Paper number ITS-TP1800

EU AUTOPILOT project: Platooning use case in Brainport

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Abstract

In the EU AUTOPILOT project, IoT is brought into the automotive world to transform connected vehicles — moving 'things' in the IoT ecosystem — into highly and fully automated vehicles. One of the considered use cases is the platooning use case, which is being tested at the Brainport pilot site in the Netherlands. The aim of this use case is to demonstrate the potential of IoT to improve vehicular platooning. To achieve this, several services and advanced vehicle-to-everything (V2X) connectivity technologies have been developed and tested. This paper describes theses services and technologies, as well as evaluation results of the pilot tests.

Keywords:

vehicular platooning, IoT, connected automated driving

Introduction

Automated driving is expected to increase safety, provide more comfort and create many new business opportunities for mobility services. The market size is expected to grow gradually reaching 50 % of the market in 2035. The Internet of Things (IoT) is about enabling connections between objects or 'things', connecting anything, anytime, anyplace, using any service over any network. A giant IoT network is expected to consist of up to 50 billion objects by 2020, enabling the advancement of a wide range of applications across various areas impacting our everyday life [1].

In the EU AUTOPILOT project (Automated driving Progressed by Internet Of Things), IoT is brought into the automotive world to transform connected vehicles — moving 'things' in the IoT ecosystem — into highly and fully automated vehicles. While using the IoT potential for automated driving, AUTOPILOT also makes data from automated cars available to the IoT ecosystem. The AUTOPILOT project has developed a range of driving services, which take advantage of the potential of IoT to improve automated driving. These services are tested in five different driving modes (urban driving, highway pilot, automated valet parking, real-time car sharing, and platooning) and at six different pilot sites (Tampere, Finland; Versailles, France; Livorno, Italy; Daejeon, Korea; Brainport, the Netherlands; Vigo, Spain). This paper describes the developments of the platooning use case in Brainport.

Vehicles that are platooning are automatically following each other longitudinally at a relatively close distance. Driving in a platoon requires vehicles to use inter-vehicle communication to anticipate timely on manoeuvres of other vehicles in the platoon. Several aims and motivations for vehicular platooning exist, such as improvement of traffic throughput and homogeneity, enhancement of traffic safety, and reduction of fuel consumption and emissions due to a lower air drag. Automated driving can offer additional benefits in terms of comfort, i.e. relieving the driver from the driving task.

The platooning use case demonstrates vehicular platoons consisting of a lead vehicle and one or more highly automated following vehicles, which are equipped with longitudinal control and automatic steering. In the project several IoT-based services are developed that support the driver and the system in the phases before and during platooning. These services have been tested and evaluated in real traffic conditions in several pilot tests.

The remainder of this paper is organised as follows. First, a brief review of platooning projects is given. After that, the platooning use case is described in more detail focussing on the newly developed services and connectivity technologies. Subsequently, the automated vehicles, the pilot site and the IoT ecosystem are described. Next, the developed Platoon service is explained in more detail. Finally, the conducted pilot tests are described and evaluation results are presented. The paper ends with concluding remarks.

Review of platooning projects

First demonstrations of vehicular platooning on public road date back to 1997 [2, 3], when the National Automated Highway Systems Consortium (NAHSC) performed a demonstration in San Diego with eight fully automated cars traveling together with small inter-vehicle spacing as a platoon on a closed highway, which had been equipped with magnets installed in the centre of the lanes. The EU CHAUFFEUR I project was one of the earlier demonstrations of truck platooning; CHAUFFEUR II (2000 - 2003) demonstrated the feasibility of a three-truck platoon operating in real world environments [4, 5]. The German KONVOI (2005-2009) project investigated the benefits and deployment issues associated with truck platooning operating in mixed traffic on motorways [4, 5]. The EU SARTRE (2009 - 2012) project [4, 5, 6] demonstrated a mixed platoon of cars and trucks operated in a public, mixed-traffic environment, where the platoon was led by a manually driven truck followed by automated vehicles. The Japanese Energy ITS project demonstrated a platoon of three automated trucks [4, 5]. The objective of the EU COMPANION (2013 - 2016) project was to develop and validate off-board and onboard systems for coordinated platooning (‘creation, coordination, and operation’), research potential legal solutions and standards to advance platooning adoption, and demonstrate platooning operations on European roads [7]. In 2016, the European Truck Platooning Challenge took place in which all European truck brands participated by driving platoons on public roads. The EU CONCORDA (2017 - 2020) project contributes to the preparation of European motorways for automated driving and high density truck platooning [8]. The main objective of the project is to assess the performance of hybrid communication systems, combining 802.11p and LTE connectivity, under real traffic situations. Finally, the EU ENSEMBLE (2018-2021) project aims to achieve the next step towards deployment of truck platooning, which requires an integral multi-brand approach [9]. The project ambition is to realise prestandards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the EU.

