Applications of Vehicular Communications for Reducing Fuel Consumption and CO_2 Emission: the State of the Art and Research Challenges

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***Abstract*—Environmental problems, such as pollutions, become more intensive every year. One of the major causes is a higher fuel consumption and CO_2 emission. In year 2009, 23 percent of CO_2 emission globally comes from land transportation systems, which is equal to 7,000 million tons of CO_2. This large amount of pollution gas must be reduced to slow down global environmental problems. Reduction of fuel consumption and CO_2 emission in land transportation systems, which will have immediate positive economical and environmental impacts, has become an important part of green technology to alleviate global warming due to human activities. Intelligent Transportation Systems (ITS), which aims at applications of Information and Communication Technology (ICT) in the transportation systems, has offered unique opportunities for the green ITS. This article aims to provide a survey of the latest published applications as well as the envisaged technical challenges in this research area.**

***Index Terms*—Green technology, traffic light-to-vehicle communication, TLVC, fuel consumption, CO_2 emission, intelligent transportation system, Green ITS, vehicular communications**

I. Introduction

EVIRONMENTAL problems become a serious concern for the mankind. Huge amount of pollution is released every year due to the growth of world economics, resulting in the global warming problem. There are several attempts to alleviate the global warming, such as uses of alternative natural energy; solar, wind, and water energy. However, the investment of natural energy production is very high and gives low return rate for industries. As a result, this approach is not yet achieved.

According to statistics, more than 30,000 million tons of CO_2 is emitted each year [1]. As shown in Fig. 1a, North America is the number one continent of fuel consumption and CO_2 emission, which approximately releases 14-16 tons of CO_2 per resident each year. Europe as the second highest CO_2 emission continent, are also responsible for the global warming problem with roughly almost 8 tons of emission.

The global CO_2 emission roughly comes from five sources; electricity and heat, transportation, industry, residential, and other as illustrated in Fig. 1b. It is noticed that approximately one-fourth of world CO_2 emission (7,000 million tons) is a result of the land transportation systems. Reduction of CO_2 emission in the transportation systems forms a part of solutions to alleviate the environmental problems.

ITS projects provide several underline supports for applications related to the transportation systems. Electric and hybrid vehicles are one of the attempts to reduce the amount of fuel consumption and CO_2 emission in the land transportation systems. Even though there were some commercial electric and hybrid vehicles released recently, they do not meet user's requirements yet and need further development. For example, they are relatively expensive and have limitations in terms of speed, recharging process, etc.

The other possibility for fuel consumption and emission reduction is an application of vehicular communications for more efficient land transportation systems. In order to reduce the amount of CO_2, vehicles may cooperate with each and road infrastructures by means of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The information exchange will make drivers aware of possible stops ahead, such as stops during red light period. Recent research [2] has shown that vehicular communications can be used to advise drivers in order to optimize their driving and avoid unnecessary stops to reduce fuel consumption and CO_2 emission. For example, via the communication with a traffic controller, drivers are able to learn a traffic light schedule in advance and adjust vehicles' speed to hit a green light period without stops resulting in higher energy efficiency.

Other examples of ITS based applications are electronic toll collection, cruise control, platooning, cooperative driving systems, etc. Most of the applications require information exchange and hence need a support of vehicular communications.

