Transport specific design of cloud networks: a combination of hybrid-, edge- and mobile cloud computing

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Abstract: Data about the urban transportation system is specific, has high variety, and includes security-critical attributes, as well as personal data. Transportation-related operational and development decisions are complex and require high amount of data from various sources. Data is collected and generated by multiple standalone organizations, between which data sharing is not sufficient. The potential of cloud-based data storage and computing have been recognized; however, the high complexity and variety of transport data requires new design methods. We elaborate a transport specific cloud architecture, which is a combination of hybrid-, mobile- and edge cloud computing. The hybrid cloud architecture enables a cross-organizational IT integration, improving communication, data-sharing, and cooperation between transport organizations. The edge- and cloud computing architecture induces the IT integration of edge devices. We identified two major groups of edge devices, and two application fields respectively. First, vehicular networks are considered, where edge devices are vehicles and infrastructural elements, e.g., sensors. Second, mobile devices are examined, where mobile networks enable internet-of-things concepts. The spread of 5G networks is also facilitated by the application of the elaborated model, as integrated edge devices and edge-cloud communication require a scalable, fast, reliable and high bandwidth communication system.

Keywords: networked information system, cloud computing, edge computing, information technology infrastructure

Introduction

Various concepts of cloud computing have received high attention in recent years, as *scalable, flexible, secured,* and *agile* solutions [1,2]. Design decisions (e.g., architecture selection, data storage solutions, level of integration etc.) are related to the concept of *information technology infrastructure* (ITI) [3,4]. ITI is defined [5-7], as a set of *shared, tangible IT resources, to enable present and future business applications,* such as

(1) platform technology, i.e., hardware and software systems,
(2) network and communication technology,
(3) key data, data storage and handling systems, and
(4) core data-processing applications.

ITI has two primary infrastructural types, as traditional infrastructure, and cloud infrastructure. Cloud ITIs are often utilizing data warehouses, which have first been identified for organizational integration [8]. They include a collection of subject-oriented and -integrated data storages, an application oriented operational environment, and standardized enterprise-level analysis system.

Cloud computing solutions are various. Next to ‘conventional’ cloud computing several other concepts have emerged. In this paper, we review, compare and combine hybrid cloud computing, edge computing and mobile cloud computing. The root of cloud computing models are *networked information systems.* Therefore, we proceed from a functional approach of networked information systems, as industry solutions of ITIs, conventional and mobile cloud models, and their applications.

Research gap and novelty

Hybrid-, edge-, and mobile models of cloud computing have received high attention one-by-one. We elaborated a *combined architecture*, uniting hybrid, cloud, and edge solutions, especially for the field of transportation. The proposed combined architecture has five layers, and improve the IT integration of transportation systems in two major directions, as

- cross-organizational IT integration, through a hybrid cloud architecture, enabling data-sharing and cooperation between different information systems of organizations, and
- edge device integration, through a mix of mobile cloud- and mobile edge computing networks, in which not only end-user devices, but vehicles are connected as well.

1. Networked information system models

Networked information system models have gone through significant development in recent years. Cloud computing is highly related to ITI, as well as (mobile) edge- and mobile cloud computing. In this section, we review the models of networked information systems.

The functional approach of ITI includes 8 main functions [9], as

(1) *applications management*; including database management systems (DBMS), electronic provision of management information,
(2) *communication management*, which incorporates firm-wide communication networks, and local/workstation networks (e.g., LAN),
(3) *data management*, with all related storage systems, and services,
(4) *IT education management*, meaning technology support and education services (e.g., training),
(5) *research and development*, to identify, develop and test new technologies and validate solutions based on them,
(6) *security*, including both physical- and cyber security, and
(7) *standard management*, meaning the identified standards for IT architecture, and data systems.

Several *industry solutions* are available; all of them are scalable, agile, and contain various services. We reviewed and compared three industry ITI frameworks: T-Systems' ITI framework [10], Microsoft's Azure Platform [11], and the Amazon's AWS Global Infrastructure [12]. A variety of computing concepts have emerged, as *service-based cloud computing*. Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), Infrastructure-as-a-Service (IaaS), Data-as-a-Service (DaaS), Communication-as-a-Service (CaaS), and Hardware-as-a-Service (HaaS). Those give the backbone of any up-to-date cloud platform and can be identified in a 5-layer architecture, as on Figure 1.

