Integrating Connected Vehicles in Internet of Things Ecosystems: Challenges and Solutions

Soumya Kanti Datta, Rui Pedro Ferreira Da Costa, Jérôme Härri, Christian Bonnet
Communication Systems Department, EURECOM, Biot, France
Emails: {dattas, ferreira, haerri, bonnet}@eurecom.fr

Abstract—**Vehicles are becoming the next frontiers for Internet of Things (IoT) based platforms and services. Connected vehicles, Intelligent Transportation Systems (ITS) together with IoT technologies have the potential of unleashing efficient and more sustainable transportation system which is fast becoming an important societal challenge. This paper formulates several main research and engineering challenges for integrating connected vehicles into IoT ecosystems. The challenges include – (i) a suitable alternative of cloud platform to support real time connected vehicular scenarios, (ii) uniform description and data collection mechanisms from vehicular sensors, (iii) integrating smart devices into transport systems, (iv) uniform mechanism for data fusion and analytics and (v) integrating all heterogeneous elements into a standard IoT architecture for connected vehicles. To mitigate these challenges, we propose a novel IoT framework. The solutions, operational phases of the framework, software elements & their implementations and advantages are described in details. The building blocks of the framework are integrated into an oneM2M standard architecture. Finally, the paper concludes with best practice recommendations and lessons learnt from the prototyping.**

Keywords—Connected vehicle; Internet of Things; Intelligent Transportation System; Named Data Networking; oneM2M architecture; V2X communication; Web of Things.

I. INTRODUCTION

With the ongoing wave of modernization of city infrastructures, "always-connected" trend, strict emission standards for vehicles, the necessity of improving efficiency and safety of transport have made the development of more sustainable transportation systems one of the fundamental societal challenges. Intelligent transportation systems (ITS) and connected vehicles together with the Internet of Things (IoT) have the potential of providing a more efficient and sustainable transportation systems that minimizes the impact on the environment. To enable connected vehicles, it is of paramount importance to - (i) design V2X communication systems allowing relevant actors to exchange information in real time and with high reliability, (ii) integrate sensing devices to monitor the vehicular and their environmental conditions, (iii) deploy middleware for local data processing, data management, repository and (iv) seamless integration of vehicular communication networks, mobile devices and deployment platforms. However, these are not sufficient to integrate connected vehicles into an IoT ecosystem. To accomplish that, there must be additional ingredients including – (i) data fusion platform that combines sensor data from multiple domains, (ii) scopes of resource discovery to search for intended sensors, actuators in the vehicles, (iii) data representation and storage subsystems, (iv) network and low power communication protocols and more. Towards that goal, we consider the vehicles as a resource for the IoT ecosystems to provide consumer centric services in connected vehicle domain. We provide two use cases to for illustration in this context. Consider a connected vehicle which is equipped with sensors and an On Board Unit (OBU). A smart city application (running in a cloud) procuring data to measure air and noise pollutions in the city could discover if any connected vehicle has such sensors and obtain data from them. This allows the city to utilize the existing vehicular infrastructures to obtain real time data for an IoT application without deploying new infrastructure. As a result, the city can save resources. The city dwellers can connect to the application to look into the noise and air pollution level into different regions and modify their route to destinations. This is a consumer centric IoT service that benefits from connected vehicle resources. Similarly, autonomous vehicles can also take advantage of IoT platforms. If an IoT application deduces that there is fog in the environment through which the autonomous vehicle is driving, the application can send that information (fog) as a derived intelligence to the vehicle (consumer in this context) and some suggestions (reducing speed and turning on fog lamps). Such computation must be deployed to a (edge computing) platform located near to the vehicles since the autonomous vehicles need to react to their environment in real time. These two use cases clarify the integration of connected vehicles into the IoT ecosystem and the related consumer centric services.

Bringing connected vehicles, ITS and IoT together cerates several research challenges due to the mobility, nature of communication technologies and many other factors. Seven main challenges are identified and explained below.

