Conceptual Approach of a Hierarchical Cloud Architecture for Intelligent Transport Systems

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Abstract—**Intelligent Transport Systems (ITS) can improve safety, mobility and productivity for cities, but the ITS ecosystem lacks efficient methods to ease content integration and communication between different road transport modes. We believe that an emerging technology able to provide relevant capabilities to integrate content, applications and services for ITS users is Cloud Computing. This technology offers the delivery of computing services through the network and is characterized by different service and deployment models, which can allow scalability, reliability, pay as you go, shared resources and service customization for the heterogeneous ITS users. In this paper, we propose a Conceptual Approach of a Hierarchical Cloud Architecture for ITS that is able to provide content integration, and may also provide the possibilities to create different business models based on the Cloud and the ITS ecosystem.**

Keywords—Cloud Computing, Intelligent Transport Systems, Business Models, Cloud Architecture.

I. Introduction

The entire set of technologies that in one way or another affects the road transport sector have given birth to a new concept: Intelligent Transport Systems (ITS). As a concept ITS offers several innovative benefits and improvements for the road transport sector regarding safety, mobility and productivity, but also poses many challenges in partnership related infrastructures (for example cities) in order to be efficiently deployed (i.e., standardization, interoperability, privacy and security mechanisms) [1] [2] [3] [4] [5] [6]. For instance, it is estimated that by 2020 there will be over 152 million connected vehicles [7] producing about 11 petabytes of data annually. This tendency of constant and ubiquitous connectivity as well as data processing has to be managed efficiently.

On the other hand, ITS users have a wide variety of needs that must be satisfied. As an example we can mention, multimedia content accessibility, reliable information about vehicles and surroundings as well as access to a variety of ITS and non-ITS applications and services. Furthermore, the ITS environment lacks of efficient methods to ease content integration and communication between different road transport modes (e.g., private vehicles, buses and trains).

Given these requirements, it has been already recognized that cloud computing will play a key role in the development of real ITS services. In short, cloud computing is down to delivering computing services through the network. Therefore, cloud computing looks to be the right paradigm to meet the needs driven by data storage and processing, also impacting on the integration of content, applications and services.

Cloud computing is an emerging and very interesting technology that presents different service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). These service models can satisfy and adapt to the different needs of the stakeholders (e.g., ITS facilities, OEMs, Drivers and Passengers). Furthermore, cloud computing also presents different deployment models: Private, Public and Hybrid. These deployment models offer a bunch of interesting benefits, including costs reduction, more appropriate implementations and maintenance, as well as improved business agility. They can be used according to the entities involved and their respective requirements (e.g., particular organizations and general public).

However, deploying cloud computing in ITS scenarios requires specific considerations, such as a coordinated adoption by stakeholders, new technologies integration and data security. Technologies such as Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and Vehicle to Person (V2P) communications [8] are being examined rigorously by organizations (e.g., U.S. Department of Transportation) to provide a seamless connectivity. Furthermore, Long Term Evolution (LTE), technology already implemented in recent vehicles, provides persistent connectivity, hence transforming road transport vehicles into Internet hotspots that can leverage much more applications and services [9].

The integration of the aforementioned technologies together with cloud computing may pave the way to provide pervasive computing within the ITS environment; where ITS entities (e.g., drivers and passengers) can easily interact with devices, applications and services, performing any daily task transparently regardless of their location. Nevertheless, despite the benefits cloud computing bring to ITS, its integration is not that easy to deploy. It is extremely important that we consider the proper service models and deployment models to support the different scenarios of the ITS environment. Moreover, privacy and security mechanisms must be deployed, building a secure and prudent overall scenario enabling users to access and share information safely.

Cloud computing aspects such as Data tracking and Auditing, management of Service Level Agreements and

Data Jurisdiction are still representing challenges [10]. This set of challenges significantly increases when dealing with wide mobility scenarios, raising many concerns remaining unsolved, as follows.

- Can cloud providers adapt their services to the users' mobility?
- Would cloud users receive efficient mechanisms to configure their cloud services?
- Are cloud service and deployment models flexible enough to provide interoperability within the ITS environment?

Therefore, in order to provide more adaptable and efficient cloud functionalities to ITS, we propose an architecture that can facilitate the provisioning of content, applications and services to ITS users, through a staggered approach, in which users may be able to access their corresponding services from either vehicles or -in case they need more computing and storage capabilities – other entities serving as cloud service providers (e.g., ITS facilities, rental cars and bus companies).