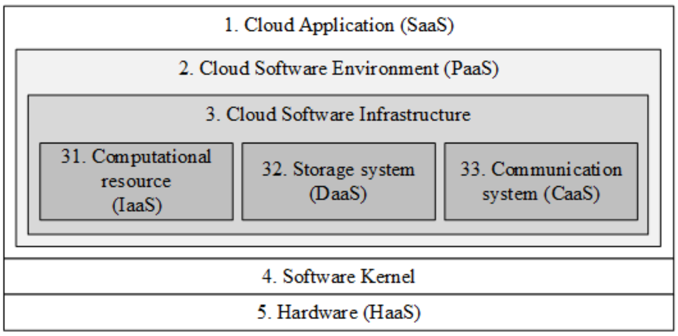

Figure 1. The five-layer cloud computing ontology, based on [13].

SaaS is used by business users for completing business tasks. PaaS unites development and deployment, and handles application and service testing, as well as integration. System managers are using IaaS for creation of platforms for service application testing, including instruments like virtual machines, operating systems, and backup services [14]. Industry solutions include general service management instruments, such as process management, performance monitoring and analysis, and intelligent network supervision. Tasks can either be executed locally, in which case, local workstations are part of the ITI, as well as by using virtual computer environments. Regarding virtual environments, the ITI may include operating systems, applications, API dashboards, and control systems as services for end-users.

Data centers are crucial part of the infrastructure, as they provide both computing and storage resources [15]. Data center design usually includes not only the data storage systems, but the required energy management system, security, and communication networks. Computing and storage clouds are classified into public-, private- and hybrid cloud models [16-18]. *Public clouds* are services offered on public domains. Their main advantages are lower deployment costs and time. *Private clouds* are deployed within an organization, offering data and computing capacity for internal users. *Hybrid clouds* are utilizing both public- and private cloud models. They maintain a higher level of security, while having reduced costs. The downside of public clouds is the complex integration of different internal and community architectures.

Data centers are *secured* by various instruments. Different layers have different security requirements, and thus, different security solutions are applied [19]. Distributed Denial of Service (DDoS) attacks are most typical against any TCP/IP computer network [20]. In a cloud environment, virtual machines are exposed to DDoS attacks; thus, all industry solutions contain multiple, often redundant security mechanisms. Blockchain protection and centralized authentication protocols are most common in this regard. Patching is also an effective instrument of system protection; by releasing/deploying new builds, the risk of issues is reduced [21].

Cloud networks are either standalone or are embedded into an enterprises' information system. For different environments, different *architectures* and *communication relations/solutions* are proposed. Embedded cloud systems can communicate with local networks; thus, those are usually hybrid cloud systems. Communication resources are *limited.* When optimizing the communication network [22], we consider *latency*, *reliability*, *velocity*, and *bandwidth.* Next to rather conventional networks (e.g., LAN, (SD-) WAN, W-LAN, Wi-Fi etc.) concepts of mobile cloud- and edge computing (MCC, MEC) have emerged [23,24]. The most relevant, fog computing is *a distributed computing paradigm that acts as a layer in between cloud datacenters and devices/sensors in IoT networks*.

MEC brings computational facilities closer to data sources and executes data processing with edge networks [25]. This enables decentralized cloud- and low latency computing with suitable energy consumption and high network traffic capability. Management of high network traffic capability, and low energy consumption are attempted by *performing analytics on edge devices,* though collective analytics for the system cannot be effectively done on a device [26,27]. Edge devices can also be used for *malware detection,* and thus be an innovative instrument of data security and network protection. Overall, edge computing models support IoT by the integration of edge devices, as well as the distribution of computing amongst edge devices.

