5-1-2018

ECONOMIZED SENSOR DATA PROCESSING WITH VEHICLE PLATOONING

kailash kumar yadav Yelasani
Southern Illinois University Carbondale, yelasanikailash7@gmail.com

ECONOMIZED SENSOR DATA PROCESSING WITH VEHICLE PLATOONING

by

KAILASH KUMAR YADAV YELASANI

B.Tech., Jawaharlal Nehru Technological University, 2014

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Computer Science
in the Graduate School
Southern Illinois University Carbondale
May 2018

THESIS APPROVAL

ECONOMIZED SENSOR DATA PROCESSING WITH VEHICLE PLATOONING

By

Kailash Kumar Yadav Yelasani

A Thesis Submitted in Partial

Fulfillment of the Requirements

for the degree of

Master of Science

in the field of Computer Science

Approved by:

Dr. Henry Hexmoor

Dr. Bidyut Gupta

Dr. Koushik Sinha

Graduate School
Southern Illinois University Carbondale
March 26, 2018

AN ABSTRACT OF THE THESIS OF

KAILASH KUMAR YADAV YELASANI, for the Master of Science degree in COMPUTER SCIENCE, Presented on March 26, 2018, at Southern Illinois University Carbondale.

TITLE: ECONOMIZED SENSOR DATA PROCESSING WITH VEHICLE PLATOONING

MAJOR PROFESSOR: Dr. Henry Hexmoor, Ph.D.

We present platooning as a special case of crowd-sensing framework. After offering a policy that governs platooning, we review common scenarios and components surrounding platooning. We present a prototype that illustrates efficiency of road usage and vehicle travel time derived from platooning. We have argued that beyond the commonly reported benefits of platooning, there are substantial savings in acquisition and processing of sensory data sharing the road. Our results show that data transmission can be reduced to low of 3% compared to normal data transmission using a platoon formation with sensor sharing.

Key Words – cloud network, collaboration, internet of things, social network.

DEDICATION

I dedicate my thesis firstly to my family, my advisors and my friends who were with me all throughout this time. I feel gratitude for my loving parents, Uma Devi and Suresh, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve. My sister Shailaja's love and support sustained me throughout my life .

I would also like to dedicate this thesis to Dr. Henry Hexmoor and Dr. Bidyut Gupta who have been encouraging me into many new endeavors all through my time in this university. I will always remember the words of wisdom they have shared with me.

ACKNOWLEDGEMENTS

I use this very opportunity to thank my academic advisor Dr. Henry Hexmoor, who has not left any stone unturned for helping me out. This research would not have been possible without you, Professor. Thank you!

I would also like to thank my committee members Dr. Bidyut Gupta and Dr. Koushik Sinha for their immense support and guidance. I would also take this as an opportunity to thank them for reviewing my report.

I would like to thank the Department Chair Dr. Shahram Rahimi and the whole Department of Computer Science at Southern Illinois University, Carbondale for giving me a chance to perform this research and also providing me with assistantships which have helped me develop as a person professionally and financially.

Finally, I would also like to thank my friends and colleagues who have always supported and motivated me throughout my research work. It would not be possible to have continued with this research without their love and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Platooning and autonomous cars have been talked about a lot in recent years. It is estimated that currently there are more than 1 billion registered motor vehicles worldwide, and that the number will be doubled within the next 10 to 20 years. Due to an increase in the number of road users, there is a high increase in critical issues concerning the modern transport systems such as traffic congestion, traffic accidents, energy waste, and pollution. Traffic congestion is one of the key factors for the air pollution and increase of carbon emissions. Although investing in road construction may be a solution for this problem to some extent, there are limitations of huge construction costs and limited land availability. An effective approach for this problem would be changing the driving pattern from individual driving to platoon-based driving and introducing self-driving cars as 80% of accidents are caused by human error. Thus, self-driving cars will be efficient in reducing the human error rate.

Alphabet and Elon Musk were the first to introduce self-driving cars such as Waymo and Tesla. Along with these, Google and many other leading companies in the auto industry investing into self-driving cars, clearly defines the future of our transportation industry. Many leading cities like Dubai are planning to replace their existing public transport system with autonomous cars. Autonomous cars being the future gives a good scope for new contributions from researchers.

Getting into technical terms, Platoon is defined as a group of cars driving together to increase the capacity of roads. A Platoon decreases the distance between the vehicles using electronic and mechanic coupling. This would allow the vehicles to accelerate or brake simultaneously. Previous works showed that platoon-based driving can bring many benefits. As the vehicles in a platoon are at a much closer distance, road capacity can be increased, and traffic congestion decreased. The platoon pattern helps to decrease the energy consumption and exhaust emissions considerably, as the vehicles in the platoon are streamlined, resulting in minimal air drag. Driving in a platoon environment would be more safe and comfortable.

Mobile crowd-sensing is an emerging discipline that capitalizes on 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, infrastructure and pedestrians, communication clouds may form permanently or as-needed transient communication networks as well as impromptu, transient social networks [2], [3], [4]. Such impromptu networks would form a small world 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 allows 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 driven vehicles or a mix of driverless and manual vehicles will also experience the full spectrum of platooning benefits. We will not further elaborate on the myriad of desirable platooning properties such as platoon spacing, string stability, and issues that arise from interaction among multiple platoons.