- The Cloud based IoT platforms and services depend heavily on RESTful web services and IP technologies to provide interoperability and ease of development. The automotive industry is currently examining the potential of using IPv6 natively to connect vehicles with any cloud platform [1]. But the cloud dependent scenarios would be prone to higher latency and less QoS and are not suitable for real time applications. Given the nature of safety and highly autonomous vehicular scenarios, it is important to evaluate edge computing platforms [2].
- With the inclusion of many heterogeneous sensors and actuators into vehicles, data collection using a uniform mechanism is becoming another challenge. The data collection is also coupled with data communication to the network access points (Road Side Units in most cases). Descriptions of the sensors as well as their configurations are also necessary to investigate.

- Mobile (smart) device integration in vehicle and transport systems can pave way for collecting the data about the vehicular environment. Combining the vehicular sensor data with environment data at a computing platform is challenging since the data formats and contents are different as well as there is no standard mechanism for the data fusion.
- Collecting and communicating sensor data and maps (for autonomous vehicles) are two basic pillars for enabling data fusion and data analytics which can derive high level intelligence. This in turn can be used to send notifications to the highly autonomous vehicles to react to the driving environment. This challenge relates to data processing and actuation.
- Current cloud based IoT platforms utilize the underlying IP infrastructure for dissemination of derived the high level intelligence from raw data. But IP communication was neither designed to support mobility natively nor is data centric. Therefore, Information Centric Networking (ICN) [8] should be used.
- Seamless integration of vehicular network, mobile devices, edge computing and storage platform pose numerous challenges since all these building blocks are heterogeneous in terms of their natures, capabilities, dependencies on infrastructure and software elements. This can be solved by focusing on IoT data centric aspects rather than the infrastructure and communication networks. This will decouple the dependencies among the building blocks and promote interoperability.
- Beside these, there is an engineering challenge in terms of integrating the connected vehicle resources into a standard IoT architecture. This is a challenge due to the emergence of several competing IoT standards (oneM2M, IEEE P2413) and ongoing efforts from W3C Web of Things and Automotive Working Group.

This paper introduces a novel IoT framework that mitigates the above challenges to integrate connected vehicles as a part of IoT ecosystems. The main contributions of the paper are – (i) designing an IoT framework that includes an edge computing system for the connected vehicles to offer consumer centric services, (ii) uniform mechanism for describing and collecting data from vehicular sensors, (iii) integrating smart devices as a part of the overall system, (iv) mechanism for sensor data fusion from multiple domains leading to novel applications, (v) integration of Named Data Networking (NDN) for dissemination of high level intelligence to the vehicles, (vi) seamless interoperation among building blocks of the framework and (vii) integration of the IoT framework into oneM2M architecture. Combining all these building blocks connected vehicles can truly transform into a smart vehicle within a much larger IoT ecosystem.

The rest of the paper is organized as follows. Section II portrays the IoT framework, describes the novel approaches to solve the mentioned challenges. Section III discusses its prototype implementation and integration into oneM2M standard architecture. Section IV concludes the lessons learnt for the prototyping and best practice recommendations.

II. PROPOSED IOT FRAMEWORK INTEGRATING CONNECTED VECHICLES

This section concentrates on the proposed IoT framework for connected vehicles, its building blocks, software elements, their operation phases and benefits. The mechanisms employed to mitigate the mentioned research and engineering challenges are also described in details. Figure 1 depicts the proposed framework. It promotes a data driven approach and attempts to be independent of the deployed infrastructure. The performance and functional requirements have been presented in [14].

The framework primarily utilizes an edge computing platform to support network switching, resource discovery, provisioning, local processing for data fusion and storage of the high level intelligence for vehicular scenarios. The cloud platform is used as a repository for ontologies, datasets and SPARQL queries used in semantic web based data fusion [9] in the edge server. Utilizing semantic web technologies provide benefits in terms of interoperability in uniform descriptions of vehicular and smart device sensors and actuators as well as providing uniform treatment of data leading to data fusion. The building blocks of the framework and their novelties are described below.