Due to the wide prevalence of mobile devices, MCC has received high attention as end users usually prefer to run necessary applications on their personal devices. Heterogeneity of mobile devices, as heterogeneity of software, hardware, and technology is a limiting factor of MCC [28]. Moreover, numerous cloud services are available. Such variations cause major challenges in the application of MCC [29]. MCC, MEC, and fog computing together are the base of 5G applications in cloud computing.

2. Applicability of cloud computing models in transportation

The transportation system has high heterogeneity in many senses. There are various *stakeholders,* such as passengers, service providers, infrastructure- and traffic management centers, and governance both on local/regional and national levels. The stakeholders perform multiple functions, from passenger decision support, through payment, booking, till design, and maintenance etc. In the case of several stakeholders, smart device applications are used, resulting an interconnected and complex system. For the sake of simplicity, we consider *mobility- and non-mobility service providers, infrastructure & traffic managers, and governance* as the four main stakeholders. Passengers appear as users of both services and infrastructure, as well as certain edge devices (e.g., smartphone, vehicles).

2.1 Hybrid cloud models

Hybrid cloud models unite private and public cloud storages. They recognized as a great tool to integrate enterprise software and hardware systems with cloud systems. In the first step, we elaborate the hybrid cloud model on Figure 2.

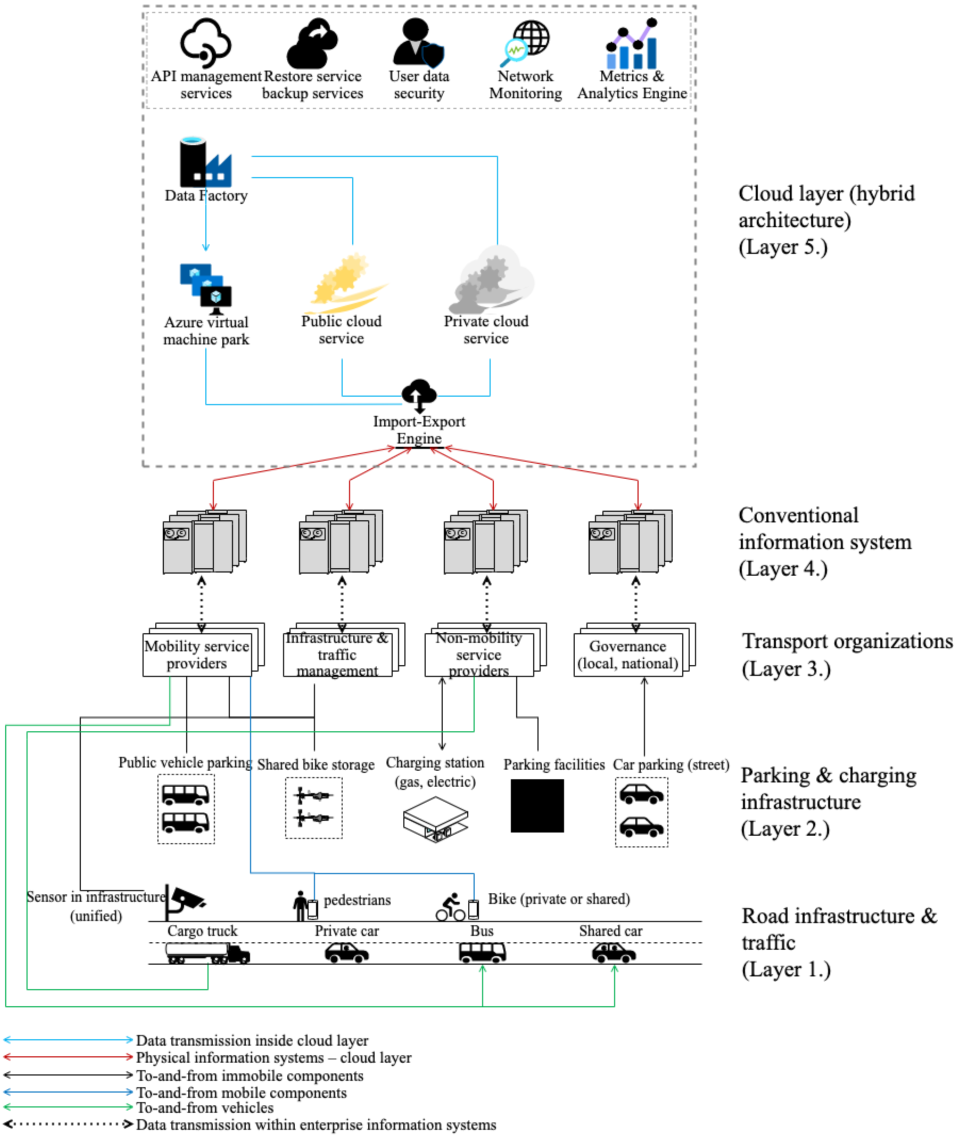

Figure 2. Enterprise-level application of the hybrid cloud model

We introduced four layers:

(1) physical layer, in which vehicles, infrastructure, passengers, and parking/charging facilities are illustrated,
