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Context-Aware Cloud-Based Systems: Design Aspects

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Abstract The advantages of cloud computing including easy access, cost-effectiveness, and the ability of overcoming the limitations of resources draw attentions to this technology in designing and developing mobile applications. Relying on cloud computing, the new generation of systems with the capability of context-awareness succeeds in offering remarkable services to users as well as improving the service quality. This paper is dedicated to investigating the cloud-based context-aware systems. To this end, a framework is proposed to investigate and classify the cloud-based context-aware systems. The proposed framework consists of three aspects including principles, system design, and context-awareness, each of which consists of several classification parameters. Current research projects are investigated and classified based on different criteria of the proposed framework. Finally, the results, conclusion remarks and open research directions in this field are discussed.

Keywords Cloud Computing · Mobile Computing · Context-Awareness

1 Introduction

The significance and development of cloud computing in recent years have drawn considerable attention to this technology. Besides, increasing growth of smart devices and their high speed network access have paved the way for utilizing advantages of cloud computing. The commercial model of cloud computing strives to present software programs, programming platforms, data storage and computing infrastructure as services to users [1].

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In the domain of system design, the main objective is to achieve the satisfactory functioning in dynamic environments with the minimum user intervention[2], that is, the application should adapt its behavior to the environment. In other words, the application is required to be context- aware[3]. Context-aware systems try to understand the situation by collecting contextual information and adapt their behavior, accordingly[4]. Many of these systems run on smart phones with limited resources. Thus, mobile cloud computing is utilized and diverse systems are developed based on this technology.

Given the importance of cloud computing and context-awareness, numerous papers have been published in each of these fields [4-7]. However, to our best knowledge, a comprehensive study in the field of cloud-based context-aware systems is yet to be conducted. This paper aims to investigate cloud-based context-aware systems and proposes a framework, which consists of three dimensions including principles, system design, and context-awareness. Each of these dimensions comprises some major classification parameters. System design and context-awareness are important aspects of these systems. In the dimension of principles, the application developers purpose for using cloud is investigated. Intensive processing, storing a huge amount of data, and permanent access are among these typical goals. The other principle parameter is the type of cloud the developers make use of.

In the second dimension, the projects are investigated from the system design perspective. System design plays a major role in developing cloud-based systems that heavily influences their non-functional properties. In the first step, the type of cloud service that the system uses is investigated. One of the salient challenges faced in new computing models is users privacy. The strategies applied for protecting it are investigated, subsequently. Finally, systems are investigated from the view of offloading, implementation tool, and the supporting operating system.

Context-awareness as the third dimension plays an important role for mobile applications and includes two parameters of context information type, and the context acquisition method. Depending on the system, the type of utilized contextual information can be different. Some elements of context can be collected by sensors of smart phones, while other parts may be gathered by the sensors embedded in the environment.

The paper is organized as follows. Background concepts such as cloud computing, ubiquitous computing, and context-awareness are described in section 2. In Section 3 we describe the proposed framework for classifying cloud-based context-aware systems. Furthermore, the projects are investigated from the principle dimension in this section. Sections 4 and 5 are dedicated to investigation of projects from the system design and context-awareness dimensions, respectively. The final section discusses the conclusion remarks as well as open directions for research.

2 Background

This section brings up the most notable concepts regarding literature review. Cloud computing, mobile cloud computing and related topics (such as offloading and cloudlet), ubiquitous computing, and context-awareness are the concepts with highest relevance with the subject. Cloud computing is regarded as the newest paradigm of distributed computing. It aims to provide everything as a service to users. Mobile computing is the computing model in which computational nodes are mobile. Finally, ubiquitous computing is the newest paradigm in which the computational resources are generalized to many new devices. It aims to provide services in everywhere and in anytime to users. In continue, any of these computing models are elaborated in details.

2.1 Cloud Computing

In the past decade, cloud computing has become increasingly important[8] and now is considered as a novel computing model for service delivery via Internet[9]. According to NIST [10] "Cloud computing is a paradigm for enabling ubiquitous, and on-demand network access to a shared pool of computing resources that can be quickly provisioned and released with minimal management effort."

Users are able to benefit from cloud services including infrastructure (such as server, networks, and storage), platform (such as programming frameworks, middleware services and operating systems), and software (such as applications), only by paying a negligible cost[11]. Amazon EC2[12] and Flexiscale[13] are two famous infrastructure service providers. Software service providers are exemplified by Google Docs[14] and Rack Space[15]. Furthermore, on-demand storage on the cloud has become a separate kind of service[16]. Some of notable examples of this service type are Amazon S3[17], Google BigTable[18], and Apache HBase[19].

2.1.1 Mobile Cloud Computing

Mobile cloud computing, a combination of cloud computing and mobile computing, has become a significant research topic in IT in the recent years. Mobile tools face numerous challenges regarding their resources such as battery, storage, and bandwidth as well as problems with their communication, like mobility and security[20]. Mobile cloud computing is capable to solve the above-mentioned issues by running mobile applications on the externally-provided resources[21, 22] and to remove the performance-related obstacles (such as battery lifetime, storage, and bandwidth), environment-related obstacles (including heterogeneity, scalability, and availability), and security-related ones (like reliability and privacy)[11]. Following the ubiquity of mobile cloud computing, new concepts emerged such as offloading and cloudlet, both of which aiming to enhance the operation capacity of this technology.

2.1.2 Offloading

Offloading is one of the principal features of mobile cloud computing. It prolongs the devices battery lifetime and improves the performance of system[23]. Offloading technique has been proposed with the purpose of transferring heavy computations and complicated processing operations from devices with limited resources to the cloud server. As a result, mobile phones can dynamically increase their computing and storage resources using computational and nearby storage servers [24]. The efficiency of offloading technique is tested several times and its significant effect on energy storage improvement is proved. For instance, employing offloading technique during image processing reduces the energy consumption to 41%, contributing to battery lifetime extension[25].

2.1.3 Cloudlet

The offloading of components to the cloud, results in an increase in communication time; therefore, real time applications cannot make use of it easily. The proposed solution for this challenge is users adjacency to a cloudlet[26, 27]. Satya describes cloudlet as [27]: a cloudlet is a trusted, resource-rich computer or cluster of computers that is well-connected to the Internet and available for use by nearby mobile devices

By applying cloudlet, users can benefit from cloud advantages without any concern about WAN delay. Mobile phones have the capability to compensate their lack of resource by using a resource-laden cloudlet. They fulfill their need for an immediate interactive response with short and single-point delay by connecting to a cloudlet from a wireless communication with high bandwidth[27].

2.2 Ubiquitous Computing

Mark Weiser has referred to ubiquitous computing as the computing perspective of 21st century, believing that the deepest technologies are the invisible ones; they are so intertwined in our daily lives that are not recognizable[28]. The environment of ubiquitous computing is filled with computational and communication capabilities. They have become so integrated with users life that they seem like an invisible technology[29]. The purpose of this third wave of computing technology[30] is to create a world in which objects are able to compute and process as well as communicate with the global network. Also, each individual can automatically receive personalized services from invisible technology in his/her surrounding environment.

Increasing utilization of mobile devices, the provision of wireless communication, and the introduction and deployment of various sensors have prepared the infrastructure for ubiquitous computing. In the applications of ubiquitous computing, instead of traditionally receiving the inputs from users, context information is sensed implicitly from surrounding environment and a proper operation is carried out, accordingly. This type of applications are known as context-aware applications [31].