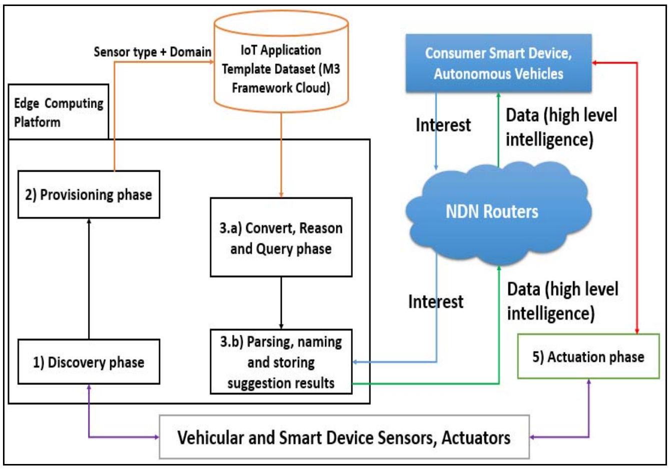


Fig. 1. Novel IoT Framework to connected vehicles in IoT ecosystems.

A. Discovery phase

With Internet of Things advocating for an ecosystem that operates with very less human involvement, discovery of resources is becoming highly important. This phase allows searching for vehicles, smart devices and associated things (sensors and actuators). To facilitate discovery of these resources, their capabilities and means to access them, the configuration of the resources need to be described. But uniform description of the heterogeneous sensors and actuators with uniform vocabulary is a challenge. Semantic based descriptions can address with providing additional benefit of easing their use in semantic web based data fusion later. To enable discovery, the vehicles must register themselves and associated things into an edge computing platform. The sensors and actuators are described in terms of events, properties and actions and the descriptions can be created at the OBU or a vehicular gateway. This allows the resource discovery element to not only deduce thing type and domain of operation but also allows to infer additional information based related to its functionalities. Thus, a greater granularity is added to the overall IoT framework. The operational steps used in this phase are highlighted Figure 2. The OBU or vehicular gateway produces resource descriptions which are communicated to the edge server over a network access technology. The "Configuration API" extracts the actual descriptions and caches them locally. During the discovery phase, the API for resource discovery triggers a mechanism that involves searching in a local storage directory for required resources. The response includes a list of descriptions from which means to interact with the resources to get raw data can be obtained. The sensors are multimodal as well as heterogeneous which can be settled using Sensor Markup Language (SenML). It allows encoding the measurement along with attributes like unit, type, timestamp, software version, name and ID creating a metadata. The discovery phase mitigates the challenges related to uniform data collection and resource description. Also it allows the smart device sensors to be included in the discovery process setting the basis of smart device integration in connected vehicle scenarios.

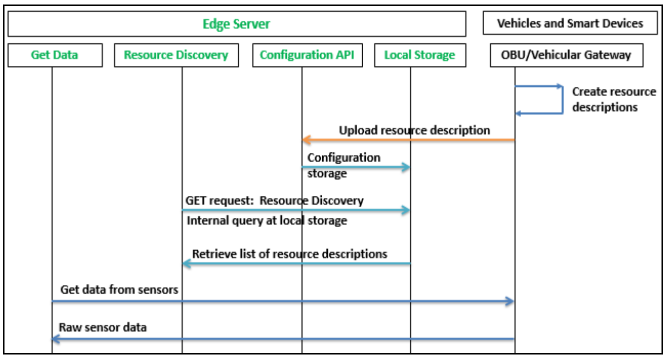


Fig. 2. Operational steps of discovery phase.

B. Provisioning phase

The provisioning phase prepares the edge server for vehicular and other domains' data fusion and analytics [13]. The discovery phase retrieves a set of available sensors to provide raw metadata. This phase looks for resource type and domain of operation (from SenML metadata and descriptions) The provisioning information is communicated to a cloud computing platform (shown in Figure 1) that houses a semantic web framework called Machine-to-Machine Measurement (M3) framework [3], [12]. It contains the necessary application development templates (comprising of ontologies, datasets, rules for semantic reasoning and SPARQL queries) for data fusion and analytics. The appropriate template for the scenario in question is downloaded into the edge computing platform in real time.