CHAPTER 2

BACKGROUND ACTIVITY

Our approach in this work is to extend the existing platoon environment to economize the sensor data processed and reduce the redundancy. In this section we discuss some background work related to our approach. Vehicular ad-hoc networks (VANETs) are the building blocks for any platoon. VANETs are created by applying principles of mobile ad-hoc networks (MANETs) spontaneous creation of network with vehicles and road-side units for data-exchange. VANETs consists of In-vehicle communication, vehicle-to-vehicle (V2V) communication, vehicle-to-roadside (V2I) infrastructure, vehicle-to-broadband (V2B) cloud.

Key features of each communication type:

In-vehicle communication: Communication between all on-board units of vehicle can be called on Intra-vehicle communication. This communication places a key role, as this helps in monitoring vehicle performance and driver status. Vehicles consisting of various sensors are monitored continuously, any failure of the vehicle functions are monitored and reported using this mode of network.

Vehicle-to-vehicle(V2V) communication: Communication between two vehicles on a road, can also be called as Inter-vehicle communication. V2V communication plays a crucial role in VANETs as the critical information being forwarded is done V2V. Data shared between the vehicles include their position, speed and sensor capabilities.

Vehicle-to-roadside(V2R) units: Communication between a vehicle and road-side units. Road-side units are network nodes which are equipped to communicate with vehicles and exchange data with them. Roadside units share the important information about the road conditions. Real-time traffic, weather updates including critical information like accidents or emergencies are communicated to vehicle by these roadside units.

Vehicle-to-infrastructure (V2I) cloud: Vehicles communicate via wireless broadband mechanisms like 4G/LTE with cloud. As broadband cloud consists of more traffic information and real time vehicle tracking. Vehicles communicate with cloud to access the real time traffic information and for on board infotainment. This communication helps in active driver assistance and vehicle tracking.

VANET CHARACTERISTICS

The characteristics of VANET’s are unique compared to that of MANET’s. This distinguishing feature help VANET’s increase network performance and at the same time considerable challenges. These features include:

High Mobility

Nodes in VANET’s are usually moving at great speeds. This makes it harder to predict the nodes position from time to time. It gets tougher to ensure the node privacy.

Rapidly changing Network Topology

Due to high mobility of nodes and random speed of nodes, position of node changes frequently. As a result, network topology in VANET’s change very frequently.

Unbounded Network Size

VANET’s can be extended from small region to cities and countries. That’s the reason network size in VANET’s is geographically unbounded.

Frequent Exchange of Information

Due to high mobility of nodes and change in network topologies, nodes are forced to gather huge information from other vehicles and road-side units.

Wireless Communication

VANET’s are designed for wireless communication, hence nodes are connected, and information is shared wireless. Hence security concerns are applicable in communication.

Time Critical

Due to high mobility of nodes, information in VANET’s has to be delivered in time so that the destined vehicle can take appropriate decision. Hence delivery of messages should be meeting the requirement.

Sufficient Energy

Nodes should be equipped with sufficient energies as the consumption plays a key role in carrying out all the operations.

In VANET’s communication between the entities plays crucial role. However due to characteristics of VANET’s high mobility and network topologies existing routing algorithm used in MANET’s doesn’t not support in VANET’s. Hence researchers are not showing any interest to improve the existing algorithms instead they are coming up with new routing strategies depending upon number of vehicles in a platoon. Some of these routing strategies are unicasting, multicasting, broadcasting and geo-cast.

Unicasting

In unicasting one vehicle will send message to exactly one vehicle. If vehicle must send messages to multiple vehicles. It has to send multiple unicast messages, each message addressed to specific vehicle. Example of Uncasting routing mechanisms is greedy traffic-aware routing (GyTAR).

Multicasting

In Multicasting one vehicle sends message to group of vehicles at single instance. Multicasting routing will be very useful among group vehicles in case of roadblock, traffic slow down and accidents etc.

Broadcasting

In broadcasting one vehicle sends out messages to all vehicles within its range. This communication is helpful when we must send information to unknown destinations like roadside units. Some of the broadcasting routing mechanisms are SADV, FROV etc.

Geo-casting

Geo-casting is a special case of multicasting. In Geo-cast message is send to group of vehicles in specific geographic region. Geo-casting would be helpful when we have to send out warnings for complete geographic region.

CHALLENGES IN VANET’S

Security of VANET’s is crucial aspect many researchers are working on. While many came up with solutions to protect the network from adversary and attacks still the security in VANET’s is questioned. Let’s classify the Challenges in VANET’s:

Vehicular security challenges

Network Attacks

Denial of service attacks.

Sybill Attack.

Application Attacks

Fabrication Attack.

Alteration Attack.

Social Attack

Tunnel Attacks.

Monitoring Attack

Eavesdropping.

Vehicular Network Challenges

Mobility.

Volatility.

Privacy Vs Authentication.

Privacy Vs Liability.

Network Scalability.

Bootstrap.

Vehicular Technical Challenges

Network management.

Congestion and collision control.

Environmental impact.

MAC design.

