Field Operational Test of a new Delay-Based Traffic Signal Control Using C2I Communication Technology

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Abstract

This paper presents the setup of a field operation test of a novel delay-based traffic signal control. That signal control utilizes vehicles' delay times for the green time adjustment. The delay times in this test are measured by C2I-equipped test vehicles and are transmitted to a common signal controller. The signal controller is upgraded with a road side unit (RSU). The RSU includes a communication and an application unit. The communication unit is required to receive the communication telegrams from the vehicles with their coded delay times. The delay-based control logic is executed on the application unit which is basically a small computer. The RSU is linked to the signal controller via one of the controller's standard interfaces. The utilized interface is a port which is usually used for connecting induction loops with the signal controller. The delay-based signal control sends an impulse from the RSU to the induction loop port to trigger the signal controller for a phase change. The test site is located at the non-public property of the German Aerospace Center (DLR) in the city of Braunschweig, using the facilities of the Application Platform for Intelligent Mobility (AIM). Test cases are defined to evaluate if the control logic reacts in the expected way. The overall objective of the field operational test is to prove the technical feasibility of the delay-based control by applying only standard equipment. The successful proof is the requirement for a continuative and extensive field operational test in the public space which will investigate the control's impacts on traffic flow, waiting times and emissions.

1. Introduction

Signal control strongly influences the quality of traffic within urban street networks. For this purpose several signal control approaches have been applied in the field, trying to minimize vehicles' delay times. This is done despite the fact that these approaches cannot directly measure delay times but often use surrogate measures. Due to innovation in C2I (car-to-infrastructure) communication technology the measurement of vehicles' delay times becomes feasible in a wider scope which leads to further options in traffic signal control. Based on this progress a new traffic signal control was developed. It directly processes on-line measured delay times for signal time adjustment. This new signal timing method is completely vehicle actuated and based on an exhaustive queue clearing policy. Further details about the control method are explained in [5, 6]. To benchmark this new delay-based control several microscopic simulation studies were done, comparing the new method to conventional approaches. The simulation results were promising and showed an improved traffic flow and reduced delay times [4].

In this paper a first operational field test of the new delay-based control is described. This field test should demonstrate the technical feasibility of the new control by applying only standard equipment and a common signal controller. The impact on real traffic flow is important as well and will be investigated in a further and more extensive field operational test. In the field operational test presented here, C2I communication technology is used to transmit the self-measured delay times directly from test vehicles to the traffic signal controller. The test site is the non-public property of the German Aerospace Center (DLR) in the city of Braunschweig and the research facilities are provided by the Application Platform for Intelligent Mobility (AIM). With AIM, the German Aerospace Center, together with the state of Lower Saxony, the city of Braunschweig and other partners, is creating a unique way of linking up research, development and applications for intelligent transportation and mobility services and uses the entire region and its real traffic infrastructure as a research area [1]. On special focus in AIM is on controlling traffic signals and the delay-based signal control is a first use case.

2. Delay-Based Signal Control

For the clarification of the technical setup of the field operational test, it is necessary to briefly explain the basic control strategy of the delay-based signal control. The delay-based control requires the delay times of all approaching vehicles at an intersection for the green time adjustment. A vehicle i is considered to have a delay d_i, if its current speed v_i is below a maximum achievable speed v_{max}. This maximum achievable speed v_{max} has to be defined and could be the speed limit. The small time increment Δt between two subsequent measures depends e.g. on the frequency of the GPS readings. In this field operational test, it is required to have at least one measure every second. This is because of the simultaneous frequency of the signal controller for triggering the traffic lights. If the current speed v_i of the vehicle exceeds the maximum achievable speed v_{max}, then its delay d_i is set to 0:

$$d_i = \Delta t \cdot \left(1 - \frac{v_i}{v_{max}}\right) \quad (1)$$

Summing up the single delay times d_i for all vehicles n results in the delay time d for the whole approach:

$$d = \sum_{i=1}^{n} d_i \quad (2)$$

Due to these definitions of the delay time, the control strategy can be explained which utilizes a queue clearing policy: Considering a fixed minimum and maximum green time (g_{min} and g_{max}), a running green phase with its already elapsed green time g is terminated, as soon as all delayed vehicles on an approach have been cleared. In this case the measured delay time d becomes less than a critical value d_{crit}. That critical value is defined close to zero to cope with detection errors. This condition for the phase change can be summarized as:

$$((d < d_{crit}) \cap (g > g_{\min})) \cup (g > g_{\max}) \quad (3)$$

The following figure 1 illustrates the delay-based control method: As soon as the delayed vehicles (red) have been cleared on the northbound approach (left), the phase is changed and the delayed vehicles on the eastbound approach (right) are served. This pattern is sequentially repeated in every cycle.