C. Data fusion, analytics and storage phase

This phase tackles the research challenges related to transforming raw data originating at vehicular and smart device sensors into a high level intelligence. It can be perceived by onboard passengers and autonomous vehicles. The intelligence can also be used to send commands to actuators allowing the connected vehicles to react to the environment. Toward this objective, this paper utilizes semantic web technologies for data fusion. This provides twofold advantages – (i) uniform treatment of SenML metadata (M2M Data in Figure 3) into high level intelligence providing interoperability at IoT data level, (ii) making the overall process independent of the underlying V2X communication network and infrastructure. The downloaded template (in previous step) is capable combining sensor metadata coming from different domains through the steps shown in Figure 3 [3]. The received metadata (at the edge server) must be converted into RDF (i.e. Semantic M2M data) before semantic rules can be applied on them to determine new domain concept. It is then classified according to domain ontology and domain dataset is applied on that setting the step for cross domain application. Following the reasoning in the final step which completes the data fusion and analytics, a high level intelligence is derived. It is locally cached and indexed according to the named data networking (NDN) naming convention. Apart from that, an interesting engineering challenge in this phase is to develop a lightweight version of the M3 framework suitable to run on an edge computing platform. This has been accomplished and detailed in the Section III.

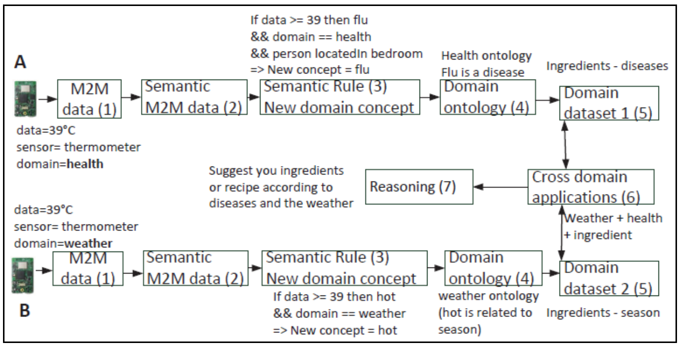


Fig. 3. Steps towards sensor data fusion and analytics.

D. Data dissemination phase

The inherent challenge here is to address the mobility while disseminating the derived intelligence. As mentioned before, the IP technology that is used widely does not support mobility natively. This is overcome using Named Data Networking (NDN), a kind of ICN, for data dissemination. NDN does not need host name resolution and provides scalability, usability, data security by design and support for mobility. NDN philosophy is based on two types of packets namely interest and data. The interest packets correspond to the interest of onboard passengers and/or the autonomous vehicles. For example, if the fuel level sensor metadata indicates that the fuel level is low, the connected vehicle can ask for nearest fuel stations as interest. Each of such interests are represented using an URI and is forwarded to a set of NDN routers which route the interest packet towards the node with corresponding data (for this example, the GPS co-ordinates of the nearest fuel stations). Dissemination of the high level intelligence resulted from the data fusion is done over NDN [11].

E. Actuation phase

During this phase, the smart mobile devices of passengers and/or the autonomous vehicles can take decisions and send commands to the vehicular actuators to react to the environment or situation. If an autonomous vehicle receives an indication that it is driving in a foggy environment, it can send a command to its fog lamps to turn them on.