2.2.1 Context-Awareness

The information used to describe an entity is called context. An entity may be a person, place, or an object related to the interaction between user and application. The user and application can also be considered as entities [32-34]. A context-aware system is a system that employs context information for providing information or services relevant to the users task[33, 34]. In fact, context-aware applications are capable of adapting their action to the users context, which is provided by sensing the environment[4].

So far, several classifications have been suggested for context information. Schilit et al. classify the context based on where you are, who you are with, and what objects are nearby, which only includes the information regarding location and identity[35]. Ryan et al. categorize the types of context information into location, environment, identity, and time[36]. The classification provided by Abowd and Dey is more prevalent. In their opinion, location, time, identity and activity are the most salient types of context, called primary context. They define the context derived from different types of primary context as the secondary context[33].

3 The investigation Framework

We propose a reference model with three aspects for studying mobile cloud computing area. Currently, context-awareness is the inseparable part of designing and developing mobile applications. As shown in figure 1, the investigation and classifying framework for cloud-based context-aware systems consists of three aspects of: principles, system design, and context-awareness. In continue, the framework is elaborated.

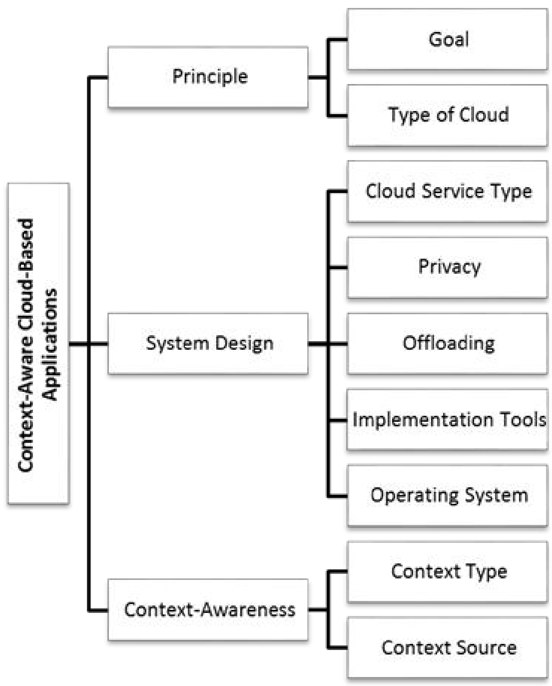

Fig. 1 The proposed framework for investigating context-aware cloud-based systems

3.1 Principles

In this dimension, the projects are generally investigated from two perspectives: the purpose of using cloud computing, and the type of cloud used. Prior to this, a general overview of related projects is presented (Table 1).

Due to increase of multi-media services on the Internet, users spend a great deal of time to find what they seek, sometimes leading to inappropriate results. Among the investigated projects, OVP[37], CCMR[38], and MRUB[39] offer services related to multi-media. These systems recommend some videos to the user based on their context. In OVP the online video player attempts to provide the users selected videos based on available codec on his/her mobile. In AML[40] the educational videos are presented to the students by making use of context information in a cloud-based environment.

Since we are facing a wide range of web services today, one of users concerns is to find the convenient web service. DaaS[41] provides a web service discovery framework that presents the appropriate service considering the users demand and other context parameters. On the other hand, designing and developing a large amount of mobile applications in various fields lead to users confusion in decision making. AppaaS[42] is a context-aware platform which provide users with the appropriate mobile applications in the form of on-demand cloud services. In cloud2Bubble[43], a framework is introduced for developing applications in cloud computing environment. Considering the collected context information and with the aim of promoting the quality of experiences, this framework supplies the users with relevant and personalized services.

Meanwhile, mobile devices also attract attention as personal digital assistant. In ICAC[44, 45] the required settings are applied to the mobile device, automatically considering the available context information in the profile and sensors data. These settings may include automatically turning the screen brighter or darker, or enlarging the icons. In CasCap[46], an energy management framework is proposed for the mobile device, which benefits from cloud computing capabilities in order to create a safe, inexpensive and efficient energy management framework.

Healthcare is also seen to be the core idea of several studied projects. MoCAsH[47] is an infrastructure for the healthcare assistant system. Collected context information by sensors is transferred to the cloud middleware for conducting more accurate analysis as well as storage and processing. In ECGAS[48], a supervision system is provided for patients with heart attack, which sends ECG data to the cloud to be analyzed, and offers its services according to the analysis. Similarly, TLD[49] aims at protecting health of the blind and visually impaired patients, while crossing the street. Processing the image of streets in cloud helps users to cross the intersections safely and conveniently. Permanent supervision on patients by collecting a huge amount of relevant data is the main purpose of IOT&CC2PH[50] and MPHD[51] systems. Also, this process can also be seen as a part of ECGAS system. In IOT&CC2PH, medical context information is gathered considering IOT pattern. Then, this information is sent to the cloud through Internet. Doctors and caregivers are able to use it according to their access right. Similarly, MPHD provides a cloud-based distributed platform with the ability of supporting a wide range of sensors as well as machine to machine (M2M) communication infrastructure to manage healthcare data. Finally, CAVS[52] presents a context-aware cyber-physical vehicle parking system, which suggests the available spaces to users for parking their car, and even reserves a parking lot for the user, if necessary.

3.1.1 Goal

One of the common things of all the investigated projects is employing cloud. However, they seek different goals by cloud utilization that can be generally categorized into three classes. These classes are introduced along with the related projects as follows:

- Infeasibility: Due to the limitations of processing, computing, and storing as well as the limitations of energy in mobile phones, many of systems are not able to run completely on users computing device. Smart phones are at least three times weaker in processing, 8 times in memory, 5 to 10 times in storage capabilities, and 10 times in network bandwidth compared to a PC or laptop in certain circumstances[8]. On the other hand, cloud environment provides an application with a desirable amount of on-demand resources. Therefore, the computational capability of mobile device is improved using the benefits of cloud computing, providing the ground for developing a vast range of these applications. Thus, utilizing cloud resources is a convenient way to make feasible the deployment of these systems on smart phones.
  The main challenge in TLD is the need for real-time image processing, while mobile devices are not capable of immediate recognition because of the processing resource limitation. In AppaaS, cloud consists of a rich server of Android applications that is impossible to be stored on user's device. Therefore, by

Table 1 Projects overview

Project	Organization	Publication		Situation
		Journal	Conference	
OVP[37]	Tsinghua University, China	✓		Designed
CCMR[38]	University of Porto, Portugal		✓	Implemented
MRUB[39]	Huazhong University of Science and Technology, China	✓		Implemented
AML[40]	Saints Cyril and Methodius University of Skopje, Macedonia		✓	Simulated
DaaS[41]	Queens University, Canada	✓		Semi-Implemented
AppaaS[42]	Queens University, Canada	✓		Semi-Implemented
Cloud2Bubble[43]	Imperial College London, United Kingdom		✓	Implemented
ICAC[44, 45]	Norwegian School of IT, Norway	✓		Semi-Implemented
CasCap[46]	Aalto & University, Finland		✓	Semi-Implemented
MoCAsH[47]	University of technology, Australia		✓	Semi-Implemented
ECGAS[48]	University of Melbourne, Australia	✓		Semi-Implemented
TLD[49]	Purdue University, USA		✓	Semi-Implemented
IOT& CC2PH[50]	University of the Aegean, Greece		✓	Semi- Implemented
MPHD[51]	University of the Aegean, Greece		✓	Semi- Implemented
CAVS[52]	China University of Technology, China	✓		Designed

storing this vast range of applications on the cloud, the users are able to use them without any concern. CCMR, MRUB, AML, and OVP require high rate of data communication and heavy processing on a large amount of multi-media files in order to have an efficient recommendation. For instance, CCMR cannot complete the recommendation process effectively without connecting to users contextual information profile, applying similar data of other users, and searching among metadata of the media files. Moreover, the recommendation process and inference from users preferences need a high data communication in the process of feature classification. Thus, the capabilities of cloud environment are necessary for using and processing this large amount of data.