The platooning use case

The aim of the platooning use case in AUTOPILOT is to demonstrate the potential of IoT to improve platooning. To achieve this, several services and advanced vehicle-to-everything (V2X) connectivity technologies have been developed, tested and evaluated.

To assess the potential of IoT, a platooning baseline configuration has been defined in which vehicles communicate with each other using vehicular ad-hoc networks (VANETs). As basis, the ITS-G5 communication technology and message standards are used. For the platooning automated driving mode, the communication is mainly focussed on sharing a limited amount of (safety-critical) information between the vehicles, e.g. the acceleration of the preceding vehicle. The communication range of the ITS-G5 technology is typically in the order of 500 m on highways [10, 11], but dependent on the placement of antennas, environmental conditions and the used radio system, i.e. 'short range' (also referred to below as V2V range), which is sufficient for 'normal' platooning, where vehicles follow each other at close distances.

In the IoT context, the platooning vehicles are moving 'things' in the IoT ecosystem. Instead of connecting a few vehicles in an ad-hoc network, the idea is to connect anything, anytime, anyplace, using any service over any network. In terms of V2X communication, this means that 'long range' communication technologies are added to the existing short range connectivity. Further, connecting anything also means that information of other 'things' is also available and can be used, e.g. traffic light information, positions of other vehicles, speed advices.

In the platooning use case the following services have been developed:

- Platoon service: this is the main service supporting the platooning, not only during the platooning automated driving mode, but also before that to form the platoon. The service is described in more detail in a separate section below.
- Traffic Light Control (TLC) service: provides real-time information (e.g., time-to-green) of traffic lights.
- Traffic Monitoring (TM) service: provides aggregated information such as average speed and status (e.g., open or closed) of each lane.
- Local Dynamic Map (LDM) service: extends the range awareness of vehicles with real-time high-level information of targets (vehicles) that are detected by the Video-Based Monitoring (VBM) service along the motorway of the test site.
- HD map service of TomTom: provides HD maps.

Besides these services, the following connectivity technologies are used:

- ITS-G5: baseline V2V communication technology for platooning.

- Cellular communication: commercial 4G and Hi-5 (TNO pre-5G) technologies.
- Ultra-Wide Band (UWB): a direct V2V communication technology and a potential candidate for a redundant V2V backup channel next to ITS-G5.

In the sections below, the systems are described in more detail.

Vehicles, pilot site and IoT ecosystem

Vehicles

Realizing the use case requires specially instrumented vehicles. A platoon consists of at least one leading and one following vehicle, communicating with each other. Direct V2V communication is achieved with NXP/Cohda MK5 devices using ITS-G5 technology, which transmit a custom message set. This includes the necessary information to form and manage a platoon and to enable cooperative driving where the follower acts upon the transmitted (desired) acceleration of the leader (Cooperative Adaptive Cruise Control - CACC). Communication of both the vehicles and their drivers with the platoon service, which is located in the IoT cloud, is done by a mobile terminal device with a SIM card connected to the internet via cellular technology. This enables the vehicles to share information while being out of V2V range. A tablet is installed to enable the driver to interact with the platoon system (in-vehicle) and the platoon service. With the HMI application on the tablet, *platoon formation* can be requested or cancelled and when the formation is done, i.e. the vehicles found each other, a *platoon engage* request can be given to start the automation part of the functionality. The automated driving functionality involves actuation of the vehicle, i.e. execution of acceleration/deceleration and steering, based on sensed objects (other traffic participants) and lane markers. The sensed objects are obtained from radar and camera sensors, but can be extended with other objects received from the LDM service. Using highly accurate GPS and interfacing with another service, the HD map service, the system gains additional information about the lanes and its in-lane positioning. Another addition to the vehicle instrumentation is UWB communication technology, consisting of NXP and Decawave technology.