This approach may provide new opportunities to identify: a) several business models based on cloud service delivery; b) new applications and value added services, and; c) new actors that may get benefits from this innovative integration.

In this paper, we propose a Conceptual Approach of a Hierarchical Cloud Architecture for ITS, leveraging the creation of novel business models on a joint scenario mixing cloud computing capabilities and the ITS ecosystem, clearly identifying new actors that may benefit from this collaborative environment.

This paper is organized as follows. Section II provides an overview of recent cloud computing literature. Section III presents the conceptual approach of a hierarchical cloud architecture for ITS presented in this paper. Section IV introduces first version of a model to preliminary estimate the average level response time for our Hierarchical Cloud approach. Then, Section V provides a glimpse to business models that can be implemented based on cloud service delivery for ITS, which may be adopted to provide adequate services, also identifying new actors that may benefit from these business models. Finally, Section VI concludes the paper.

II. Cloud Computing Overview

One of the most promising technologies that can actually provide integration and distribution of relevant content, applications and services is cloud computing. This technology can be used as an innovative method for ITS resource management, directly endowing end-users with more computing and storage capabilities.

In this section we provide a very brief overview of the characteristics and benefits of a cloud computing environment.

A. Cloud Computing Service and Deployment Models

The Cloud Computing environment describes a broad range of services supported by different types of service models:

- Infrastructure as a Service (IaaS)
- Platform as a Service (PaaS)
- Software as a Service (SaaS)

A generally accepted definition for each one of these service models comes from the National Institute of Standards and Technology [11]. To sum up, SaaS provides applications and services designed for end-users, delivered over the web. PaaS is the platform bringing together the set of tools and services enabling users to easily and efficiently develop web applications. Finally, IaaS is the hardware and software that powers it all – servers, storage, networks, operating systems.

Another relevant characteristic of Cloud Computing is that it relies on several deployment models:

- Private Cloud: cloud Infrastructure provisioned for exclusive use by a single organization.
- Public Cloud: cloud Infrastructure provisioned for open use by the general public.
- Hybrid Cloud: cloud infrastructure is a composition of a public and private cloud.

B. Benefits of Cloud Computing

Cloud computing provides a large set of well-known benefits. For instance, cloud computing enables end-users to access their applications and services ubiquitously throughout the SaaS model. Other included benefits can be summarized as:

- Scalability - where users have the ability to access additional compute resources on-demand.
- Reliability - reliable cloud environments take advantage of the available servers for redundancy purposes.
- Pay as you go – users only pay for the services they use, either by subscription or transaction-based models.

The above mentioned general benefits of cloud computing, may be extended when cloud computing is integrated in an ITS environment. A key extension focuses on ITS resources sharing. Indeed, by enabling ITS resources to be consolidated, multiple users share a common infrastructure, reducing cost with no need for sacrificing the security of end-user's data.

III. Proposed Architecture

Lending the cloud capabilities to ITS –especially to road transport vehicles- is a smart and efficient decision that, for instance, makes high level operations, such as route planning, analysis, and decision making easier for travelers. This interaction can also help to provide accurate real-time information on vehicle schedules, road conditions and weather predictions. Along with these benefits, we believe that by connecting road transport vehicles directly to the

Fig. 1. Hierarchical Cloud Concept for ITS

cloud, we are able to systematically collect, process and correlate real-time, multi-modal data from connected vehicles, devices, and infrastructure. Transportation Agencies can bring multiple pieces of data together for a more accurate and dynamic picture.

For instance, using cloud services to store, analyze and visualize fleet data can have a great impact on the transportation industry. There are many vendors (i.e., Transwide, LeanLogistics, JDA) already providing online hosting or software as a service (SaaS) models to transportation organizations, transforming and enhancing the efficiency of transport management. Moreover, integrating Cloud Computing capabilities –incorporating all service models -, not only for ITS organizations but also for other users (i.e., Drivers, Passengers and Pedestrians) can accrue greater benefits. Therefore, in order to provide both a wider range of applications and an enriched service-level improvements as well as fully integrate the physical and informational aspects of the road transport environment, we propose a novel cloud conceptual approach based on a hierarchical architecture for ITS.

The hierarchical cloud architecture proposed in this paper is composed by a set of 3 different levels: Local Cloud, Intermediate Cloud and Conventional Cloud, as shown in Figure 1.

