Co-operative Traffic Light: Applications for Driver Information and Assistance

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Abstract. In this paper a new approach towards co-operative intersection management systems based on traffic flow detection and analysis shall be proposed which uses on the one hand standard in-vehicle equipment and on the other hand standard traffic light control systems. The main communication concept will be placed into a low-cost modular unit which connects the systems of the vehicles and the traffic light control systems in order to enable traffic data information exchanged such as traffic light switching information for the individual traffic and speed recommendation for a co-operative traffic light management.

1 Introduction

The amount of traffic has strongly increased in recent years. In many places the infrastructures are not able to react to the traffic increase efficiently, whether by road construction or rebuilding of infrastructure. The continuous increase in traffic and environmental problems as well as the demographic change are a challenge in many regions of Germany and Europe. The expansion and reconstruction of the traffic infrastructure are still advanced in many countries, however this is mainly concentrated on maintenance and repair in German regions and conurbations. With the use of existing infrastructures, an innovative, telematic based traffic management offers new options.

1.1 Current Traffic Light Control Systems

The transport infrastructure (road, rail, water and air) provides mobility to our society today. Improvements to this infrastructure enhance this mobility. Unfortunately the communication infrastructure has not been able to keep the pace of these developments. Recent developments in digital networks, however, allow the communication infrastructure to catch up.

Nowadays the basic principals of traffic management are based on the measurement and control of traffic flows. One basic mechanism for this is the usage of traffic light control systems. This is especially true for inner-urban areas where signal control substantially determines the traffic and mobility management. Because the traffic

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light controls are very important for the traffic management of today, their impact to traffic flows can be assumed as very denotative.

The traffic light control systems are based on signal programs which are in general adapted to the prevailing traffic situations. In the planning phases of the traffic management development and in planned intervals, the expected traffic situations are analyzed using traffic flow measurement and various analysis mechanisms such as simulation 1 or traffic models 234. The cycles of the signal programs of the traffic light controls are chosen in order to cover the varying load levels as they might occur during daytimes, different days of a week or at special times.

These systems shall generally increase traffic safety and improve the traffic flow quality. The following criteria 5 can be proposed in order to define the traffic light control programs adapting to the traffic situations:

- traffic volume
- interrelations between the traffic volumes
- degree of occupancy
- speeds

The signal programs are mainly based on two coordination principles which are the time dependent traffic light control and traffic-actuated traffic light control. Normally the traffic light control programs vary over times of days and weeks between programs following the time and traffic dependant strategies.

The time dependent traffic light controls are especially useful for forecasted high-load periods of days of weeks. They offer the advantages that these traffic flows can be diverted effectively, especially for streets of known heavy traffic. A strategy which can be particularly used here is the progressive signal system such as Green Wave where the signals of multiple light-signal systems are switched consecutively.

Traffic-actuated traffic light control programs offer the strategy to adapt the switching to the local traffic which is detected around the intersection. The road networks are full of detectors, but these detectors are specialised for local traffic light controls. For this reason they are mostly located near intersections which are controlled. For traveller information pre-trip and on tour, traffic parameters not usually measured for local traffic light control are of more interest, for example the speed profile along stretches. Furthermore these mechanisms offer short term traffic adoption but are for now limited to light traffic situations as they are assumed beforehand. For instance in situations when there is a sudden rise of traffic volume, such as during detours or after public events, the traffic flow can often not be managed satisfyingly by strategies of traffic management due to a lack of feedback coming from the local traffic detectors on the one hand and a limited foresight of these detectors concerning the upcoming traffic on the other hand. Several strategies to solve these problems have been proposed recently, one of them is to use the local vehicle movement of data in order to measure tailbacks in the inflow of traffic light controlled intersections 67. The new concept that shall be proposed here aims at a co-operative approach where the collaboration of vehicles together with the infrastructure tend to achieve a better traffic organization for both sides.

1.2 Co-operative Concept

Currently a high fraction of vehicles in the individual traffic is equipped with up-to date ITS such as navigation systems or PDAs enabling well known HMI, GPS and WLAN or GSM communication modules. These in-vehicle systems are already able to measure and calculate the vehicles own Floating Car Data (FCD). The proposed new approach of traffic control aims to make the already calculated parts of traffic flow data of the traffic participant available to the road authorities in order to improve the management of traffic flows by traffic light control systems.

