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IoT sensing framework with inter-cloud computing capability in vehicular networking

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Abstract In order to improve convenience, efficiency, and safety in vehicular networking applications (VNA), we propose a novel business model based on platform production services (PPS), design an inter-cloud architecture, and then apply this emerging scheme to vehicle maintenance services (VMS). Both internet of things (IoT) sensing framework and inter-cloud computing architecture are the crucial factors in implementing PPS business model. In the proposed scheme, implementation concept, system architecture, and scalable applications are introduced. Then we design IoT sensing framework for VNA, including cloud services and computation level scalability, inter-cloud architecture supporting telematics applications, and telematics application scenarios. After dissecting mobile cloud computing forming mechanism, we carry out the semantic modeling analysis for inter-cloud service model, and then design a VMS event processing flow to allow the management and cooperation among

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diverse components by means of event manager. The performance evaluation exemplified by VMS is implemented by means of probabilistic methods. The results show that convenience and efficiency increase in VNA as compared to existing schemes.

Keywords Wireless sensor networks · Internet of things · Vehicular networking · Inter-cloud computing · Semantic modeling · Event processing flow

1 Introduction

In recent years, the advances in the fields of wireless technology, multimedia communications and intelligent systems have exhibited a strong potential and tendency on improving human life in every facet, including transportation, entertainment, socialization, business, health-care, education, etc [4,39]. For example, the concept of internet of things (IoT) has become particularly popular through some representative applications (e.g., greenhouse monitoring). Generally, IoT has four major components, including sensing, heterogeneous access, information processing, applications and services, and some additional components (e.g., security and privacy) [7,8]. Essentially, both vehicular networking and wireless sensor networks (WSNs) belong to IoT, since both of them contain the same components mentioned previously. The differences just are the proportion of the design among the four components.

With the development of advanced network techniques, innovative control theories, and emerging cloud computing, vehicular networking serves as one of the most important enabling technologies, and is producing some novel telematics application scenarios [14,17]. These applications are more than novelties and far-fetched goals of a group of researchers and companies. Vehicular networking that aims to streamline the operation of vehicles, manage vehicle traffic, assist drivers with safety and other information, along with provisioning of convenience applications for passengers is no longer confined to theories, and test facilities of companies [22]. Up to now, the main examples of such services have included driver assist systems, automated toll collection systems, and other information provisioning systems. The importance and potential impact of vehicular networking have been confirmed by the rapid proliferation of consortia involving various government agencies, vehicle manufacturers, and academia. Recently, it has become increasingly obvious that vehicular networking opens new vistas for location-based services, such as vehicle maintenance services (VMS) and the fast-growing mobile entertainment industry [31,43].

IoT sensing framework adopts inter-cloud computing technology to deal with the dynamic traffic environments, and to help such systems cope with large amounts of storage and computing resources required to use novel inter-cloud architecture and service model in vehicular networking [28]. The mobile cloud computing for vehicular networking could provide many services (e.g., sharing entertainment resources, and safety information). With WSNs technology, an IoT sensing framework based on platform production services (PPS) business model for vehicular networking applications (VNA) is both feasible and effective. However, the large-scale use of VNA will lead to the emergence of a complex mobile cloud computing forming mechanism and an unexpected level of overload, which requires innovative inter-cloud service architecture. In order to handle this problem, we specially carry out the semantic modeling analysis for inter-cloud service model.

The dependability factors like real-time and reliability are required for part of IoT applications, because failures of most mission-critical systems (e.g., healthcare) may result in great loss of finance, life and even disaster [20,21]. Therefore, to schedule low-energy, real-time and reliable message in IoT sensing environments is imperative and significant work. In [12], an event-driven architecture for monitoring public spaces with heterogeneous sensors in smart city was proposed. Aiming at the special VNA field, we make efforts on an event processing flow to allow the management and cooperation among diverse components by means of event manager.

1.1 Contributions

The main contributions of this work are as follows:

(1) A novel PPS business model and service architecture in vehicular networking are proposed, and this scheme is applied to VMS.
(2) The inter-cloud computing architecture supporting telematics applications and inter-cloud service model including semantic modeling are designed.
(3) The proposed VMS event processing flow can allow the management and cooperation among diverse components, ensure the communications to users in case of emergency, and enhance the detection of anomalous event.
(4) The performance of our proposed PPS scheme against prevalent schemes is evaluated on the basis of probabilistic methods.

1.2 Organization

The rest of this article is organized as follows. In Sect. 2, we briefly review IoT architecture and applications, vehicular networking, cloud computing and event-based architecture. The PPS business model in vehicular networking is proposed and designed in Sect. 3. In Sect. 4, the proposed PPS business model are applied in VNA, including cloud services and computation level scalability, inter-cloud architecture, telematics application scenarios, and the semantic modeling analysis for mobile cloud computing is considered. In Sect. 5, a VMS event processing flow to allow the management and cooperation among diverse components is designed. The performance evaluation for VMS is carried out by means of probabilistic methods in Sect. 6, and the conclusion is given in Sect. 7.

2 Related work

This work targets IoT sensing framework and inter-cloud computing in VNA, which requires knowledge from many fields, such as computer science, traffic technique, electronics, sensor technologies and control science. This article is focused on three main parts: (1) PPS business model and IoT sensing framework in vehicular networking, (2) inter-cloud computing architecture and its semantic modeling analysis, and

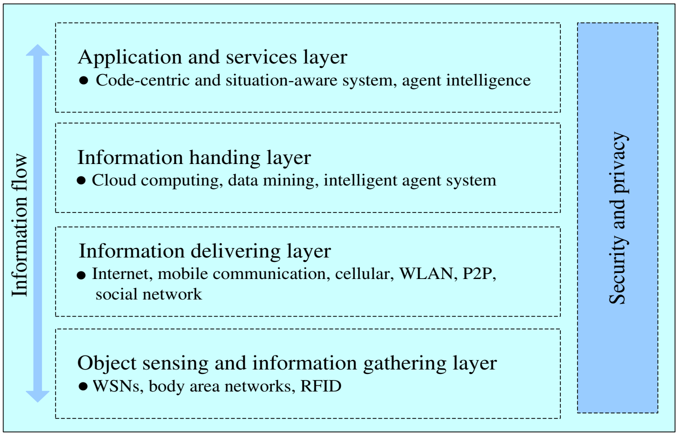


Fig. 1 IoT architecture

(3) event processing flow in VNA. Therefore, this section is split into five subsections: IoT architecture and applications, key technologies of IoT sensing network, vehicular networking, cloud computing and event-based architecture.

2.1 IoT four-layer architecture and application domains

The four-layer architecture and some additional components, such as security and privacy for IoT shown in Fig. 1, were described as follows [4].

(1) *Object sensing and information gathering* The first step of enabling smart services is to collect contextual information concerning objects of interest. For example, sensors can be used to continuously monitor human's physiological activities and actions, such as health status and motion patterns; RFID techniques can be utilized for collecting crucial personal information and storing them in a low-cost chip that is attached to an individual at all times.
(2) *Information delivering* Various wireless technologies can be used for delivering information, such as WSNs, body area networks (BANs), WiFi, Bluetooth, Zigbee, GPRS, GSM, cellular and 3G. Such diverse communication techniques can accommodate more emerging applications into the complicated systems.
(3) *Information processing* Ubiquitous machines must process information in both "autonomic" and "smart" way in order to provide pervasive and autonomic services. For example, the meaningless information could be filtered out according to the users' interests in social networks.
(4) *Applications and smart services* According to different users' requirements, application-specific design should be developed to improve heterogeneous network performance in terms of bandwidth utilization, computing capability, energy efficiency, etc.

Due to the co-existence of a large number of ubiquitous devices competing for sharing resources, lots of challenging issues still remain for designing smart and flexible applications. However, one of major issues is about security and privacy. To alleviate this issue, some security mechanisms will be further developed.