Pilot site

The Brainport Pilot site concerns the region of Helmond-Eindhoven in the Netherlands. Platooning takes place at the Dutch Integrated Test site for Cooperative Mobility (DITCM). This 8 km test site is part of the regular road network and contains 4 km of motorway (A270), 2 km of interurban road, 2 km of urban road and 4 signalised intersections. The site contains various roadside equipment, such as 50 cameras for real-time vehicle detection and tracking at 100 m intervals and a fixed base station, which transmits correction data for real-time kinematic (RTK) GPS positioning. Finally, the control centre of Siemens/TASS includes sensor fusion facilities and application platforms. In the platooning use case, the traffic light and vehicle detection information is published to the supporting IoT platform.

IoT ecosystem

The IoT ecosystem consists of federated IoT platform(s), services and nodes (vehicles) as show in Figure 1. The oneM2M standardized IoT platform takes a central role in the sense that it interconnects all services and IoT nodes by facilitating their discovery and enabling data exchange between them. On the same platform, the Platoon service runs as well as a logging component that stores data for evaluation. The oneM2M platform is also interoperable and connected to the IBM Watson IoT platform that is used by services of other partners in the project. The Siemens/TASS platform hosts the LDM, VBM, TM and TLC services. Finally, the TomTom platform provides HD maps for the vehicle to achieve lane-level localization.

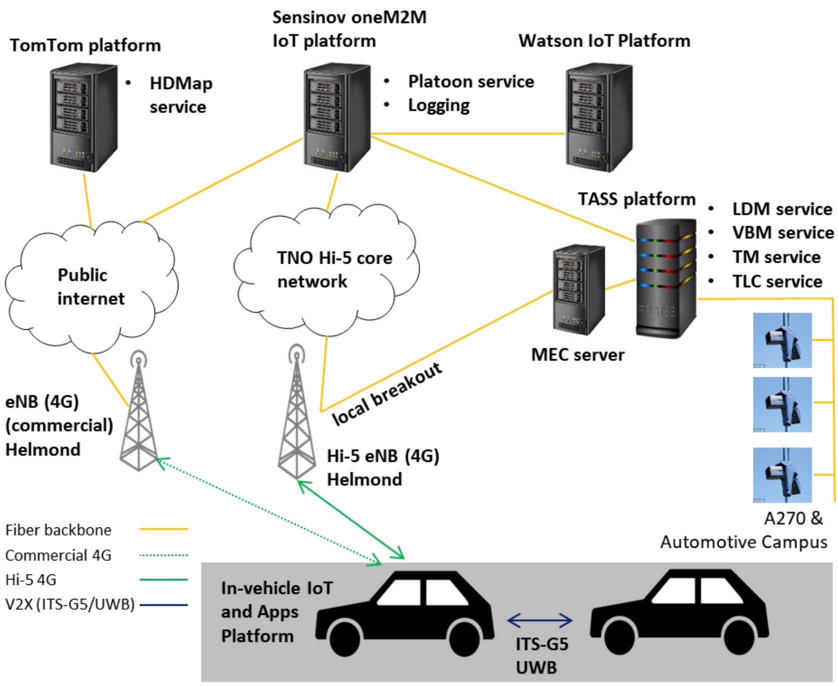

Figure 1 - Pilot site architecture overview for the platooning use case.