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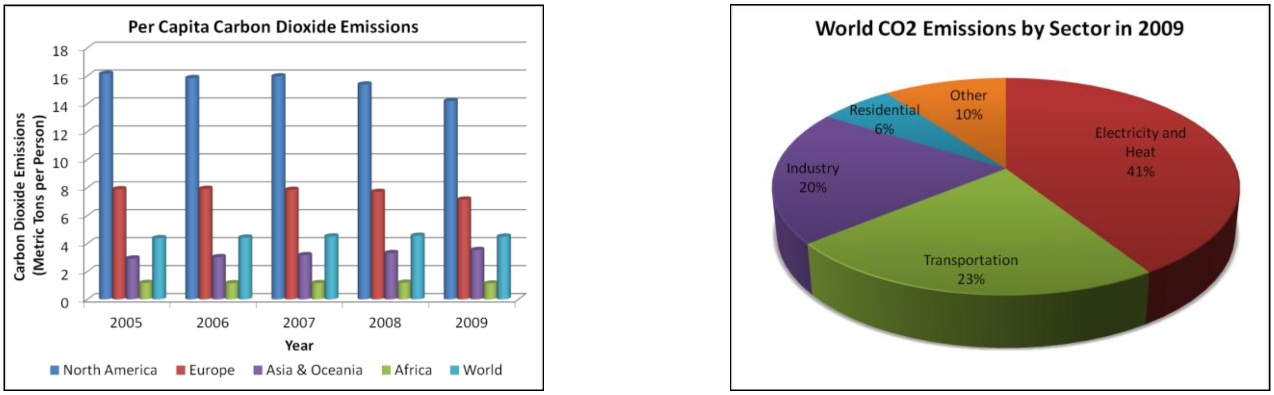

(a) CO_2 emission per capita categorized by continental area from 2005 to 2009

(b) World CO_2 emissions by sector in 2009

Fig. 1 World CO_2 emission statistics (Source from [1])

The main focus of this article is to review the state of the art of green applications based on ICT for fuel consumption and CO_2 emission reduction in the land transportation systems. ITS applications for energy efficiency are presented in section II. Section III surveys the state of the art on applications based on vehicular communications for fuel consumption and CO_2 emission reduction. Challenges, issues, and future trends of research are highlighted in section IV. Finally, section V concludes the article.

II. ITS's Fuel Efficiency and CO_2 Emission Reduction Approaches

Fuel efficiency and CO_2 emission reduction approaches can be broadly categorized into two categories; traffic reduction, as well as fuel consumption and CO_2 emission reduction as shown in Fig. 2.

A. Traffic Reduction

The traffic reduction approach aims to directly reduce the number of vehicles used by residents which causes intense traffic density. To achieve this aim, each city may need to be convenient and have a good city plan; major places are in walking distances. The number of vehicles used and the amount of fuel consumed by residents will be decreased since they choose to walk or use public transportations instead of drive.

Some cities may not be well planed, thus re-planning an existing city becomes very difficult. However, the number of vehicles and the traffic can be reduced by other means, such as a well provision of public transportations; e.g. bus, train, and boat. The public transportations can easily reduce the amount of fuel consumption by transporting a large number of people at the same time. This will be achieved only if there are enough number, good quality and service, and reasonable cost of the public transportations for passengers.

The other solutions may be a promotion of a driving behavior, such as car pool and car sharing. People who tend to travel on a same route can possibly travel together with the same vehicle to reduce number of vehicles in the traffic.

B. Fuel Consumption and CO_2 Emission Reduction

Some people may not be comfortable to walk, use the public transportation systems, or do car sharing with others. Thus, the number of vehicles cannot be reduced in this case. However, instead of reducing the total number of vehicles as aimed by the traffic reduction, the amount of fuel consumption and CO_2 emission can also be decreased by others approaches; drivers' behavior promotion, vehicles and highways improvement, as well as applications of vehicular communication technology.

1) Drivers' Behavior Promotion: basically, people would like to reach destinations as soon as possible. However, the fast-driving is not fuel-efficient. In contrast, traffic congestion can also delay the journey leading to fuel-inefficiency. Therefore, driving too fast or even too slow consumes larger amount of fuel consumption and hence lower the efficiency in term of gas mileage; an indicator shows how far vehicles move per one unit of fuel consumption.

Fig. 3 shows fuel and CO_2 efficiencies of gasoline vehicles. At low vehicular speed, the gas mileage is quite low. This means that the vehicles cover only a short distance by consuming one gram of fuel. However, when the speed of vehicles increases, the gas mileage increases, but the gas mileage will start decrease, when speed passes the threshold again. Consequently, the optimal speed of fuel efficiency is at 55-60 km/h approximately. Driving faster or slower than this speed will decrease the fuel efficiency.