A. *Local Cloud*

Vehicles, individually and collectively, represent an extraordinary distributed computing resource, in terms of storage and processing capabilities.

The proposed hierarchical cloud architecture is based on a "Local Cloud" (bottom layer), represented by the user's vehicle (e.g., car, bus and train). These connected vehicles can locally accommodate a variety of ITS and non-ITS applications and services, ensuring the efficient response of applications with strict time constraints. In this environment, each road transport vehicle is able to simultaneously gather, process and share relevant information to both the cloud as well as other road transport vehicles.

Leading applications for the Local Cloud can be urban sensing, inter-vehicular video and audio communications, safe driving, content analysis and distribution, and advertising. These are some of the applications that can definitely attract commuters and potentially have a great impact on energy consumption and CO_2 emissions. Furthermore, a Local Cloud can allow users to stay connected and productive while they commute, but more importantly, since vehicles are effective observation platforms (through all their sensors) for the environment, a Local Cloud can enhance or provide new safety features for road transport vehicles. Moreover, one of the key benefits of a Local Cloud is the possibility to provide complex event processing, applying analytics to time sensitive streaming data, which is critical to attain real-time view of operating conditions for drivers and to provide the ability to take proactive steps to ensure efficient and more reliable actions.

We envision a Local Cloud as the infrastructure setting the possibility to create an interconnected ecosystem, where mobile devices, users and vehicles can constantly interact with each other and their surroundings. Clearly, this new ecosystem will produce an overwhelming amount of raw sensor data, requiring large processing capabilities, which can surpass the capacities this level is able to provide. This limit in the capacities is due to the fact that, unlike

Conventional Clouds, which can increment their storage and processing capacities exponentially, vehicles (where the Local Cloud resides) have considerable restrictions regarding space availability for additional hardware. It is certain to say that the majority of the capabilities incorporated by the Local Cloud level will be provided by vehicle manufacturers, due to the complexity and sensitivity of the features involved.

In order to illustrate the proposed local cloud scenario and provide a comprehensible idea of its performance, let's suppose a user that just had an accident. With local in-built cloud capabilities within the vehicle, the user will be able to inform in detail about the accident to all relevant authorities (i.e, hospital, insurance company and police department) as well as the surrounding vehicles, hence shortening time response and maximizing effectiveness for all involved entities.

B. *Intermediate Clouds*

There will be situations where users will require more processing, extended storage capabilities, or just different applications and services, which are definitely not provided by the local cloud. For these scenarios, users should be endowed with the capacity to access to other cloud services, from different entities, through what we call "intermediate clouds". The intermediate clouds may be optional and will be available for more adequate response time, due to additional computation resources. They can handle more complex and time consuming tasks while simultaneously providing much more applications, services and information to the users through a content-based secure networking, where new content is continuously added from the corresponding entities (e.g., ITS facilities, OEMs, insurance companies, etc.).

As cities become smarter, they are also creating a suitable ecosystem for the provisioning of the aforementioned resources - through IoT adoption -, enabling processing and storage capabilities directly from city's infrastructure (e.g. traffic lights, street lights, buildings, etc.). With these resources available to set intermediate clouds, cities can offer applications and services such as Emergency Vehicle Notifications, Real-Time Vehicle Tracking and Geospatial Data Analysis (GIS and Weather Environmental) to name a few.

Many companies can benefit from this particular level of the Hierarchical Cloud Architecture, offering their services to a broad range of users and also meeting individual user needs. Any company appropriately equipped to provide storage and computation resources and to host applications and services for users, is now able to offer their services within this level.

C. *Conventional Cloud*

A cloud at a higher level, or what we call a "Conventional Cloud", can provide an efficient and cost effective integration of computational resources and distributed storage for stakeholders (e.g., drivers, passengers, pedestrians, public and private organizations). Applications can be managed (updated and distributed), from a central location, within a highly resilient and redundant infrastructure. In addition, applications in the cloud can be updated more smoothly and more frequently without having the need to redistribute to each client, or causing disruption to individual customers. For this high cloud level strong Service Level Agreements (SLAs) from the cloud service providers are a must in order to ensure the expected performance.

The conventional cloud level will extend and enlarge the aforementioned levels, providing improved mobility to daily commuters by identifying optimal routes and transportation means, multi-modal route pre-planning based on historical data, as well as a wider range of streaming services for infotainment. Benefits provided by the conventional cloud will affect the complete ecosystem (cities, users, companies) and will certainly bring solutions to several key foreseen issues: Urban Planning, Transport Planning, Social Inclusion, Energy Consumption, etc.