PLATOONING

Platoon is defined as group of vehicles travelling in group to increase the road capacity. Platoon helps in decreasing the fuel consumption and carbon emission. In a platoon distance between the vehicles is reduced by electronic or mechanic coupling. This feature helps them to accelerate or brake simultaneously. Vehicles need to be deployed with latest sensors to perform above actions and normal vehicles without any network commute capabilities are not suitable.

Actors involved in platoon are leader and follower. Leader plays a important role in platoon based driving. Another important concept over here would be leader election.

Leader election, there have been many ideas involving the leader election. Each idea showing its own parameters in leader election and showing its efficiency compared to existing leader election algorithms. We will talk about a simple leader and follower platoon prototype where first vehicle in the platoon is the leader and rest vehicles in platoon are followers. The leader vehicles set the platoon into cruise control and operations by leader are replicated by the following vehicles.

Platoon can be further categorized into 4 types.

Platoon driving

In a platoon driving all the vehicles in a platoon move in a straight line resembling a road-train. All vehicles in platoon accelerate and brake at a time, these are set on adaptive cruise control. This is a basic platoon with leader and following vehicles. Leader guiding the following vehicles actions.

Platoon Splitting

After forming a platoon, if a vehicle in a platoon wants to take exist and leave the platoon, it communicates with leader and takes the exist. Once the vehicle splits from the platoon it drives on its own without any help of the leader and rest of the platoon continues the same way with leader and following vehicles.

Platoon Merging

If a vehicle joins an existing platoon, we term it as platoon merging. Once the vehicle gets into the platoon, new vehicle is controlled by the leader and commands passed by leader are executed by the joining vehicle.

Co-operative Driving

In co-operative driving, all the vehicles on the highway drive on their own without any inter-dependency. Vehicles use there own inbuild sensors to read the road side environment and take corresponding actions and mutually communicate among the neighbor cars.

Next section, we continue to extend platooning and illustrate our platoon formation.

CHAPTER 3

PLATOON FORMATION

Most important in any platoon formation is the leader election. In our work, the leader is elected depending upon the level of vehicle automation. Depending upon the make of the vehicle, features, and sensors deployed, vehicle level is determined.

Vehicles are classified from level 0 to level 5.

Level 0

These are the basic cars without any special features or sensors. There is no automation in these cars. The driver takes the full-time responsibility of the driving. The driver executes steering, acceleration and deceleration. Monitoring of environment is also done by the human. These cars are not supportive in platoon forming.

Level 1

These are assisted driving cars, level 0 cars with some system assistance. Assisted systems help one of the following operations: steering control, acceleration and deceleration. Monitoring the environment has to be done by a human. For example, vehicles only equipped with cruise control and adaptive cruise control. These cars can be idle followers in our platoon.

Level 2

Partial automated cars: these cars are partially automated, and the system can take the responsibility of all the system operations like steering control, acceleration and deceleration. A human has to perform all the other aspects of driving. Monitoring the environment is still done by the human. This can be considered a part-time autonomous car. These cars can be good followers in our platoon.

Level 3

Conditional automation: these cars are equipped with all required sensors and can take the complete responsibility of driving including the environment monitoring. Cars read the environment, control the steering, acceleration and deceleration. The human driver can intervene in the car performance whenever necessary. These cars can be good followers in our platoon.

Level 4

Highly automated, these cars are upgraded versions of level 3. These cars don't require any human monitoring. Vehicles are designed to safety critical functions and monitor road conditions. However, there are certain limitations compared to fully automated vehicles. These can be leaders in our platoon if level 5 cars are not available.

Level 5

Fully automated, these cars don't require any human monitoring, being fully equipped with all the sensors, and can drive in any critical situation. These cars make the best leaders in our platoon.

These cars are classified into levels depending upon the sensors they are built with, here are the sensors that are deployed in cars –

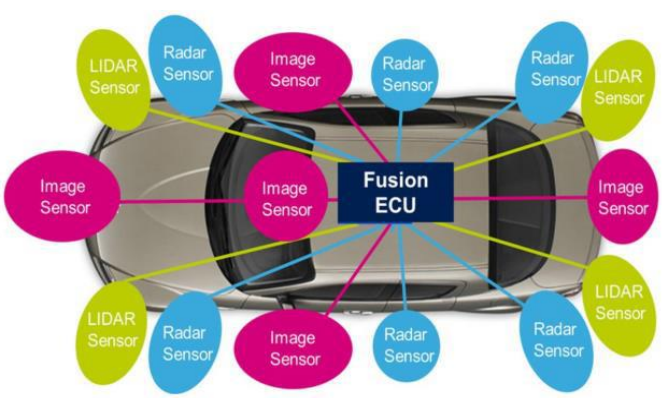

Fig 1: Common sensors in a Modern Vehicle

Ultrasonic Sensors

Ultrasonic sensors emit short, high-frequency sound pulses at regular intervals. These 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 computes 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".