The vehicles act as IoT nodes and are connected to IoT services and platforms via both commercial and Hi-5 (TNO pre-5G) communication links. When in range of the Hi-5 eNB placed along the A270 motorway, the vehicles switch their cellular connection to TNO's Hi-5 network, which is used in the project for experimenting with Mobile Edge Computing (MEC) technologies. In particular, a local breakout takes place to redirect data traffic concerning the LDM service directly to the TASS platform. Other data traffic goes to the TNO Hi-5 core network (situated in The Hague) before reaching the oneM2M platform. The TASS platform is physically close to the Hi-5 eNB situated along the N270, thereby benefiting the vehicle with low-latency information of surrounding objects provided by the LDM service. In addition, the vehicles also use V2X short-range communication technologies, i.e., ITS-G5 and Ultra-Wide Band (UWB) for exchanging time sensitive information when engaged in platooning. Figure 2 gives a logical overview of the IoT components described above and how these are connected. All services and the Watson IoT platform use HTTP Restful API to interact with the oneM2M platform. Vehicles use WebSocket to get pushed notifications from services and/or via the oneM2M platform, since their address is hidden by Network Address Translation (NAT) in the 4G network. To download HD maps from the TomTom platform on demand, HTTP is employed. Finally, the VBM service streams messages of detected objects via a RabbitMQ queue service that is more suitable for real-time data exchange.

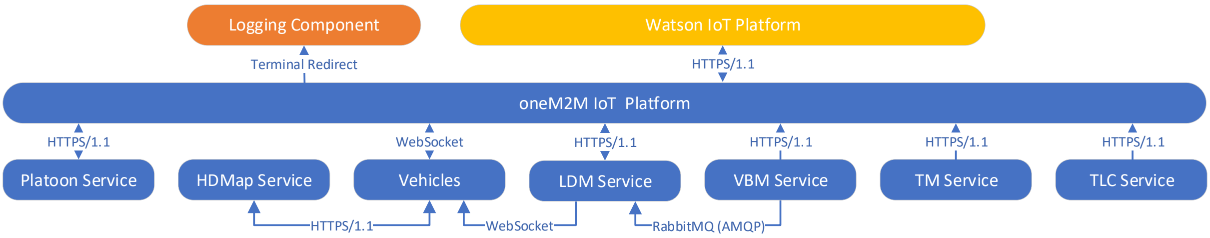

Figure 2 - Logical overview of IoT components used in the platooning use case.

Platoon service

The Platoon service component acts as a central controlling unit and IoT data collector in the platooning system. This service is responsible for communicating the platooning partner match (obtained from an umbrella mobility service supporting multiple use cases), guiding matched vehicles close to each other by generating individual speed advices when the vehicles are not yet in V2V range (so-called formation phase), and providing optimal speed and lane advices to an operational platoon in the so-called platooning phase. Schematically, these two platooning phases are depicted in Figure 3.

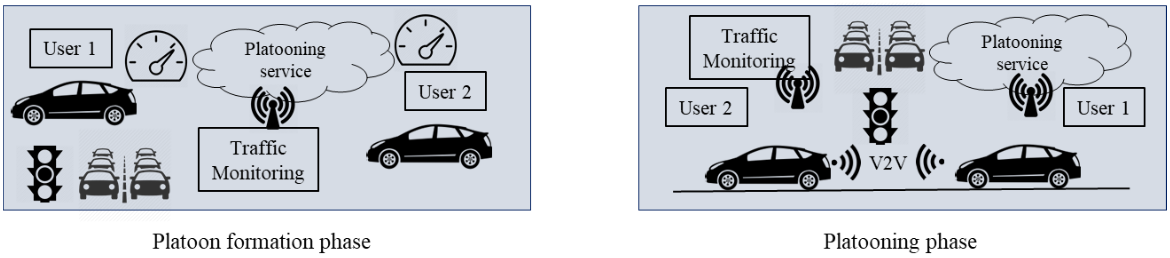

Figure 3 – Schematic representation of the platoon formation and platooning phases.

The Platoon service takes the output of multiple components in the IoT ecosystem into account for generating these speed and lane advices. For example, a platoon can be advised to drive a certain speed while approaching a traffic light to make sure all vehicles belonging to this platoon will be able to cross an intersection before the traffic light turns red by using information from the TLC service, a platoon can be advised to avoid a certain lane if this lane has been closed by a road operator by using information from the TM service, or a platoon can be advised to drive in a certain lane in a situation with dense traffic because the average speed for this lane is higher by using information from the VBM service.