It is strictly necessary for the aforementioned hierarchy to provide a layered architectural design to meet and efficiently handle every particular task requested by users. For example:

- A platform layer for handling computational resources, data storage and communications.
- A data acquisition and analysis layer to handle the accessibility to raw sensor data.
- A service and application layer for handling applications, services and internal processes.
- A management and integration layer to increase efficiency and provide scalability of infrastructure, applications and services.
- A privacy and security layer to handle data integrity and provide security measures.

All these layers must be replicated in every level of the hierarchical cloud architecture.

An illustrative case of this architecture is given in Figure 2. Let's suppose a set of public buses connected to a high-speed mobile-broadband network and therefore able to be equipped with cloud capabilities. These buses can provide a wide variety of resources to the passengers (i.e., applications, services, processing and storage), which will be able to perform any daily task (e.g., document editing or application development) transparently regardless of their location.

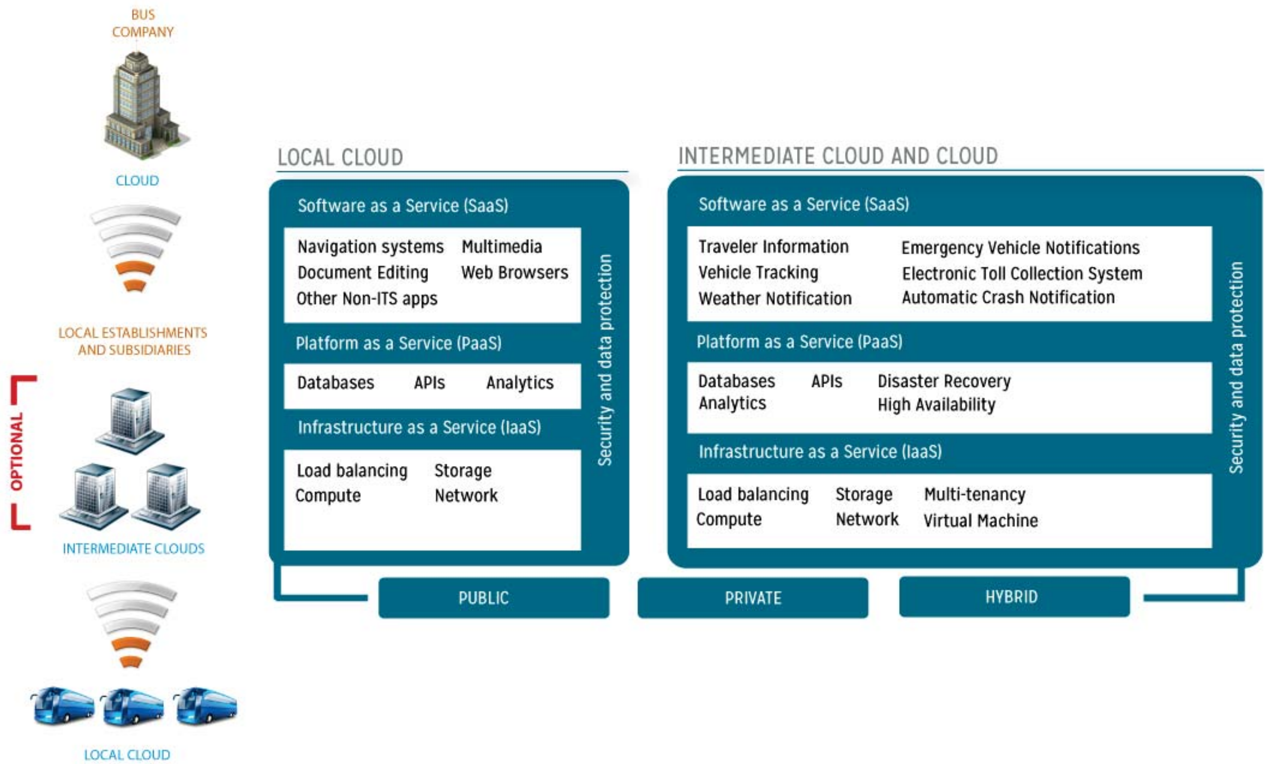

Fig. 2. Staggered Approach of Cloud Services.