The software elements for resource discovery, provisioning, data fusion, analytics and dissemination are deployed in mobile edge computing platforms. Due to their geographical distribution, closeness to the vehicles and lightweight implementation, the framework operates in real time ensuring consumer centric IoT services. All phases combined together solves the main challenge and establishes edge computing platforms as a suitable alternative of cloud platform for connected vehicles. In essence, the proposed IoT framework accomplishes – (i) integration of heterogeneous resources in connected vehicles and consumer smart devices into an IoT platform, (ii) provide uniform mechanisms to describe resources and exchange their data, (iii) fusion of sensor data originating at multiple domains and (iv) incorporate NDN for data dissemination which is independent of mobility. These are also the advantages of adopting this framework for development. A mapping of the framework elements into physical infrastructure is shown below. The left column shows the high level elements from the proposed architecture and the right column depicts their corresponding infrastructure.

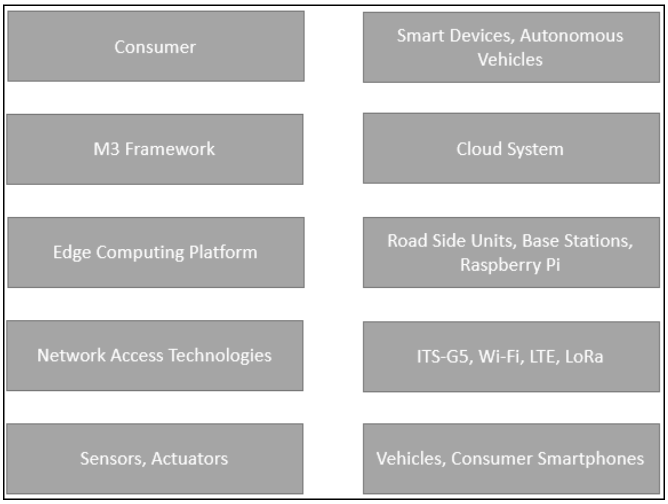


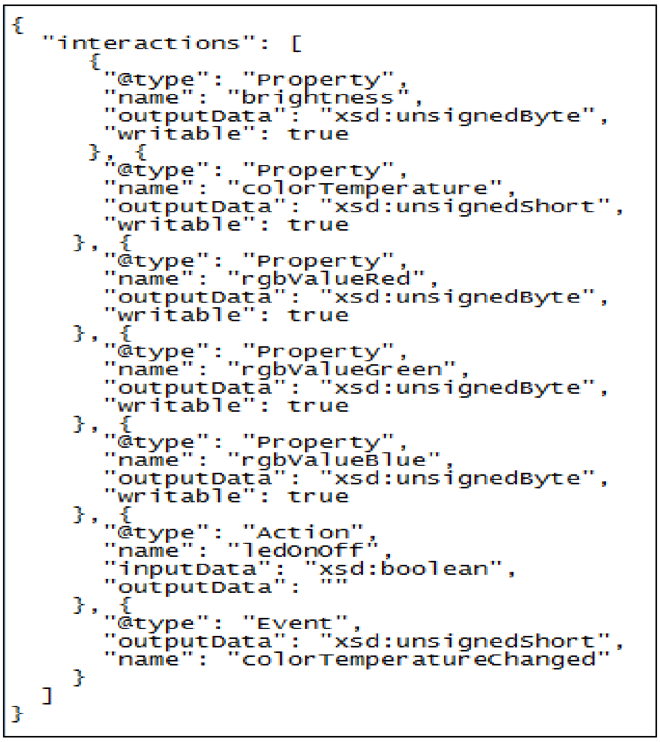
Fig. 4. Mapping of framework elements with physical insfrastructure.

III. IMPLEMENTATION AND INTEGRATION INTO ONEM2M ARCHITECTURE

This section focuses on prototyping details of the IoT framework for connected vehicles and its integration into oneM2M standard architecture. They address the challenges related to lightweight implementation of the framework and its integration into an IoT standard. Seamless interoperability among the elements are also highlighted.

