

## **ENABLING SMART CLOUD SERVICES THROUGH REMOTE SENSING: AN INTERNET OF EVERYTHING ENABLER**

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### **ABSTRACT**

The recent coming out and accomplishment of cloud-based services has empowered remote sensing and made it very possible. Cloud-assisted remote sensing (CARS) enables distributed sensory data collection, and data sharing. Global resource, remote and real-time data access and elastic resource provisioning CARS has great potentials for enabling the so-called Internet of Everything (IoE), thereby promoting smart cloud services. In this paper, we survey CARS. First, we describe its benefits and capabilities through real-world applications. Second, we present a multilayer architecture of CARS by describing each layer's functionalities and responsibilities, as well as its interactions and interfaces with its upper and lower layers. Finally, discuss the sensing services models offered by CARS.

Index Terms—Cloud computing, Internet of Everything (IoE), remote sensing, smart cloud services

### **INTRODUCTION**

Remote sensing plays a key role in the acquisition of data about and from everything without needing physical field visits. With the recent emergence of

cloud computing, remote sensing has been empowered and made possible even more than ever before. Unlike conventional ways of collecting and processing sensory data, cloud-assisted remote sensing (CARS) now enables: 1) decentralization of data sensing and collection, where sensory data can now be sensed and collected from everywhere instead of being restricted to limited areas; 2) sharing of information and cloud resources, where data and resources can be shared and used globally by all users; 3) remote access to global sensed information and its analytics, where sensed data can easily be accessed and analyzed online from everywhere; 4) elastic provisioning of cloud resources, where users can scale up and down their requested resources in real time based on demand; and 5) pay-as-you-go pricing models, where users can request (and hence pay for) only resources that they need based on their demand. CARS can then be viewed and foreseen as an emerging technology that has great potential for enabling the so-called Internet of Everything (IoE), thereby enabling smart cloud services.

IoE is a new Internet concept that tries to connect everything that can be connected to the Internet, where everything refers to people, cars, televisions (TVs), smart cameras, microwaves, sensors, and basically anything that has Internet-connection

capability. A recent study by Cisco predicts that IoE is projected to create \$14 trillion net-profit value, a combination of increased revenues and lowered costs, to private sector from 2013 to 2022 [1]. IoE is not seen as an individual stand-alone system, but as a globally integrated infrastructure with many applications and services [2]. When coupled with IoE, CARS gives birth to what we call Everything as a Service or Sensing as a Service (SenaaS) [3]. For example, a radio station can rely on CARS to lease a set of driverless cars which it can use to cover road accidents and broadcast traffic information [4]. This is becoming a commercially viable solution, especially after states such as Nevada, Florida, and California legalized driverless cars to operate in public roads [5]. Another example is to have traffic lights communicate with and control approaching vehicles upon sensing the presence of pedestrians and bikes [6]. Smart phones, which are typically (or can be) equipped with specialized sensors, can also be used to provide sensing and monitoring services for environment, healthcare, and transportation [7], [8]. These application domain examples are just a few among many others

that can benefit from CARS to offer SenaaS.

In this paper, we survey the topic of using cloud computing to enable remote sensing services, referred to, throughout the paper, as CARS or simply CARS. First, we describe in Section II the benefits and uses of CARS by giving several real-world application domains where CARS can be applied. Second, we present in Section III a layered architecture for CARS that consists of four layers. For each layer, we describe the functionalities and responsibilities of the layer, as well as its interactions and interface

with its upper and lower layers. Third, we discuss in Section IV three different models of sensing services that ARS can offer: infrastructure-based, platform-based, and analytics based models. Fourth, we go over in Section V popular commercial CARS platforms that have already been developed and been ready to use by highlighting their capabilities and their offered service models.

## **CARS SERVICES AND APPLICATIONS**

CARS can be found useful in many real-world applications in various domains, including industrial, medical, social, and environmental. Essentially, CARS services and applications extend traditional sensor network applications by enabling:

- 1) distributed data collection and sensing, where sensory information can be sensed and collected from everywhere;
- 2) global data and resource sharing, where sensory information and resources can be shared globally;
- 3) remote and real-time data access, where sensed data can be accessed and analyzed in real time from anywhere;
- 4) elastic resource provisioning and scaling, where service users can provision and scale up and down their needed resources based on demand;
- 5) pay-as-you-go pricing, where cloud users can request, release, and pay for resources whenever needed.

CARS usages and benefits are classified into three categories:

- 1) **Remote tracking and monitoring:** CARS enables remote tracking and monitoring of things of interest in real time, thereby

allowing alerts to be raised and appropriate actions to be taken in a timely manner whenever needed. CARS can potentially be used for tracking and monitoring animal behaviors, moving-object locations (e.g., vehicles), environmental conditions, building surveillance and security, patient-health conditions, smart-grid operations, aviation and aerospace safety, and vegetation production quality, just to name a few.