The advances in IoT research were reviewed in [3]. The potentialities offered by IoT make possible development of a huge number of applications, of which only a very small part is currently available to our society. Many are the domains and the environments in which new applications would likely improve the quality of our life. Now, these environments are equipped with objects with only primitive intelligence, most of the time without any communication capabilities. Giving these objects, the possibilities to communicate with each other and to elaborate the information perceived from the surroundings imply having different environments where a very wide range of applications can be deployed. These can be grouped into the following domains, such as smart environments, transportation and logistics, personal and social domains, and healthcare.

Among the possible applications, we may distinguish between those either directly applicable or closer to our current living habitudes and those futuristic, which we can only fancy of at the moment, since the technologies and/or our societies are not ready for their deployment.

2.2 Key technologies of IoT sensing network

IoT sensing framework with inter-cloud computing capability in VNA requires many key technologies of IoT sensing network, such as scheduling scheme, mobile agent technologies, energy-efficient itinerary planning, multimedia sharing technologies, and simulation model.

Zhou [45] developed the distributed scheduling scheme for video streaming over multi-channel multi-radio multi-hop wireless networks in order to minimize the video distortion and achieve certain fairness. Zhang [44] proposed a taxonomy of mobile agent technologies for ubiquitous computing environments, analysed the strengths and weaknesses of existing technologies, and designed a series of solutions from the viewpoint of various roles of mobile agent. Chen [5,6] proposed the multi-agent itinerary planning and the energy-efficient itinerary planning for mobile agents in wireless sensor networks, and designed an itinerary energy minimum for first-source-selection (IEMF) algorithm, as well as the itinerary energy minimum algorithm (IEMA), the iterative version of IEMF.

Lai [9] proposed a DLNA-based multimedia sharing system for OSGI framework with extension to P2P network, so that users can access multimedia resource on P2P network via DLNA, and P2P network users can apply P2P network mechanism in OSGI bundle to access shared DLNA multimedia resource in home network. Zou [46] designed a novel simulation model of Cyber-Physical Systems for unmanned vehicle with wireless sensor networks navigation in order to verify the new theories and methods.

2.3 Vehicular networking

In the past decade, we have witnessed the emergence of vehicular networking, specializing from the well-known mobile Ad Hoc networks (MANETs) to vehicle-to-vehicle

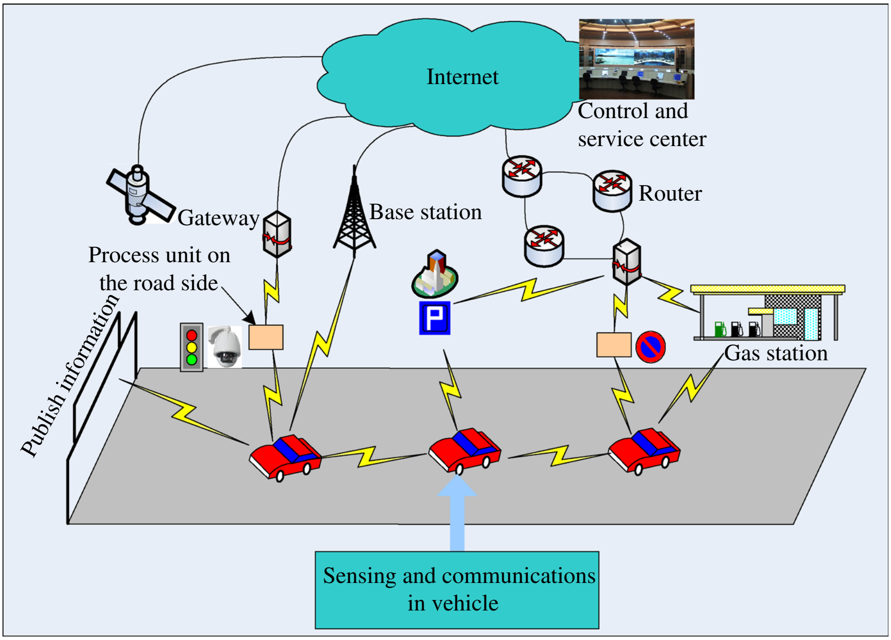


Fig. 2 Basic vehicular networking architecture

(V2V) and vehicle-to-infrastructure (V2I) wireless communications (see Fig. 2). Up to now, the research results mainly have focused on the following aspects: traffic engineering (e.g., traffic monitoring, models for traffic flow, and vehicle motion) [23], initiatives (e.g., U.S. and European) [33], applications (e.g., safety-related vehicular applications, location-based services, and use of infrastructure in vehicular networking) [24,26], networking issues (e.g., mobile Ad Hoc routing in the context, and localization in vehicular networking) [15], protocols (e.g., mobile payment protocol for vehicular ad-hoc networks) [18,19], simulations (e.g., vehicular mobility models, and vehicular network simulators) [29], and human factors (e.g., users' interest and acceptance) [13,40].

[35,37,41] proposed that cyber-transportation systems (CTS) are the special scenarios of intelligent transportation systems and the evolution of current vehicular networking by integrating more intelligent and interactive operations. The design of CTS takes a multi-disciplinary approach that combines cyber technologies, transportation engineering with human factors [27]. CTS are helpful for improving road safety and efficiency using cyber technologies, such as wireless technologies and distributed real-time control theory.

2.4 Cloud computing

In recent years, cloud computing as a very new field in internet computing has provided novel perspectives in inter-networking technologies and raised issues in the architecture, design, and implementation of existing networks and data centers. The relevant

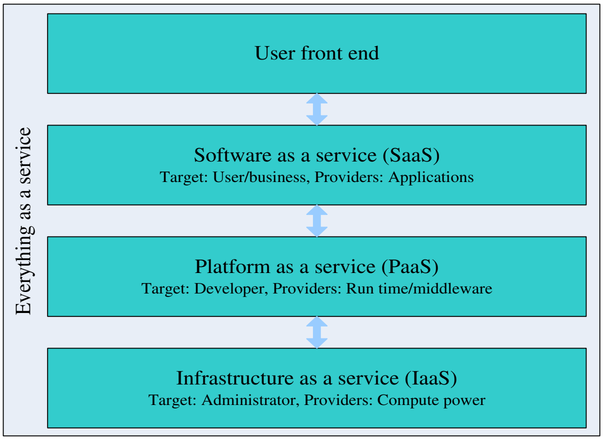


Fig. 3 A general layered architecture of cloud infrastructures

research has just recently gained momentum, and the space of potential ideas and solutions is still far from being widely explored [32]. Now, the research concerning cloud computing involves many aspects, including applications [10], architecture [1], storage [16], semantic modeling [34], and security and privacy [38].

From a technical viewpoint, a cloud's system elements include processing, network, and storage elements. Figure 3 shows a cloud infrastructure's general layered architecture, with additional user interface layer, which enables seamless interaction with all the underlying everything-as-a-service layers. Generally, the cloud architecture consists of three abstract layers: infrastructure, platform, and application.

(1) *Infrastructure* The infrastructure is the lowest layer and is a means of providing processing, storage, networks, and other fundamental computing resources as standardized services over the network. Servers, storage systems, switches, routers, and other systems handle specific types of workloads from batch processing to server-storage augmentation during peak loads. Cloud providers' clients can deploy and run operating systems and software for their underlying infrastructures.
(2) *Platform* The middle layer provides higher abstractions and services to develop, test, deploy, and maintain applications in the same integrated development environment. This layer provides a runtime environment and middleware to deploy applications by programming languages and tools that the cloud provider supports.
(3) *Application* The application layer is the highest layer and it features a complete application offered as a service.