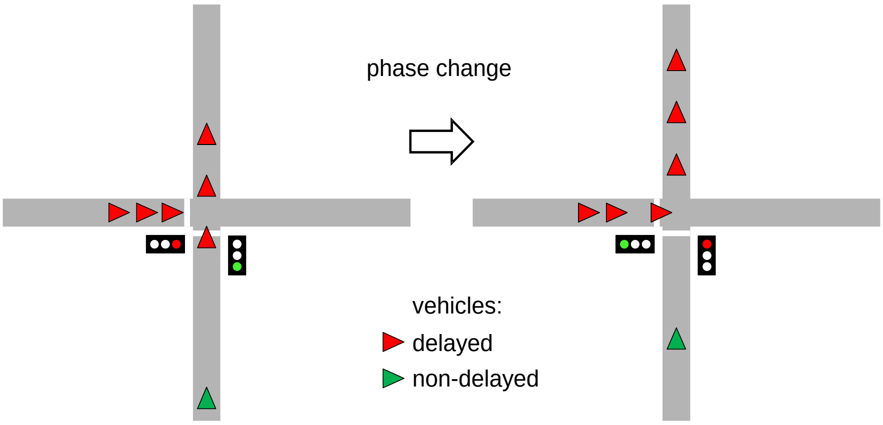

Figure 1: The delay-based signal control terminates the current green phase as soon as all delayed vehicles (red colour) have been cleared.

3. Technical Setup

To prove the technical feasibility of the new traffic signal control in a field test, the used signal controller must fulfil two basic conditions: It must be able to receive the vehicles' communication telegrams, which include their delay time states, and it must be capable to process these measured delay time states by using the delay-based logic for triggering the signals. Common signal controllers can usually not comply with these requirements. This is because of lacking interfaces for integrating novel traffic data sources into traffic signal control. Typically a signal controller only provides interfaces for connecting induction loops, infrared detectors and cameras, but no C2I communication devices. The measures of these common data sources are headways, occupancies or tailbacks and so far there was no need to process vehicles' delay times. This also means that there are no software libraries available which could handle the vehicles' delay times as an input value for setting up the new signal control logic.

The workaround to avoid these restrictions for the field operational test is to upgrade a common signal controller. A communication device for receiving the C2I telegrams and a platform for executing the delay-based signal control must be added. To get the permission for a further field operational test in the public space, it must made sure that the signal controller itself is not modified, due to safety issues. A better solution is to outsource the required functionalities to an additional device and connect this device via one of the signal controller’s standard interfaces. For this purpose the already available hardware within AIM is used. Currently about 30 intersections in the city of Braunschweig are getting equipped with road side units (RSU) [2,3] to broadcast the controllers’ signal states and other information for the application of e.g. a green light optimal speed advisory (GLOSA). These RSU include components for the communication with the test vehicles and a computer for processing source code [2, 3], like the control logic of the delay-based control. Until now the communication link is only unidirectional from the signal controller via the RSU to the test vehicles. For the field operational test of the delay-based control it is necessary to upgrade this link to a bidirectional communication. The communication from the test vehicles to the RSU works already but so far there is no connection to forward commands from the RSU to the signal controller.

For the following described implementations and the field operational test, a signal controller of the type series Siemens C940V and two test vehicles (so-called FASCars®) are used. This controller type in combination with a RSU is installed at most of the intersections to be regarded in AIM. The laboratory device is used to benchmark new configurations and modifications before applying them in them in the real life. Considering this the task is implementing a link from the RSU to the signal controller via one of the signal controller’s standard interfaces. The used standard interface is an input port which usually connects an induction loop with the controller. The RSU is upgraded with a relay that is linked with the controller’s induction loop port. The relay itself is controlled by the application unit. The delay-based signal control logic is executed on the application unit. Whenever the condition for a phase change is fulfilled, referring to (3), the relay is energized and sends an impulse to the induction loop port. The control logic executed on the Siemens C940V controller recognizes this impulse at the port. The impulse is considered to represent a vehicle passing the induction loop and causes the intended phase change. The control logic for the Siemens C940V signal controller guarantees only a fixed minimum and maximum green time and terminates a running green phase as soon as it recognizes an impulse at the port. That means in the field operational test it is only used to trigger the signals but not to execute the delay-based control logic. The setup of the signal controller and RSU is shown in figure 2.