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

$$C = C0 + 0.6\ T$$

$$C0 = 331 \text{ m/s}$$

$C0$= 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 the 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. Central control unit processes the raw data of four to six cameras. Range varies between 0 and 120 meters. These cameras use the algorithms to automatically detect objects, classify them, and determine the distance from them. For example, the 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. Weather limitations such as fog, rain or low sun increases risk of failure. The latest highdefinition cameras use powerful processors, which use millions of pixels per frame (some able to shoot 30 to 60 frames per second) to develop intricate imaging. Due to the large number of frames per second, this requires a high amount in megabytes of data to be processed during that second-long span. Consequently, the costs of processing power can be astronomical since manufacturers tend to cram as many cameras in different areas throughout a vehicle as possible.

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 (D) = C.t/2

Radar range varies between 0 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 Radars. Short Range Radar (SRR) and Long-Range Radar (LRR). Radars are used in blind spot detection, lane-change assistant, collision warning or collision avoidance, park assist, cross-traffic monitoring, brake assist, emergency braking, and automatic distance control.

LIDAR

LIDAR stand 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.

LEADER VEHICLE CONTROL MESSAGE

Flag	Vehicle Id	Vehicle Position	Vehicle Level	Status

Fig 2: Leader Vehicle Control Message

Leader Vehicle Control Message

For the creation of platoons, we define a leader vehicle control message that is composed of the five fields: (see Fig 2).

- Flag,
- Vehicle_id,
- Vehicle_position,
- Vehicle_speed,
- Status field

Status field in the control message which gives the information about the vehicle status. 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:

Beacon message (00),

LV_Join message (01),

LV_Confirm message (10),

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 them 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 PLATOON PROTOTYPE AND COMMON CASES.

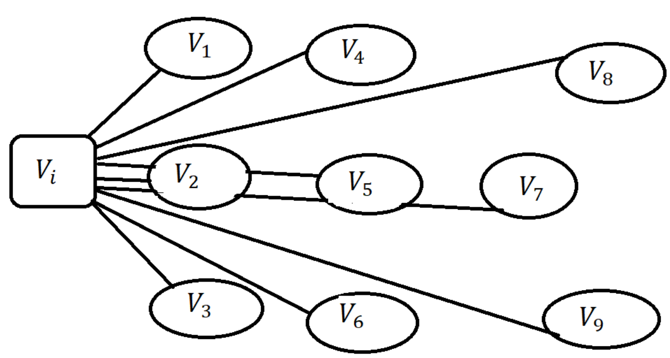

Fig 3: Case one: -Normal Platoon Formation

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 vehicle is *no-platoon status*. Each vehicle computes its position based on beacon messages, vehicle with level 4 or above send out a 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 (V1 to V9) 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 (Vi) receives positive reply for its LV_Join message from all vehicles following it, (Vi) will transmit the LV_Confirm message. LV_Confirm message adds all the following vehicles into platoon with Leader (Vi) and commands all the following vehicles to turn off their sensors and stop using them until further commanded. This continues until (Vi) sends LV_Leave message. If a platoon follower wishes to exit the platoon, it sends out an exit request to leader and the leader commands the vehicles in platoon accordingly. Then, the vehicle changes lane and takes the appropriate exit. Once the vehicle takes the exit, remaining vehicles in platoon re-arrange their positions in the platoon.

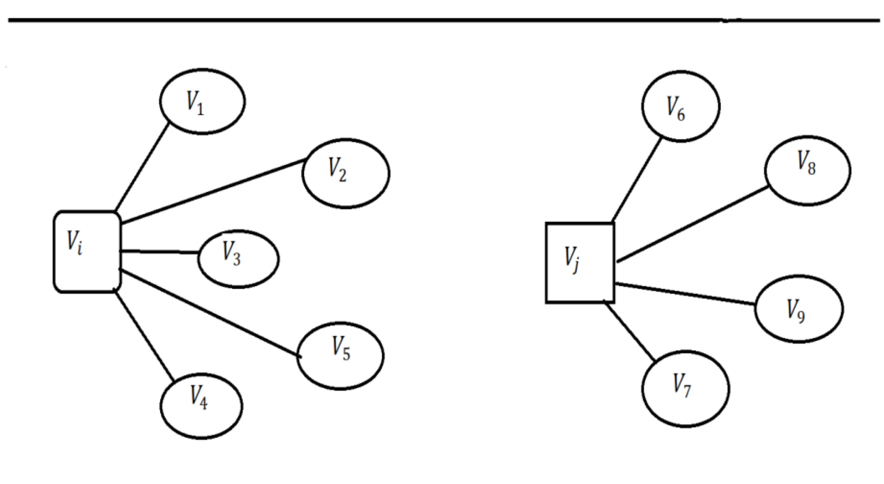

Fig 4: Case two: -Multi Platoon with Multi Leaders

Case two: Multi Platoon with Multi Leaders

In Fig 4, Vi and Vj are two vehicles with level 4 or Level 5 and Vj is not in the sensor range or Vi. In this case, each platoon runs independently without any involvement. Platoon lead by Vi commands vehicles V1 to V5 and platoon lead by Vj commands vehicles V6 to V9.

