IoT Platform for Precision Positioning Service for Highly Autonomous Vehicles

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***Abstract*—This paper describes an IoT Platform for precision positioning service for highly autonomous driving (HAD). The platform fuses IoT with cooperative ITS technologies, protocols, and algorithms to achieve highly precise localization for future autonomous vehicles. The paper also offers an insight about the IoT Platform architecture, its functional components, prototype implementation, and best-practice guidelines.**

***Index Terms*—IoT; Highly Autonomous Driving; Positioning Service; WoT.**

I. Introduction

The Internet of Things (IoT) and Cloud Computing are impacting several industries including the automotive. Connected Cars bring several benefits to the consumers, businesses, and municipalities. The IoT is starting to be utilized in highly autonomous driving (HAD). One of the benefits HAD will bring is increased safety of Vulnerable Road Users (VRUs) and other vehicles. Thus, future autonomous vehicles must have strong geo-temporal awareness i.e. to know their position with strong confidence and centimeter level accuracy [1]. The awareness is targeted to be beyond the accuracy and continuity of GNSS. The EU H2020 project HIGHTS investigated and developed algorithms for determining precision positioning. IoT technologies are used to accomplish - (i) vehicular cooperation for advanced sensing, data, and contexts exchange, (ii) provide accurate Local Dynamic Maps (LDM), (iii) sensor data fusion, and (iv) provisioning of precision positioning algorithms. This paper describes in details the architecture of the proposed IoT Platform (also known as European Wide Positioning Service Platform or EWPSP), its components, brief prototype experiments, and best practice guidelines.

II. Platform Architecture

This section describes the IoT Platform architecture offering precision positioning for the HADs and its operation steps. The architecture consists of a Cloud system that is housing positioning and other web services. It is shown in Fig. 1 and consists of three layers (i) secure web services deployed in a Cloud infrastructure, (ii) highly autonomous cars with Cloudlets at the Edge layer, and (iii) V2X communication with various infrastructure (e.g. Geo-reference features, non-reference features, vulnerable road users, static ITS Stations) for positioning purpose. Following is a description of the functional elements.

A. Cloud Based Web Services

The functionalities of the platform are exposed the autonomous vehicles and other consumers through secure and

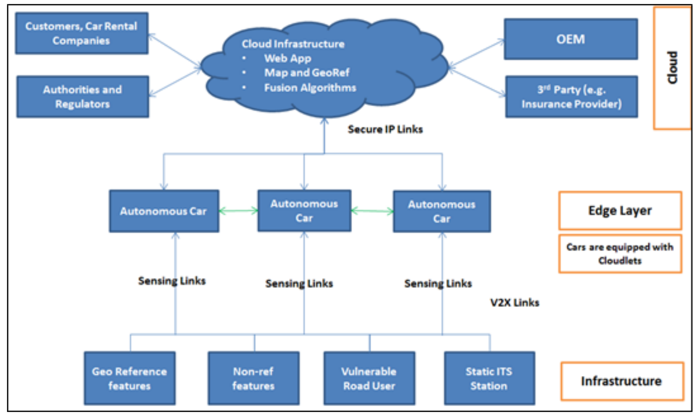

Fig. 1. Architecture of the Proposed IoT Platform

open web services mentioned below. The internal and external interfaces of the Cloud system along with the described web services are portrayed in Fig. 2.

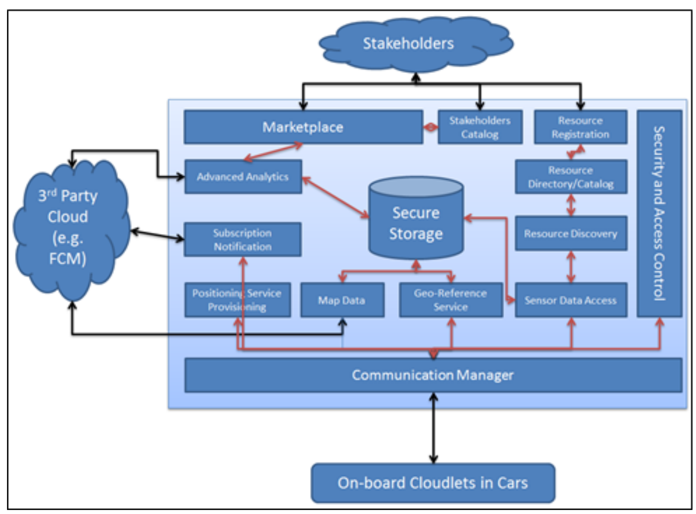

Fig. 2. Interfaces of IoT Platform Cloud Services.