On the one hand standard in-vehicle equipment shall be used along with standard traffic light control systems. The main communication concept will be placed into a low-cost modular unit which connects the systems of the vehicles and the traffic light control systems in order to enable traffic information exchanged, such as traffic light switching information for the individual traffic and traffic flow information for a co-operative traffic light control management.

On the basis of transferred information between vehicle and traffic lights, the local control can be optimised by supporting the driver on the one hand and on the other by making the traffic light control aware of the approaching traffic flows. The interaction between vehicle and infrastructure can help to improve both traffic flows and advanced driver assistance systems. The research proposed here aims to gather the requirements of co-operative traffic light control systems 89 and to characterise the results of the first developed prototype in order to prepare an industrial development of a practicable co-operative technology.

2 Requirements for a Co-operative Traffic Light Control

The main aim is the combination of the advantages of the global and the local intersection management. It shall lead to a management of the traffic flows based on both local feedback of detections together with progressive signal systems (e.g. Green wave) over a wider area of the road network. This enables advantages for both: the road authorities because of reduction of the environmental pollution and noise, and enhancement of the public road traffic. Furthermore it brings advantages for individual traffic participants because their travel times and fuel consumption can be reduced and therefore the acceptance towards co-operative traffic strategies can be enhanced. In order to achieve such an advancement of intersection management, different requirements must be fulfilled for the traffic light control systems and for the drivers.

The main requirement for the traffic light control systems at intersections is:

- Optimisation of the traffic light phases to the traffic flows

Therefore the traffic light systems need information on the traffic flows which consist of:

  - Current speed of vehicles
  - Direction of vehicles
  - Current position of vehicles

The main requirement towards the traffic participants is:

- Optimisation of the vehicle speed towards the traffic light phases (progressive speed)
- Reduction of stops

In order to encourage the participants of the traffic to drive co-operatively, the following information can be offered:

  - o Announcement of traffic light switching to the drivers
  - o Information about optimized speed in local sections of the intersections

This information can also enhance the positive side effects of co-operative traffic management systems towards the reduction of environmental pollution because the drivers of the vehicle groups can be animated to an optimised driving speed and an early off-switching of engines when waiting for the next green phase.

2.1 Requirements towards Investment and Safety Reasons

Apart from the function of the co-operative system itself, some more requirements have to be regarded in order to realize an effective co-operative intersection management especially regarding acceptance:

- The equipment used should be cost efficient for the drivers and the local authorities

The efficiency of a co-operative system depends on the penetration rate (significant amount of equipped vehicles) This can only be achieved by using systems that are already part of most cars, such as navigation systems, PDAs or mobile phones. For the public authorities, the requirement results in the original usage or a low-cost upgrade of the control systems in use.

The aim is to enable a maximum benefit with minimum costs.

- Installation in traffic light control systems, regarding safety and security issues, requires standardized interfaces and long lasting and modular components

In order to avoid safety and security failures, a modular device shall be developed which is connected to the traffic light control systems via standardized interfaces, like they have been proposed in 9. The modular and standardized approach offers one more positive side effect: the device can be applied and removed wherever and as long as it is needed at a traffic management system at an intersection. This enables the local authorities to apply the communication systems of traffic and infrastructure data exchange as traffic light detectors for special times such as times of building works and detours. The modular approach also enables a good possibility towards future requirements. The device technology of traffic light control systems has a long application duration and life span which also leads towards a modular device which is easily updatable and programmable. The traffic light control systems in use may not have been designed to calculate superior traffic flows out of wireless delivered FCD. Therefore the modular system has to be able to process additional data.