2.5 Event-based architecture

In [30], the event-driven architecture was reviewed. In this overview report, the power of event-driven architecture in conjunction with service-oriented architecture was demonstrated. To make "information" in the physical world available for smart ser-

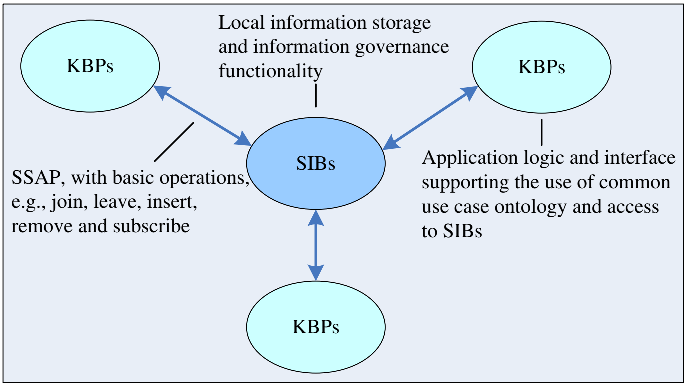


Fig. 4 Functional architecture

vices in embedded and ubiquitous systems, some research projects make it possible to mash-up and integrate information between all applications and domains spanning from embedded domains to the Web. The SOFIA (smart objects for intelligent applications) project is a three-year ARTEMIS project started in January 2009 and involving partners from four different EU countries [2]. The main goal of the SOFIA project is to create a semantic interoperability platform and a selected set of vertical applications to form smart environments based on embedded systems. In SOFIA, the main concepts from function perspective include SIBs (semantic information brokers), KBPs (knowledge-based processors) and SSAP (smart space access protocol), as shown in Fig. 4.

(1) *SIBs* A SIB is a computer service that automatically provides semantic mapper services, and is frequently part of a semantic middleware system that leverages semantic equivalence statements. To qualify as a SIB product, a system must be able to automatically extract data from a message and use semantic equivalence statements to transform this into another namespace.
(2) *KBPs* The KBPs are used for processing packets in computer networks. They are essential for the long term success of the IPv6 network. The build out of the IPv6 network is inevitable as it provides the means to an improved and secure networking system. It has been built from the ground up to address the issues of available addressing and security concerns.
(3) *SSAP* The SSAP is used for performing operations on the semantic net. KBPs can access the information within the smart space by connecting to the SIB and invoking the operations offered by SSAP interface.

3 PPS business model in vehicular networking

3.1 Implementation concept of PPS business model

Mobile computing and wireless communications have experienced large improvements that have lead to the development of vehicular networking. The focus in vehic-

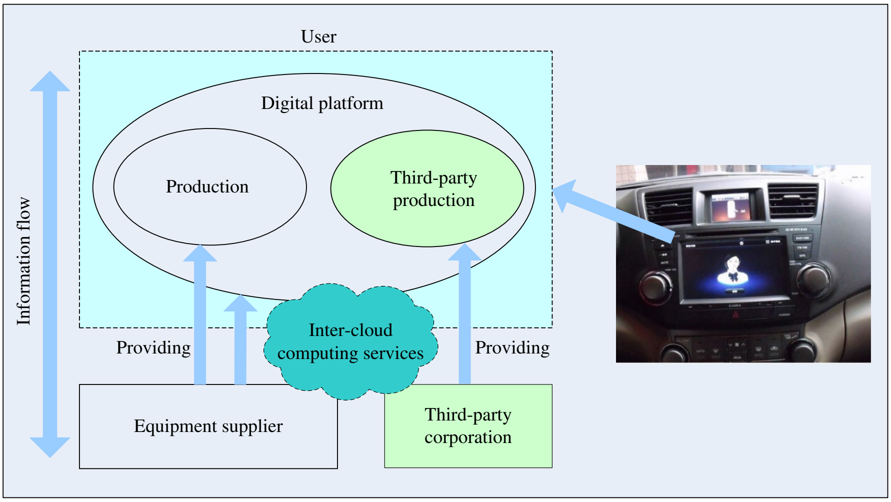


Fig. 5 Proposed implementation concept of PPS business model

ular networking is on improving safety on the roads (e.g., intersection collision avoidance, public safety, sign extension, vehicle diagnostics and maintenance, and information from other vehicles) and providing comfort applications (e.g., GPS navigation, and entertainment). Except for some application scenarios, such as automated toll collection systems and GPS navigation systems, most of emerging VNA are still confined to laboratory and test facilities of supplier. In order to promote vehicular networking industry, we propose PPS business model by integrating more equipment suppliers with the related third-party corporations to provide many convenient, comfortable and effective services for users. The proposed implementation concept of PPS business model is shown in Fig. 5. This scheme includes three basic elements: digital platform, production, and services.

(1) *Digital platform* The digital platform possessing some preliminary functions such as navigation and entertainment is a complicated embedded system installed in vehicle. Also, the digital platform interaction is achieved by communicating among platforms, body electronics, neighboring vehicles, and cloud computing services.
(2) *Production* After designing the digital platform, equipment suppliers usually set up some necessary applications (e.g., navigation). At the same time, the related productions (e.g., entertainment) of third-party companies also may be downloaded and ran in this platform to offer more luxuriant services.
(3) *Services* Through implementation concept PPS business model, the users will achieve more emerging services (e.g., VMS, emergency roadside services (ERS), real-time traffic information, and 24-hour customer services).

According to the above analysis, the efficiency and performance of PPS business model F is affected by various factors. As a whole, F may be described as a 5-tuple:

$$F = (D, P, S, I, C) \tag{1}$$

where D is the digital platform provided by equipment suppliers, P is the production designed by equipment suppliers and third-party corporations, S is the diverse services, I and C are IoT infrastructure and inter-cloud service respectively.

From Eq. (1), all elements from different perspectives together determine F. This article will pay attention to services, IoT sensing and cloud computing, denoted by S, I and C separately.

(1) *S* In order to simplify analysis for real-time response, we select parameter S to evaluate the performance of PPS business model. Since the services include many types and some types (e.g., problem occurring) conform to the exponential distribution in a maintenance period, we adopt probabilistic methods to verify the validity in this article.
(2) *I* IoT sensing framework includes all kinds of wired/wireless sensors, heterogeneous network, service cloud and smart devices. Many uncertainty factors affect the quality of service (QoS). We design an event-based architecture to ensure the communications to users in case of emergency.
(3) *C* Inter-cloud computing is very imperative for providing various services in VNA. We establish an inter-cloud computing architecture supporting telematics applications and inter-cloud service model including semantic modeling analysis.

3.2 Service architecture

Figure 6 shows the service architecture for PPS business model. From the point of view of the computational levels, the architecture may be grouped into three spatial regions: inter-cloud, vehicular clusters, and vehicle range. The inter-cloud computing provides some telematics applications (e.g., monitoring, VMS and ERS) by means of remote communication technologies (e.g., cellular networks and WiMAX). The communications between vehicular clusters and vehicle range adopt short-range wireless technologies such as MANET (mobile ad hoc networks), WMN (wireless mesh networks), WSNs and VANET (vehicular ad hoc networks) as follows:

(1) *MANET* These consist of a collection of wireless nodes with arbitrary mobility patterns. Nodes are usually battery-operated, making energy efficiency one of the important design issues.
(2) *WMN* These are a particular case of ad hoc network in which nodes are like static base stations that are able to communicate using multi-hop routes.
(3) *WSNs* These consist of a set of generally tiny wireless devices with very limited energy, computation power, and memory.
(4) *VANET* These are a particular case of MANET in which nodes are vehicles moving at very high speeds.

We further summarize the differences between these different kinds of short-range wireless networks in Table 1. As can be seen, VANET have emerged as a specialization of MANET in which participating nodes are expected to be vehicles. Of course, this raises a number of issues such as the need for high scalability, the importance of making use of valuable information (e.g., position of nodes, and street maps) to enhance the performance of the protocols, and so on.