The similar bell-shaped tendency is observed in term of CO_2 efficiency. The CO_2 efficiency is a measurement of how far the vehicles move per one gram of CO_2 emission. The higher value of CO_2 efficiency gives the better performance. It is noticed that moving too slow or too fast also emit unnecessary amount of CO_2. The optimal point of CO_2 efficiency is close compared to fuel efficiency at 60-70 km/h.

Therefore, the recommendation speed for the gasoline vehicles should be between 55-70 km/h. Drivers should be educated to change their driving behaviors according to the recommendation driving speed.

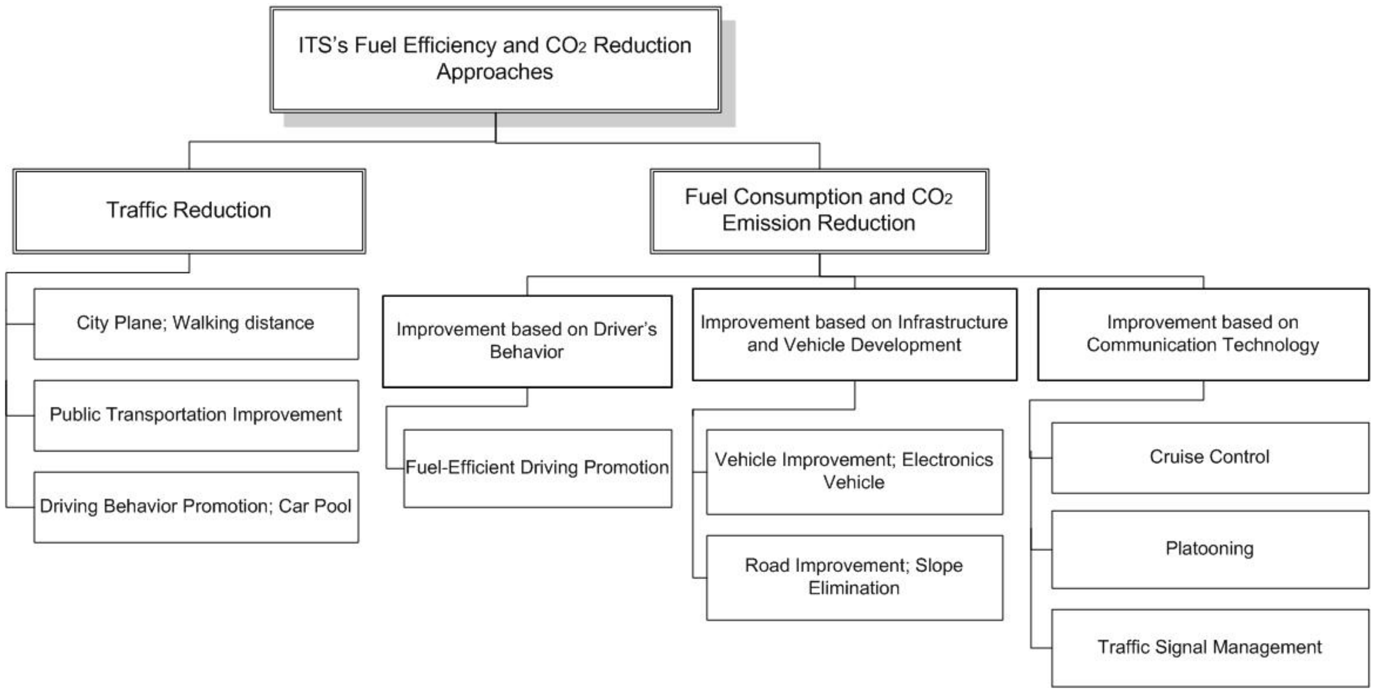

Fig. 2 ITS's fuel efficiency and CO_2 emission reduction approaches

2) Vehicle and Highway Improvements: vehicles and highways play a major role in fuel saving. Low performance vehicles; unchecked vehicles, may consume higher amount of fuel than frequently-checked vehicles. Thus, all vehicles must be checked for performance as frequently as possible.