2.2 Requirements Conclusion

Putting together the requirements of a co-operative traffic light system into a solution, the decision was made to use two different communication systems in order to set up a co-operative traffic light system enabling traffic data exchange with participating vehicles of the traffic. On the side of the traffic, an application for transferring vehicle data such as speed and position was designed for a customary PDA. Such PDAs equipped with GPS sensors are already widely-used for navigation applications. They also offer operating systems which make it possible to develop a WLAN based communication interface. This vehicle-sided application was developed in Java and offers vehicle announcement at the communication unit of the traffic lights and furthermore self locating algorithms in order to deliver positioning and speed data to the communication unit.

The modular communication unit for the communication between the traffic light to the traffic is a new set-up which is suitable for connecting the traffic light signal and for updating standardised interfaces. The communication interface is realised by the concept of a Set Top Box (STB) for traffic light control systems.

3 The Set Top Box: A Central Communication Unit for Co-operative Traffic Light Control Systems

The STB works as a communication mediator and data analysing unit of an intersection managing traffic light control systems between the traffic light system and the traffic flows of approaching vehicles.

The vehicles announce themselves at the STB and transmit information about their own speed, position and the intended direction through a customary PDA.
One STB at each intersection is located in the control cabinet of the traffic light system. Using the received individual vehicle data such as position and speed, it calculates the traffic flow data concerning the traffic flow density and flows for each lane of the intersection. The STB is connected to the traffic light device via a standardised LAN connection. As a virtual detector it informs the traffic light control systems about approaching traffic flows and optimisation of switching programs. The traffic light can therefore react better to topical flows of traffic and this allows a more dynamic control of the road traffic.

Furthermore the STB can establish a connection to the traffic calculator of the traffic management centrals. The local traffic information can then be used to create global traffic management strategies due to more distinctive information concerning the traffic flows at crossings. Here the STB enables the feedback from local detectors towards an overall traffic management.

Several Set Top Boxes can furthermore be interconnected to each other by WLAN or UMTS communications centralised using a server or even decentralised. Via this interconnection, information about traffic flow movement and changes can be communicated and used for adaptive traffic light switching such as adaptive progressive signal systems.

3.1 Hardware Setup of the STB

The main hardware of the Set Top Box is based on a specialised industrial PC with a custom-made board. So far, the communication to the vehicles is established using a low-cost personal digital assistant (PDA) which enables WLAN-communication (802.11) by an access point. The communication is suitable for vehicle speeds about 50km/h as they are due in areas of urban intersections. These PDAs are mostly equipped with GPS-devices already what makes them usable for a use as navigation systems in cars. The communication from the STB to PDAs enables a vehicle type independent communication.

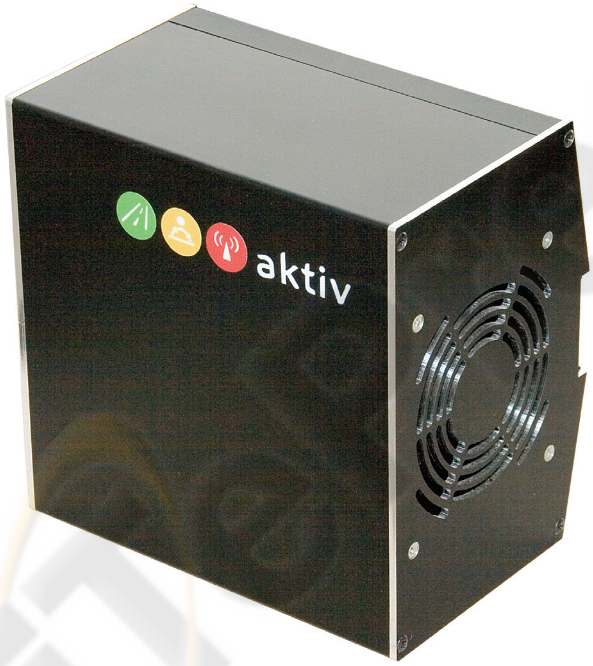

Fig. 1. Set Top Box.

One of the main advantages of such a box as it is shown in figure 1 is its flexibility because it can be built in wherever and for as long as needed. It just requires a traffic light system. The system of the traffic light control stays untouched, therefore the usage of a STB does not threat the safety of an already running traffic light system. Therefore certifications of the traffic light control program are not altered either. The box does not interfere with the set control programs, but can be used to optimise their switching. The STB can be adapted to the interfaces of the manufacturer-specific control devices. If many traffic lights are equipped with these boxes as it is shown in figure 2, the traffic information can be gathered and used for a broad area for the needed time. Because of these manifold usages, the financial costs for the local authorities can be reduced by additionally enabling a forward-looking traffic detection and traffic management.