(2) transport organizational layer, where four main organization types are distinguished, as mobility- and non-mobility service providers, infrastructure and traffic management companies, and governance,
(3) layer of conventional information systems, and
(4) the cloud layer, in which the hybrid cloud architecture is proposed.

The hybrid cloud architecture consists of private- and public clouds, a data factory, and several services. Data factories are identified in Microsofts' Azure framework [30]; however, there are units with similar function in all industry solutions. The *data factory*, as a logical element, is feasible for processing data for analysis and reporting, as well as it provides data in a structured manner [31]. Data is transferred to and from private and public clouds into the data factory. Cloud services provide safe and fast-access data handling. Data is sorted by the import-export engine into-and-from private and public clouds. Data stored in private clouds are only accessible for authorized users. Authentication is performed in the import-export engine as well.

A cloud framework (in this case, MS Azure) is required to manage cloud computing services, APIs, as well as to carry out network analytics. Users access cloud services (data and computing) through the platform of the cloud service provider. We suggest user applications (e.g metadata search engines, data exchange platforms for organizations) to be developed as web applications optimized for the cloud service providers' system (e.g., utilizing virtual SQL machines in Azure).

2.2 Inserting mobile- and edge computing into the architecture

In order to facilitate the integration of end-users (pedestrians, passengers), and end-devices, we extend the presented architecture 'under' the physical layer (Layer 1.), as on Figure 3.