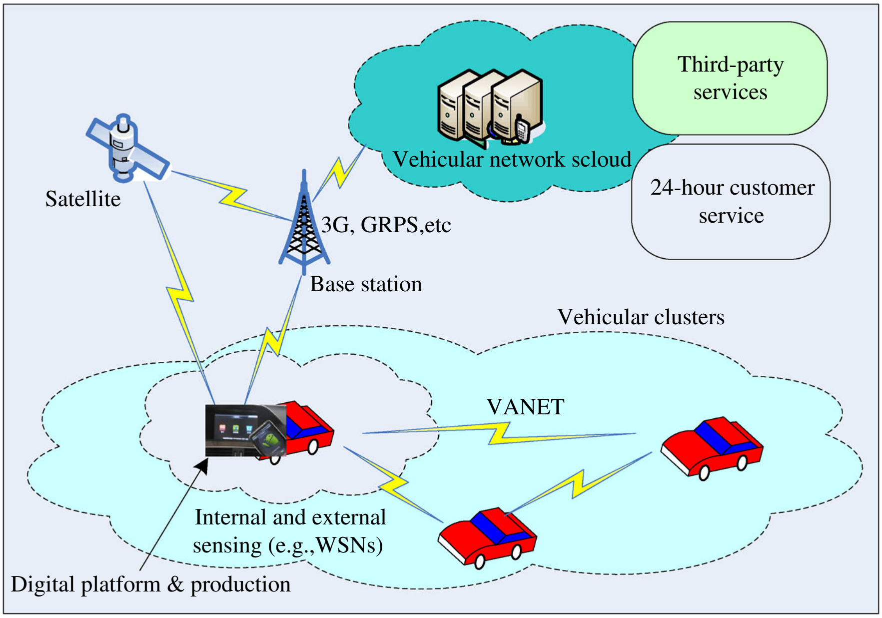


Fig. 6 Proposed service architecture for PPS business model

Table 1 Properties of different types of AD Hoc networks

Property	VANET	WSNs	WMN	MANET
Network size	Large	Large	Moderate	Medium
Energy limitations	Very low	Very high	Very low	High
Node's mobility	High, nonrandom	Mostly static	Static	Random
Location dependency	Very high	High	Very low	Low
Node's computation power	High	Very low	High	
Node's memory capacity	High	Very low	High	

3.3 Scalable applications based on PPS business model

In Sect. 2.1, we briefly summarize VNA domains and related major scenarios. However, many of them are still confined to laboratory and test facilities of companies. Based on the proposed PPS business model, some innovative applications from spatial region perspective have been achieved by cooperation between equipment suppliers and related third-party corporations. Table 2 shows the scalable applications from laboratory into reality. Figure 7 shows the scalability of application scenario based on PPS business model.

In the vehicle range, the digital platform senses internal and/or external real-time parameters to provide a reference for user's decisions and realize man-machine interaction through voice-input mode. By means of VANET, vehicular clusters are dynam-

Table 2 Scalable applications based on PPS business model: from laboratory into reality

Spatial regions	Applications	Services realized by platform and supplier	Services provided by platform and third-party corp.
Vehicle range	Voice-input	√	
	Interaction between phone and platform	√	
	Neighboring environment sensing	√	
Vehicular clusters	Sharing entertainment resources		√
	Sharing safety information	√	
Telematics	VMS		√
	ERS		√
	Human help for path planning	√	
	Real-time traffic information		√
	Reservation service (e.g., hotels reservation)		√

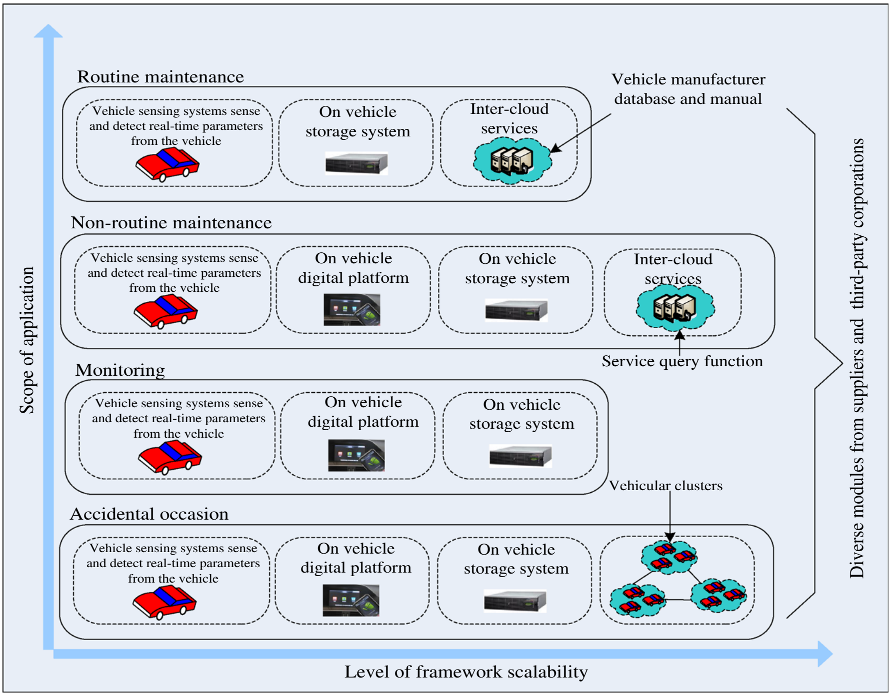


Fig. 7 Scalability of application scenario based on PPS business model

ically formed within a specific space, and resources (e.g., entertainment resources and safety information) can be shared under some safety mechanisms. With the development of vehicular networking industry, an increasing number of suppliers and third-

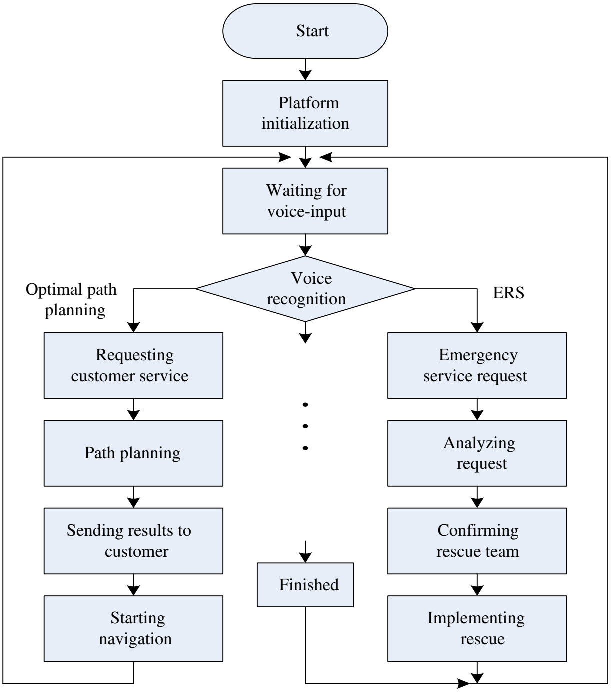


Fig. 8 Flow diagram of customer service process

party companies gradually bring into being composition of forces to facilitate VNA from laboratory into reality. Under the proposed innovative inter-cloud architecture, some services, such as VMS, ERS, human help for path planning, real-time traffic information and reservation, have gradually become a reality in recent years.

We give the customer service process as shown in Fig. 8. The telematics applications exemplified by optimal path planning and ERS are to provide more efficient and convenient services for users. The voice-input mode realizing the real-time interaction between user and 24-hour customer service is a dramatic superiority. Also, more services can be provided from various third-party corporations by means of IoT sensing framework and inter-cloud computing.