Furthermore, these road transport vehicles can share collected information, such as their locations or the amount of passengers, hence offering relevant data to public and private organizations for emergency and public transport management. Bus passengers can access a variety of services (Multimedia, Travelers Information, Storage, etc.) offered by the bus. In case the passengers need more resources - computing and storage – or any other services that are not offered from the bus, they will be able to access other cloud services that may be offered from the nearest establishment of the company or any subsidiary, which is able to provide more efficient capabilities. Once again, the user –any passenger with access to the cloud - has the possibility to go further and access more reliable and efficient cloud capabilities from the central headquarters of the bus company. This access to different cloud services can be handled through either an integrated subscription model or a transaction-based model.

The accessibility to an intermediate cloud can offer personalized and customized services to specific users (e.g., users can access information and services oriented to their respective locations) and also can reduce communication delays. In this constantly connected environment, certified developers can satisfy users' requirements with personalized solutions, developing regulated applications and services (e.g., entertainment, navigation, fleet management and traffic information).

Indeed, the deployment of cloud computing capabilities will be beneficial for ITS with cloud computing architectures that efficiently support the mobility of end-users. However, current designs of service delivery models for cloud-based architectures are not taking into account the concept of user mobility under tight real-time constraints [12]. Furthermore, standards for cloud interoperability setting the rules for data exchanging across different cloud providers are not well defined. For an efficient ITS-Cloud synergy it is extremely important to ensure interoperability between different cloud deployment models and services providers.

On the other hand, as it is stated in [13], when a consumer leverages applications and information that relies on services from different clouds, the security requirements has to be enforced for both ends. Cloud security is a shared responsibility between service providers and users. While service providers must guarantee highly reliable and secure services delivery through the cloud infrastructure, the users must also run good practices in the specific areas (access, authentication procedures, data content.) they have control over.

IV. CLOUD ACCESSIBILITY AND RESPONSE TIME

Clearly, significant challenges exist in providing and managing the offered on-demand cloud resources with the required level of Quality of Service (QoS), especially for real-time and streaming applications [14].

In order to provide a smooth computing in a cloud environment, five factors must be considered [15]: On-demand Self-Service, Network Accessibility, Multitenancy, Elasticity and Measure of Service. The main contribution of this section is the provision of a model to estimate the Average Level Response Time (ALRT) for accessing services from our Hierarchical Cloud approach at a given time. This model may hence participate as part of one of the important factors previously mentioned, which is the Measure of Service. The model explained in this section has been adopted from memory cache systems (where it has been already proved for calculating average memory access time).

Next paragraphs are positioned to represent a model of the proposed Hierarchical Cloud Approach. Assuming that the intermediate cloud is present, let's consider CC, IC, LC as our Conventional Cloud, Intermediate Cloud and Local Cloud levels respectively. Then, we define accessing to LC with a response time of T_{r1}, IC with a response time of T_{r2} (considering LC to IC interchange after access failure to the requested service for LC), and the additional time T_{rf} (considering an access failure in LC and IC) then:

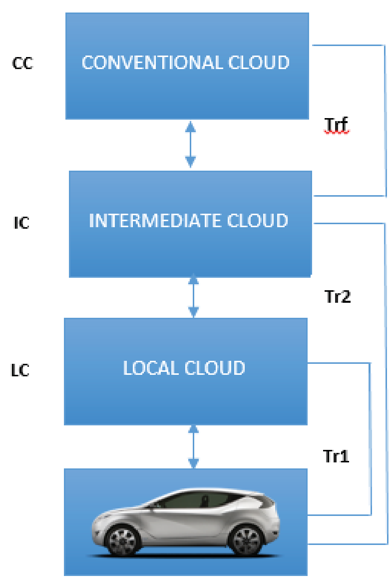

Fig. 3. Simplified model for ALRT.

1: Service access time in LC indicates the lowest response time and any additional request for IC and CC will be cancel.

2: Service access time in IC indicates a longer response time and the request to CC will be cancel.

3: Service access time in CC will provide the highest response time.

Therefore, we can proceed to denote ALRT as follows:

$$ALRT = (1-P_1)\ T_{r1} + P_1(1-P_2)T_{r2} + P_1P_2(T_{r2}+T_{rf}),$$

Where $(1-P_1)$ indicates the hit rate for LC, $P_1(1-P_2)$ indicates the miss rate for LC and the hit rate for IC and P_1P_2 indicates miss rate for both LC and IC.