Besides, due to the advance in vehicular technology, in future, hybrid and electric vehicles will be other alternatives for fuel saving by utilizing a combination of fuel and electricity energy together. Even though the price of such vehicles is high nowadays, we believe that in the near future the price will be dropped due to a mass production. People will afford to buy them, leading to less fuel consumption.

Conditions of roads and highways also affect fuel consumption and CO_2 emission. Road and highway's surface is one major factor affecting fuel consumption and CO_2 emission in the land transportation systems. Vehicles, especially truck and bus, generally cause deflection of road's surface. The surface deflection absorbs a part of vehicles energy and causes larger amount of fuel consumption and CO_2 emission. Therefore, less flexible materials, such as concrete, are more preferable to make road's surface than softer materials, such as asphalt.

Too many or too sharp slopes also make drivers accelerate and decelerate vehicles frequently. Frequent speed-changing results in low fuel and CO_2 efficiencies. Therefore, these slopes must be avoided during a design of roads and highways as well.

3) *Applications of Vehicular Communication Technology:* applications of ICT [4], such as cruise control, platooning, and traffic signal management, can also help to promote fuel consumption and CO_2 emission reduction.

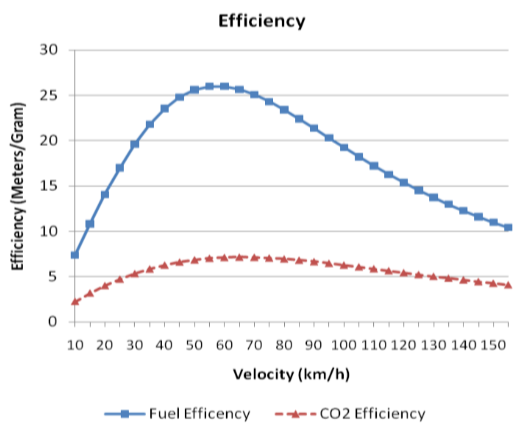

Fig. 3 Efficiencies of gasoline vehicles [3]

a) Cruise Control

Fuel consumption and CO_2 emission can be reduced by making road traffic flow continuously. Cruise control is one possible solution to smooth traffic, increase road capacity, and avoid traffic congestion in road and highway.

An Adaptive Cruise Control (ACC) assists drivers by automatically adjusting vehicles speed to keep distance between each pair of vehicles as constant as possible. According to emerging technology in vehicular communications, ACC is further developed to Cooperative Adaptive Cruise Control (CACC). By exchanging information among vehicles, the drivers can cooperate with the others to make the overall traffic much smoother than that provide by ACC.

Entrances of expressway normally become traffic bottle-neck, because drivers usually are not aware of these entrances and tend to stop there. CACC based on vehicular communications helps to give drivers better perception of the entrances to avoid this bottle-neck. By reducing vehicles' speed in advance, the number of unnecessarily stops at the entrances is also reduced, resulting in traffic congestion alleviation and fuel consumption reduction.

b) Platooning

ITS has promoted several green applications including vehicle platooning with data propagation using vehicular communications. With the vehicle platooning; vehicles travelling together in compact groups, the vehicles can reduce an effect of air resistance and also have shorter inter-vehicle distance. Therefore, the vehicle platooning is promised to provide fuel consumption and CO_2 emission reduction as well as higher traffic capacity by automatically controlling vehicles accelerator and steering in order that the vehicles are able to travel in groups closely but safely.

Therefore, vehicle-to- vehicle communications (V2V) play an important role in providing benefit for an automated platooning system. Vehicles can obtain data used in platooning from vehicular communications which is impossible to measure via their own on-board sensors.

c) Traffic Signal Management

Vehicular fuel consumption and emission is directly related to the number of accelerations and decelerations. To reduce the number of both accelerations and decelerations, vehicles must avoid as many stops as possible, since the vehicles normally consume huge amount of fuel and emit large amount of pollution gas during slowing down to stop and speeding up to reach a free flow speed again.