As discussed above, the Platoon service is responsible for guiding matched vehicles close to each other in the formation phase. The formation algorithm allows a platoon to be formed between two or more vehicles. In the AUTOPILOT implementation, several assumptions are made in order to create a proof-of-concept implementation of the formation algorithm. It is assumed that the vehicle destination and its route are known and that the routes will have an overlapping segment. It is further assumed that the

speed limits are available with the route, just as information about the traffic lights on the route.
To initiate the formation phase, a user does a request for formation by pushing the ‘formation request’ button on the HMI in the vehicle. The HMI will show that it is connecting and as soon as a connection with the platoon service is made, the vehicle will start to receive messages from the service. The vehicle in turn will start periodically sending its position to the service. The user will see on the HMI that the platoon service starts searching for a partner. Once the vehicle(s) at the other location(s) perform the same action, the service will match one or more vehicles to form a platoon. The user will see that the system goes into ‘Forming’ state once this was successful. In the service, the formation algorithm is started, which will generate speed advices for each individual vehicle. These speed advices are received in the vehicles and displayed to the respective drivers, who will try to follow these by ‘manual’ driving, optionally supported by ACC. The formation algorithm information is periodically updated (5 s period) and with each update the vehicles get a new speed advice. To avoid speeding and hazardous situations due to too slow driving, the speed advice is bounded.
The formation algorithm also includes functionality that monitors the current status and ‘time to change’ that is advertised by the traffic lights on the route. First, the status information is used to determine the expected traveling time to the meeting point by considering the average waiting time of the traffic lights. Second, the ‘time to change’ information with respect to the nearest traffic light is used to adapt the speed advice in the following cases:

- Stopping at a red traffic light can be avoided by a slight slowdown of the vehicle.
- If stopping cannot be avoided, either by a speed reduction in case of a red traffic light or if the traffic light will turn red before it is reached, the speed advice will realise a smooth stop at the traffic light.

When the vehicles are successfully guided within V2V range and are in the correct order, the platooning driving mode can be initiated by the driver of the following vehicle and the Platoon service is informed that the vehicle has found its platoon leader.
During platooning (platooning phase), the leader vehicle driver is supported by ACC and lane keep assist, while the driver in the follower vehicle can enjoy automated driving. The Platoon service keeps providing speed and lane advices to the platoon.

Pilot tests and evaluation of results

The platooning use case is piloted and evaluated on the public road in the Brainport region. Four pilot weeks are held in 2018 and 2019, one of which will be combined with live demonstrations during the ITS European Congress 2019. Two pilots have been successfully run and analysed at the time of writing. A single pilot test run comprises both a platoon formation and a successive platooning phase. Figure 4 shows a typical pilot run with the trajectories of two vehicles. One vehicle (purple trajectory) starts its trip in the city of Helmond (upper right corner in Figure 4), and a second vehicle (beige trajectory) starts from the Automotive Campus in Helmond. Both vehicles request a platoon service via the motorway to Eindhoven (motorway starts at the bottom left corner in Figure 4). Both vehicles receive an itinerary to form a platoon somewhere on the interurban road (N270) from the campus or when entering the motorway (A270) (part where both trajectories overlap in Figure 4). As explained above, the exact meeting point is planned and adapted dynamically, depending on the start locations and timing, traffic conditions and traffic light states in every test run.

Figure 4: Platoon formation and platooning test run on the public road in the Brainport area.

In the first two pilot weeks, a total of 63 test runs were executed and evaluated. Log data was collected from the automated driving functions, positioning and communication in the vehicles, the oneM2M IoT platform, and the platoon and traffic light services. All log data is provided in a common AUTOPILOT format, and collected and analysed in a central repository, as presented in [12]. The automated data analysis includes checking of data quality and sanity (e.g. time offset checking, speed versus position change), communication and positioning performance, and the detection of relevant events (e.g. platoon formation done, platooning).

