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oneM2M-Based, Open, and Interoperability IoT Platform for Connected Automated Driving

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Abstract

The European Commission's Horizon 20202 AUTOPILOT (Automated Driving Progressed by Internet of Things)[1] project aims to create a connected IoT ecosystem for automated vehicles. The AUTOPILOT IoT ecosystem connects the vehicles, as moving "things", to infrastructure sensors and devices, and to external services and applications (mobility, traffic authorities, autonomous driving services). The goal is to improve safety and comfort by improving and widening the environmental perception of automated vehicles, and transforming them from the traditional isolated "egocentric" entities into connected "cognisant" things. The AUTOPILOT open IoT platform and ecosystem consist of a network of distributed and interconnected IoT platforms and things, where interoperability is facilitated through the adoption of the oneM2M standard and standards-based common data models. This paper presents the activities carried out in AUTOPILOT, pertaining to the IoT platform for autonomous driving (AD) and the interoperability challenges addressed by the project.

Keywords: IoT, autonomous driving (AD), oneM2M, interoperability

Introduction

Automated vehicles largely rely on on-board sensors (LiDAR, radar, cameras, etc.) to detect the environment and make reliable decisions. While on-board sensors and technologies (e.g., computer vision) are getting more and more powerful and reliable, the environmental perception models created using in-vehicle sensor data have limitations. They remain attached to the vehicle's point of view and are, therefore, unable to "see" beyond what can be physically seen from the vehicle's point of view. For instance, a vehicle may not be able to "see" through the vehicles ahead, to anticipate situations upfront. Potential exists to improve the autonomous vehicles perception and awareness of their environments and vice-versa, by interconnecting the vehicles and their surrounding infrastructure and "things" (e.g., infrastructure cameras, traffic light radars, road sensors, other vehicles, etc.). This may lead to new ways of designing automated vehicle systems, potentially reducing costs, while improving safety and comfort. This will, in turn, help push the SAE (Society of Automotive Engineers) level of

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[1] AUTOPILOT website: http://autopilot-project.eu/ | Grant Agreement Number: 731993 | Call Identifier: H2020-IOT-2016 | Topic: IoT-01-2016 | Large-Scale Pilot

driving automation[2] towards full automation, keeping the driver out of the loop.

AUTOPILOT (Automated Driving Progressed by Internet of Things) [1] is a European-funded project that aims to address the above challenge. Its objective is to create an IoT ecosystem where vehicles (considered as moving "things"), external sensors, devices, services, and applications are inter-connected through an open IoT platform, and may exchange information. In addition to increasing the safety and comfort of automated driving, this is expected to facilitate the creation of new applications and business opportunities for mobility, by allowing developers to create novel IoT and autonomous driving services and plugging them to the IoT ecosystem in an easy way.