3.4 Analysis of convenience and efficiency exemplified by VMS

In this subsection, we analyze the convenience and efficiency exemplified by VMS. Through the comparisons of real-time performance (e.g., processing response time) in VNA, we adopt probability theory to test and verify the efficiency of proposed method against prevalent schemes. The proposed scheme based on PPS business model includes several important factors, such as vehicle location, service center location, vehicle status, status of spare components, and time parameters.

```
if VehicleProblemOccur(VehicleID, ProblemOccurTime) then
  VehicleStatus = CollectVehicleParameters ();
  if Analyze (VehicleStatus)= NeedMaintenance Then
    VehicleLocation = DigitalPlatformLocation();
    ServiceCenterLocation= StartCloudServices (VehicleID);
    ConductCloudServices(VehicleLocation, ServiceCenterLocation) = SpareComponentsStatus;
      if Analyze (SpareComponentsStatus) = Acceptable   Then
      PathPlaning(VehicleLocation, ServiceCenterLocation);
      ConductProcessProblem(VehicleID, StartProcessTime);
      ConvenienceEfficiency = Analyze (StartProcessTime, ProblemOccurTime);
end if
```

Once a fault occurs, the current real-time parameters of vehicle are collected by detecting system together with digital platform. Then the related location parameters (e.g., VehicleLocation and ServiceCenterLocation) are obtained by GPS navigation and function StartCloudServices (VehicleID) respectively. Function ConductCloud-Services (VehicleLocation, ServiceCenterLocation) gives the status of spare components for each service center. If the return value of function Analyze (SpareComponentsStatus) is Acceptable, function PathPlaning (VehicleLocation, ServiceCenter-Location) will calculate a rational path depending on the given location parameters. In addition, function Analyze (StartProcessTime, ProblemOccurTime) will easily gives a rough evaluation concerning convenience and efficiency.

In order to achieve a quantitative analysis, the cost to be evaluated is calculated over the difference between time of start process and time of problem occurring. Therefore, we give the cost function as follows:

$$J = Min(T_p - T_s) \tag{2}$$

where T_p and T_s are the time of start process and time of problem occurring respectively.

For simplicity, we have made certain assumptions:

- A problem suddenly occurring is not fatal, and vehicle can run under high-risk status.
- The maintenance period is known (e.g., half a year).
- The probability of problem occurring approximatively conforms to the exponential distribution.

We adopt the following the distribution function to evaluate the proposed scheme for specific applications:

$$F(x) = \begin{cases} 1 - e^{-\lambda x} & x > 0 \\ 0 & x \leq 0 \end{cases} \tag{3}$$

According to Eq. (3), the fault rate of problem occurring continually increases in a maintenance period. Meanwhile, the processing response time J gradually shortens over time.

4 Inter-cloud computing architecture for VNA

When services are provided by a single cloud system, an unexpected level of overload (e.g., traffic from the Internet), or a natural disaster may request to supplement reserved resources. However, reserved resources held by a single cloud are usually limited, and ability of a single cloud to continue services may reach limits. In order to make the cloud system to be able to continue to satisfy demands for guaranteed QoS availability and performance, even in such cases, it is indispensable to organize that cloud systems complement each other, such as to procure resources from other cloud systems by cooperating with other cloud system (inter-cloud) connected via broadband networks.

4.1 Cloud services and computation level scalability

In VNA, the cloud services and computation level scalability are shown in Fig. 9. According to the range of spatial regions, the services can be divided into three deferent computational levels: vehicle, location, and cloud. In the vehicle range, the digital platform acquires both environment and body parameters, and provides man-machine interaction in terms of wired/short-range wireless technologies. Also, the other function modules from third-party corporations can be integrated into this open digital platform. The vehicular clusters usually formed by VANET give more comfort

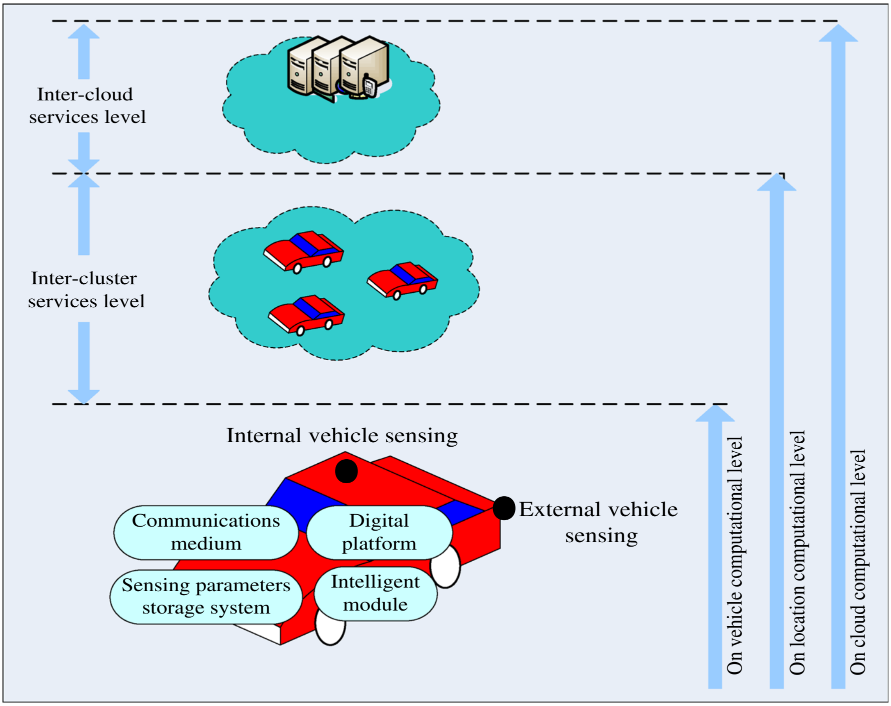


Fig. 9 Cloud services and computation level scalability

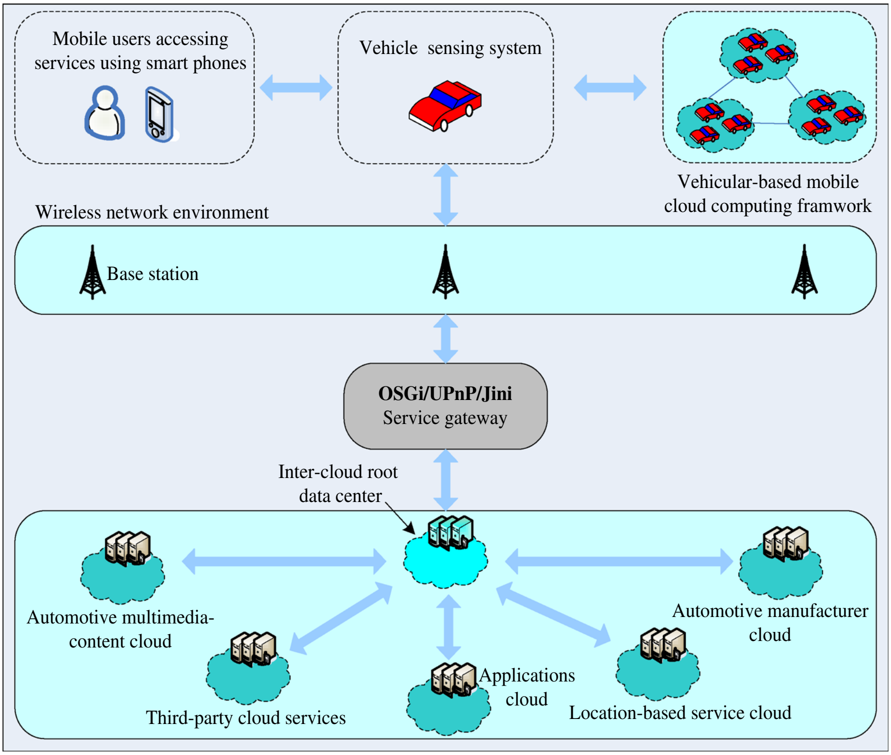


Fig. 10 Novel inter-cloud architecture in VNA

and convenience (e.g., sharing of entertainment resources and safety information) to users. In addition, with the development of cloud computing, an increasing number of services supplied by diverse suppliers and third-party corporations gradually are becoming a reality.