1) Animal Behaviors: CARS can track and record locations of animals (livestock or wild) by collecting global positioning system (GPS) data in real time and storing it in the cloud [9].

2) Environmental Condition Monitoring: CARS can be used to monitor environmental condition changes by having distributed sensors, which collect and send data to the cloud. Data to be collected can, An environmental specialist can then access this data and use it to monitor climate changes, estimate concentrations of dangerous chemicals in water and air [10], monitor and alert of possible forest fires [11], and get alerted by possible avalanche occurrences [12].

3) Agricultural Monitoring: CARS has potential uses for monitoring vegetation remotely, combating crops-threatening pests, and improving farming system productivity. Smart camera technology is being used for remote vegetation monitoring by collecting and processing field images on the fly, generating performance reports, and sending processed reports to the cloud.

4) Building Surveillance and Security: CARS can also be used to monitor and detect safety and security patterns, such as malicious human activities and building

structural problems, allowing to raise security alerts in a timely manner [13,14].

5) Healthcare Monitoring: Healthcare too requires an automated system that allows continuous monitoring of patients' health conditions and real-time reporting of abnormalities and condition alerts to physicians. [15,16].

6) Smart Meter Readings: CARS can be very handy in measuring and collecting smart grid operation information, allowing easy integration and automation of smart grid components. [17].

7) Aviation and Aerospace Safety: CARS can be used to improve security and safety of crew and air vehicles. [18].

**B. Real-Time Resource Optimization and Control :** CARS can also enable real-time optimization and control of various resources, where resources vary from one application domain to another. Waste management, traffic control, smart parking, water/irrigation management, and guided navigation are a few applications where resources can be optimized and controlled efficiently via CARS.

1) Waste Management: CARS allows remote monitoring of recycling containers, making recycling waste pickup and routing processes effective. Waste management is a complex process that involves generation, on-site handling, collection, transfer, processing, and disposal of waste. [19].

2) Smart Parking: Using CARS, one can provide real-time information about parking availability to locate parking spots faster and more efficiently, which saves time of car drivers and reduces energy consumption. This can be achieved by quickly identifying

and reserving a free parking spot in the vicinity of the drivers' final destination [20].

3) Traffic Control: CARS enables quick collection of real-time traffic information that can be used to avoid traffic jams, report accidents, report road constructions, and reduce fuel consumption. Traffic information can be sensed and collected by designated sensors, or by participatory sensing devices (e.g., smart phones and smart cameras) to monitor roads and traffic conditions in cities [21]. In addition, CARS can also be used to manage fleets in public and private transportation [22].

4) Healthcare: CARS can be used in healthcare systems to study and control disease transmission, and support independent living of elderly, inferior, and people with disabilities. In [23], sensors are used to construct a social network of high school students to control disease transmission. Mobile phones and specialized wearable sensor networks are being utilized to detect elderly people body posture and biological signals to enable efficient allocation of needed clinical resources for diagnosis, treatments, and surgeries [24, 25].

**C. Smart Troubleshooting:** Identify, Diagnose, and Repair CARS makes remote problem identification, diagnosis and repairing possible and efficient. Application domains where this technology can be applied to are diverse; aviation and aerospace, automotive, network systems, buildings, smart grids, and oil and gas pipelines are some examples.

1) Aviation and Aerospace: CARS can remotely provide pilots, dispatchers, and space mission controllers with necessary and useful information that help them quickly identify, locate, and fix problems. [26].

2) Automotive: This industry has been witnessing a paradigm shift, as makers have been installing hundreds to thousands of sensors and embedded systems in their vehicles. One key use of these sensors is for enabling smart and efficient maintenance. As an example, Hull et al. [27] develop a computing system that takes advantages of these deployed sensors to collect, process, and visualize sensed data to enable remote and in-vehicle preventive diagnosis.

3) Network Systems: CARS provides networking and information technology (IT) troubleshooters with the ability to remotely diagnose and identify networking component failures, and repair them also remotely and in a timely manner. For

example, CARS has been used for providing real-time monitoring of data cloud centers to identify and repair (hardware and software) faults [28] and to make wise energy management decisions so as to reduce energy consumption in data centers [29]

4) Buildings: CARS can render buildings and bridges act smarter. It can enable easy and fast detection and localization of flight failures, air conditions stalling, or structural defects. [30]

5) Smart Grids: Power grids are becoming very complex in size, heterogeneity, and behavior. CARS can play an extremely critical role in keeping these grids operational at minimum costs. One potential use of CARS is to help maintain these grids fault-free for as long as possible by enabling remote failure detection

and diagnosis so that repairs can be made quickly [31].

