evident. With sensor data sharing, once a platoon is formed, a leader vehicle performs the work for the remainder of following vehicles in the platoon.

Various sensors are used in autonomous vehicles for obstacle detection and driving. Each and every vehicle is equipped with similarly capable sensors. Information captured from these sensors is passed to the Electronic Control Unit (ECU). The ECU reads all the incoming data, runs vehicular algorithms and yields the results. These results are passed to internal units of the vehicle for immediate execution. This information is captured, processed, and outputs the results in a few seconds, for which, we need high-end and efficient processors. Our proposed model of platooning with sensor data sharing provides a convincing solution for reducing computation and communication overhead of data processing. Once a platoon forms with a leader, the leader assumes the responsibility for all vehicles in the platoon. Sensor limits plays a crucial role in this model. The leader cannot accommodate a vehicle into the platoon which is not in its sensory range. Once the platoon is formed, the leader uses its sensors and reads the data within its sensor range. In the initial period of platoon formation, leader analyzes all the following vehicles in its platoon, gives each vehicle a unique token and a unique position in the platoon with sufficient braking distance from its neighboring vehicles. All the vehicles in the platoon are given a specific identity, specific lane, and a specific position in the platoon. All following vehicles will have a unique lane and a unique position in the platoon. Once a leader assigns IDs and positions in the platoon, it suspends processing the same data again until any of the following vehicles send out an exit request. All the vehicles are set in cruise control that is all the vehicles in the platoon move at the same speed. This is as if a *road train* is formed moving at a uniform speed among pairs of vehicles.

When a leader receives an exit request from any of its following vehicles, then it re-senses its data, runs the analysis and sends out unique commands to different vehicles in the platoon, so that a vehicle that has to take an exit, changes its lane and takes the exit. Once the vehicle makes an exit, remaining vehicles in the platoon are repositioned with different vehicle IDs. This helps reduce the enormous amount of data processing on the central processing units and improves the efficiency and reduces data usage. Along with these, simulation results showed efficiency of time, lower fuel consumption, reduction in CO_2 emission, and efficiency in road usage. We are striving toward validation of our position, and our prototype described in the next section is a modest step forward.

VI. Platoon Simulation and Results

We developed an Anylogic model with normal highway conditions and platooning conditions. Fig. 8 shows the platoon model on the normal model. We have considered a five-lane bidirectional highway with the length of 250 meters.

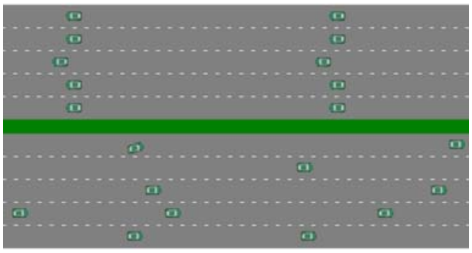

Fig. 8 A Highway with Platoon on top and normal at bottom

Simulation Parameters

1) Length of model = 250 meters.
2) Length of vehicle = 5 meters
3) Initial velocities of vehicles = 80 km/h, 70 km/h, 70 km/h
4) Preferred velocity of highway= 60 km/h
5) Acceleration= 2 meters per second
6) Deceleration= 4 meters per second
7) TimeInModel= (Total time-entry time)
8) Rate of entry = 12 vehicles per minute.

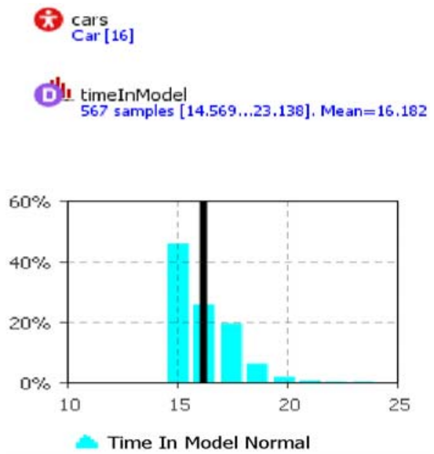

Fig. 9 TimeInModel for Normal Highway

Time taken for a vehicle to traverse the complete 250 meters highway is termed "Time in model". In normal highway conditions, vehicles enter from the left side and end on the right side of the highway, and in the platoon model, its opposite applies, i.e., starting on the right end and ending on the left end. Focusing on the lower portion of Fig. 8 where vehicles drive normally, they appear scattered without a discernible pattern, whereas in the platoon model shown in the upper portion of Fig. 8, all vehicles are organized in a respective platoon and move in fixed paths with inter-vehicular and inter-platoon distances. We have performed the simulation for different time intervals starting from 5 mins to 60 mins and all the simulations replicated similar results. For reference, we report on a 10-min simulation data. Figs. 9 and 10 show the TimeInModel for vehicles in the platoon and with normal models.

In the normal highway scenario, 567 vehicles drove the complete 250 meter highway with a TimeInModel mean time of 16.182 seconds with maximum and minimum values ranging between 23.138 seconds and 14.569 seconds. Whereas in the platooning setting, 585 vehicles completed the 250 meter highway with a TimeInModel mean value of 14.835 seconds with maximum and minimum time spanning the range of 14.906 seconds and 14.569 seconds. It is evident from the results that the interval mean of the TimeInModel is 16.113 for a normal highway model, whereas it is 14.801 for the platoon model. The difference is 1.3 seconds. In the 10-minute interval, 585 vehicles have traversed the highway; therefore, 585 multiplied by 1.3 per vehicle is 760.5 seconds. Hence, using by the platooning model, we are economized a cumulative time of 12.5 minutes of time in total.

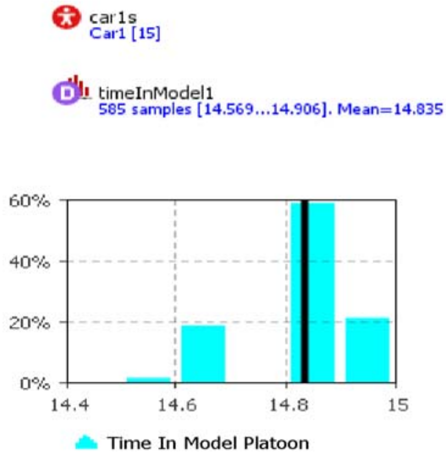

Fig. 10 TimeInModel for Platoon Highway

VII. Conclusions

We have used vehicle platooning as an instance of crowd sensing. Platooning provides many benefits including increased safety for vehicles, reduced vehicular emissions, and lower rates of sensor use by follower vehicles. Our small prototype showed a 6% saving in travel time with platooning. It is difficult to precisely quantify the amounts of sensory data acquisition and processing economized by allowing follower vehicles in a platoon to forego their own and rely on a leader vehicle to guide them. We plan to extend our work to quantify other platooning benefits as well as issues concerning multiple platoons. Other avenues for research include policies surrounding platooning and possibilities of emergent and recurring platoons.

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