4.2 Considered inter-cloud architecture in VNA

An inter-cloud world includes multiple cloud systems running with different policies and interworks with each other to share resources, so that end-to-end QoS to users can be maintained even in the event of large fluctuations in computing load that cannot be handled by a single cloud system. Figure 10 shows a novel inter-cloud architecture supporting telematics applications in VNA. The interactions among the different types of clouds are achieved through inter-cloud root data center that are connected to wireless network environment under the help of service gateway. The gateway involves a lot of technologies, protocols, standards and services to allow communication and integration between devices. Some developments are focused on software modes, for example [11,25,36]:

- Jini;
- UPnP (Universal Plug and Play);
- OSGi (Open Services Gateway Initiative).

The vehicle sensing systems (e.g., digital platform) form vehicular-based mobile cloud computing framework, and accomplish the communications among mobile users accessing services using smart phones and mobile base stations. With the proposed inter-cloud architecture, it is very convenient for users to get the services of automotive manufacturer cloud, automotive multimedia-content, and third-party cloud.

4.3 Semantic modeling analysis for inter-cloud service model in vehicular networking

In extreme heterogeneous IoT environment, all kinds of resources, such as computing resources, storage resources, bandwidth resources, software resources, data resources, generally indicated by ontology, are integrated as a global database of information resources and information processing platform, to provide users with the integration of information and application service (e.g., computation, and storage access). Semantic models provide a set of generic standard protocols for interface definition, method calls, heterogeneous and distributed computing.

It is necessary to build the semantic modeling analysis for inter-cloud service model in vehicular networks in order to find the desired data from mass data, realize the real intelligence, and improve the functional portability, data application, and QoS.

4.3.1 Mobile cloud computing forming mechanism

Mobile cloud computing is an emerging cloud service model including lots of mobile devices (e.g., vehicles) which are closely associated with their users. They will be contained in many cloud service activities which extend the cloud boundaries into the entire complex systems.

Figure 11 shows the mobile cloud computing forming mechanism. The mobile cloud (vehicular cluster) is formed by opportunistic topology of vehicular communication range. Also, the mobile cloud formation can be facilitated through service gateway. The vehicles with digital platform in the mobile cloud have potential capability for message sending, receiving, computing and processing. The service interchanging between vehicular cluster and service gateway includes intelligent process interchanging, historical service data querying, and sensing data interpreting.

4.3.2 Semantic modeling analysis

The information with the semantic is easy to understand and handle for the computer in the inter-cloud service. The ontology technology is used to implement information semantic interaction and sharing in IoT. Following is the semantic model design considerations in inter-cloud.

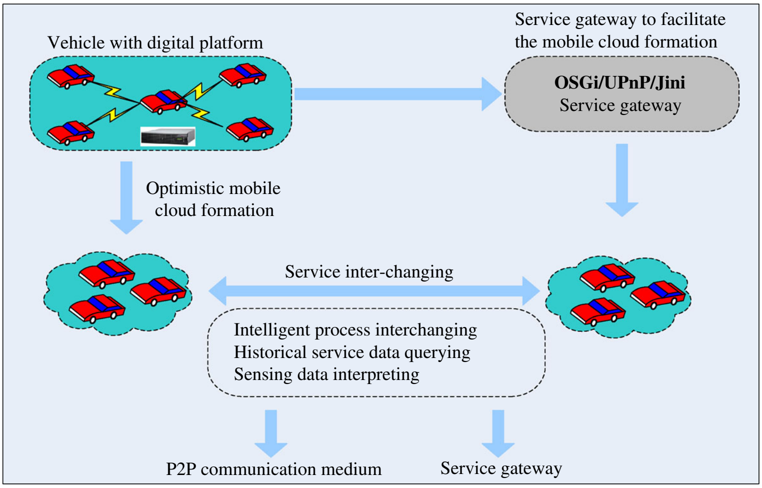


Fig. 11 Mobile cloud computing forming mechanism

Semantic Model Design Considerations in Inter-Cloud

Input: Real-Time Information Collected by Vehicle
Parameters: Semantic Model, Inter-Cloud Service Parameters, Service Querying Parameters
Method:

1. Semantic Operation

(a) The semantic operation is used to define specific data that query from the cloud data center.
(b) A resource description framework called SPARQL (service querying function) is used to query data in the inter-cloud system.
(c) SPARQL is a very powerful SQL-like language which makes semantic information easy to understand and handle for the inter-cloud system.
(d) Clouds manage their operations via Web services, but these service interfaces vary from vendor to vendor. However, the operations' semantics are similar. Metadata with annotations of generic operational models could consolidate the service interfaces and enhance interoperability among the heterogeneous cloud environments.

2. Inter-Cloud Service

(a) The automotive manufacturer creates a data center to store all related information about every single produced vehicle.
(b) The main cloud is located in manufacturer headquarter, while cloud cluster can be dispersed among vehicle maintenance service center. These clouds have unique contents that will be query to join service framework by invoking information from the inter-cloud root.
(c) The cloud responses the query by XMPP-based inter-cloud transport protocol. The reliable protocols, such as XMPP based inter-cloud transport protocol, are needed for the collaboration of the cloud instances.

3. Capabilities of Inter-Cloud

(a) Individual inter-cloud capable clouds will communicate with each other, as XMPP clients, via XMPP server environment hosted by inter-cloud roots and inter-cloud exchanges.
(b) The various XMPP-based control plane operations are implemented for inter-cloud.
(c) The cloud provider not only offers lots of computing resources, but also supplies complete visibility and transparency for these resources to ensure that the services and resources meet the architectural, functional, and strategic requirements of other cloud providers.

(d) The semantic model which obtains the features and capabilities is available from a cloud provider's infrastructure.
4. Application of Semantic Models in Inter-Cloud
(a) Semantic models are useful for inter-cloud computing from the aspects of functional definition, data model, service description enhancement, and so on.
(b) The ability to specify application functionality and QoS details in an uncertain platform manner can extremely benefit the inter-cloud community. It is especially important for application code porting horizontally. Lightweight semantics are specifically applicable for the portability and flexibility of data and codes.
(c) A critical difficulty is porting data and codes horizontally across clouds. It is a significant challenge to move data from a schema-less data store to a schema-driven data store, such as a relational database. The origin of this difficulty is the lack of an uncertain platform data model. It would be a significant advantage to set up the semantic modeling of data to provide a platform independent data representation in the inter-cloud space.