In CAVS, a great deal of data including road situation, weather condition and traffic information requires to be processed in large scale, and users computational device is not practically able to do this, so it applies cloud environment to deal with this issue. In IOT&CC2PH and MPHD, applications sense a great amount of data that should be properly processed and analyzed, while mobile tool is not capable of storing such amount of data due to the limited memory space. A considerable part of patients physiological data is also collected by a set of sensors in MoCAsH and this system stores the context information of patients surrounding environment such as temperature, humidity, voice, noise, etc. as well as his/her medical record information. Obviously, Users mobile phone does not have the capability of storing, processing and analyzing such information in a long time interval.

- Improving reliability and security: Unique features of cloud computing provide several security advantages, including security centralization, data and process segmentation, redundancy, and high availability[53]. Moreover, data storage and running systems on the cloud are effective methods for improving the reliability. For example, cloud can be utilized for protecting the digital copyright law. In addition, services such as virus scanning, malicious code detection, and remote authentication are provided for mobile users[11]. A few projects employ cloud with this purpose.
  Increasing the reliability and security is a pivotal issue in healthcare systems, and keeping them in storage servers is an essential requirement. In IOT&CC2PH, the advantage of secure medical data storage in cloud is utilized. These healthcare systems create a large amount of medical data, which are required to be appropriately managed and stored. Cloud computing with elasticity and capability of ubiquitous access to shared resources is a proper solution for this challenge. All communications between cloud infrastructure and other components are secured by authentication processes and data cryptography using symmetric cryptography technique. To distinguish sensors uniquely, all of them are identified by a unique key.
- Anytime, Anywhere Service: Today mobile phones are equipped with the communication capability and users are able to access Internet services regardless of geographical and time limitation. One of the major features of cloud services is their ubiquitous availability. Among the reviewed systems, ICAC, ECGAS, and MPHD make use of cloud computing with this purpose. In ICAC, the users device interface is remotely adjusted regardless of its type and location. Besides, he can benefit from this program on all of his devices by registering only once. In ECGAS and MPHD, information is presented to the caregivers and they can retrieve their required information everywhere at any time.

3.1.2 Type of Cloud

Many developers prefer to diminish their operation costs with the aid of public cloud, but the reliability and security advantages of private cloud matter much more to others[9]. Cloud service providers offer different cloud environments proportional to users needs. The utilized cloud types are classified into three groups:

- Public cloud: A public cloud offers its resources and services publicly. They are easily accessible to everyone and their price is proportional to the usage rate. The main benefit for using this type of cloud is the lack of need for primary investment on the infrastructure and transferring the risk to the infrastructure service provider. But it has some security-related shortages, which reduce its efficiency[9].
  The majority of the investigated systems use public cloud for development. One of the most popular public clouds used is the Amazon EC2 cloud, which focuses on providing infrastructure services[54]. It is utilized in DaaS, AppaaS, TLD, ECGAS, Cloud2Bubble, and MPHD. Amazon AWS is a web service, which provides changeable computational capacity in the cloud environment and its simple interface facilitates its usage. Since all the control is performed by web service APIs, the system can reduce or augment its resources automatically, if needed. Amazon EC2 allows the user to create a configuration of CPU, storage, and Boot partition for his/her application. Cooperation of Amazon EC2 and Amazon VPL provides the user with an acceptable level of security[12].
- Private cloud: A private cloud is created for exclusive use by a specific organization and holds the highest rate of control on performance and security[9]. The incentive for establishing a private cloud in an organization can be analyzed from different perspectives. It can be a security standpoint toward critical data privacy, or even optimizing the usage of in house resources[55]. In some cases (e.g. OVP project), academic centers (Tsinghua University) attempt to create private clouds for research and educational goals.
- Hybrid cloud: A hybrid cloud is created through the combination of public and private clouds and attempts to eliminate the limitations of both types. It is more flexible and secure compared to public clouds. In hybrid clouds, part of the cloud environment is accessible only to certain users using a firewall, and its public part has a more public access

level[56]. Given the requirements of a system, the components with private accessibility are developed on private cloud and other components are deployed on the public cloud. Among the reviewed systems, MoCAsH uses a hybrid cloud. In order to present a better solution for problems of scalability, security, privacy and load balancing, it introduces a federated cloud to manage the distributed clouds. Following that, public and private clouds interconnect by p2p topology and create a federated cloud.

Table 2 summarizes the purpose of using cloud computing and cloud type and provider.

3.2 System Design

In the system design aspect, systems are investigated from five parameters including cloud service type, privacy, offloading, implementation tool, and operating system. Cloud may provide various service types including IaaS, PaaS, SaaS, and DaaS. Privacy is a salient and considerable point for users and is protectable by techniques such as anonymity. Offloading is an important process in cloud systems, which affects the efficiency of applications, significantly. The offloading can be performed statistically or dynamically, each of which has their specific characteristics. Several tools such as Google App Engine have been exploited for implementing the cloud-based systems. Finally, given their features, applications can run on specific operation systems such as Android. In section 4, the system design dimension and its related parameters are discussed and the studied projects are classified accordingly.

3.3 Context-Awareness

Context-awareness is the last dimension that is discussed. It consists of parameters of context type and acquisition method. Given their nature, systems utilize different types of contextual information like personal or social context. The resources for acquiring context are different. The context acquisition resources may include users mobile, cloud service, or static infrastructure. Section 5 explains this aspect thoroughly and the projects are investigated accordingly.

4 System Design

In this section, the projects are investigated considering the system design dimension, which includes cloud service type, privacy protection, offloading, implementation tool, and operating system.

4.1 Service Type

Generally, the studied projects provide three major types of cloud services that are described as follows. Platform as a service (PaaS) supports the software lifecycle, enabling the cloud users to develop their applications directly on the cloud platform. MoCAsH is the only project that offers platform service. This system provides a context-aware middleware in the cloud platform layer. Given the context information of the sensors, this layer manages and processes the surrounding environment. The collected information by sensors is sent to the cloud context-aware middleware to be stored and processed, and analyzed, more accurately. This middleware receives context information from mobile agents dynamically and has the capability of data analysis, context recognition, and dynamic update.

Data as a service (DaaS) is the cloud storage service that enables users to exploit it proportional to their need. Among the projects, IOT&CC2PH, ECGAS and MPHD use the cloud to store and retrieve information. In IOT&CC2PH and MPHD, cloud does not perform any processing on the gathered data, providing its users with this information by imposing proper access control. In ECGAS, cloud also performs processing on Electrocardiogram (ECG) data and all results are stored in patients account. The patient and medical staff are allowed to access the records ubiquitously and the doctors benefit from the recorded data to diagnose heart attacks.