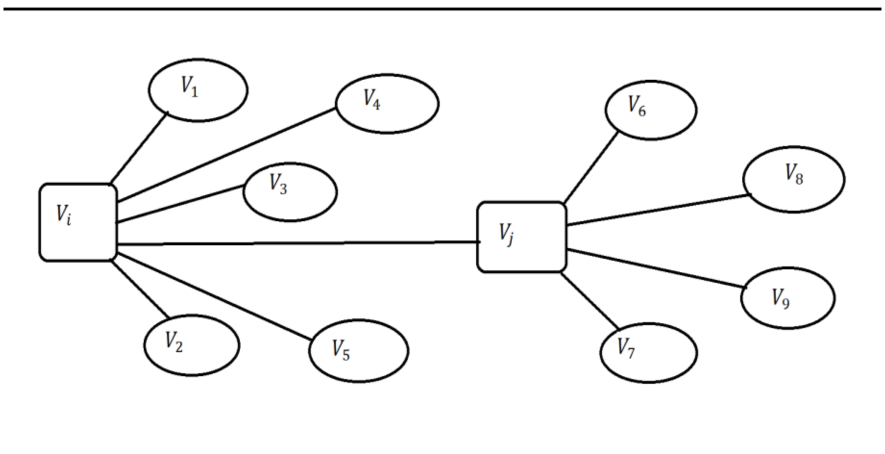

Fig 5: Case Three: - Cooperative Leader Platoon

Case Three: Cooperative Leader Platoon

In the situation depicted in Fig 5, vehicle Vj is already a platoon leader and vehicles V6 to V9 are following it. When Vj receives the follow request from Vi. Vj communicates with Vi saying j is leading a platoon with n vehicles. After Vi Analyzes the data and determines whether its sensor ranges can sense for all vehicles in the platoon lead by Vj. If all the vehicles in platoon Vj are in sensory range of the vehicle Vi, all vehicles V1 to V5, Vj, V7, V8, and V9 will all join the platoon with Leader Vi. In case Vi is unable to sense all the vehicles in platoon lead by Vj, it commands the Vj to remain the leader of its own platoon as well as follower of it. This means Vj will be a follower of Vi and will act accordingly to commands of Vj, at the same time will sense the sensors for its following vehicles and acts as leader to them. This is so because, if vehicle in platoon lead by Vi may take exit the move out of platoon and if the Vi can accommodate all vehicles in Vj platoon they can form a single platoon.

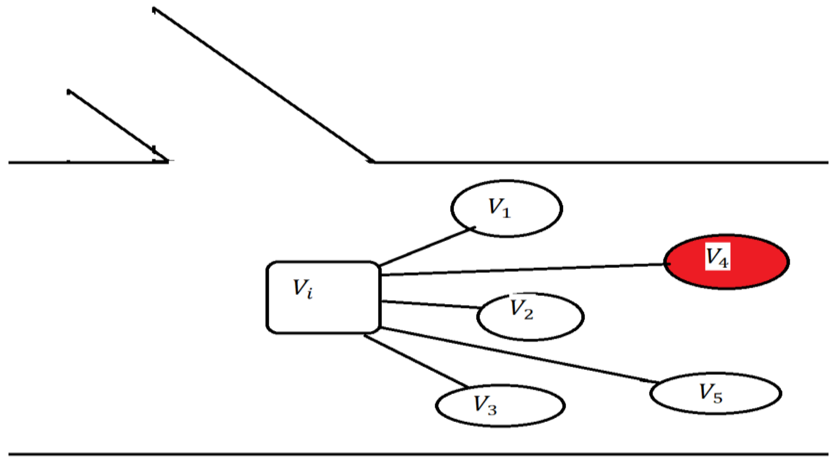

Fig 6: Case Four: - Vehicles Taking an Exit

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 "V4" wants to take the exit. "The leader commands the vehicles in 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.

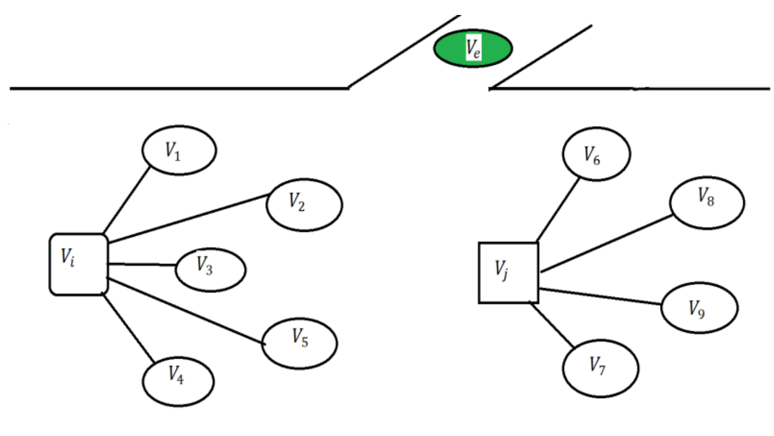

Fig 7: Case Five: - Vehicles Joining the Highway

Case Five: Vehicles joining the Highway

When a vehicle wants to enter the highway, and is entering the 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 following vehicles if leaders are not in sensor range or joining vehicle. In this situation leader Vi, checks whether it can accommodate another vehicle joining its platoon, else ignores the beacon message. Leader Vj, 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.

CHAPTER 4

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 for 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 preferable 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). 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 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 play 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, the 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. Once the 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, i.e 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 the vehicle which has to take an exit changes the lane and takes the exit. Once the vehicle makes an exit, the remaining vehicles in the platoon are repositioned with different vehicle IDs. We can observe the changes using the following example.