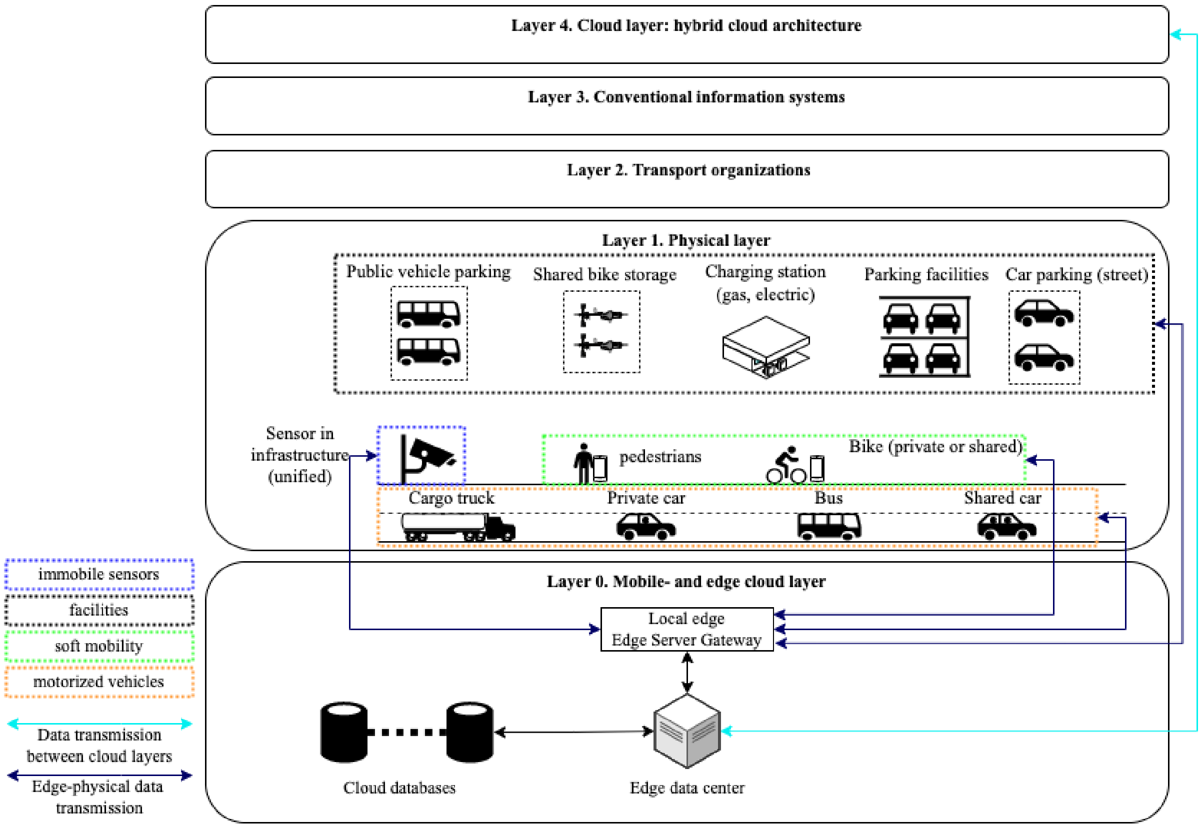

Figure 3. Combined cloud computing architecture

The developed architecture is *combined*, as it unites the hybrid cloud architecture with MCC and MEC. We have categorized edge devices into four groups, as

(1) immobile sensors, which are sensors installed along or in the transportation infrastructure,
(2) parking and charging facilities, which typically have their own sensors and/or computers,
(3) soft mobility users, in which case vehicles usually do not have onboard computers, but passengers may use their own smart devices, and
(4) motorized vehicles, in which vehicles are installed with complex onboard information systems, as well as drivers/passengers are equipped by smart device.

Data is collected *and processed* by edge devices. The processed data is then transmitted to the edge data center, through the server gateway, which labels data. The edge data center consists of several cloud databases and is connected to the hybrid cloud layer.

MEC and MCC applications are to be integrated with the central database management of the hybrid architecture as a result of connection of the edge data center and the hybrid cloud layer. This integration induces a wide variety of applications, such as mobile localization, passenger tracking, collection of user data etc.

2.3 Unified architecture

In order to exploit advantages of the hybrid cloud architecture, as well as mobile- and edge cloud computing, a complex approach is required. Cloud architectures are either focused on cloud computing or edge computing. In order to achieve high functionality of cloud-, mobile cloud- and mobile edge computing combined, we introduce a novel design method, as on Figure 4.

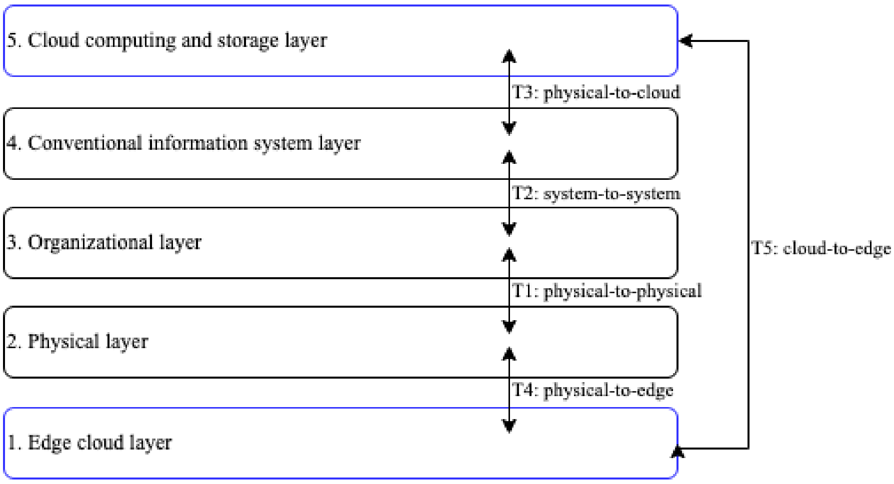

Figure 4. Combined cloud architecture

Figure 4. represents a general, unit-oriented approach based on the previously introduced models. We propose five layers, and five types of transmission.