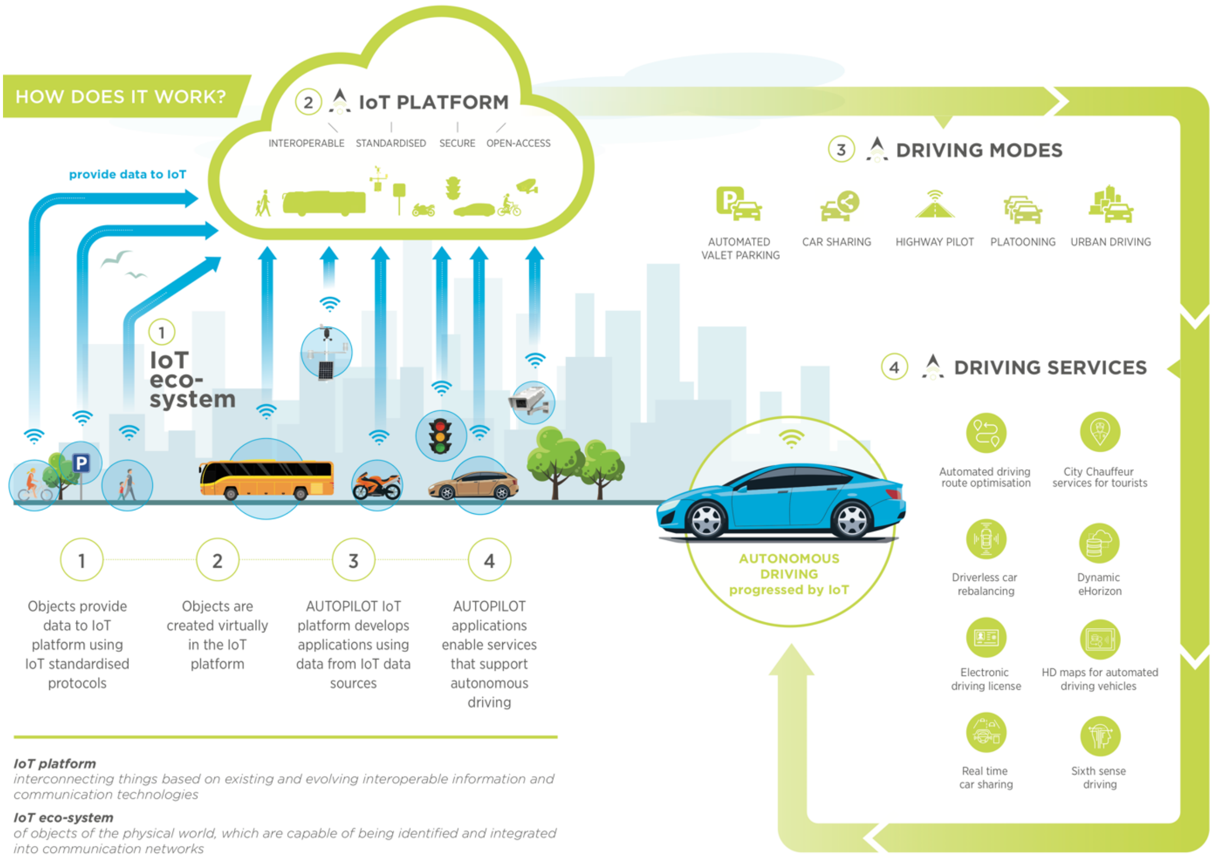

Figure 1 - The AUTOPILOT overall concept

The overall concept of AUTOPILOT is illustrated in Figure 1 above. As can be seen in this figure, the AUTOPILOT IoT ecosystem consists of vehicles, infrastructure sensors and devices, and people, all connected, and exchanging information, through an IoT platform: the AUTOPILOT Open IoT Platform for Automated Driving. The IoT ecosystem and platform enable a wide range of autonomous driving applications and services listed in Figure 1.

[2] SAE Levels https://www.sae.org/standards/content/j3016_201806/

In this paper, we focus on the AUTOPILOT IoT architecture and the interoperability challenge addressed by the project.

AUTOPILOT Use Cases

The AUTOPILOT concept is being implemented and demonstrated in 6 large pilot sites: Tampere (Finland), Versailles (France), Florence-Livorno (Italy), Daejeon (Korea), Brainport (Netherlands), and Vigo (Spain).

The AUTOPILOT concept and IoT ecosystem and platforms are being implemented and validated through the following use cases, pertaining to the use of IoT for autonomous driving.

- Automated Valet Parking (AVP): A driverless system that finds a free parking space for the vehicle, which then drives itself to the parking spot, and parks itself. IoT is used in AVP to guide the car to the free parking spot (e.g., identified by a camera, another vehicle, or a drone), and to alert the vehicle of any obstacles on the way to the parking spot.
- Platooning: AD function by which two or more vehicles follow each other in a line relatively close to each other. In this use case vehicles may be considered as moving “things” that communicate with each other to manage (e.g., join, leave, start) and operate the platoon.
- Car Rebalancing: The driverless car rebalancing service relocates, according to demand, AD vehicles distributed over several pickup points within a car sharing service. The AD vehicles drive automatically between dedicated pickup points on specific areas, using pre-defined and 3D-mapped tracks and IoT data to improve their world models.
- Highway Pilot: A function that automates highway driving, meaning that steering and speed adjustments are executed by the automated driving system. The highway pilot function is extended by IoT, through the identification of road hazards (e.g., bumps, potholes, etc.) and the communication of hazard information between vehicles.
- Car sharing: A service that drives the most convenient available cars to interested customers to drop them off at their desired destinations. IoT is used to optimise the allocation, routes, pickup and drop-off locations based on real-time information received from the IoT ecosystem (e.g., traffic jams, incidents, road closures, etc.).
- Urban driving - Urban Driving, assisted by IoT has the main objective to support connected and automated driving functions through the extension of the electronic horizon of an automated vehicle.