- **Positioning Service Provisioning.** The EU H2020 project HIGHTS developed several precision positioning algorithms. In future, 3rd party developers will also implement similar algorithms. Each algorithm depends of a specific set of external sensors and communication technologies to determine absolute position with certain accuracy. During the course of driving, it might happen that the car looses access of one or more sensors and/or communication technologies. But the calculation of positioning should continue based on available infrastructure elements. This dynamic context switching is enabled by the Cloud system as a web service. For example, consider a car with GNSS and UWB ranging driving on a road with no ITS-G5 connectivity. The car is using only GNSS for localization which offers absolute positioning with Grade 1 (e.g. accuracy of GNSS). But, as soon as the car enters a highway with ITS-G5 connectivity, it can use a better algorithm (available from the mentioned platform) that provides absolute positioning with precision beyond GNSS. Fig. 3 shows the steps necessary to achieve this. The vehicular on-board Cloudlet detects a change in sensors and/or communication technologies available for positioning. The Cloudlet securely communicates that to the IoT Platform positioning service which determines the suitable algorithm based a decision tree [2]. The positioning calculation algorithm is then communicated back to the car over a secure channel. The platform thus acts as a provider of precision position as a service.

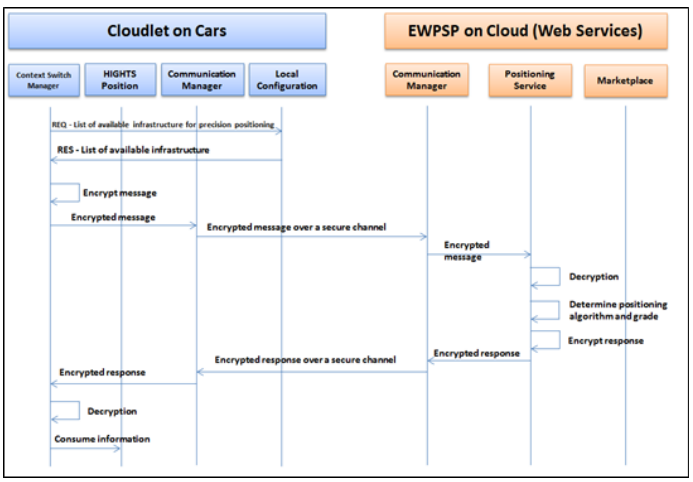

Fig. 3. Operational Steps for positioning service provision through the proposed IoT Platform.

- **Map Data and Geo-Reference Service.** High definition maps and Geo-reference features are widely used in the precision positioning algorithms. The Platform exposes them as another secure web service allowing the autonomous cars to download them in real time. The map data is provided by different map and navigation service providers.
- **Marketplace.** We introduce a marketplace in the Platform enabling businesses offer positioning services and/or relevant maps, features required for positioning directly to the autonomous cats. The marketplace also supports secure payment for subscription to or purchase of a precision positioning algorithm. For example, referring to Fig. 4, if a car does not have the positioning algorithm installed in its Cloudlet, the car can purchase that. In that case, the HIGHTS position calculation element of the Cloudlet created a secure purchase request and utilizes the communication manager to send it to the marketplace web service. When it completes the secure payment, the car can download the algorithm in real time. The marketplace brings together the stakeholders of the Platform including autonomous car OEMs, insurance providers, regulators, and car rental companies.

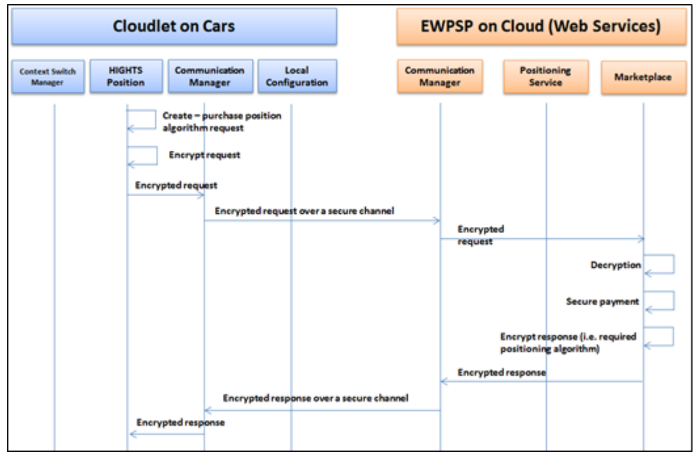

Fig. 4. IoT Platform marketplace operations.