Software as a Service (SaaS) enables users to publish their applications on a cloud hosting environment to which other users can access through network. The majority of studied projects provide the software layer service, mostly in the following domains:

- Healthcare: People health is a vital issue, and cloud capabilities facilitate healthcare processes[57]. Many of these applications provide services such as threat alarm, medical data storage for sharing and easier access, and permanent supervision on patients conditions. For instance, nowadays the Type-2 diabetes becomes a common illness and patients blood sugar level is very important in it[58]. T2DLM[59] is a cloud-based management system that helps Type-2 diabetes patients to manage their mellitus lifestyle and control their blood sugar level. In another project, Chang et al. propose a context-aware m-health system for diabetes patients and caregivers by utilizing Internet of Things (IoT) technology[60]. TLD helps blind and visually impaired people find their path in unfamiliar environments, and increases users experience and safety in buildings, campuses, and cities. After collecting data from ECG and extract-

Table 2 Projects review according to goal and cloud type and provider

Project	Goal	Type of Cloud			Cloud Provider
		public	private	hybrid	
OVP[37]	Infeasibility		✓		Tsinghua
CCMR[38]	Infeasibility	✓			Oracle (APEX)
MRUB[39]	Infeasibility		✓		-
AML[40]	Infeasibility	✓			Oracle (APEX)
DaaS[41]	Infeasibility	✓			Amazon(EC2,AWS)
AppaaS[42]	Infeasibility	✓			Amazon(EC2,AWS)
Cloud2Bubble[43]	Infeasibility	✓			Google(AppEngine) or Amazon(EC2,AWS)
ICAC[44, 45]	Anytime, Anywhere Service	✓			Google(AppEngine)
CasCap[46]	Infeasibility	✓			Google(AppEngine)
MoCAsH[47]	Infeasibility			✓	-
ECGAS[48]	Infeasibility & Anytime, Anywhere Service	✓			Amazon(EC2,AWS)
TLD[49]	Infeasibility	✓			Amazon(EC2,AWS)
IOT& CC2PH[50]	Infeasibility & Security and confidence increase	✓			Jelastic
MPHD[51]	Anytime, Anywhere Service & Infeasibility	✓			Amazon(EC2,AWS)
CAVS[52]	Infeasibility	✓			-

ing the features related to its waveform, ECGAS concludes whether a patients heartbeat is regular, thereby enhancing the healthcare process for patients with heart attack. In MoCAsH, a cloud-based portal is designed on which the users, depending on their access level, are able to observe the status and medical data of sensors and control the mobile device. They can also update context-aware regulations and define an emergency situation scenario. This portal actually has a website, which is connected to its context-aware middleware on the cloud platform.

- Learning: Using cloud for educational purposes causes the dynamic and attraction of the education process. The main feature of cloud-based educational programs is that they can present the necessary education to user anytime and anywhere based on his demand. Sotsenko et al. investigate the related research on the design of mobile learning applications in cloud computing environment. They also propose a flexible contextualization service to support personalized learning environment for mobile learners[61]. The only project in this category is AML. It analyzes a set of context information including students mobile bandwidth setting and his/her profile (which shows the students preference of audio or visual educational content) in the cloud and provides the user with the appropriate educational content.
- Urban and transportation: In this domain, applications offer convenient services related to urban issues and transportation such as traffic management[62], accident avoidance, and providing facilities to the drivers[63]. The cloud is capable of delivering such services more dynamically, resulting in facilitation and cost reduction in regard to urban issues and transportation. Nowadays organizations focus on reducing accidents. Also the vigilance level is very affective in road injuries. Hu et al. propose a Mood-Fatigue An-

alyzer (MFA) that is a context-aware cloud-based mobile sensing application for safe driving[64]. In another project Hu et al. propose SAfeDJ, that is a situation-aware music delivery for safe driving[65]. Among the projects, CAVS supplies the vehicles, drivers, and traffic authorities with a context-aware dynamic parking service scenario. Given the recorded users profile and the environment conditions available in the cloud, Cloud2Bubble processes the data in the urban environment, while considering users requirement and preferences. Afterward, it provides the user with a relevant and personalized service. As a scenario, imagine a person who intends to commute by bus. He/she sends the temperature to the cloud using the sensors embedded in the bus. After necessary processing, the cloud replies whether the environment temperature is proper based on users need and, if necessary, suggests a new route to the user in order for him/her to experience a more desirable circumstance during urban commute.

•Multimedia: Due to unique capabilities such as ubiquitous availability, the cloud can perform effectively in the domain of media, resulting in facilitation of using multi-media products, such as movies. OVP, CCMR, and MRUB are multimedia recommenders. In addition to recommending online videos, OVP alters the video format in accordance with codecs available on users mobile phone and fulfills their needs for installing new codecs to watch their preferred videos.

•Personal setting: These systems enable the user to adjust his/her mobile devices more accurately, and in other words, they personalize users device. This category is exemplified by ICAC and CasCap. ICAC receives the available information in users Google account and the data of her mobile sensors and presents her required settings automatically. For example, it changes the screen brightness in accordance with environmental light. In CasCap, the user sends a request with her mobile device by clone[66] to the network mapping service in the cloud. The network mapping service provides her with some information like the number of connected users to each access point as well as average data rate of its users. If the user relocates, her phone's accelerometer recognizes the movement, and the new map of signal strength of access points is retrieved and presented by the mapping service. If signal strength is too low to download the file in the new location, the downloading process will be automatically delayed and a new request is sent for switching the access point.

•General facilities: Other projects aim at presenting general services to public. For instance, CroudSTag uses a set of pictures are stored on the cloud and the face recognition cloud server to forming social groups on Facebook[67]. Among the investigated projects, DaaS and AppaaS are classified into this category. In DaaS, the system benefits from users context and preferences to have a better perception of their goal. Then, it receives the capabilities and the limitations of their device to introduce the web services that can run on the device. In order to provide better web services, the system uses certain types of information such as environmental information and the rank of services given by users. Each user sends their request to the cloud through an interface, and cloud provides them with discovered web services via the same interface. Similarly, AppaaS suggests mobile applications to users in the form of a cloud service by applying access limitation in accordance with the contexts. It assists users who face this challenge of finding the proper application. These applications are not confined to a special domain.

4.2 Privacy

Protecting peoples private data is an integral part of cloud-based systems, and the users should be assured that their private contextual information, is never going to be disclosed. Otherwise, the system reliability is under question. Since in mobile cloud computing, information exchange occurs frequently among devices, there are some concerns regarding privacy protection. These concerns even increase if the users are anonymous and the mobile cloud has been created opportunistically[21].

Adopting a proper approach for protecting peoples privacy is a challenging issue. For instance, multiparty computation using cryptographic techniques is one of the common methods for privacy protection. But this method requires massive computations as well as producing and maintaining multiple keys[68]. Furthermore, high rate of communication and dynamic circumstances in mobile cloud computing makes the problem more difficult. Information requirements are different in various systems. Some systems provide services with the aid of their users personal information, showing their emphasis on users privacy. Some other may ignore privacy protection due to certain reasons. Various projects are categorized in terms of privacy protection as follows:

•Ignoring privacy: The reasons for ignoring privacy can be diverse, but can be categorized into three groups:
  øNon- private data: Some applications do not rely on personal data for presenting their services.

Therefore, there is no concern regarding disclosure of users personal information and system designers neglect the privacy. TLD, AML, MRUB, and DaaS do not make use of users private data at all. In AML, the utilized data is related to mobile phone, including type and operating system (which are not considered as private data). In TLD, the only data that is used in the cloud is the images taken from street lights.

øReliable cloud: In some cases, the exploited data is private. However, the entire system is transferred to the cloud environment, which is supposed to protect the users privacy in default. Several pieces of research have been done for preserving privacy in cloud environment[69, 70]. Hence, the threats to users privacy are overlooked. That is to say, the cloud environment is assumed to be reliable, and protective of users privacy. In Cloud2Bubble, the application needs to be aware of users origin and destination, but no approach is offered to protect privacy. The same assumption is done in ECGAS where patients medical data is recorded in the cloud.