- T1 First the data is transmitted from the physical layer to the organizational layer, as organizations collect data (e.g., data collection with roadside sensors, data transmission from the sensors to the organization),
- T2 this data is then used, processed in the organization, using organizational information systems,
- T3 the data is then uploaded to a cloud platform, which in this context, is the hybrid cloud architecture,
- T4 the fourth connection is between the physical- and the edge cloud layers. Edge devices are processing and transmitting data, as well as running applications (e.g., smartphone route planning application, based on traffic data from the cloud),
- T5 the edge cloud layer receives this data and connects to the hybrid cloud layer (e.g., by monitoring passenger movement, speed, modal choice etc.).

3. Discussion

High variety of functions can be introduced by complex usage of cloud computing, MEC, and MCC. High volume, dynamic data collection and processing is a key challenge in novel information systems. When connecting organizational information systems, and various edge devices (onboard computers, sensors, mobile devices etc.), significant computing capacity is required, which is achieved with utilizing not only organizational information systems, and computers, but also cloud computing resources, as well as edge-devices, such as cars or smartphones. Mobile devices are

(1) *smart devices* of passengers, drivers and pedestrians, as smartphones,
(2) *private vehicles* with onboard information systems, and
(3) *public vehicles*, connected to a fleet, managed by fleet management information systems.

The impact of the combined cloud architecture can be explained in three directions.

(1) First, establishment of *vehicular networks* is considered. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is available in the edge network. Data generated by vehicles and infrastructure is exchanged through and stored in the edge cloud layer. Vehicular networks require a stable, fast, and high availability network with high bandwidth rate.
(2) Second, based on recent literature, this network should be a *local 5G network*. The establishment of 5G networks can be supported by MCC and MEC applications in transportation.

(3) Finally, as there are several edge devices in the combined architecture, we identify *Internet of Things* (IoT) as a relevant concept as well.

Conclusion

Several concepts emerged regarding cloud computing in the past years. Conventional models, such as the hybrid cloud model are appropriate for cross-organizational integration, while mobile and edge-cloud computing models are supporting the integration on the edge of information systems.

In this paper, we elaborated the concept of a *transport specific combined architecture*. The concept includes a hybrid cloud architecture, as well as an object-oriented mix of mobile edge- and cloud computing. The elaborated concept is applicable as a use-case of vehicular network-, 5G- and IoT-related development.

The development of vehicular networks and IoT applications is supported on the edge cloud layer. Vehicles are connected to each other and to the infrastructure in the edge layer. Sharing of computing capacity as well as V2V and V2I communication is possible via these connections. Furthermore, mobile devices are connected to each other, sharing computing capacity and data, forming an IoT network.

Currently, the majority of transport organizations are using conventional (local) information systems. Data sharing between companies is insufficient, therefore, development towards intelligent- and smart transportation is problematic. Those development processes require high magnitude of data, furthermore, their real-time applications (e.g., multimodal route planning) are based on dynamic data from multiple stakeholders. The collection, storage, processing, and utilization of such databases must be done in a controlled, and unified manner. The application of cloud technologies is feasible, as there is great development regarding IoT and 5G networks. The proposed, combined architecture utilizes not only web-based applications in the hybrid cloud model, but also induces IoT networks and possibly 5G with the edge cloud layer.

Further research is required in the context of operational methods, especially data distribution between network elements. One of the major benefits of the application of our framework is the increased data sharing between stakeholders. Therefore, the coordination mechanisms of data exchange are a key challenge. Data distribution mechanisms, transmission technologies, and authentication protocols are in the scope of our future research. System- and data security is another major issue; in which case, our main research question is if and how current security tools and technologies can be applied in this complex system.

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