- **Subscription and Notification.** This web service manages the subscription to predefined events and notifies the subscribers when such an event occurs. The notification to consumer devices running Android or iOS is achieved through Firebase Cloud Messaging (FCM) or Apple Push Notification (APN) respectively. The consumer must register itself at the Googles Firebase Cloud Messaging (FCM) service and obtain a unique ID for itself. The unique ID is then communicated to the EWPSP subscription notification service. When the subscribed event takes place, the EWPSP web service send a notification message with the unique ID to the FCM which in turn pushes the message to the consumer device with the unique ID.
- **Resource Registration.** For a stakeholder to offer a service, its capabilities and other features (e.g. pricing etc.) should be registered on the IoT Platform. Similarly, if an autonomous car would like to provide its sensor data for computation of precision positioning in another car, the car sensor descriptions must also be registered to the platform as resources. The Platform thus considers vehicles as a resource for the underlying IoT system [3]. Such descriptions can be created using CoRE Link Format [4] or JSON-LD 1.0 [5]. We suggest the second option since it allows representing the resource capabilities in terms of events, properties and actions. The resource registration web service is based on CoRE Resource Directory.
- **Resource Discovery.** It allows real time discovery of desired services (e.g. positioning algorithms) or other resources (e.g. Geo-reference resources). This service reuses the CoRE Resource Discovery concept from re-

source registration [6].

- **Sensor Data Exchange.** Calculating position with a precision beyond GNSS requires accessing multiple sensor data like camera, Lidar, UWB, HD maps, environmental sensors and other on-board sensors. These sensors communicate using different technologies and protocols. To access external sensor data, a car must discover and consume the corresponding Thing Description. Following that, the car can determine which protocol binding, communication technology and security parameters are to be used when access the sensor data either directly or through the Cloud.
- **Security and Privacy.** Security and access control mechanisms ensure adequate privacy of the data and sensitive information (e.g. payment) in the platform. For this purpose, this web service supports security key generation, rotation, exchange, secure communication, authentication, authorization and integrity checks. However, this list is non-exhaustive and additional security measures must be put in place for a more secure IoT Platform.
- **Data Analytics.** It supports the application logic of business use cases of the stakeholders and provides a user interface (through web browser or mobile application) to the stakeholders. This web service is accessed by the marketplace which is the default entry point for the stakeholders.
- **Positioning Data Visualization.** Visualization of positioning data calculated by the precision positioning algorithms is highly important for the Platform stakeholders. For this purpose, we implemented a leaflet.js based visualization service. The tool provides lightweight, reliable, and a robust visualization medium.

B. *Vehicular On-Board Cloudlet*

A Cloudlet is a mobility-enhanced small-scale cloud datacenter. The main purpose of the cloudlet in this context is to support resource-intensive and interactive mobile applications by providing powerful computing resources to cars with lower latency. The vehicles requiring precision positioning is required to tackle smart mobility and intensive computation at real time. So, Cloudlet for Edge Layer of the IoT Platform is a natural choice. The internal architecture of the Cloudlet is shown in Fig. 5.

- **Communication Proxy.** This is a novel aspect of the Cloudlet. The sensors and Cloud based web services use multitude of communication technologies (e.g. IP, ITS-G5) and protocols (e.g. HTTP, CoAP, MQTT) for data exchange. The communication proxy unifies them all by integrating their software libraries and making open interfaces internally. Using these interfaces, the Cloudlet components can effectively communicate with the external stakeholders and web services.
- **Vehicular Gateway.** Each vehicular and external sensor may generate data in a different frequency and the data format varies due to different manufacturing standard. Thus, direct processing or fusion of sensor data is not possible. As a result, this gateway is introduced for making uniform representation of the sensor data to ease the processing on HIGHTS positioning service subsystem. Along with the sensor measurement, additional information like unit, timestamp, sensor type, update frequency are added which results into sensor data annotation. Sensor Measurement Lists (SenML) to represent the sensor metadata in a standardized format (based on JSON schema). This eases the sensor data fusion in the LDM in the next step.

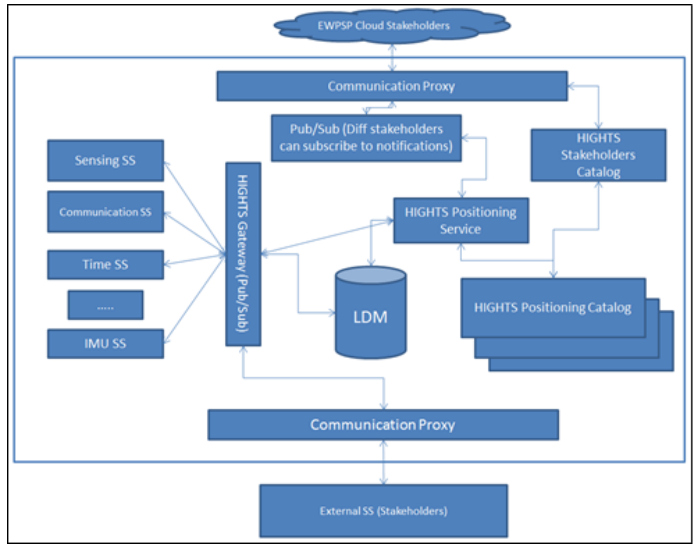

Fig. 5. Functional components of the on-board Cloudlet.