6) Oil and Gas Pipelines: These rely heavily on fast failure detection typically enabled through monitoring of special parameter

values (e.g., leakage and high pressure) collected via designated sensors that are spread out along the pipelines (length could be thousands of kilometers). CARS can make data monitoring, collection, and analysis more efficient than ever, thus reducing pipeline maintenance cost and increasing pipeline productivity [32].

### CARS ARCHITECTURE FOR ENABLING IOE

The different CARS applications are discussed above. Here a new architectural design of CARS in order to be able to enable smart cloud services. This motivation is triggered by the unique characteristics and features that distinguish CARS from other traditional distributed systems. Sensory infrastructure deployment and sensing technique development across different domains may share common challenges and specificities, which should be taken into account when designing architecture.

The proposed CARS architecture: Such architecture can be viewed as a geographically distributed platform that connects many billions of sensors and things, and provides multi-tier layers of abstraction of sensors and sensor networks. Fig. 1 shows the proposed CARS architecture. The CARS architecture has four main layers: 1) fog layer; 2) stratus layer; 3) alto-cumulus layer; and 4) cirrus layer.

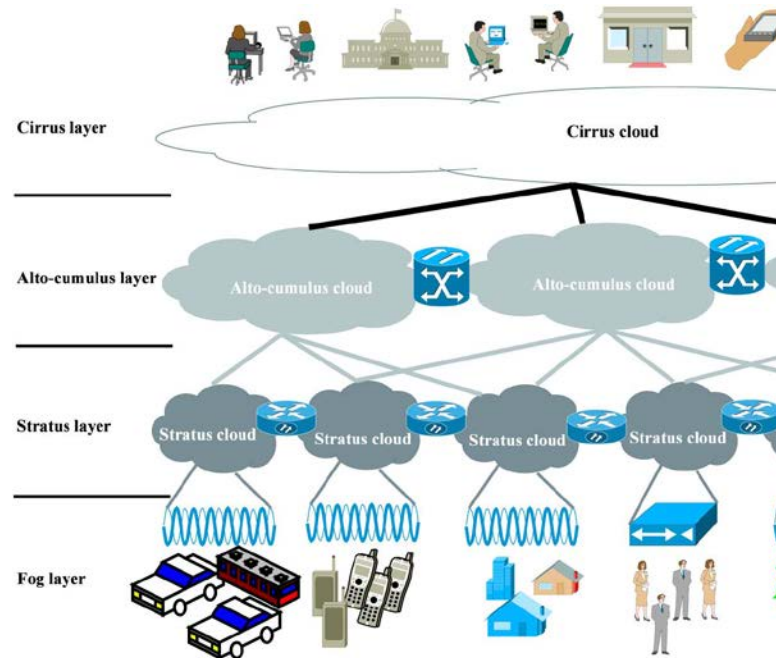


Fig 1: CARS Architecture

1. Fog Layer: Fog layer encapsulates all physical objects, machines, and anything that is equipped with computing, storage, networking, sensing, and/or actuating resources, and that can connect to and be part of the Internet. The sensory elements of this layer are those that collect and send raw sensed data to stratus layer, by either being pulled by stratus layer or being pushed by fog layer to stratus layer.

Major functions of fog layer are to provide:

- 1) Heterogeneous networking and communication infrastructure to connect billions of things
- 2) Unique identification of all things through Internet Protocol Version 6
- 3) Data aggregation points to serve as sensing clusters.

Although the capabilities of sensing elements of this layer may vary depending on

their type and purpose, it is safe to consider that they are very likely to be resource (e.g., power, memory, and CPU) limited and that they may operate on opportunistic wireless access mode only. As a result, sensor clustering and network virtualization techniques have emerged as possible ways to tackle such resource limitation of sensory devices, thus enabling distributed CARS services. When mobility is considered as the metric for categorization, we have the following three types:

- 1) fixed SANs, where sensors are stationary, and network connectivity is known and controllable;
- 2) mobile SANs, where sensors are mobile, but their locations are known and controllable (e.g., Google driverless vehicles), and network connectivity is known and may be controllable;
- 3) participatory SANs, where sensors are private devices (e.g., smart phones) owned by people who, at their will, may or may not choose to participate in sensing tasks [7, 8]. Network connectivity could be intermittent and may or may not be known, but definitely not controllable.

**2. Stratus Layer :** Stratus layer is a mid, tier-2 layer that consists of thousands of clouds whose main resources are sensory devices and SANs. Each stratus cloud manages and acts as a liaison for a different group of SANs that share similar features, context, or properties.

The functions of stratus layer include:

- 1) Abstracting and virtualizing physical SANs through

virtual network embedding (VNE) techniques;

- 2) Handling and managing virtual SAN migration and portability across different clouds;
- 3) Managing and ensuring operations and functionalities of virtual SAN instances
- 4) Enabling and managing (physical or virtual) SAN configurations to ensure network connectivity and coverage;
- 5) Controlling the layer's operations and functionalities to ensure that customers' service level agreements (SLAs) communicated from higher layers (as detailed later) are met.