øPrivate cloud: Private cloud is built by an organization in order to protect data and users privacy as well as having control on security issues. Private clouds have considerable security advantages over public clouds. They limit the access levels by a centralized data protection scheme. MoCAsH and MRUB are the projects that adopt a private cloud for protecting the privacy of medical data. In MoCAsH, a pre-designed Grid infrastructure is employed to create a private cloud computing platform known as Active Grid[71]. The unique features of Active Grid are used to implement some key characteristics of the cloud including supervision and system management, authorization/authentication/accounting, resource virtualization, and scalability.

•Considering privacy: Various techniques have been used for privacy protection including multiparty computation and anonymity. In multiparty computation, cryptographic methods are applied to protect the privacy. Eliminating persons name from the stored data is another method for privacy protection. In this approach, users personal data is anonymously transferred and stored.

In OVP, user supervision is used to protect the privacy. In fact, the users permission is required and asked at the time of collecting context information. In CasCap, a clone is assigned to each mobile device and each users context is sent only to his/her special clone, diminishing the risk of jeopardizing context information. Designers of this system opine that a clone-based method outperforms the traditional proxy-based method in resolving privacy concerns. The Cumulocity platform in MPHD is established on Amazon AWS infrastructure and is capable of maintaining privacy by using cryptography and anonymity techniques. Amazon Web Services (AWS) is a complex of cloud services, which provides computational and storage resources. Similarly, information anonymity technique is used to protect privacy in CCMR, in a way that the data is anonymous in the recommendation process. Privacy protection in ICAC is provided using multiparty computation and Google authentication process. Moreover, IOT&CC2PH use cryptography and authentication to protect the information as well.

4.3 Offloading

The intention for conducting the offloading process and selecting its effective parameters may vary based on the requirements. In terms of offloading, the systems are generally categorized into two groups:

•Not performing offloading: The majority of studied systems do not perform offloading, such as CCMR, DaaS, AppaaS, and MPHD. The common point of most of these projects is that the whole program runs on the cloud and is presented to the user as a software service. In other words, user connects to the cloud by a user interface through Internet, and the system is represented as a webpage in users device. Generally, offloading is applied only where the application is completely installed on users computing device.

•Performing offloading: Due to the differences among offloading techniques, these systems are generally categorized into two following groups:

øStatic offloading: In case of static offloading, the application is previously segmented at the development phase. One advantage of static segmentation is its negligible overhead at the runtime, but this technique is suitable only when the effective parameters of segmentation are predicted properly[23]. TLD and CasCap are the projects that perform the offloading statically. In TLD, image processing algorithms, which are utilized for quick recognition of objects and traffic light, run on the cloud, while processes of positioning, image taking and frame pre-processing are executed on users side. Since the offloading component is previously determined, the offloading is performed statically in this system. In CasCap, a software program is installed on users mobile phone that runs one component locally and the other one on the cloud. Following that, the mapping component on the cloud provides the user with a list of access points with appropriate signal strength for file downloading.

øDynamic offloading: In this process, the components to be executed on the cloud and on users device are not pre-determined. Alternatively, they are determined according to dynamic contextual information such as mobile resources (e.g. processor speed, memory space, bandwidth, delay, and charge level). This dynamic decision making may impose a high overhead rate on the system. Among the studied projects, MoCAsH benefits from dynamic offloading. Data collected by mobile or sensor networks is sent to the "mobile cloud" middleware to be analyzed, stored and processed; Simple analyses are directly conducted on the mobile phone. The mobile cloud middleware consists of two parts: user side and cloud side. Before performing offloading, the amount of processing tasks that is supposed to be performed on the data is used as context information. Then, the extent of processing to be performed on user side and on the cloud side are decided. That is, if mobile is able to process, it processes the data. Otherwise, the data is transferred to the middleware on the cloud to be processed.

4.4 Implementation Tool

Applying development tools under cloud environments enables the developers to implement their program quicker and cheaper, while benefitting from various resources such as computational and storage as much as required. For instance, Google App Engine is a cloud-based platform presented by Google and supports programming languages such as Python and Java[72]. Moreover, Microsoft Azure is a platform presented by Microsoft. It is a growing set of integrated services, such as computational, storage and network services. Azure supports all types of operating systems like Windows and Linux as well as languages of C# and Java. Moreover, it provides services based on SQL server, which enhances platform power[73]. Software pack presented by Amazon AWS provides users with federated tools to develop applications. For instance, one of these packs is an open source plug-in for Java Eclipse IDE that allows the development and implementation of Java-based applications. Furthermore, designed plug-in for Microsoft Visual Studio enables the development and running of .NET-based applications[74].

Among the studied projects, ICAC, Cloud2Bubble and CasCap use Google App Engine, while MoCAsH and Cloud2Bubble benefit from Amazon services. In MoCAsH, in addition to using Amazon EC2-S3 for the public cloud component, Globus Grid computing Toolkit 4.0 is utilized for task scheduling, security management and service quality in the private cloud component. Nimbus Toolkit is used as an open source tool for federating the clusters in the cloud. Some projects, including CCMR and IOT&CC2PH, use Java as their programming base. AppaaS uses Android SDK which is a software pack for creating Android platform systems. In MPHD, Cumulocity operates as a cloud platform in the form of horizontal machine-to-machine (M2M), presented by Nokia Siemens Networks (NSN).

4.5 Operating System

The last parameter to be discussed in the "system design aspect" is related to the operating system. Given the capabilities of each of the operating systems, the provided mobile services for users and designers vary significantly. Some of the most popular mobile operating systems are Android, IOS, Symbian, and Blackberry OS. Android, for instance, is able to pave the way for development of context-aware applications by its special capabilities such as being open source, and providing the capability of simple communication with sensors embedded in the mobile phone. In some cases, the application may be portable. This enables users to utilize the application through different mobile operating systems.

Android has a large contribution among the investigated projects. The systems such as OVP, ECGAS, and AML do not have any specified operating system. Table 3 presents the classification of studied projects in terms of the system design aspect.

5 Context-Awareness

Context information is an inseparable part of new generation systems. Generally, context-awareness aspect is being investigated from two perspectives: the types of used contextual information in service providing process, and the context acquisition resource. These two views are discussed as follows.

Table 3 The results of investigating projects according to the system design aspect

Project	Service Type			Privacy	Offloading	Implementation Tool	Operating System
	PaaS	SaaS	DaaS				
OVP[37]		Multimedia		User supervision	×	-	General
CCMR[38]		Multimedia		Anonymity	×	Java EE	Android
MRUB[39]		Multimedia		No private information	×	-	Android
AML[40]		Learning		No private information	×	OPNET	General
DaaS[41]		General Facilities		No private information	×	-	Android
AppaaS[42]		General Facilities		-	×	Android SDK	Android
Cloud2Bubble[43]		Urban & Transportation		Secure cloud	×	Google App Engine	Android
ICAC[44, 45]		Personal Setting		Access Control & Authorization	×	Google App Engine	Android
CasCap[46]		Personal Setting		Clone Cloud	Static	Google App Engine	Maemo
MoCAsH[47]	✓	Healthcare		Private cloud	Dynamic	Nimbus Toolkit & Globus Grid computing Toolkit 4.0	Android
ECGAS[48]		Healthcare	✓	Secure cloud	×	Amazon EC2	General
TLD[49]		Healthcare		No private information	Static	-	Android
IOT& CC2PH[50]			✓	Access Control & Encryption	×	Java EE	Android
MPHD[51]			✓	Anonymity	×	Cumulocity	Android
CAVS[52]		Urban & Transportation		-	×	-	-

5.1 Context Type

Depending on their requirements, different applications utilize different contextual information for service providing. Typically, context elements in the studied systems are categorized into three groups:

- •Local context: This type of context describes a local entity. This entity may be either the user or his computational device. As a result, local context could be categorized in the following subclasses:

øDevice context: Some applications provide services that are required to adapt part of their functionality to the device on which they are running. This type of contextual information may include elements such as mobile operating system, bandwidth, and storage and processing capacities. Among the investigated systems, the browser type and screen size of the mobile phone are exploited in OVP and DaaS. Available bandwidth, network condition, session quality, and users bandwidth setting are other elements of context-information, which are used in OVP, MRUB, DaaS, MoCAsH, and AML. In OVP, other contextual information such as installed software on users device, available codecs, screen resolution, and CPU frequency are applied.