There are several causes making the vehicles stop frequently. However, one of the primary causes is a traffic light. A lot of vehicles have to stop at the traffic light during a red light period and re-accelerate afterwards. This results in waste of energy and unnecessary emission, especially for heavily loaded vehicles, such as truck and bus.

Traditionally, drivers are not able to learn a schedule of traffic light in advance. They totally rely on their perceptions to estimate a green light interval. However, the driver can see the traffic light only for a short period of time and have no clues when the light will change, leading to a large number of unnecessary stops.

There are some traffic signals that light with the time remaining to switch. However, with an only short period of time shown, it is still difficult for the drivers to manage to pass the traffic light without stops. Besides, it can cause larger amount of fuel consumption and CO_2 emission, because some drivers may drastically accelerate to pass the traffic light with a short remaining time to switch.

To avoid unnecessary stops and accelerations, the drivers should be able to know the schedule of the traffic light (the whole cycle of yellow, red and green lights) in advance by means of V2I. A traffic light controller periodically broadcasts the light scheduling information to vehicles in its vicinity called Traffic Light-to-Vehicle Communication (TLVC). The drivers, who receive the light scheduling information, adjust their speeds accordingly to pass the traffic light during green light period. The idea of stop avoidance during a red light period helps to reduce vehicular fuel consumption.

However, in some cases, even the drivers know the traffic scheduling in advance, they still cannot hit a green period because they have to move very fast or very slow to pass the traffic light during the green period. As previously described, driving too fast or too slow also causes high amount of fuel consumption and CO_2 emission. Consequently, instead of one-way communication of the static traffic light scheduling; the communication from the traffic controller to vehicles only, two-way communication could be introduced to provide dynamic traffic light scheduling based on information of vehicles, such as locations and speeds at a particular time.

The traffic controller gathers information of all approaching vehicles and calculates an optimal traffic light schedule, so that most of vehicles do not have to adjust or rarely adjust the speed to hit the green light period. The traffic will become smoother compared with that of the static traffic light scheduling. In this scenario, the dynamic traffic light scheduling can contribute to additional reduction of fuel consumption and CO_2 emission.

However, due to dynamic nature of vehicular environment; varied vehicle entering and leaving rates, real time scheduling becomes very challenging and need to be carefully conducted and studied. One small error may cause an unexpected event, such as an accident.

III. The State of the Art

Information and communication technology, such as vehicular communications, enables and enhances performance of several emerging ITS based applications aiming to reduce the amount of fuel consumed and CO_2 emitted. Applications of ICT in three different categories; cruise control, platooning, and traffic light signals, become promising solutions for fuel

TABLE III
A Summary of the State of the Art on TLVC

Protocol	Main Contributions	Traffic Model	Fuel Consumption and CO_2 Emission Models	Type of Communication	Gear choices	Traffic Light Schedule	Results
EEFG	Impacts of regions of interest (ROI) on Fuel Consumption and CO_2 emission	INTEGRATION	VT-Micro	One-Way TLVC	No	Static	1) The larger ROI, the better Fuel and CO_2 reduction
GCD	Impacts of gear choices and distances from the traffic light on Fuel Consumption and CO_2 emission	VISSIM	PHEM	One-Way TLVC	Yes	Static	1) An optimal distance for TLVC is 600 m 2) The fuel and CO_2 reduction reaches up to 22% and 80% respectively 3) An implementation of gear choices for future cruise control
OTR	Impacts of unpredicted events on Fuel Consumption and CO_2 emission	Veins	EMIT	One-Way IVC	No	N/A	1) Re-routing for long-lasting events and staying on the same route for short-lasting events

consumption and CO_2 emission reduction. This section presents the state of the art of these applications.

A. Applications of ICT in Cruise Control

Several researches have been investigated in the area of CACC to improve performance of the cruise control application based on vehicular communications.