This automatic analysis confirmed that during 42 runs (out of the 62 runs) platoon formation succeeded and platooning was achieved. Figure 5 shows the state of each of the two vehicles in a successful run (VehicleMode, green); the lead vehicle with stationId 3101 (solid line) and the following vehicle with stationId 3103 (dotted line). Both vehicles start from a standalone mode, and after searching and connecting to the platoon service, start 'Forming' a platoon. After some 4 minutes the following vehicle reaches the rendezvous point ('Formation Done'), starts 'Engaging' and switches to 'Platooning' when it has joined the lead vehicle into a platoon. The lead vehicle itself changes by default to the 'Formation Done' state when the follower vehicle has joined the platoon. As intended in our state machine, the lead vehicle continues driving in the 'Formation Done' state, even when the following vehicle is in the 'Platooning' state. This is because the controller of the follower vehicle is in platooning or engaging mode, but the lead vehicle is manually driven. Figure 5 further shows the headway; it can be clearly seen that at the motorway (maximum speed 100 km/h) the vehicles are able to keep a constant headway of about 25 m during platooning. Further, note that the headway varies with speed. This is because a speed-dependent spacing policy is used in the longitudinal controller.

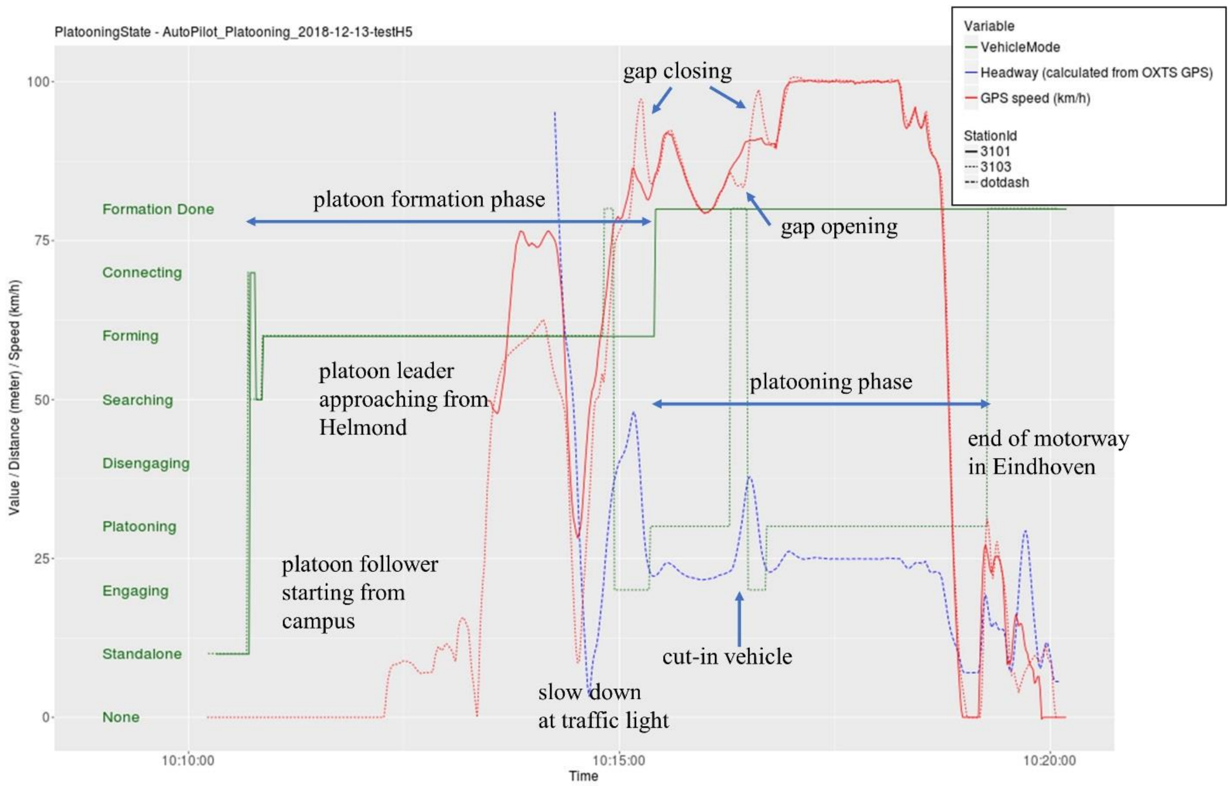

Figure 5: Analysis of a platooning run, showing states and speeds of the vehicles and headway.