Figure 2 – Field operational test installation (left) with the signal controller Siemens C940V (middle) and the road side unit (right).

To summarize the described setup for the field operational test, it can be distinguished between three major parts: The first part is the institute’s two test vehicles equipped with transceivers. The second part is a road side unit (RSU) [2, 3] which includes a communication and an application unit. The third part is the traffic controller Siemens C940V which is linked to the road side unit and triggers the lights. The data exchange between these three parts is initiated by the transmission (step 1) of the self-measured delay times from the test vehicles to the road side unit's communication unit using the IEEE 802.11 p communication standard. These delay times are processed in the application unit, a Linux pc system, where the logic of the new delay-based signal control is executed. The so adjusted signal times are transmitted (step 2) to the signal controller of the type series Siemens C940V by the controller's induction loop input port to finally trigger the lights (step 3). Current status information from the signal controller back to the RSU can be received via the interface Siemens VMK. This connection from the signal controller back to the RSU is additional for logging the displayed signal states. It is not necessary for the proper functionality of the delay-based signal control. The whole system setup is shown in figure 3.

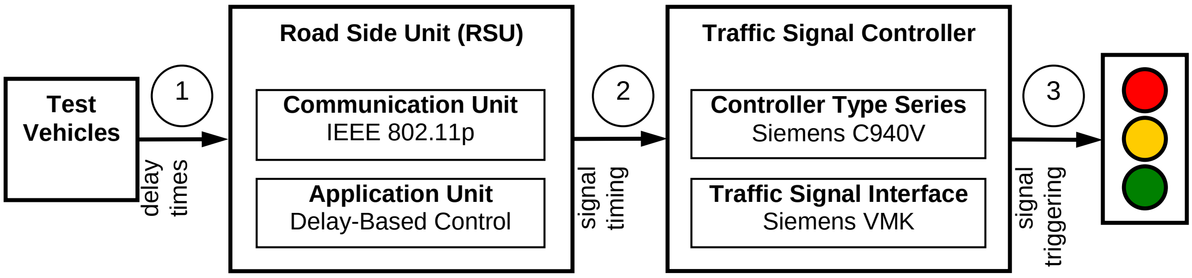

Figure 3 – System setup with the used components and transmitted information. The delay times of the vehicles are received via the communication unit and are processed by the delay-based logic on the application unit. An impulse is sent from the road side unit to the signal controller's induction loop port to trigger a phase change.

At the time of writing this paper the implementation of the described system setup is still in progress: The link between the relay and the induction loop port is completed and the signal triggering logic for the Siemens C940V controller is ready for execution. Only the delay-based logic still needs to be implemented on the application unit.

4. Test Cases

The principle of the delay-based signal control can be completely tested with the available combination of the institute's one modified signal controller and the two C2I-equipped test vehicles. For the control it is not important to determine the total number of delayed vehicles. The only required information is if the sum of the delay times on an approach crosses the critical delay time value, referring to (3). That means one vehicle, with the two possible states of being delayed or non-delayed, will cause the same actuation of the control like a whole platoon. Due to these considerations the layout of the test site includes only two crossing one-way streets. These two streets form a simple intersection and are separately controlled by the signal controller's two signal groups. The location of the test site is the non-public property of the German Aerospace Center (DLR) in Braunschweig. An intersection out of the network of minor streets is chosen to install the mobile signal controller. Details about the test site are depicted in figure 4.

Figure 4: The test site is a simple intersection consisting of two crossing one-way streets, each signalized by a separate signal group (left). The intersection is located at the non-public property of the DLR in Braunschweig (right).