A. Uniform mechanism for resource description and data exchange

JSON for Linked Data (JSON-LD) [10] is utilized for the semantic based descriptions of vehicular and smartphone resources (sensors, actuators). Figure 5 shows an example of description (in terms of events, properties and actions) of a LED of a connected vehicle.



```
{
  "interactions": [
     {
      "@type": "Property",
      "name": "brightness",
      "outputData": "xsd:unsignedByte",
      "writable": true
     }, {
      "@type": "Property",
      "name": "colorTemperature",
      "outputData": "xsd:unsignedShort",
      "writable": true
    }, {
      "@type": "Property",
      "name": "rgbValueRed",
      "outputData": "xsd:unsignedByte",
      "writable": true
    }, {
      "@type": "Property",
      "name": "rgbValueGreen",
      "outputData": "xsd:unsignedByte",
      "writable": true
    }, {
      "@type": "Property",
      "name": "rgbValueBlue",
      "outputData": "xsd:unsignedByte",
      "writable": true
    }, {
      "@type": "Action",
      "name": "ledOnOff",
      "inputData": "xsd:boolean",
      "outputData": ""
    }, {
      "@type": "Event",
      "outputData": "xsd:unsignedShort",
      "name": "colorTemperatureChanged"
    }
  ]
}
```

Fig. 5. Example of a LED light description for an connected vehicle.

The uniform sensor data exchange has been carried out using SenML. It is implemented using JSON and an example is shown below.

{"e": [{"n": "Engine-Temp", "v": 30, "u": "Cel", "t": "1380897199", “ver”: “1.2”, “type”: “Temperature”, “domain”: “automotive”}]

In the above example, the temperature sensor is called “Engine-Temp” which is giving a value of thirty degrees Celsius at the given time. The SenML software version is 1.2 and the domain of operation is automotive. The metadata provides enough information to enable data fusion and analytics at a later stage. Utilizing JSON eases development of the software elements.

B. Resource discovery and provisioning

The resource discovery element is shown in Figure 6 [5] and makes use of resource descriptions. The software development of the element has been done using python and Flask framework. The functionalities of resource discovery are exposed through RESTful web services. making the IoT framework compliant with Web of Things best practices [6]. The element includes a proxy layer to accommodate the different communication technologies and protocols used by the heterogeneous things. This allows a broad range of things to be included in the overall IoT framework. The discovery request is analyzed by a search engine which looks for appropriate things in the configuration registry. The lifetime attribute is analogous to a time duration during which a vehicle remains discoverable by an edge server implementing the discovery aspect. Following the discovery, the provisioning of sensor type and its domain is done by the edge computing platform through its embedded intelligence.

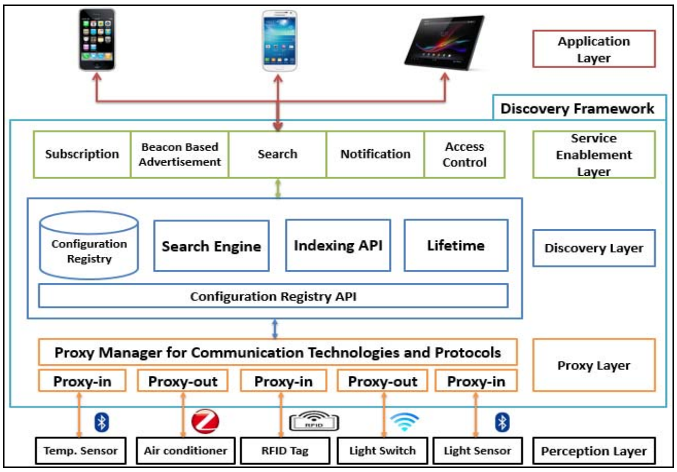


Fig. 6. Resource discovery framework.

C. *Data fusion using semantic web technologies*

Based on provisioning, IoT application template for data fusion is downloaded from a Google Cloud Platform housing the M3 framework. It has been developed using Apache Jena Framework. To support the semantic web treatment and data fusion of the vehicle sensor data with environmental sensor data at the edge computing platform, it is necessary that the platform supports Jena Framework. For edge servers supporting that, M3 capabilities could run directly. But to create a lightweight implementation for the data fusion, AndroJena is considered. It is a lightweight Jena Framework library intended for Android powered devices. Our edge server runs on an Android powered device.