Even when vehicles successfully formed a platoon, events such as a cut-in by a normal vehicle (around 10:17 in Figure 5) can temporarily require the platoon to increase the headway, as close distance driving is only safe if information is received from the vehicle ahead by V2V communication. When considering the velocity profiles of the vehicles and the headway it is observed that the gap is first opened and then closed again during ‘Engaging’. Further, it can be observed that the state of the follower vehicle changes from Platooning (CACC), to Formation Done (ACC), to Engaging (gap closing), to Platooning (CACC). The most likely reason for test runs where platoon formation fails is due to differences between actual timing of the traffic lights and the average traffic light behaviour the planner uses for the calculations. In addition, the trajectory is relatively short with a limited amount of traffic lights. With only few traffic lights, taking average traffic light waiting times to calculate arrival times leads to mismatches if the variations in waiting time are large.

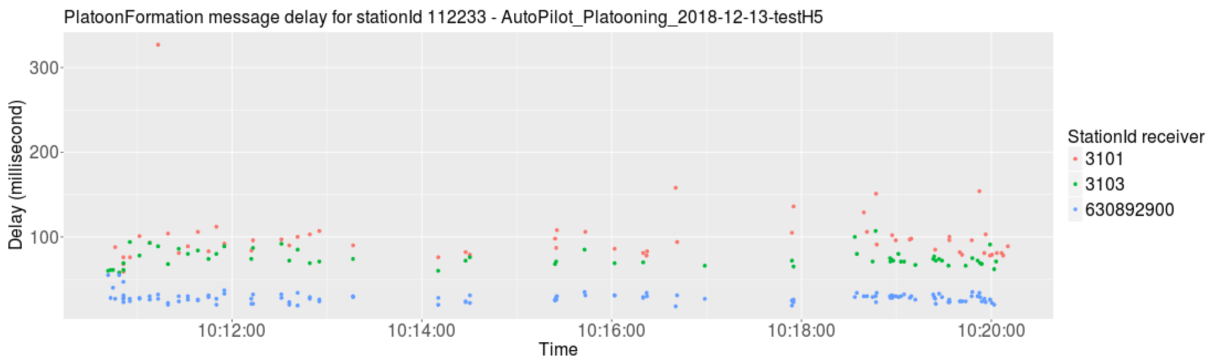

Figure 6: Analysis of message delay to the different units.

The facilities and services to support automated driving and platooning are also evaluated. Communication performance is compared for example for V2V communication and communication via 4G cellular network and the IoT platform to relevant cloud services. Figure 6 shows the delays of individual platoon formation messages from the platoon service (stationId 112233), via the oneM2M IoT platform (stationId 630892900) to the vehicles. This plot can be used to check the correct and timely transmission between the different parts of the system.

Delays in V2V communication via UWB and ITS-G5 are 3 to 7 ms, measured over the 2 cars together. Note that this includes sw-processing of the messaging protocol. As these delays are much lower compared to what is achieved via the 4G cellular connections (without MEC), V2V messages exchanged via the IoT platform (without MEC) are not used for platooning. At the moment of paper writing, analysis results with MEC are not yet available, so no values can be provided.

Concluding remarks

Among the large amount of platooning projects, the platooning use case in AUTOPILOT aims to demonstrate the potential of IoT to improve platooning. Several services and advanced vehicle-to-everything (V2X) connectivity technologies have been developed, tested and evaluated in a platooning use case in Brainport, the Netherlands. The Platoon service is the main service supporting the platooning, not only during the platooning automated driving mode, but also before that to form the platoon. Particularly in the platoon formation process, the potential of IoT is evident, as it not only enables the formation of the platoon from a long range, but also uses information of other sources to guide matched vehicles close to each other by generating individual speed advices. Finally, the tests and evaluation results prove the effectiveness of the formation algorithm, showing a large number of successful formation runs.

Acknowledgements

TNO acknowledges the cooperation with partners TomTom, Siemens/TASS, Technolution and NXP within this project, which has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 731993.

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