AUTOPILOT IoT architecture

Overall, the AUTOPILOT IoT architecture builds on, and borrows, building blocks from relevant IoT architectures such as AIOTI[3], CREATE-IoT[4] [3, 4] and IoT-ARM[5].

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[3] Alliance for Internet of Things Innovation (AIOTI): https://aioti.eu

[4] Create-IoT: https://european-iot-pilots.eu/projects/create-iot

As shown in Figure 3, the AUTOPILOT IoT architecture has four functional layers:

1. **Things Layer:** Includes the AUTOPILOT "things" (vehicles, cameras, drones, road side units, etc.) and external services provided by public offices or private web services.
2. **Network Layer:** Enables communication throughout the IoT ecosystem.
3. **IoT Layer:** Enables the IoT functionality through a set of IoT building blocks: *device management, context management, process & service management, semantics, analytics and security*. Each of these functional building blocks is specified in detail in the AUTOPILOT deliverable D1.3 [5].
4. **Application Layer:** Contains services that leverage the AUTOPILOT IoT, such as real-time routing, car sharing, platoon management, car rebalancing, etc.

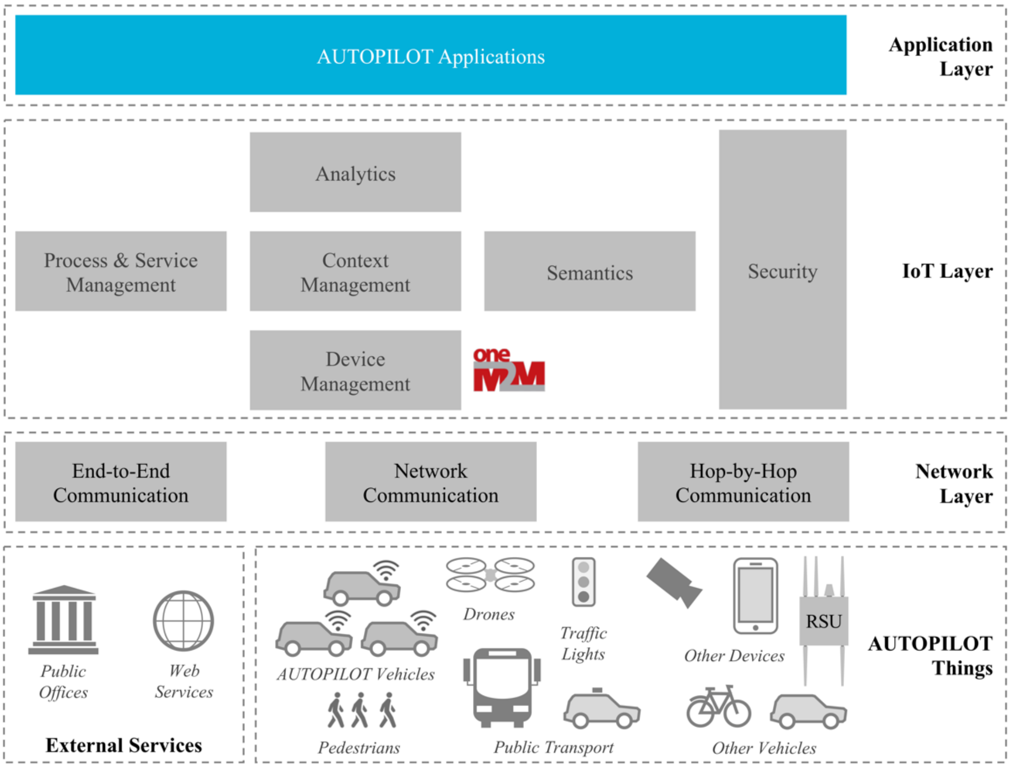

Figure 2 – AUTOPILOT IoT Architecture: Functional View

The architectural components and devices of the open IoT platform (infrastructure, IoT devices, services, etc.) are inherently physically distributed. AD functions themselves have varying requirements in terms of speed of access (latency), throughput, availability, and range (covered area). Some localised mission critical functions, such as warning other vehicles in the immediate proximity that a pedestrian is jaywalking, need to be accessible within low latency. Other functions, such as notification about a parking spot being made available, need to cover wider areas but are less demanding in terms of latency. Therefore, as mentioned previously and illustrated in Figure 2, the