The early ACC generally deployed radar technology for measuring distance to the preceding vehicle and controller technology to control the distance to the preceding vehicle. The paper in [5] studied an improvement of traffic flow by utilizing vehicular communications for CACC. The proposed CACC utilized communication technology as well as position systems to enhance the overall performance of the application by reducing an impact of a traffic shock wave on the flow of traffic; upcoming vehicles make a chain of severe brakes due to sudden brakes made by vehicles in front. This traffic shock wave is a major cause of unsmooth traffic flow.

The investigation shows that the shock wave of the road traffic can be reduced by CACC based on the vehicular communications, because the CACC provides anticipatory brakes, and hence it can avoid severe brakes made by upcoming vehicles. This shockwave reduction results in a smother traffic flow.

In [6], CACC was proposed with direct communication with the preceding vehicle only. The proposed approach aims to deal with heterogeneous traffic by considering communication delay as well as graceful degradation of CACC when the communication fails.

The results show improvements in terms of traffic flow stability and traffic flow efficiency, since CACC provides more stable as well as shorter inter-vehicle distances, and hence yield higher traffic throughput than ACC.

Performance of CACC was also investigated in [7]. As mentioned previously, the cruise control application's performance can be improved by utilizing the vehicular communication technology. However, vehicular communications may cause communication delay due to imperfection of wireless communication channel, and this could compromise the overall performance of CACC. The paper proposed Networked Control System (NCS) framework to analyze impact of communication delay on CACC's performance.

The results show that tradeoff between the performance of CACC and communication specifications need to be made to achieve the preferred level of the overall performance.

In cruise control applications, ACC primarily manages relative speed and distance with only the closest preceding vehicle, while CACC, in contrast, collects information from many vehicles further in front and use this information to improve overall traffic flow. The paper in [8] proposed a combination of both ACC and CACC as a new cruise control approach called Mixed Cooperative Adaptive Cruise Control (MCACC). MCACC was evaluated by using different traffic and network models, such as single lane traffic with both loaded and unloaded vehicles as well as dynamic network models. Communication delay and noise were taken into consideration during the evaluation as well.

The simulation results show that MCACC achieves in providing an improvement on traffic flow characteristics. Switching between ACC and CACC modes of operation helps to make vehicles travelling close to each other. At the same time, it also helps to avoid possible collisions under any critical situations.

Table I shows a summary of cruise contril applications and study for traffic flow improvement. Main contributions, cruise control models, applied methods, as well as results of all studies are compared in the table.

B. Applications of ICT in Platooning

Vehicle platooning is also one of the promising application to provide fuel consumption and CO_2 emission reduction

The paper in [9] focused on the platooning in Automated Highway Systems (AHS). The paper also proposed an implementation of a navigation system not only for positioning, but also for providing a desired safety inter-space with both preceding and flowing vehicles. In addition, Millimeter-Wave Radar (MMWR) is implemented to avoid vehicle collisions. A measurement of preceding vehicle's positions is transmitted via vehicular communications to following vehicles. The measurement from the navigation system in conjunction with MMWR's measurement will be processed by a controller unit so that the following vehicles can maintain the safety inter-space with the other vehicles.

The simulation results show that the proposed approach can achieve in maintaining the inter-space between vehicles with low spacing error; less than 1 meter. This leads to not only the reduction of fuel consumption and CO_2 emission, but safer driving environment as well.

The paper [10] proposed a dynamic platooning management method called Filter Multicast. Filter Multicast deals with frequently changing of platooning members due to fast vehicular mobility by implementing dynamic platooning. Filter Multicast is comprised of three modules; dynamic platoon formation, platoon-filter management, and packet propagation

TABLE II
A SUMMARY OF THE STATE OF THE ART ON PLATOONING

Protocol	Main Contributions	Method	Results
AHS	Provide a desired safety inter-space	Implementation of - Navigation system - Millimeter-Wave Radar (MMWR)	1) maintaining the inter-space between vehicles with low spacing error; less than 1 meter
Filter Multicast	Deal with frequently changing of platooning members	Combination of - Dynamic platoon formation - Platoon-filter management - Packet propagation in platoon multicast	1) high packet arrival rate results in an efficient dynamic platooning with high vehicular mobility

in platoon multicast.