D. *Dissemination of derived intelligence and actuation*

Thereafter, the NDN functionalities are integrated following the CCNx implementation which can be found at [7]. The main code base for CCNx (provided by PARC) is written in C language. Consumer systems create and propagate interests which are forwarded by NDN routers [16] to a “producer” that has data corresponding to the interests. The data then follows the reverse path to the “consumer”.

Finally, the actuation is done using SenML extensions [4]. For seamless interoperation, the first all phases except the dissemination are implemented using RESTful web interfaces. No dependence on infrastructure also promotes interoperation.

E. *Integration into oneM2M architecture*

The entire building blocks, software elements of the IoT framework are integrated into oneM2M standard architecture (shown in Figure 7) to further promote interoperability with similar frameworks. The M2M devices map into the vehicular and smart device sensors and actuators. The middle node houses the software elements for resource discovery, management, storage, data fusion & analytics and access control and is mapped to the edge server of the IoT framework. The infrastructure node is analogous to the Google Cloud Platform housing the entire M3 framework. The connected vehicle based consumer centric application logic runs into smart device or the vehicle itself. In most of the cases, this logic is running onto the smart devices as an application. The details of the taxonomy and oneM2M capabilities are discussed in [13].

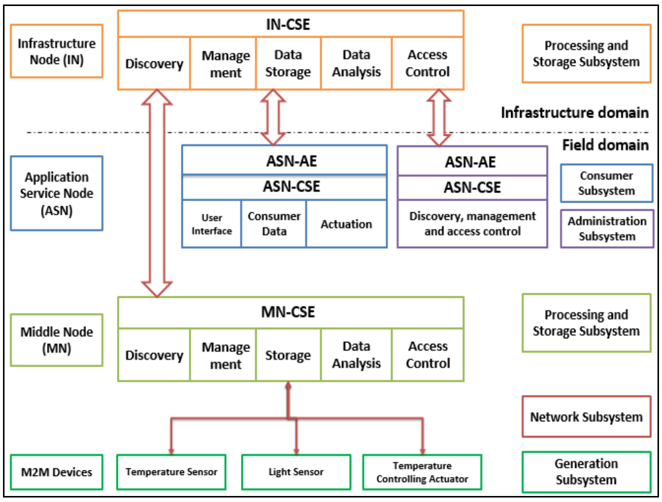


Fig. 7. oneM2M architecture integrating the IoT framework.

F. *Prototype evaluation*

Early evaluation of the software elements has been done in terms of memory footprints. Both the JSON-LD based descriptions and SenML sensor data typically consume 500 – 900 bytes. The python script implementing the web services for discovery and provisioning require less than 10KB of memory. The data fusion element is utilizing many semantic web components for which its memory footprint is around 10MB. The overall CPU consumption in accomplishing the operations of the framework amount to 6% (on an average). Measuring the memory and CPU metrics, the developed platform can be considered as lightweight and highly scalable. This is another novel aspect of the paper.

IV. CONCLUSION

In a nutshell, the paper attempts to outline the challenges and solutions for integrating connected vehicles into IoT ecosystem. We present an IoT Framework to address the challenges, describe the building blocks, operational phases and practical implementations of the software elements. We recommend open & RESTful web interfaces, JSON based implementations and utilization of semantic web technologies for seamless interoperation among the architectural building blocks. An important aspect of the prototyping experience was to create lightweight software paving way for scalability while maintaining usability and reliability of the overall functionalities. Integration of the entire IoT framework into oneM2M and mapping of the elements are also mentioned. As for future work, we are concentrating on expanding the ecosystem bringing together components from ITS, IoT, edge & cloud computing, big data and connected vehicles paving way for the Internet of Vehicles (IoV) [15]. IoV could be efficiently utilized in cooperative ITS and cooperative mobility management. Towards that goal, we are also studying the possibility of developing and deploying a test bed for IoV.

ACKNOWLEDGMENT

This work has been performed within the frame of the French research project DataTweet (ANR-13-INFR-0008) and the HIGHTS project funded by the European Commission (636537-H2020).