Stratus layer provides an abstraction of the physical world represented via fog layer to alto-cumulus layer. This layer does not interact directly with CARS customers, but serves them through requests received from higher layers. Conceptually, stratus clouds are optimized to handle heterogeneous connectivity of SANs by having software-defined networking interfaces with alto-cumulus layer.

**C. Alto-Cumulus Layer:** Alto-cumulus is a middle layer that serves as a point of liaison between stratus and cirrus layers. It facilitates negotiations related to pricing, policy and regulations, and SLAs between stratus and cirrus layers, and ensures that the agreed upon terms are not violated. While stratus clouds are domain specific; i.e., each cloud is very likely to be concerned with one application domain (e.g., medical, environment, and agriculture), an

altocumuluscloud may map to and orchestrate multiple stratusclouds belonging to different domains. As mentioned earlier, this can enable inter-cloud resource sharing, thereby increasing resource elasticity and scaling.

Major functions of alto-cumulus are as follows:

- 1) Serving as a point of liaison between cirrus and stratus layers by translating policy and regulation requirements expressed by cirrus layer into domain-specific requirements understood by stratus;
  - 2) Enabling business and payment transactions between cirrus and stratus layers by providing two-way brokerages services;
  - 3) Enabling and facilitating SLA negotiations between cirrus and stratus, and monitoring and ensuring that these SLAs are met; i.e., playing the role of a policy enforcement agent;
  - 4) Coordinating and facilitating inter-cloud interactions, data exchange, task migration, and resource sharing across different stratus clouds.
4. Cirrus Layer: Cirrus layer is the highest layer in the CARS architecture, and its main role is to interact with CARS service customers and satisfy their requests with the aid of lower layers. It does not deal with resource virtualization, nor does it need to know which cloud handles which resources. It just needs to communicate customers' requests specified via their SLAs to alto-cumulus clouds.

The major functions of Cirrus layer are as follows:

- 1) Acting as the customers' entry point to CARS systems by allowing them to specify their required services via SLAs and to select their desired service models;
- 2) allowing CARS customers to set up their sensing task requirements and do whatever their chosen service model allows them to do (e.g., software configuration/deployment)
- 3) Negotiating SLAs with customers and communicating them to alto-cumulus layer.
- 4) Providing online applications for remote data analysis to be used by customers to visualize their data in real time.

This layered CARS architecture essentially consists of connecting sensory devices (fixed, mobile, and participatory) through the fog layer, managing SAN virtualization and embedding through stratus layers, managing cloud domains and these virtual SANs through the alto-cumulus layer, and providing abstractions of cloud services to customers through the cirrus layer.

#### IV. CARS SERVICE MODELS

The objectives of CARS are to provide cloud customers with flexible access to data and sensing services, allow them to develop their own domain-specific applications, and allow clouds to share physical resources. The services offered by CARS into three smart models those are 1) IaaS; 2) PaaS; and 3) SaaS.

These models are Sensing and Actuating Infrastructure as a Service (SAIaaS), Sensing and Actuating Platform as a Service (SAPaaS), and Sensing Data and Analytics as a Service (SDAaaS).

- A. SAIaaS: SAIaaS model requires that physical sensor and SAN resources serve multiple sensing tasks concurrently. Customers cannot make changes to physical resources (i.e., SANs and sensors), but have full control over their allocated virtual instances.

Fig. 2 depicts an example of multiple virtual SANs.

In this illustration, three sensing tasks are requested to be carried out by the platform, leading to the creation of three virtual SANs (two mobile and one fixed).

- B. SAPaaS: SAPaaS model offers sensing platforms as a service. In this model, CARS customers are provided with a set of application programming interfaces (APIs) and libraries that they can use to develop their own sensing and actuating applications without worrying about the physical (SANs).

- C. SDAaaS: Many practical applications need only to have access and be able to process sensed data without needing to change anything in the physical sensors or in the virtual realizations of SANs. CARS service customers using this service model, referred to as the SDAaaS model, are only interested in the context in which sensed data is collected, its accuracy, and its sufficiency to be able to generate meaningful inferences.

## CONCLUSION

This paper surveys CARS applications and services. The survey starts off by describing the potentials and capabilities of remote sensing when empowered via cloud services. It supports these CARS' capabilities and benefits through applications taken from real-world scenarios. The survey then presents four-layer architecture for CARS by describing the functionalities, responsibilities, and inter-layer interactions of each layer. The survey then describes three different CARS services models and presents some existing commercial platforms. Finally, it describes key design components that are required for enabling CARS and discusses some of its major challenges.

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