Dynamic platooning formation assigns different roles to different vehicles according to their communication ranges and occurred events to dynamically create platooning group. To distinguish one platoon from the others, platoon-filter management deployed dynamic platoon-ID regarding to information from inter-platoon, instead of using fixed platoon-ID as implemented in other platooning systems. The deployment of dynamic platoon-ID aims to deal with dynamic mobility of vehicles. Platoon-filter is broadcasted along with packets by each sender. This platoon filter information will be investigated by receivers to identify whether they are in the inter-platoon area or not.

The simulation results show that Filter Multicast has an accomplishment in providing low communication traffic with high packet arrival rate. This high packet arrival rate results in an efficient dynamic platooning even in an environment with high vehicular mobility.

Table II shows a comparison of both AHS and Filter Multicast in terms of main contributions, methods, and achievements of each protocol.

C. Applications of ICT in Traffic Signal Management

The idea of TLVC is quite new, and only a few numbers of research papers have been available during recent years. In this subsection, the state of the art of research based on information and communication technology, including TLVC, will be reviewed.

The article in [11] proposed new Economical and Environmentally Friendly Geocast (EEFG) protocols. The paper studied impacts of regions of interest (ROI) on fuel consumption and emission, stopping time, recommendation speed, and average acceleration rate. ROI is defined as a distance at which vehicles are informed about traffic light information by any means, such as wireless communications. The paper does not focus on a communication point of view. Therefore, it is assumed that at every defined ROI, all vehicles already received the traffic information.

This paper implements INTEGRATION as a vehicular traffic model and VT-Micro as a model for fuel consumption and emission based on real data and a prediction model with correlation coefficients ranging from 92% to 99%.

The results show that the vehicles need to be informed by the traffic light at least 1 km in advance. At ROI shorter than 1 km, vehicles do not have enough distance and time to adjust their speeds, and hence they have to stop in front of the traffic light causing large amount of fuel consumption and CO_2 emission due to unavoidable decelerations and re-accelerations. However, if the vehicles are informed within 1 km or more, they can avoid stop periods and hence reduce the amount of fuel consumption and emission drastically. Consequently, the larger ROI is defined, the better performance the protocol gains.

In [12], the authors aim to study impacts of gear choices and distances (GCD) from the traffic light at which vehicles are informed. The paper implements VISSIM as a vehicular traffic model. The VISSIM is a microscopic simulation for a multimodal traffic flow modeling, e.g. cars, buses, and trains. In addition, Passenger car and Heavy duty Emission Model (PHEM) is implemented to estimate the amount of fuel consumption and emission from instantaneous changes in speed and acceleration. The paper assumes two types of communications; perfect (a precise information system) and fuzzy (a specific information system selected with a probability 0.95). The simulation results show that a distance at 600 m. is an optimal distance for TLVC, because the larger distance does not give a significant reduction in terms of fuel consumption and emission. In addition, the results show that with the TLVC, the amount of fuel consumption and CO_2 emission in the transportation systems can be reduced up to 22% and 80% respectively.

The Gear choices, in addition to a speed advice, have been proposed and studied for fuel consumption and CO_2 emission reduction. It could become a feasible solution for future cruise control applications as well.

Unexpected events, such as accidents, can suddenly occur in driving environment. It results in traffic congestions and also unnecessary stops. To alleviate the problem, the paper in [13] is proposed to deal with unpredicted events by calculating an optimal travel route (OTR); re-routing or stay on the same route. The paper implements Veins (Vehicles in Network Simulation) on OMNeT++ as a vehicular traffic model, and deploys EMIT as fuel consumption and emission models.

The simulation results show that a routing advice mainly depends upon how long the event tends to remain. If the event tends to last for a long time, re-routing becomes an appropriate solution. In contrast, if the event lasts for a short period, it is better for vehicles to stay on the same route, since taking another route may cause higher amount of fuel consumption and emission as well as longer travel time. Therefore, in the future, navigation systems must be more intelligent to optimize traffic flows in case of several unexpected events. However, a determination of how long each event will last is quite challenging and need to be well modeled.