- **Local Dynamic Map (LDM) Subsystem.** This is the main information storage entity for raw sensor (local, cooperative), as well as for processed output from the overall positioning service entity. Our IoT Platform relies on the ETSI LDM specification EN 302 895, with extensions for supporting Position and Time (PoTI) messages. The vehicular Gateway and the Positioning Service entities implement the subscription/push/pull messages defined for the LDM in order to be able to store the sensor data obtained from various sources. The Positioning Service entity further implements a search mechanism to identify the information available on the LDM to match it with the required sensor data indicated in its Positioning catalog.
- **Precision Positioning Service.** This service is receiving the precision position calculation algorithm from the IoT Platform to calculate the precision position. The vehicular gateway is continuously posting the SenML formatted sensor metadata and using the fusion algorithm, a position is calculated. The updated position is then stored in the LDM and make available to the stakeholders who subscribed to receive the position in real-time.
- **Positioning Catalog.** We consider that each of available precision positioning algorithms are described in an abstract way as a list Positioning Solution $precisiongrade, sensorlist$ tuple, indicating the required sensors and the precision capabilities. Similar to a music catalog, the positioning catalog component

keeps a list of potential positioning algorithms that are locally stored and available. The decision tree in [2] is based for instance on a catalog of four positioning solutions. As function of the available sensors (V2X, LIDAR, RADARs, GPS,..), the Positioning Service will select from the catalog the best matching positioning solutions. It will then apply them and compute the precise and highly accurate position. If no matching solutions is available, it will then contact the IoT platform Stakeholders catalog to retrieve one remotely. The IoT Platform Positioning Catalog is a first step in the direction of Knowledge-based Positioning, as contrary to traditional positioning system, which only rely on Information (sensor, GPS, V2X) for its fusion strategies. The EU H2020 project HIGHTS proposed to have multiple options at hand, and rely on a contextual knowledge to select the right algorithm which is one of the novel aspects.
- **Stakeholders Catalog.** The Stakeholders Catalog is a database containing a list of high precision positioning solutions developed by various stakeholders, and which could be used by the IoT Platform in a particular (known or unexpected) context. The catalog has been designed in order to create a community of stakeholders that could develop or contribute to the Platform by providing algorithms, data, HD maps, or crowed sourced map details. The Cloudlet Stakeholders Catalog is a local storage of a larger Stakeholder Positioning Marketplace Service, including search and retrieving capabilities from the main Cloud Stakeholder Catalog located on the IoT Platform Cloud entity, and accessible through web services.

III. Prototype Implementation and Best Practices

The overall architecture (e.g. Cloud and Cloudlet components) has been implemented in a testbed hosted in EURECOM. A test vehicle (BMW X5), its sensors exposed through CAN bus, and ITS-G5 OBU/RSUs are utilized as a part of the testbed. A Cloud infrastructure hosts the web services in of the EURECOM IoT Platform. The on-board Cloudlet is implemented using an Android Auto Application (AAA) and is hosted on the test vehicle.

A. Best Practice Guidelines

We share our learnings, best-practices, and recommendations for implementation of the IoT platform web services and the Cloudlet below.

- Implementing web services by following W3C Web of Things recommendations would achieve interoperability in services, data and security. This is shown to be effective to counter the increasing fragmentation in ITS and IoT markets.
- For sensor data representation, we recommend using SenML and its JSON based implementation. Parsing JSON objects is very simple and the vehicular gateway can parse several such metadata in parallel. This preserves the real time aspect in the positioning service.
- For publish/subscribe type messages, MQTT should be used. There are several open source MQTT brokers available for research and development.
- The web services in the Cloud system should be implemented using microservices. They extend the concept of service oriented architecture (SOA) and enable creating an ecosystem composed of loosely coupled services. Apart from that, other benefits of using microservices are lightweight, container-based deployment, broken object handle, and rapid development.
- The resource descriptions should be in terms of events, properties and actions to support granular descriptions.
- CoRE Resource Directory is suggested for Thing repository as the former provides a standard way for storage of resource descriptions and resource discovery.
- JSON (JWT) based authentication can be used for identifying the connected cars and consumers in the Cloud system.

IV. Conclusion

The paper discusses the importance of geo-temporal awareness of the future autonomous vehicles. In this context, to provide accuracy beyond GNSS, we need many additional sensors, C-ITS principles, and sensor data fusion. We presented an architecture that exploits IoT and ITS together to achieve that goal. The Platform also showcases precision positioning service provisioning and calculation for highly autonomous driving scenarios. Our prototype validates the presented architecture and is also lightweight in terms of memory, and CPU utilization.

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