[5] ARM-IoT: https://developer.arm.com/products/architecture/system-architecture

AUTOPILOT IoT ecosystem and platform consist of a network of interconnected, sensors and IoT platforms that are distributed over various physical infrastructures.

- Inside a vehicle, sensor data are collected and exchanged through an in-vehicle IoT platform. The in-vehicle IoT platform deals with real-time data collected by the sensors and used by the autonomous driving system.
- In the same way, road-side IoT platforms are responsible for collecting and exchanging data from road-side sensors (cameras, traffic lights, road signs, etc.) and the neighbouring vehicles. This typically has very low latency to enable tactical operations, such as the vehicle to vehicle communications required to operate a platoon, or harsh break alerts, etc.
- In the wider local area (e.g., pilot site), dedicated IoT platforms are responsible for exchanging information relevant to the specific geographic area in question, such as the traffic jams, the crowd detection, etc.
- At a wider scale, cloud IoT platforms are responsible for large-scale data needed by services and applications (e.g., car sharing service, platoon management, dynamic maps, routing, etc.).

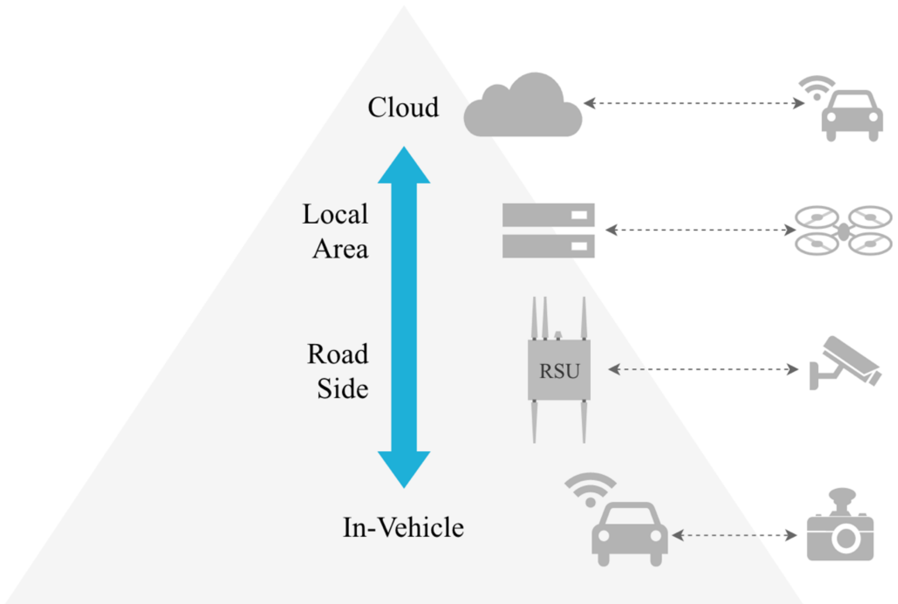

Figure 3 – the AUTOPILOT – data sources and services

As shown on Figure 3, data may flow from any level to another as required. At a given level, data may be processed to generate new information that may be published to an IoT platform at another layer. For example, sensor data collected by the in-vehicle platform may be processed inside the vehicle and, upon detection of an object or hazard on the road, an alert may be published on the road-side and cloud IoT platforms. In this way, relevant vehicles may be informed of the road hazard and may be able to avoid it.