Table III summarizes all studies of the TLVC for fuel consumption and CO_2 emission reduction. The table shows main contributions, models implemented in all studies including vehicular traffic models and fuel consumption and CO_2 emission models, type of communications, traffic light scheduling, as well as results of all studies.

IV. Challenges, Issues and Future Researches

ITS introduces a number of projects related to vehicular environment, such as safety applications, but only few of them deal with fuel efficiency and CO_2 emission reduction. ICT can play an important role in saving the amount of fuel consumed and CO_2 emitted by the ground transportation systems.

CACC aims to smooth the traffic flow and avoid the traffic shock wave. However, very few researches focus on an interaction between drivers and CACC system. Unwell design of an interface has potential to distract drivers causing less-safe environment. Consequently, the traffic flow may be frequently stopped due to accidents and other unexpected situations. Therefore, the drivers' interface is another interesting research topic in the future design of CACC systems. The accuracy of positioning information is the other concern that can affect the reliability of the CACC systems. Small error in vehicles' position may cause the traffic flow shock wave. Therefore, a well design of positioning systems is required in the future as well as a study of impact of vehicles' positioning information on the performance of the future proposed CACC systems must be taken into account.

Vehicle platooning also aims to improve aerodynamic of vehicles moment by travelling in group to reduce the amount of consumed fuel and emitted CO_2. However, dynamic nature of vehicular networks can make the communications fail occasionally, leading to an unsafe situation due to short inter-vehicle distance. The future design of the platooning systems may require other technologies as complementary approaches in case of the communication failure. The complementary approach must be further proposed and investigated to make the platooning system more reliable.

TLVC can also reduce fuel consumption and gas emission rate by decreasing number of stops at the traffic light. A pioneer concept is to allow vehicles to learn a traffic light schedule and adjust their speeds in advance to save energy. However, the vehicles still need to decelerate and accelerate to adjust speeds according to the static traffic light scheduling.

The other solution is a dynamic traffic light scheduling. The traffic light learns the numbers, types, positions, and speeds of vehicles surrounding. This information will be used to determine an optimal traffic light scheduling so that most of the vehicles can pass the traffic light without speed adjustment.

This concept makes a design and an implementation of the system more complicated and challenging. Real time optimization algorithms are required to determine the optimal traffic light scheduling. The algorithms need to be fast and precise. Long delay or a small error of the traffic light scheduling determination may lead to lost, such as an accident. Therefore, the optimization algorithms need to be well evaluated before implementation.

Besides, there are different types of vehicles ranging from eco-cars to heavily-loaded trucks. These different types of vehicles cause diverse ranges of fuel consumption and emission rates. Therefore, it is important to make sure that the trucks stop as less frequently as possible because they consume and emit larger amount of fuel and CO_2. Consequently, a priority scheme must be taken into account in a design of a system and a protocol. This becomes interesting and challenging researches as a promising approach for vehicular fuel consumption and CO_2 emission reduction in the future.

V. Conclusion

Due to a limitation of fuel supply and an intensity of the global warming problems, the reduction of fuel consumption and emission must be taken into account of all researchers and industries, especially in the land transportation systems. Electric and hybrid vehicles are a possible approach to save an amount of consumed fuel and reduce the amount of released pollution gas, but the approach is not yet successful now, due to technical challenges and pricing barriers.

Applications of vehicular communications as a part of ITS projects are the other solution to alleviate fuel shortage and the global warming problems. However, only few researches in this area have been recently conducted so far. This article gives a survey of the state of the art of the green applications of vehicular communications and point out challenges and issues of this area of research for the further investigation.

In future, with a combination of successfully-developments of electric vehicles and green applications based on ICT, the fuel consumption as well as CO_2 emission in the land transportation systems will drastically decrease. Consequently, the energy and the environmental problems will be alleviated as well.

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