REFERENCES

[1] P. Matzakos, J. Härri, B. Villeforceix and C. Bonnet, "An IPv6 architecture for cloud-to-vehicle smart mobility services over heterogeneous vehicular networks," Connected Vehicles and Expo (ICCVE), 2014 International Conference on, Vienna, 2014, pp. 767-772.

[2] S. K. Datta, C. Bonnet and J. Haerri, "Fog Computing architecture to enable consumer centric Internet of Things services," Consumer Electronics (ISCE), 2015 IEEE International Symposium on, Madrid, 2015, pp. 1-2.

[3] A. Gyrard, S. K. Datta, C. Bonnet and K. Boudaoud, "Cross-Domain Internet of Things Application Development: M3 Framework and Evaluation," Future Internet of Things and Cloud (FiCloud), 2015 3rd International Conference on, Rome, 2015, pp. 9-16.

[4] S. K. Datta, C. Bonnet and N. Nikaein, "An IoT gateway centric architecture to provide novel M2M services," Internet of Things (WF-IoT), 2014 IEEE World Forum on, Seoul, 2014, pp. 514-519.

[5] S. K. Datta, R. P. F. Da Costa and C. Bonnet, "Resource discovery in Internet of Things: Current trends and future standardization aspects," Internet of Things (WF-IoT), 2015 IEEE 2nd World Forum on, Milan, 2015, pp. 542-547.

[6] S. S. Mathew, Y. Atif, Q. Z. Sheng and Z. Maamar, "Web of Things: Description, Discovery and Integration," Internet of Things (iThings/CPSCom), 2011 International Conference on and 4th International Conference on Cyber, Physical and Social Computing, Dalian, 2011, pp. 9-15.

[7] The CCNx project, http://blogs.parc.com/ccnx/.

[8] P. TalebiFard et al., "An Information Centric Networking approach towards contextualized edge service," Consumer Communications and Networking Conference (CCNC), 2015 12th Annual IEEE, Las Vegas, NV, 2015, pp. 250-255.

[9] A. Gyrard, C. Bonnet and K. Boudaoud, "Enrich machine-to-machine data with semantic web technologies for cross-domain applications," Internet of Things (WF-IoT), 2014 IEEE World Forum on, Seoul, 2014, pp. 559-564.

[10] S. K. Datta, and C. Bonnet, "Describing Things in the Internet of Things," Consumer Electronics-Taiwan (ICCE-TW), 2016 IEEE International Conference on, Taiwan, 2016.

[11] S. K. Datta, and C. Bonnet, " Integrating Named Data Networking in Internet of Things Architecture," Consumer Electronics-Taiwan (ICCE-TW), 2016 IEEE International Conference on, Taiwan, 2016.

[12] A. Gyrard, S. K. Datta, C. Bonnet and K. Boudaoud, "Standardizing generic cross-domain applications in Internet of Things," Globecom Workshops (GC Wkshps), 2014, Austin, TX, 2014, pp. 589-594.

[13] S. K. Datta, A. Gyrard, C. Bonnet and K. Boudaoud, "oneM2M Architecture Based User Centric IoT Application Development," Future Internet of Things and Cloud (FiCloud), 2015 3rd International Conference on, Rome, 2015, pp. 100-107.

[14] S. K. Datta, C. Bonnet, R. P. F. Da Costa and J. Haerri, “DataTweet: An Architecture Enabling Data-Centric IoT Service”, Region Ten Symposium, IEEE, Bali, 2016.

[15] F. Yang, S. Wang, J. Li, Z. Liu and Q. Sun, "An overview of Internet of Vehicles," in China Communications, vol. 11, no. 10, pp. 1-15, Oct. 2014.

[16] H. Yuan, T. Song and P. Crowley, "Scalable NDN Forwarding: Concepts, Issues and Principles," 2012 21st International Conference on Computer Communications and Networks (ICCCN), Munich, 2012, pp. 1-9.