In MRUB, the device type as well as the network type are utilized. Similarly, other types of context elements used in DaaS include software platform, types of inputs, NFC support, supports callback, and supports color. Besides, AML uses the type of mobile operating system. Finally, device profile is used in AppaaS for identifying the proper version of an application that conforms to device platform.

øUser context: The application adaptation to this personal information results in providing personalized services. This type is exemplified by users location, job, current speed and activity and is categorized into two groups:

∗Location context: It is associated to the current location of the user. It may include information regarding users location, available people nearby, and the available objects around the user. User location is the most common context element, which is used in OVP, CCMR, MRUB, ICAC, CAVS, DaaS, AppaaS, MoCAsH, IOT&CC2PH, TLD, CasCap, and MPHD. Besides, DaaS uses nearby objects and landmarks as well.

∗Personal context: It is related to users personal information and covers a wide range of descriptive information about him. Among the projects, users preferences, which show their interest are used in OVP, MRUB, CCMR, DaaS, and Cloud2Bubble. The history of video watching, which somehow represents their interest are utilized in OVP and MRUB in order to provide the appropriate recommendations. Users profile, which contains personal information is used in MRUB, AppaaS, MoCAsH, AML and Cloud2Bubble. Besides, CCMR, ICAC, and IOT&CC2PH utilize users activity.

Personal information is widely used in healthcare systems. MoCAsH, IOT&CC2PH, ECGAS, and MPHD use some elements of physiological information and users bio-signals including heart rate, body temperature, pulse, movement acceleration and oxygen saturation. In ECGAS, ECG history is applied as well as other information including patients sleeping time, gender and age. Patient motion and warning about their fall are other types of context applied in MPHD. Users leisure and work time in ICAC, and users emotion in Cloud2Bubble are other types of exploited personal context information.

•Social context: Today, social networks are emerging, increasingly, and are embraced by users, becoming a salient resource of a new type of contextual information known as social context. This type of context assists the applications that provide services in social domain such as friend making, marketing, and community discovery. Users contact list and the groups in which the user is a member of are some examples of social context. Among the projects, OVP, MRUB, and ICAC use this type of information. The users preferred communities as well as their contact list are used in OVP and CCMR. CCMR also applies users social communications and activities. Besides, social activities and meetings are considered in ICAC.

•Other: General contextual information such as weather condition, temperature, street traffic level, etc. are sometimes exploited in domain-specific applications. Among the projects, the users environmental condition is used in CCMR, ICAC, CAVS, DaaS, MoCAsH, IOT&CC2PH, and Cloud2Bubble. These environmental conditions comprise a set of information elements such as temperature, humidity, noise level and environment brightness level. The status of the communication network around users location is considered in DaaS and CasCap. In CasCap, the current number of connections and signal strength are also used. Besides, DaaS considers other types of information such as bandwidth and data rate.

In the multimedia domain, CCMR and MRUB use media category and video genre and length as context. Moreover, MRUB applies other types of context including video resolution, bit rate, and video age regarding media files. CCMR takes into account the time of the day (morning, noon, evening, etc.) and the day of the week. In addition, the time of users login and logout is used in MRUB, AppaaS, and the duration of car parking is applied in CAVS. DaaS utilizes the information regarding the services, searched keywords by the user, and users ranking, which is a mechanism for receiving their feedback in order to discover the relevant web services. CAVS uses road conditions, rush hour, traffic prediction and the status of parking garage. TLD benefits from traffic light situation and Cloud2Bubble uses quality of experience to improve the users experience. Table 4 shows the summary of projects considering different types of used contextual information.

Table 4 The Summary of investigated projects according to the utilized context type

Project	Context Type				
	Local context			Social context	Other
	Devise	User			
		Location	Personal		
OVP[37]	✓	✓	✓	✓	-
CCMR[38]	-	✓	✓	-	✓
MRUB[39]	✓	✓	✓	✓	✓
AML[40]	✓	-	✓	-	-
DaaS[41]	✓	✓	✓	-	✓
AppaaS[42]	✓	✓	✓	-	-
Cloud2Bubble[43]	-	-	✓	-	✓
ICAC[44, 45]	-	✓	✓	✓	✓
CasCap[46]	-	✓	-	-	✓
MoCAsH[47]	-	✓	✓	-	✓
ECGAS[48]	-	-	✓	-	-
TLD[49]	-	✓	-	-	✓
IOT& CC2PH[50]	-	✓	✓	-	✓
MPHD[51]	-	✓	✓	-	-
CAVS[52]	-	✓	✓	-	✓

5.2 Context Source

Applications usually obtain their required contextual information from various sources. The context acquisition resource in the studied projects are classified as follows:

- Wearable and mobile sensors: New mobile phones are equipped with various types of sensors and are considered as a significant resource for contextual information. Wearable sensors are another resource for context acquisition. Applications may utilize the information acquired from wearable and mobile sensors using different strategies. These strategies are generally divided into two main groups: direct usage and context reasoning. In the direct usage, the application uses these context elements directly in its processes. In the studied projects, a considerable part of contextual information is exploited, directly. Except of Cloud2Bubble, all other projects use directly some contextual information obtained from wearable and mobile sensors such as medical sensors, accelerometer, thermometer, and GPS. These types of context elements include location, time, environment light, noise level, users device connectivity to networks, network capabilities in users surrounding environment (signal strength and bandwidth), users mobile features (such as platform, operating system, browsers, screen size, screen resolution, processing speed and storage capacity), users movement data, and physiological information.
In the context reasoning, the application infers its required high-level context elements from sensed data by conducting the reasoning processes. CAVS and MRUB process the collected information in users device in order to infer the parking duration of the vehicle and user cluster, respectively.

- Cloud: The capabilities of cloud enables the systems to use it for acquiring some parts of contextual information. In this approach, a cloud service provides the application with the required elements of context. In some cases, the application needs a context element that is only achievable by massive processing operations on a huge amount of data. Performing such operations is practically infeasible on a mobile phone. Alternatively, the cloud can obtain and send the required context to the application. A major of studied projects acquire one or more of their context elements from cloud. These contextual elements include user's preference, users feedback for ranking, the history of video watching, information about type and class of recommended media, information about recommended services, keywords associated with users request, extracted numerical data from ECG waveform, social contextual information such as contact list and preferred communities, and context information obtained by image processing.