Figure 4 shows the AUTOPILOT IoT architecture [7]. As shown in this diagram, devices, gateways and in-vehicle and road-side IoT platforms exchange information (e.g., about detected objects, hazards, vulnerable road users, traffic lights, traffic conditions, vehicle updates, etc.) with several distributed IoT platforms (that may be deployed at different levels). We distinguish the following two types of IoT platforms:

1. **Proprietary IoT Platforms:** These are used by some applications, organisations and services to exchange specific data with specific devices or vehicles. For example, the Brainport car sharing and automated valet parking services use Watson IoT Platform™ to collect data from the operated vehicles. The Brainport crowd detection service uses FIWARE[6], etc.
2. **oneM2M Interoperability Platform:** This is the central IoT platform that acts as a hub that interconnects the proprietary IoT platforms (and possibly devices and services) and allows them to exchange information (see next Interoperability section). As the name suggests, the interoperability platform is based on the oneM2M[7] machine to machine standard, which is adopted by the project as the standard for interoperability (see next section).

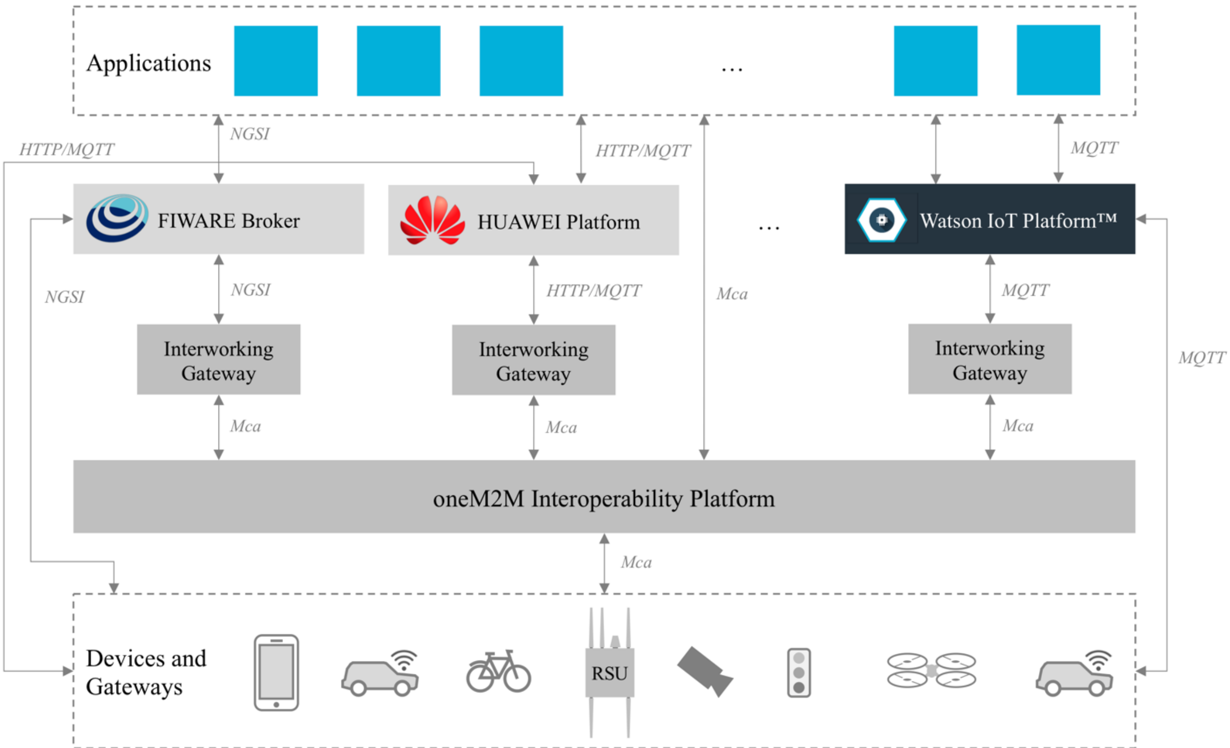

Figure 4 – AUTOPILOT Federated IoT Architecture, from [7]

The proprietary IoT platforms are connected to the oneM2M interoperability platform through oneM2M interworking gateways. The interworking gateway of a given proprietary IoT platform may be configured to share selected data types with the interoperability platform. Such data may then become accessible to all the connected IoT platforms through the oneM2M interoperability platform.