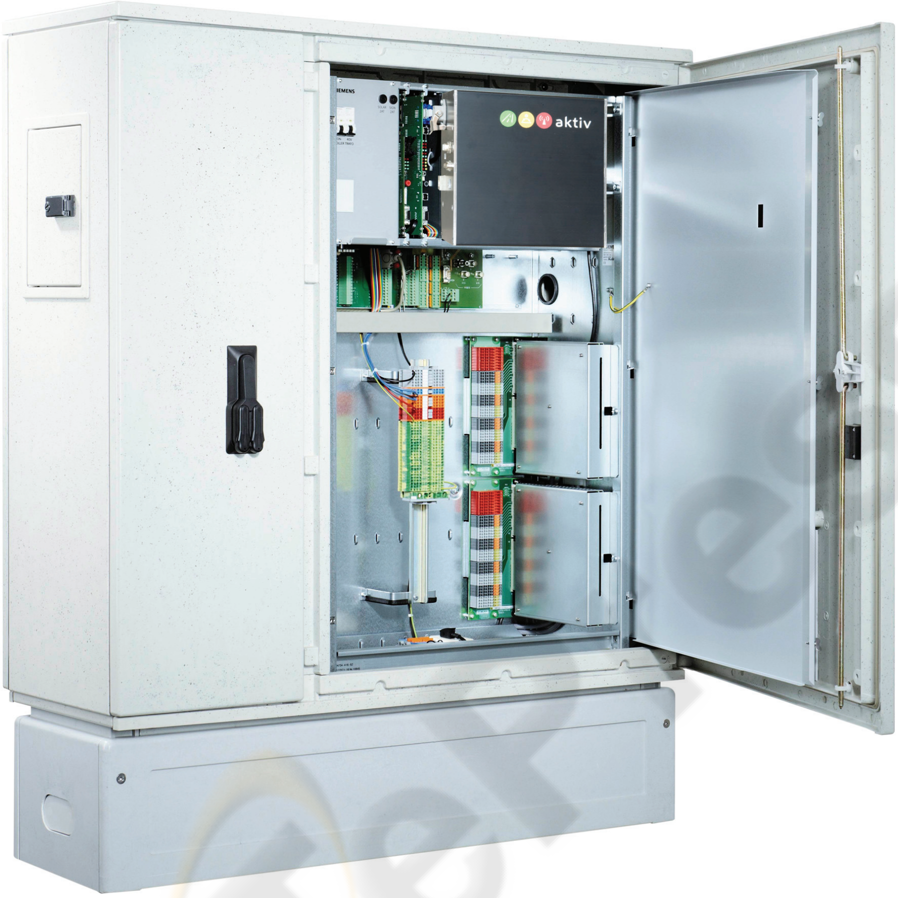

Fig. 2. Set Top Box as it is placed in a control cabinet of traffic lights.

3.2 Realised Functionalities

Regarding the requirements mentioned above several functionalities for the communication between vehicles (PDA) and STB and between traffic lights to STB are realised. An outline of the communication between Set Top Box, traffic lights and vehicles' PDA is shown in figure 3.