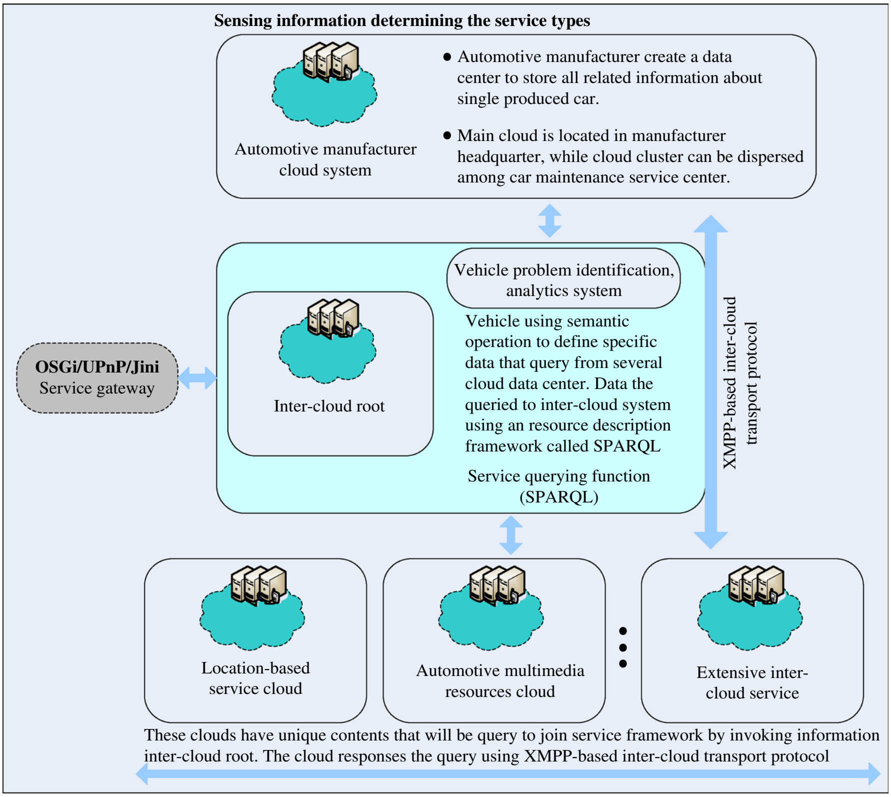


Fig. 12 Inter-cloud service model for VNA

As Fig. 12 shown, in the inter-cloud service model, the clouds can interoperate, and there is an inter-cloud root, containing services, such as automotive manufacturer service, location-based service, automotive multimedia resource service, and extensive inter-cloud services. There are inter-cloud service gateways which support the entire profile of inter-cloud service level agreements and standards.

4.3.3 Semantic web communication technologies in VNA

The communication of the heterogeneous objects in IoT is a major challenge because different objects provide different information in different formats for different purposes. The semantic web technologies and models can be used to solve this problem. RDF Schema, SKOS, OWL and RIF standards describe different forms of vocabularies and provide different levels of expressiveness.

As a common schema for representing heterogeneous information, ontologies can be used to handle semantic information. They can be used for individual vehicle modeling and services of smart roads. Semantic models are needed to annotate smart vehicle data to create linked meaningful data and describe web resources in a conceptual manner. RDF, GRDDL, RDFa and POWDER are provided by W3C to represent semantic models. RDF semantic models can be used to describe associate ontology concepts with single vehicle data in vehicular networking. The semantic model for a smart vehicle is shown as follows.