6 FIWARE website: https://www.fiware.org

7 oneM2M website: http://www.onem2m.org

This is particularly useful for sharing data relevant to all the AD vehicles and applications, such as detected hazards, vulnerable road users, objects, etc.

Interoperability

The AUTOPILOT IoT platform aims to enable a large-scale, and open IoT ecosystem, where new "things" (sensors, vehicles), services, applications, and IoT platforms may be plugged in easily and may start exchanging information with the rest of the ecosystem components. As no single "standard IoT platform" exists, The AUTOPILOT architecture has to rather cope with a multitude of proprietary IoT solutions distributed over various physical infrastructures and dedicated to different geographic areas, services, or providers. A challenge exists to connect these proprietary IoT platforms and make them communicate with each other to exchange information. This is essential to achieve the project's vision of an open federated IoT architecture where data and information can flow from one platform to another transparently.

Interoperability in AUTOPILOT is achieved based on the following three principles:

- **oneM2M IoT Standards:** Proprietary IoT platforms are interconnected through a standard oneM2M interoperability platform and oneM2M interworking gateways.
- **Standardised IoT Data Models:** IoT data requiring to be exchanged across the IoT platforms are standardised, based, whenever possible, on existing data models and standards (such as DATEX II[8] for exchanging car park availability and traffic data, and SENSORIS[9] for sharing vehicle location and object detection data).
- **Standardised Ontologies:** To achieve semantic interoperability, IoT data field values (e.g. hazard types, vulnerable road user types, detected object types, etc.) are semantically standardised using ontologies.

Each of the above interoperability principles is discussed in the following subsections.

oneM2M IoT Standards

AUTOPILOT adopts the oneM2M standards [2] for machine-to-machine (M2M) and IoT. oneM2M is the global standards initiative for machine to machine communications and IoT. The purpose of oneM2M is to develop technical specifications that address the need for a common M2M service layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide. By adopting the oneM2M standards, we aim to facilitate interoperability between the various IoT platforms, sensors, and services of the architecture. The idea is as follows.

- A oneM2M interoperability platform acts as a central hub connecting the various proprietary IoT platforms, allowing them to exchange data and information through standard oneM2M

[8] DATEX II website: https://www.datex2.eu

[9] SENSORIS website: https://sensor-is.org

protocols and APIs.

- An interworking gateway is set between every proprietary IoT platform and the oneM2M interoperability platform. Such interworking gateway is a oneM2M wrapper for the proprietary IoT platform, allowing it to expose a oneM2M Mca[10] interface for a bidirectional communication with the oneM2M interoperability platform. The Mca reference point is used to interface a oneM2M Application Entity (AE) and a oneM2M Common Services Entity (CSE).

The oneM2M platform serves as the bridge for interoperability, allowing data to flow from one IoT platform to another in both directions. Using this architecture, an IoT platform may push data to other IoT platforms and receive from them.

Mapping between the internal data representation of an IoT platform and the oneM2M message contents are specified in the interworking gateways. These also act as filters allowing only selected data to be exchanged. For example, SENSORIS data received by the Watson IoT platform from shared cars, containing their locations and detected events and objects, are filtered by the corresponding oneM2M interworking gateway, to keep personal information (such as car position and identity) private, while sharing detected hazards with the oneM2M interoperability platform.

In this architecture, data providers or consumers, such as applications, may use any of the available IoT platforms, including the central oneM2M interoperability platform itself. For instance, a data provider may publish an event to the Watson IoT platform, which can then be shared with the FIWARE IoT platform through the oneM2M platform. This means that an application or service that uses the FIWARE IoT platform can also access this event through the FIWARE IoT platform.

This approach offers flexibility to the Pilot sites and application developers. However, for this to work, data providers and consumers need to exchange data with the oneM2M platform using standard data models and vocabularies as explained in the following sections.

Standardised Data Models

oneM2M provides a standard protocol for exchanging IoT messages, but it does not specify the content of the messages, as this is domain specific. To achieve interoperability in AUTOPILOT, we have developed standardised content for the oneM2M messages exchanged between the IoT platforms, devices, applications and vehicles, through the oneM2M interoperability platform. A Data Modelling Activity Group (DMAG) was created in AUTOPILOT for this purpose.