Simplifying, then we find that,

$$ALRT = (1-P_1)\ T_{r1} + P_1\ (T_{r2} + P_2T_{rf})$$

An example has been provided below in order to illustrate the model:

Step 1. Assume a hit rate of 75 percent at the first level of the hierarchy (LC) and a hit rate 85 percent for the next level (IC).

Step 2. Assume that a service request takes 12 ns to complete if there is a hit in the level (LC) and an additional 8 ns for the next level (IC).

Step 3. Assume that service request time for a miss in the levels (LC, IC) is 100 ns.

Using the aforementioned formula the ALRT for a given service access request is,

ALRT=0.75 * 12 ns + 0.25(20 ns + 0.15 * 100 ns)= 44.5 ns

Following the aforementioned example, a result of 44.5 ns of Average Level Response Time will provide a better performance when accessing any application or service available compared to the 100 ns will take an architecture conformed only by a conventional cloud.

Clearly, a hierarchical architecture will provide elasticity, scaling resources throughout the different levels as needed, but also will enhance QoS through – by far - a better response time.

V. Business Models and New Actors

Our innovative approach for cloud service delivery within ITS open the doors to a wide range of new business models with new policies, business processes, target customers, offerings and strategies to be implemented, as well as new actors that can benefit from them. For instance, a company that offers transportation services to a wide range of users (e.g., a railway company or bus company) may be able to provide cloud services through a subscription model that could integrate the transportation and the cloud services, both accessible through different payment methods.

However, any company interested in providing cloud services along with their transportation services will have to work on providing customizable solutions, along with pay as you go pricing and on-demand availability, due to the heterogeneous needs of their users [16]. An efficient way to provide customizable solutions is storing information about user preferences, which subsequently can enable service customization. Cloud indeed provides businesses granting users with customized services dynamically adapted to foreseen but also unforeseen context changes, enabling a pure user-centric experience [17].

Additionally, the use of this approach will facilitate the inclusion of more adequate advertisement, which could be focused on user location and user destination. Furthermore, with the aforementioned approach, companies can charge for accessing all services or accessing specific services. In many cases, the profitability of integrating the cloud services can become greater than those produced by the transport services, due to the fact that users spend more time accessing applications and services than moving from one place to another. For instance, pedestrians may have access to cloud services provided by a taxi company from any place. These services can be customized to let users pick any available taxi and receive information about different places (e.g., restaurants, clubs and museums). Users may be able to access more applications and services from within the taxi, while waiting to get to their destination. Users pay for the taxi transportation service and may pay for the cloud services provided from outside of the vehicle, or they can be provided for free as value-added services to attract customer segments in an attempt to generate significant new revenues from the services provided within the vehicle.

In this context, the new actors that may benefit from a cloud service delivery are not restricted to transportation companies. OEMs can provide their respective cloud services for their corresponding brands (e.g. enhancing customer service). ITS facilities and Governmental organizations can also provide cloud services of relevant interest for drivers, passengers, pedestrians, and other public and private organizations.

Who will benefit from the implementation of the aforementioned approach? In fact, we strongly believe that this market is completely open to any company or organization that is able to provide highly customizable and efficient services for end-users.

VI. CONCLUSIONS

In this paper we propose the preliminaries of a Conceptual Approach for a Hierarchical Cloud Architecture for Intelligent Transport Systems. We believe that cloud computing can offer a suitable computing infrastructure able to provide data storage and processing capabilities for ITS users within an environment that move at the pace of a new tendency of constant connectivity. Cloud computing is able to provide several benefits such as scalability, reliability, elasticity and shared resources. However, cities must improve their existing infrastructure and invest in developing innovative methods to expand the possibilities to access relevant content and a wide variety of existing and new applications and services through this emerging technology.

In the proposed conceptual approach we emphasize that a hierarchical architecture may ease the access to content for ITS users, providing a valuable source of information and favorably impacting on QoS through better response time. We argue that for a successful cloud computing deployment we must consider many aspects to be integrated within the ITS environment, including coordinated adoption by stakeholders, new technologies and data privacy and security mechanism, to name a few.

It is also understandable that a deployment of this scope can bring several concerns about cloud providers adapting their services to user's mobility, users being able to configure their cloud services and the flexibility of the cloud services and deployment models to provide interoperability. However, we strongly consider that a staggered approach that provides cloud computing capabilities to ITS users and empower them with the opportunity to select different levels of services, computing and storage capabilities can offer significant benefits and may also foster the creation of interesting business models and new actors to benefit from them.

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