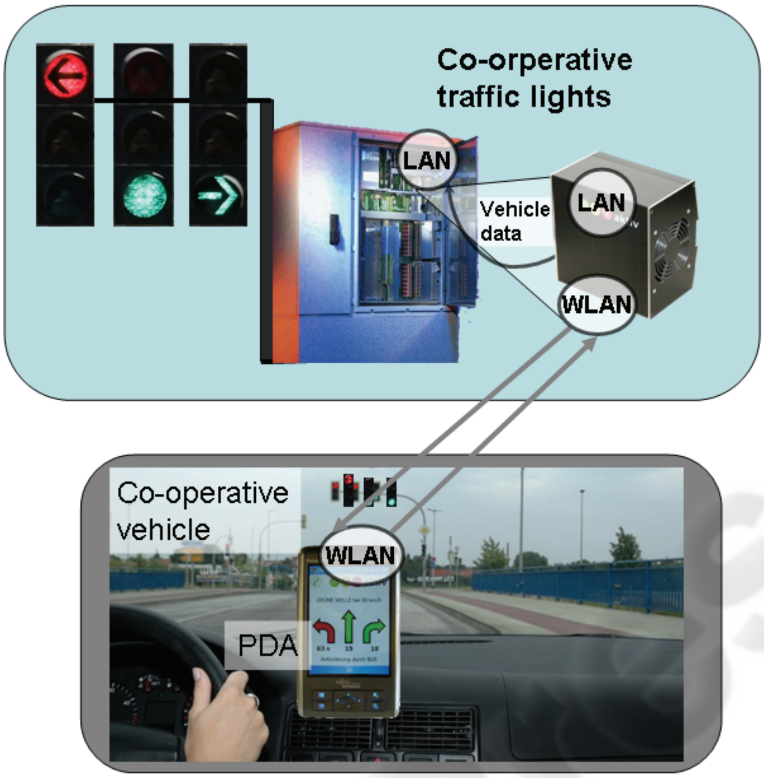

Fig. 3. Communication established by STB.

For the drivers following information based on traffic flow and traffic light system data, the following is delivered from the STB to the PDA in the vehicles:

- Transfer of cycle times of the red light and estimated waiting times till the vehicle's crossing of the intersection
- Speed recommendations in order to achieve the best travel time e.g. due to progressive signal systems
- General routing information about speed limits or congestions
- Information in cases of rapid traffic light control systems programming change e.g. because of passing emergency services

In return, the PDAs transfer the following data to the STB to be calculated and used for adaptive traffic light switching:

- Current speed and positions, especially to identify the single (heading) lanes
- If necessary the declaration of turning at the intersection

The STB connected to the control unit of the traffic light system computes the traffic flows at the intersection and offers the following detector data to the unit:

- Offering recommendations concerning switching status

Because of possible interconnections between several STBs at different cross-roads and the traffic management centrals, the exchange of topical data can be used to develop and realise global traffic management strategies.

4 Conclusions and Future Steps

The approach of a modular car-to-infrastructure communication presented here enables the combination of the advantages of microscopic and macroscopic traffic management: local traffic adaptation and global ease of traffic flows.

The prototypical solution could be proposed by the development of a Set Top Box (STB), a specialised industrial PC with LAN and WLAN communication. The box is the central communication unit, connected to a control cabinet of a traffic light system at one side and via WLAN to standard PDAs in vehicles on the other side. The STB detects traffic flows and optimal switching strategies which can be put into reality by the connected traffic light and management systems.

This vehicle – STB – traffic light communication establishes a dynamic and co-operative control of the traffic flows. The communication could be established and the main traffic and control data was transferred.

The currently used proprietary communication protocols are being tested and validated in various field tests. Tests concerning the ability of the WLAN connection during various vehicle speeds, different environmental conditions such as building development or radio noise are currently being carried out. Furthermore issues of data security have to be addressed as well as the establishment of the currently developed standard for the car-to-car communication WLAN 802.11p.

The future steps will address the interaction of navigation systems in the concept of co-operative traffic lights. Then on the one hand the navigation system users could also be aware of the current states of the traffic light and the routing could take into account possible hold-ups caused by traffic lights. On the other hand traffic flows could be predicted in order to optimise the cycle times of traffic lights. This enables smooth traffic flows in spite of more participants of the individual traffic.

Furthermore the Set Top Boxes can be used as Road Side Units 10 also enabling car to car communication 11. The applications inside the car could be updated in order to acquire more driving concerning data such as road conditions or traffic situations. The data would be transferred to and computed by the STBs. The traffic information can then be used by the traffic management centrals or decentralised by distributing it to the passing vehicles. The usage of low-cost standard vehicle equipment could achieve a high coverage of communicating cars easily which is a central key point in encouraging co-operative car-to-car and of course car-to-infrastructure technologies.

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