The scope of the data model standardisation activity in AUTOPILOT covers the IoT messages and data fields required to implement the project's use cases uniformly across the Pilot sites. This allows AD vehicles to access the same types of data regardless of their locations (Pilot sites) or IoT platforms

[10] See https://www.etsi.org/deliver/etsi_ts/118100_118199/118101/02.10.00_60/ts_118101v021000p.pdf

they are connected to, and to be able to process the data and work with it. For instance, a message notifying AD vehicles about a hazard on the road, or instructing them to avoid a given road lane, should be the same in all Pilot sites, allowing vehicles to consume these messages and react to them correctly as they are moving from one place (e.g. Pilot site) to another.

The AUTOPILOT IoT data models cover the following packages:

- Vehicle location and detection messages, based on SENSORIS,
- Event and object detection messages to be consumed by AD vehicles based on SENSORIS and DATEX II,
- Traffic situations, based on DATEX II,
- Parking availability information, based on the DATEX II parking extension,
- Messages specific to automated valet parking, car sharing, rebalancing, and platooning.

Standardised Ontologies

Data standardisation deals with the structure of the IoT messages exchanged and their field names, types, values and units of measure. This usually works only to a certain extent, as some fields remain challenging to standardise. This is specifically the case when dealing with enumerative fields whose possible values are too numerous to be specified exhaustively in advance, or are language-dependent or use-case-dependent (e.g., vehicle types, detected object types, hazard types, proprietary vehicle parameters, etc.). In such cases, the dilemma is whether to:

- Specify a high-level enumeration that covers all the cases but whose values may turn out to be too broad and useless for certain applications,
- Or leave the field values as plain text, making the data model flexible at the cost of rising semantic interoperability issues.

As can be seen, there are pros and cons for each approach. In AUTOPILOT, we solve the problem by using ontologies that define the common values of the data fields and provide semantic mappings between them. This constitutes a compromise between openness and flexibility, on the one hand, and field value standardisation on the other hand.

AUTOPILOT Standardisation Activities

As mentioned above, in the Interoperability section, AUTOPILOT is adopting the oneM2M IoT standard. The project is also contributing to the standard. In particular, the oneM2M TR-0026 “Vehicular Domain Enablement” [2] contains use cases and requirements for the oneM2M platform. The scope of the document is to examine how the current oneM2M System can be used in the vehicular domain. It includes a study of advanced features that future oneM2M releases may support for this vertical domain. Note that [2] only provides requirements. The actual status of the implementation of those requirements in oneM2M is subject to choices and priorities defined by the Architecture and Protocols groups of oneM2M.

Besides work on how oneM2M platforms will support autonomous driving, work is underway to define the data models to be supported by these platforms.

The AUTOPILOT standardisation plan is based on the following actions pertaining to oneM2M:

- Introduce the data models pertaining to the automotive domain and developed as part of AUTOPILOT,
- Create IoT data models based on use-cases derived from the AUTOPILOT project,
- Create the 'need for solution': present AUTOPILOT use cases,
- Create 'elements of solution': present data models for the submitted use cases.

A set of contributions based on AUTOPILOT results have so far been agreed upon and introduced in TR-002 pertaining to the data models and related use cases introduced above.

Conclusion

One of the key aspects to ensure the success of autonomous driving solutions is the capability to integrate the large amount of data obtained from the on-board sensors and from the surrounding environment. IoT technologies enable the exchange and analytics of such large volumes of data. They also allow services and applications to consume device data and, possibly, analyse it and produce new information and share it, with the whole IoT ecosystem or part of it, using the same paradigm and technology. oneM2M provides a standard and open platform to manage all the IoT data while facilitating interoperability, which makes it the best standard candidate, hence, adopted by AUTOPILOT. A oneM2M interoperability platform has been deployed and is allowing the integration of various proprietary IoT platforms across the project's pilot sites. The project started in 2017 and, so far, various use cases have already been implemented and tested and currently being evaluated. These will be demonstrated during the last year of the project (2019).

Acknowledgement

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