- Static infrastructure: In ubiquitous computing, smart places are saturated with a diverse range of sensors and can supply the applications with a wide range of contextual information. Due to the scarcity of smart places, a few projects obtain their contextual information using the static infrastructure. Status of the parking garage in CAVS, users location in AppaaS, network condition and session quality in MoCAsH, environment temperature in IOT&CC2PH, environmental conditions in Cloud2Bubble, and patient's vital information, motion, location and conditions in MPHD are gathered using various sensors embedded in the environment.
- Other users mobile device: Some systems obtain their required information through other users mobile device. This method is used among the applications that need to aggregate a relatively high amount of data in order to provide high-level services. This amount of data is usually gathered from other peoples mobile devices. In CasCap, the current number of connections as well as signal strength are context elements that are obtained from a crowd of smart phones connected to an access point.
- User interface: In many of the systems, forms and interfaces play a main role in receiving some contextual information directly from the user. For example, users profile, which is completed by the user in the first execution of the application, contains context elements, which are used in future processes. These context elements are rather static and cannot be measured by sensors. Among the projects, AppaaS, MoCAsH, AML and Cloud2Bubble provide a user interface for collecting some contextual information. Moreover, users preference in OVP and DaaS as well as their activities such as jogging or running in CCMR are collected by the interface.
- Assumed: In some applications, the value of some context elements is assumed to exist, and no special collection method is mentioned for them. For example, the context sources of road condition, rush hour, traffic prediction and weather condition are not declared in CAVS. Moreover, the context source of patients information including sleeping time, gender, age and identification in IOT&CC2PH, users activity in ECGAS, and QOE in Cloud2Bubble is unknown. Table 5 summarizes the projects in terms of context sources.

6 Conclusion and Future Research directions

Unique features and increasing prevalence of cloud computing have drawn researchers interest regarding this technology. In recent years, several projects have focused on designing and developing cloud-based context-aware systems. This paper proposes a comprehensive framework for investigating and classifying these systems. It consists of three main aspects, each of which involves related parameters. The first aspect, general, has been discussed from two parameters of goal and type of cloud. The second aspect, system design, comprises parameters of service type, privacy, offloading, implementation tool, and operating system. The final aspect, context-awareness, consists of utilized contextual information as well as context acquisition resources. Related projects have been investigated considering this framework. Finally, the following challenges and research open directions are concluded:

- Collecting and storing personal data in a cloud environment, regardless of the advantages, produce some concerns regarding users privacy. Some developers use private cloud and techniques such as anonymity to protect users privacy, while most of them trust the cloud. In general, creating new methods for protecting users privacy will raise the interest to the cloud. Given the unique characteristics of the cloud computing, new strategies seem to be essential in this field.
- Among various types of cloud services, SaaS is the most frequently used among the studied projects. This service is applied in diverse domains, from multimedia to urban services. Following the studying of relevant projects, several applications are known with similar services. Thus, establishing a comparing and ranking framework can be useful for users as well as developers of such applications.
- As investigated, healthcare is a growing domain for cloud-based context-aware systems and there are a few works considering some branches of this filed such as the healthcare system for patients with heart disease. Given the importance of healthcare and its extensive range, developing applications is useful and practical for other parts such as patients with Alzheimers disease and cancer, as well as children and elders.
- Although ubiquitous computing and cloud computing have been separately evolved in the past decade, their integration is in its elementary stages. As a witness, most of the investigated projects have used traditional contextual information especially location and personal context. New context dimensions such as social and urban context types have rarely

Table 5 The summary of investigated projects according to the context source parameter

Project	Wearable & mobile Sensors		Cloud	Static infrastructure	Other users' devices	Interface	Assumed
	Direct usage	Reasoning					
OVP[37]	✓	-	✓	-	-	✓	-
CCMR[38]	✓	-	✓	-	-	✓	-
MRUB[39]	✓	✓	✓	-	-	-	-
AML[40]	✓	-	-	-	-	✓	-
DaaS[41]	✓	-	✓	-	-	✓	-
AppaaS[42]	✓	-	✓	✓	-	✓	-
Cloud2Bubble[43]	-	✓	-	✓	-	✓	✓
ICAC[44, 45]	✓	-	✓	-	-	-	-
CasCap[46]	✓	-	-	-	✓	-	-
MoCAsH[47]	✓	-	-	✓	-	✓	-
ECGAS[48]	✓	-	✓	-	-	-	✓
TLD[49]	✓	-	✓	-	-	-	-
IOT& CC2PH[50]	✓	-	-	✓	-	-	✓
MPHD[51]	✓	-	-	✓	-	-	-
CAVS[52]	✓	✓	-	-	-	-	✓

been exploited. Moreover, most of the contextual information have been acquired by traditional methods such as mobile sensors, while the main technologies in ubiquitous computing such as smart places and smart infrastructure have rarely been used. These remarks show that context-aware (ubiquitous) cloud computing is in elementary stages that needs much research and attention.

References

1. L. Youseff, M. Butrico, and D. Da Silva, "Toward a unified ontology of cloud computing," in Workshop on Grid Computing Environments 2008.
2. K. Henricksen and J. Indulska, "Developing context-aware pervasive computing applications: Models and approach," Pervasive and mobile computing, vol. 2, 2006.
3. K. Henricksen, J. Indulska, and A. Rakotonirainy, "Modeling context information in pervasive computing systems," in Pervasive Computing, ed: Springer, 2002.
4. M. Baldauf, S. Dustdar, and F. Rosenberg, "A survey on context-aware systems," International Journal of Ad Hoc and Ubiquitous Computing, vol. 2, 2007.
5. S. Patidar, D. Rane, and P. Jain, "A survey paper on cloud computing," in International Conference on Advanced Computing & Communication Technologies 2012.
6. B. P. Rimal, E. Choi, and I. Lumb, "A taxonomy and survey of cloud computing systems," in International Joint Conference on INC, IMS and IDC, 2009.
7. H.-L. Truong and S. Dustdar, "A survey on context-aware web service systems," Web Information Systems, vol. 5, 2009.
8. H. Qi and A. Gani, "Research on mobile cloud computing: Review, trend and perspectives," in International Conference on Digital Information and Communication Technology and it's Applications, 2012.
9. Q. Zhang, L. Cheng, and R. Boutaba, "Cloud computing: state-of-the-art and research challenges," Journal of internet services and applications, vol. 1, 2010.
10. P. Mell and T. Grance, "The NIST definition of cloud computing," US Natl Inst. of Science and Technology, 2011.
11. H. T. Dinh, C. Lee, D. Niyato, and P. Wang, "A survey of mobile cloud computing: architecture, applications, and approaches," Wireless communications and mobile computing, vol. 13, 2013.
12. Amazon Elastic Computing Cloud. Available: www.aws.amazon.com/ec2
13. FlexiScale Cloud Comp and Hosting. Available: www.flexiscale.com
14. google docs. Available: www.google.com/docs
15. Rack Space. Available: www.rackspace.com
16. H. Vahdat-Nejad, H. Shirvani, "Storing shared documents that are customized by users in cloud computing," Computing, vol. 98, pp. 1137-1151, 2016.
17. Amazon S3. Available: www.aws.amazon.com/s3
18. Google BigTable. Available: www.cloud.google.com/bigtable
19. Apache HBase. Available: www.hbase.apache.org
20. M. Satyanarayanan, "Fundamental challenges in mobile computing," in Symposium on Principles of distributed computing, 1996.
21. N. Fernando, S. W. Loke, and W. Rahayu, "Mobile cloud computing: A survey," Future Generation Computer Systems, vol. 29, 2013.
22. D. T. Hoang, D. Niyato, and P. Wang, "Optimal admission control policy for mobile cloud computing hotspot with cloudlet," in International Conference on Wireless Communications and Networking, 2012.