Cars in Normal Highway situation

In-vehicle On-board communication

Each car uses its sensors to sense its surrounding vehicles and neighborhood. Data from cameras, LIDAR, RADAR and sensors is read and sent to ECU (Electronic Control Unit). Data sent to ECU is processed and forwarded to neighbor vehicles. Challenges involved here:

High amount of secure data to be processed.

Enormous energy is consumed.

Very low processing time (In milliseconds).

High chances of bottleneck situations.

Results after processing should be accurate.

Error rate should be zero.

Vehicle to vehicle communication

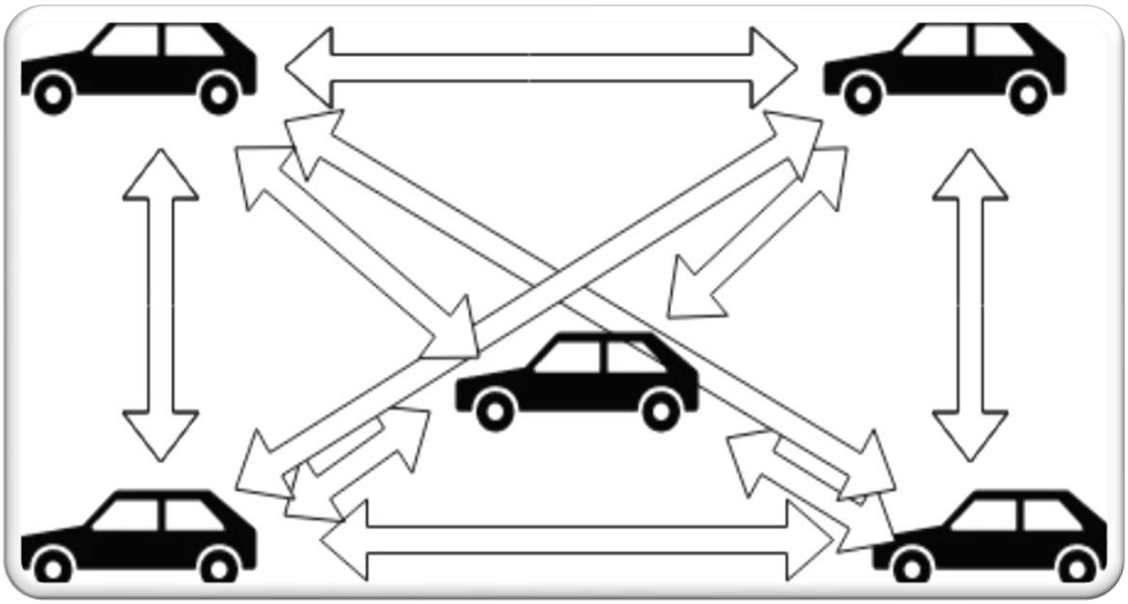

Fig 8: Transmissions between cars on a highway

Considering a highway with 5 cars.

Each vehicle transmits data to all other vehicles. Each car transmits data to 4 other cars. So, 5 cars with 4 transmissions each in a single session will be 20 transmissions. In a given session time there will be n(n-1) transmissions, where n = number of cars on highway.

Considering the Platoon situation

On board data communication

Once the car gets into a platoon, it will be either be a leader or follower. If the given car is a Leader, it resembles the same amount of work done by each vehicle in normal highway situation with additional job of assigning unique IDs and positions of following cars in a platoon.

If it's a follower, it does zero job once it gets into a platoon. It stops sensing data and processing until it's in a platoon. This method helps in reducing the challenges faced in non-platoon highway. Advantages of this method are:

Reduced Energy usage and power consumption.

No performance bottlenecks

Reduction in error rate.

Vehicle to vehicle communication on a Platoon

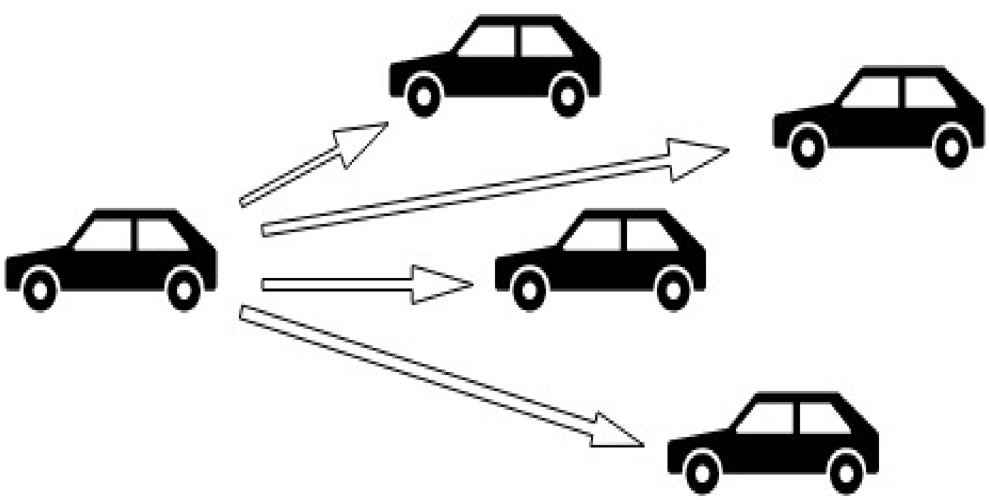

Fig 9: Transmission between cars in a Platoon

From the figure, we can see the leader vehicle sends the instructions to the following vehicles from the data processed in ECU. All the followers accept the instructions and don't reply back. At a single session there will be 4 transmissions. So, if there are n vehicles in a platoon on highway there will be (n-1) transmissions.