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#">]>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
                    xmlns:exterms="http://www.example.com/terms/">
    <rdf:Description rdf:ID="vehicle123">
          <exterms:brand rdf:datatype="&xsd;string">HongQi</exterms:brand>
          <exterms:speed rdf:datatype="&xsd;decimal">60</exterms:speed>
          <exterms:longitude rdf:datatype="&xsd;decimal">113.4</exterms:longitude>
          <exterms:latitude rdf:datatype="&xsd;decimal">23.2</exterms:latitude>
    </rdf:Description>
</rdf:RDF>
```

Semantic models can be used to share data in the inter-cloud space so that the heterogeneous data can be collected and processed by associated entities. Ontologies which define the relationships and properties can provide powerful inference capabilities. Semantic Web Rule Language (SWRL) combines sublanguages of the OWL Web Ontology Language (OWL DL and Lite) with sublanguages of the Rule Markup Language (Unary/Binary Datalog). Table 3 shows some SWRL rules that could be applied in the vehicle network.

Table 3 Examples of SWRL rules for the vehicle network

Rule	Meaning
SmartComputer(?sc) ⋀ hasURI (?sc, ?uri) => hasService(?sc, ?s)	If it is a smart computer and it has a URI, then it has a service
Vehicle(?v) ⋀ hasSensor(?v, ?s) => SmartVehicle(?v)	If it is a vehicle and it has a sensor, then it is a smart vehicle
Vehicle(?v) ⋀ hasSpeed(?v, ?s) ⋀ swrl:greaterThan(?s, 60) => HighSpeedVehicle (?v)	If it is a vehicle and its speed is greater than 60km/h, then the vehicle is high speed

Table 4 Examples of semantic queries for the vehicle network

Type	Query	Meaning
SQWRL	Road(?r) $\wedge$ hasTraffic (?r, ?t) $\wedge$ hasType (?t, ?type) => sqwrl: select (?type)	Select the type of the road traffic
SQWRL	NationalRoad(?r) => sqwrl:select (?r)	Select the national road

SPARQL	PREFIX foaf: <http://xmlns.com/foaf/0.1/>
	SELECT ?name ?type
	WHERE {
	?road a foaf:Road.
	?road foaf:name ?name.
	?road foaf:type ?type.
	}
		Select names and types of every road in the dataset

Semantic queries are carried out using information derived from semantic models and ontologies. SQWRL is a language for retrieving information from ontology, and SPARQL is a language for querying formally defined RDF data on the Semantic Web. SPARQL helps users to create unequivocal queries. Table 4 shows some examples of semantic queries suitable for the vehicle network.

Vehicular networking is a combination of heterogeneous smart objects and systems with semantics. The semantic web technologies can be applied to facilitate communication in VNA.

5 VMS event processing flow

In this section, we present a VMS event processing flow developed in the context of the SOFIA project. The mission-critical wireless messages are scheduled by event manager.

Figure 13 shows a possible information flow where data are aggregated and correlated, increasing at each step their level of abstraction from raw physical data (e.g., engine temperature) to high level event (e.g., unexpected nonfatal problem). A cloud of heterogeneous sensors performs measurements of the vehicle (vehicle status, problem occurring, mechanical stress, etc.). These measurements are managed by the WSN subsystem, which publishes the raw events (i.e., the measurements itself) in the SIB. The WSN subsystem might also perform local computation such as filter-out some readings or aggregate data. Raw and heterogeneous events (i.e., provided by different kind of sensors) are retrieved from the SIB by an event correlator which performs a further step of data aggregation, according to a suitable set of rules which exploit: 1) temporal redundancy (measurements performed in consecutive periods of time), 2) spatial redundancy (measurements performed by sensor displaced in near but different locations), and 3) dimensional redundancy (measurement of a different physical dimension performed by different clouds of sensors). The result of data correlation, enriched with a reliability index which gives a score to the likelihood of the detected

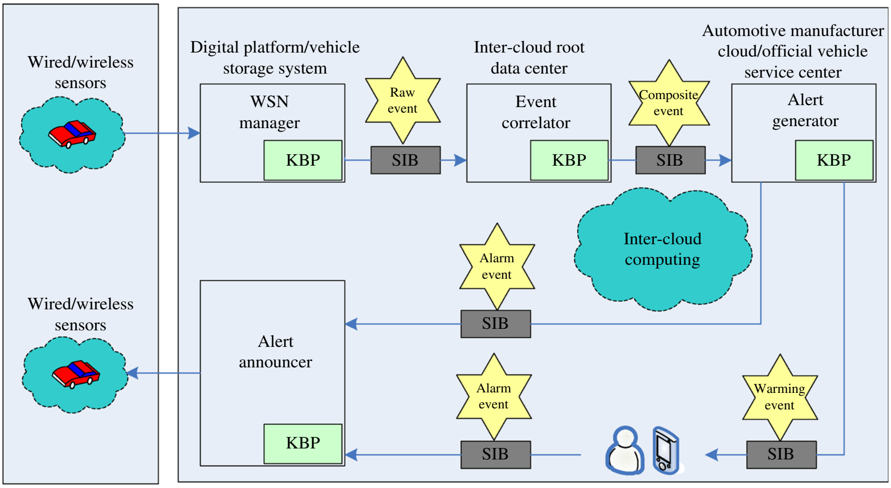


Fig. 13 VMS event processing flow

phenomenon, is a composite event published in the SIB. Eventually, the alert announcers (e.g., automotive manufacturer and official vehicle service center) inform the end-users of dangerous and/or critical situations, exploiting effective human computer interaction techniques.

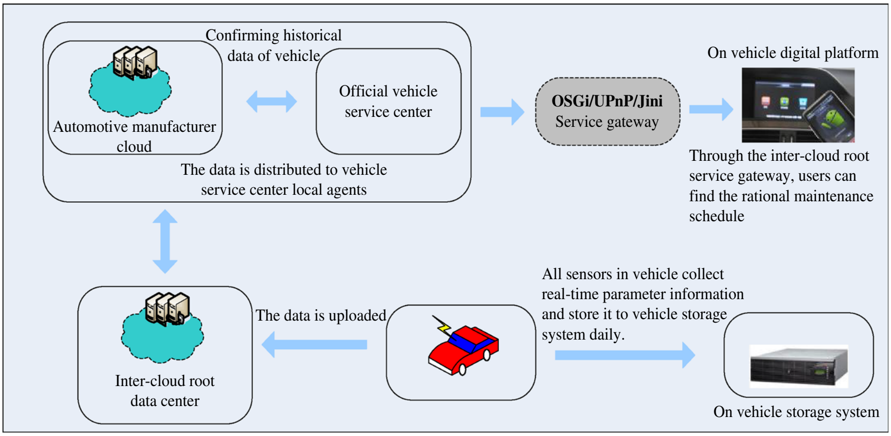
6 Performance evaluation

The PPS business model described in Sect. 3 can be applied to several situations where a telematics needs to process potential danger, such as unexpected problem occurring and routine maintenance. In this section, we select VMS to conduct the validation of our proposed approach.

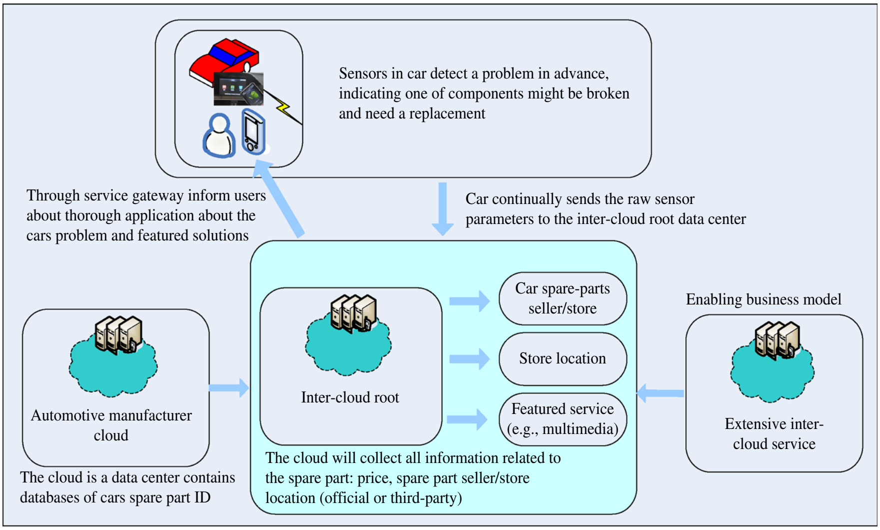
6.1 Case studies: VMS

In Fig. 14(a), two application scenarios concerning VMS are shown [42]. As shown in Fig. 14(a), all sensors in the vehicle collect the real-time parameter information and store it into the vehicle's storage daily. Also, the same data is uploaded to the vehicle's manufacturer inter-cloud root data center. The data is distributed to vehicle service center local agents. The official vehicle service center confirms historical data of vehicle with the automotive manufacturer cloud. If users want to find alternatives to the maintenance schedule posted by official vehicle service center, they can query the other services from independent service center through the inter-cloud root service gateway.

When the sensors in the vehicle detect a problem in advance, indicating one of the components might be broken and need a replacement, the vehicle continually sends the raw sensor parameters to the inter-cloud root data center, as shown in Fig. 14(b). The cloud will collect all related information about spare part price, spare part seller,



(a)



(b)

Fig. 14 VMS. **a** Routine maintenance. **b** Unexpected problem occurring

store location, and so on. Then the users are informed about the vehicle's problem and featured solutions through service gateway.

6.2 Service response time

In this subsection, we adopt the probabilistic method to analyze the processing response time and risk factor of VMS. According to the assumptions in Sect. 3.4, an unexpected nonfatal problem can not affect the running of vehicle, but lead to less

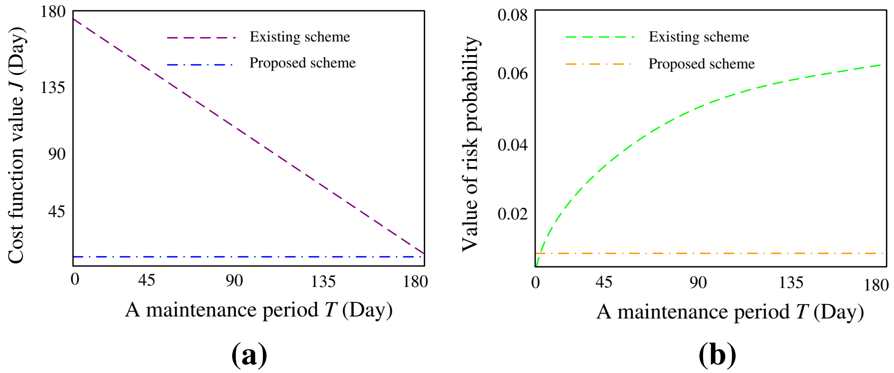


Fig. 15 Evaluation for an unexpected nonfatal problem. **a** Efficiency. **b** Risk factor

safety. Also, the fault rate of problem occurring roughly conforms to the exponential distribution in a maintenance period. The maintenance period T is usually a constant interval of values around 180 days. We assume that the parameter of exponential distribution λ is $1/2880$. Therefore, the distribution function is given as follows:

$$F(t) = \begin{cases} 1 - e^{-\frac{t}{2880}} & t > 0 \\ 0 & t \leq 0 \end{cases} \tag{4}$$

Figure 15 shows the evaluation of efficiency and risk factor for an unexpected nonfatal problem using Eq. (4). The proposed scheme adopting IoT sensing technology and inter-cloud computing can effectively and timely processes some abnormal problems. The users can receive a kindly warning and an alternative solution from vehicle service center in a day. Therefore, the cost function value (processing response time) J is usually less than one day. However, for the existing scheme the processing response time J gradually shortens over time, and the risk factor continually increases in a maintenance period. When the difference between T_p and T_s goes to 180, the value of risk probability runs to 0.06.

In the proposed scheme, for routine maintenance the data concerning vehicle status is uploaded to the vehicle's manufacturer inter-cloud root data center daily. If some potential problems happen, the official vehicle service center will immediately send a message to the user through IoT sensing framework. Also, both efficiency and risk factor satisfy the regularities as shown in Fig. 15.

7 Conclusion

Due to the need for improving convenience, efficiency, and safety in VNA, this article studied the feasibility of PPS business model by IoT sensing technology and inter-cloud computing. After proposing an innovative PPS business model in vehicular networking, we applied this scheme to VMS. Also, we designed the inter-cloud architecture supporting telematics applications, inter-cloud service model including semantic modeling analysis and event processing flow for managing the reliable messages. For the proposed scheme, the performances, such as efficiency and risk factor, are evaluated by adopting the probabilistic theory.

In the past decades, the vehicular communication and networking technology has grown into maturity, moving from laboratory into reality. As the IoT sensing technologies continually make some breakthroughs and cloud computing is gradually available, we can easily implement the proposed approach. It is clear that vehicular communication and networking will be the cornerstones of the future cyber-physical systems which will significantly change our daily life. Further research on this project will take into account of the theoretical analysis by the aid of the proposed IoT sensing framework and inter-cloud architecture.

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