To prove the delay-based control and the technical setup, some test cases must be defined. These test cases must represent the most typical arrival situations at an intersection. The control logic must be able to handle all these test cases in the expected way. That means the control's basic functionalities will be tested. Essential are the green time extension until all delayed vehicles on an approach are cleared and the accuracy of the moments of phase change. To compensate the limited number of two test vehicles, the setup of the test cases distinguishes between: (A) One vehicle on each of the two approaches and (B) two vehicles on only one approach. The additional consideration of the vehicles' delay states results in 8 possible test cases: Within (A) the vehicles on both (A1), on only one (A2, A3) or on no (A4) approach can be delayed. Within (B) are the same four cases but now with two (B1), only one (B2, B3) or no delayed vehicle (B4) in a queue. Based on the order of the phases and the delayed or non-delayed vehicles, the control must act different. For example should the control extend in (B3) the running green phase until the second vehicle has passed, while in (B4) it should immediately terminate the green phase. These described test cases with different delay time states and vehicle orders are shown in figure 5 and will be tested at the equipped intersection.

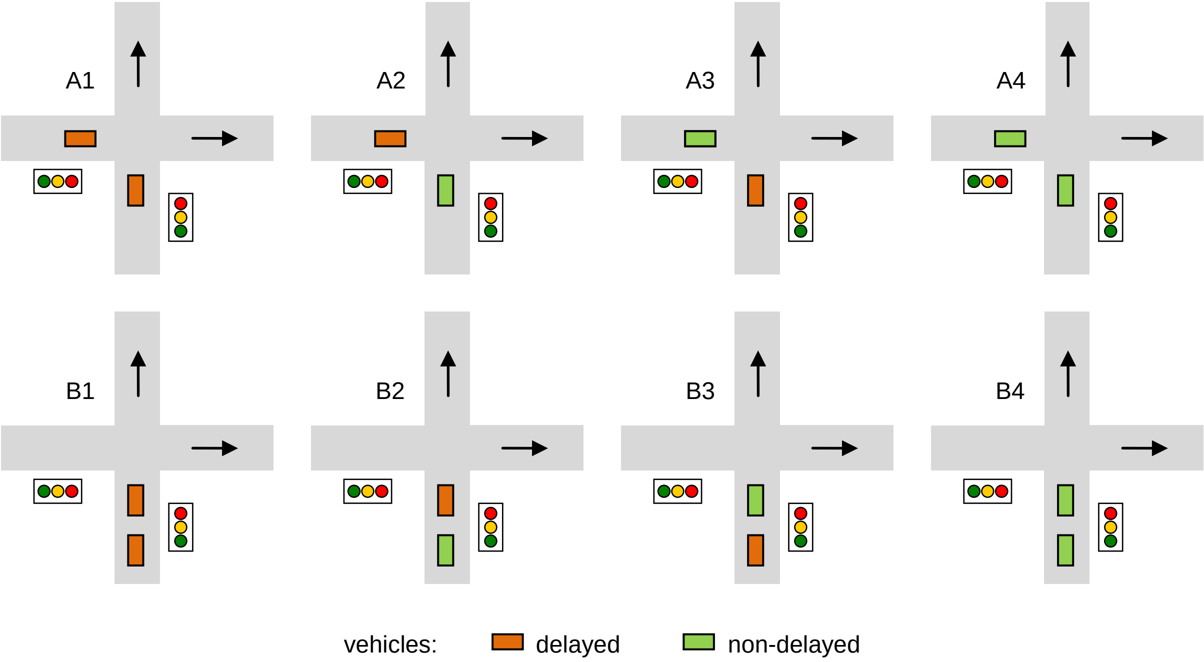

Figure 5: Eight test cases with two probe vehicles are defined: Two competing directions with one vehicle on each approach (A1-4) and one direction with two vehicles on each approach (B1-4). These test cases represent the most common combinations of delayed / non-delayed vehicles and platoons at a simple intersection.

5. Conclusions

By completing the system implementation and running the test cases, the technical feasibility of the new delay-based control will be proved. The setup of this field operational test, especially linking the road side unit (RSU) with the Siemens traffic signal controller, is in progress and detailed results will be available soon. The successful completion of this first operational test on the non-public property of DLR is the requirement for a continuative field operational test in the public space. In this second and more extensive field operational test, the impact of the delay-based approach on traffic flow, waiting times, emissions and other quality measures will be investigated.

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