Platoon data transmission with real time examples.

Average highway speed is 70 Miles Per Hour, which is equal to 102.7 Feet Per Second. Let's assume there will be 10 sessions of data transmissions in a single second and highway length is 1 mile. For simple understanding we are just considering 5 vehicles on a highway of 1 mile. So the time taken by these cars to cross the highway at a speed of 70 miles per hour, which is 102.7 foot per second, is 51.07 seconds.

Table 1: Transmissions comparison for different no. of cars.

No. of cars	Time	No. of sessions	Transmissions in Highway	Transmissions in Platoon	Percentage
4	51	510	6120	1530	25
5	51	510	10200	2040	20
6	51	510	15300	2550	16.6666667
7	51	510	21420	3060	14.2857143
8	51	510	28560	3570	12.5
9	51	510	36720	4080	11.1111111
10	51	510	45900	4590	10

Calculations for normal highway situation.

No. of Transmissions in session = n(n-1) = 5*4= 20

No. of sessions per second = (s) = 10

Time taken for cars to cross the highway = t

Total No. of sessions in time elapsed = (S) = t * s = 51.07 * 10 = 510.7

Total No. of transmissions = S * [n(n-1)] = t*s*n(n-1)

= 510.7 * 20

= 10214

Table 2: Transmission comparison for different Time Intervals.

No. of cars	Time	No. of sessions	Transmissions in Highway	Transmissions in Platoon	Percentage
5	51	510	10200	2040	20
5	102	1020	20400	4080	20
5	153	1530	30600	6120	20
5	204	2040	40800	8160	20
5	255	2550	51000	10200	20
5	306	3060	61200	12240	20
5	357	3570	71400	14280	20

Calculations for Platoon highway.

No. of Transmissions in session = n-1 = 5-1 = 4

No. of sessions per second = (s) = 10

Time taken for cars to cross the highway = t

Total No. of sessions in time elapsed = (S) = t * s = 51.07 * 10 = 510.7

Total No. of transmissions = S * (n-1) = t*s*(n-1)

= 510.7 * 4

= 2042.8

That total transmissions in a platoon situation is just 3.33% compared to that of normal highway situation. Performing similar calculations for normal highway and platoon by increase number of cars and number of miles. These results show enormous benefits in platoon highway model. Table [1], [2] shows results of these calculations. Table [1] consists of data for total number of transmissions in normal highway model and platoon model for 1-mile length of highway with cars ranging from 4 to 10. As the number of vehicles on highway increase, there is exponential increase transmissions for normal highway model whereas for a platoon model its linear increase. Percentage of platoon model transmissions to normal highway model is decreasing exponentially as the number of vehicles is increasing. Similarly, from table [2] results, we can observe that for fixed number of cars and increase in highway distance, percentages of platoon transmissions to normal highway transmissions is same.

Benefits from platoon-based highway are:

High efficiency with singe processor

Very low cumulative processing time

Very low amount of data to forward

No data duplication, save on redundant data

Low latency and high throughput

More accuracy and zero errors

Less energy consumption.

Along with these, simulation results showed efficiency of time, lower fuel consumption, reduction in co2 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.

CHAPTER 5

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 250 meters.

Table 3: Simulation Parameters.

Parameter	Value
Length of model	250 meters.
Length of vehicle	5 meters
Initial velocities of vehicles	80Kmph, 70Kmph, 70Kmph
Preferred velocity of highway	60Kmph
Acceleration	2 meters per second square
Deceleration	4 meters per second square
TimeInModel	(Total time-entry time)
Rate of entry	12 vehicles per minute.

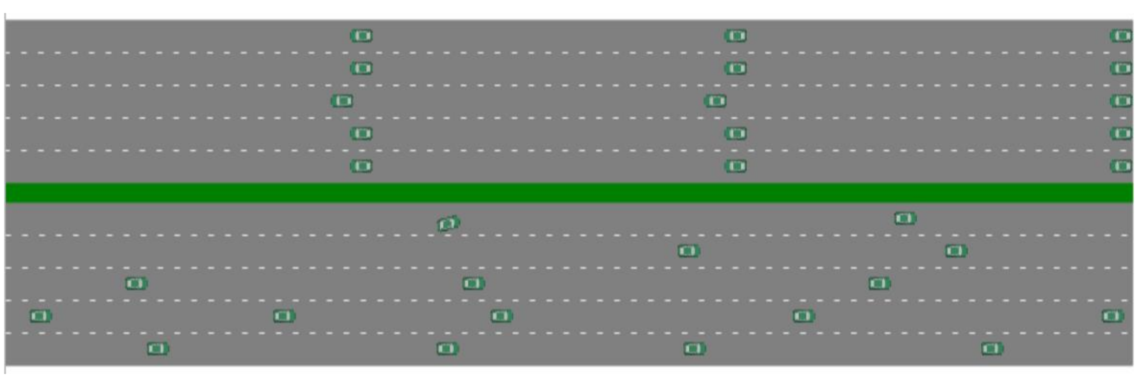

Fig 10: A Highway with Platoon on top and normal at bottom

Time taken for a vehicle to traverse the complete 250 meters highway is termed “Time in model”. In Normal highway condition vehicles enter from the left side and end on the right side of the highway and in platoon model its opposite applies, i.e., starting on the right end and ending on the left end. Focusing on the lower portion of figure 8 where vehicles drive normally, they appear scattered without a discernable pattern whereas in platoon model shown in the upper portion of figure 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. Fig 9 and fig 10 show the TimeInModel for vehicles in the Platoon and with normal models.

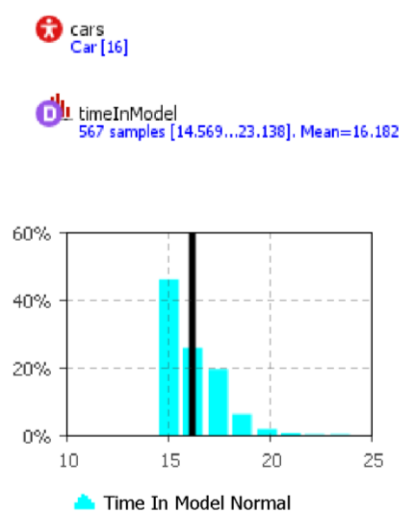

Fig 11: TimeInModel for Normal Highway

In the normal highway scenario, 567 vehicles drove the complete 250 meters highway with 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

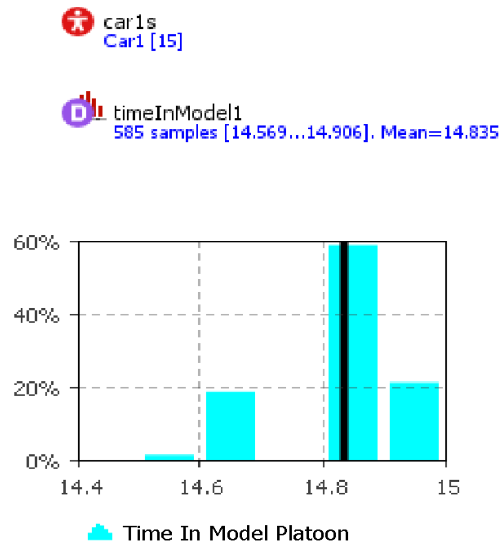

Fig 12: TimeInModel for Platoon Highway

completed 250 meters highway with 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 interval mean of 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 platooning model we are economized a cumulative time of 12.5 minutes of time in total.

CHAPTER 6

CONCLUSION AND FUTURE WORKS

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.

REFERENCES

[1] L.G., James, I. vergara-Laurens, A. Rajj, 2015. A Survey of Incentive Techniques for Mobile Crowd Sensing, in IEEE INTERNET OF THINGS JOURNAL, VOL. 2, NO. 5, pp. 370-380, IEEE.

[2] H. Hexmoor, B. Gupta, 2017a. Policies Guiding Cohesive Interaction among Internet of Things with Communication Clouds and Social Networks, In the Second IEEE international Workshop on Communication, Computing, and Networking in Cyber Physical Systems, pp. 32-36, ICDCS-2017, IEEE press.

[3] H. Hexmoor, B. Gupta, B., 2017b. Social Life Amidst the Internet of Things, In 32nd International Conference on Computers and Their Applications (CATA-17), pp. 253-258, ISCA press.

[4] A. M. Vegni and V. Loscrí, "A Survey on Vehicular Social Networks," in IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2397-2419, Fourthquarter 2015.

[5] L. Xu, L. Y. Wang, G. Yin, and H. Zhang, 2014. Communication information structures and contents for enhanced safety of Highway Vehicle Platoons," IEEE Trans. Veh. Technol., vol. 63, no. 9, pp. 4206–4220, IEEE press.

[6] D. Su, S. Ahn, 2017. In-vehicle sensor-assisted platoon formation by utilizing vehicular communications, International Journal of Distributed Sensor Networks, Vol. 13, No. 5, pp. 1-12. Sage press.

[7] A. Awang, K. Husain, N. Kamel and S. Aïssa, "Routing in Vehicular Ad-hoc Networks: A Survey on Single- and Cross-Layer Design Techniques, and Perspectives," in IEEE Access, vol. 5, pp. 9497-9517, 2017.

[8] LEVELS OF VEHICLES LEARNED FROM

https://www.sensorsmag.com/components/three-sensor-types-drive-autonomous-vehicles

VITA

Graduate School
Southern Illinois University

Kailash Kumar Yadav Yelasani

yelasanikailash7@gmail.com

Jawaharlal Nehru Technological University,
Bachelor of Technology in Computer Science, May 2014

Thesis Title:
Economized sensor data processing using vehicle platooning.

Major Professor: Dr. Henry Hexmoor