23. K. Kumar, J. Liu, Y.-H. Lu, and B. Bhargava, "A survey of computation offloading for mobile systems," Mobile Networks and Applications, vol. 18, 2013.
24. R. Balan, J. Flinn, M. Satyanarayanan, S. Sinnamohideen, and H.-I. Yang, "The case for cyber foraging," in Workshop on ACM SIGOPS European workshop, 2002.
25. U. Kremer, J. Hicks, and J. Rehg, "A compilation framework for power and energy management on mobile computers," in Languages and Compilers for Parallel Computing, ed: Springer, 2003.
26. M. Satyanarayanan, "Mobile computing: the next decade," ACM SIGMOBILE Mobile Computing and Communications Review, vol. 15, 2011.
27. M. Satyanarayanan, P. Bahl, R. Caceres, and N. Davies, "The case for vm-based cloudlets in mobile computing," Pervasive Computing, vol. 8, 2009.
28. M. Weiser, "The computer for the 21st century," Scientific american, vol. 265, 1991.
29. M. Satyanarayanan, "Pervasive computing: Vision and challenges," Personal Communications, vol. 8, 2001.
30. M. Weiser and J. S. Brown, "The coming age of calm technology," in Beyond calculation, ed: Springer, 1997.
31. H. Vahdat-Nejad, K. Zamanifar, and N. Nematbakhsh, "Context-aware middleware architecture for smart home environment," International Journal of Smart Home, vol. 7, 2013.
32. B. N. Schilit and M. M. Theimer, "Disseminating active map information to mobile hosts," Network, vol. 8, 1994.
33. G. D. Abowd, A. K. Dey, P. J. Brown, N. Davies, M. Smith, and P. Steggles, "Towards a better understanding of context and context-awareness," in International Conference on Handheld and ubiquitous computing, 1999.
34. A. K. Dey, "Understanding and using context," Personal and ubiquitous computing, vol. 5, 2001.
35. B. Schilit, N. Adams, and R. Want, "Context-aware computing applications," in Workshop on Mobile Computing Systems and Applications 1994.
36. N. S. Ryan, J. Pascoe, and D. R. Morse, "Enhanced Reality Fieldwork: the Context-aware Archaeological Assistant," in International Conference on Computer Applications in Archaeology, 1998.
37. J. Jiang, Y. Wu, X. Huang, G. Yang, and W. Zheng, "Online video playing on smartphones: A context-aware approach based on cloud computing," Journal of Internet Technology, vol. 11, 2010.
38. A. M. Otebolaku and M. T. Andrade, "Supporting Context-Aware Cloud-Based Media Recommendations for Smartphones," in International Conference on Mobile Cloud Computing, Services, and Engineering, 2014.
39. Y. Mo, J. Chen, X. Xie, C. Luo, and L. T. Yang, "Cloud-Based Mobile Multimedia Recommendation System With User Behavior Information," IEEE Systems Journal, vol. 8, 2014.
40. A. Karadimce and D. Davcev, "Adaptive Multimedia Learning Delivered in Mobile Cloud Computing Environment," in International Conference on Cloud Computing, GRIDs, and Virtualization Cloud Computing, 2013.
41. K. Elgazzar, H. S. Hassanein, and P. Martin, "Daas: Cloud-based mobile web service discovery," Pervasive and Mobile Computing, vol. 13, 2014.
42. K. Elgazzar, A. Ejaz, and H. S. Hassanein, "AppaaS: offering mobile applications as a cloud service," Journal of Internet Services and Applications, vol. 4, 2013.
43. P. M. Costa, J. Pitt, J. Falco e Cunha, and T. Galvo, "Cloud2Bubble: enhancing quality of experience in mobile cloud computing settings," in Workshop on Mobile cloud computing and services, 2012.
44. T.-M. Grnli, G. Ghinea, and M. Younas, "Context-aware and automatic configuration of mobile devices in cloud-enabled ubiquitous computing," Personal and ubiquitous computing, vol. 18, 2014.
45. T.-M. Grnli, J. Hansen, and G. Ghinea, "Integrated context-aware and cloud-based adaptive home screens for android phones," in Human-Computer Interaction. Interaction Techniques and Environments, ed: Springer, 2011.
46. Y. Xiao, P. Hui, P. Savolainen, and A. Yl-Jski, "CasCap: cloud-assisted context-aware power management for mobile devices," in Workshop on Mobile cloud computing and services, 2011.
47. D. B. Hoang and L. Chen, "Mobile cloud for assistive healthcare (MoCAsH)," in International Conference on Services Computing 2010.
48. S. Pandey, W. Voorsluys, S. Niu, A. Khandoker, and R. Buyya, "An autonomic cloud environment for hosting ECG data analysis services," Future Generation Computer Systems, vol. 28, 2012.
49. P. Angin, B. Bhargava, and S. Helal, "A mobile-cloud collaborative traffic lights detector for blind navigation," in International Conference on Mobile Data Management 2010.
50. C. Doukas and I. Maglogiannis, "Bringing iot and cloud computing towards pervasive healthcare," in International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing 2012.
51. C. Doukas, T. Pliakas, P. Tsanakas, and I. Maglogiannis, "Distributed Management of Pervasive Healthcare Data through Cloud Computing," in Wireless Mobile Communication and Healthcare, ed: Springer, 2012.
52. J. Wan, D. Zhang, S. Zhao, L. T. Yang, and J. Lloret, "Context-aware vehicular cyber-physical systems with cloud support: architecture, challenges, and solutions," Communications Magazine, vol. 52, 2014.
53. D. Zissis and D. Lekkas, "Addressing cloud computing security issues," Future Generation computer systems, vol. 28, 2012.
54. R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, "Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility," Future Generation computer systems, vol. 25, 2009.
55. T. Dillon, C. Wu, and E. Chang, "Cloud computing: issues and challenges," in International Conference on Advanced Information Networking and Applications, 2010.
56. F. Sabahi, "Cloud computing security threats and responses," in International Conference on Communication Software and Networks 2011.
57. H. Vahdat-Nejad, S. Poorejbari, "An Introduction to Cloud-Based Pervasive Healthcare Systems," presented at the International Workshop on Pervasive and Context-Aware Middleware, 2014.
58. H. Vahdat-Nejad, S. Poorejbari, "Diabetes Patients Monitoring by Cloud Computing," in Cloud Computing System and Applications in Healthcare, ed: IGI, 2017.
59. S.-H. Chang and C.-N. Li, "A Cloud Based Type-2 Diabetes Mellitus Lifestyle Self-Management System," in Trends and Applications in Knowledge Discovery and Data Mining, ed: Springer, 2015, pp. 91-103.
60. S.-H. Chang, R.-D. Chiang, S.-J. Wu, and W.-T. Chang, "A Context-Aware, Interactive M-Health System for Diabetics," IT Professional, vol. 18, 2016.
61. A. Sotsenko, J. Zbick, M. Jansen, and M. Milrad, "Flexible and Contextualized Cloud Applications for Mobile Learning Scenarios," in Mobile, Ubiquitous, and Pervasive Learning, ed: Springer, 2016.

62. H. Vahdat-Nejad, A. Ramazani, "CANS: Context-Aware Traffic Estimation and Navigation System," IET Intelligent Transport Systems, vol. 11, pp. 326 - 333, 2017.
63. H. Vahdat-Nejad, A. Ramazani, T. Mohammadi ,W. Mansoor, "A Survey on Context-Aware Vehicular Network Applications," Vehicular Communications, vol. 3, pp. 43-57, 2016.
64. W. Hu, X. Hu, J.-q. Deng, C. Zhu, G. Fotopoulos, E. C.-H. Ngai, et al., "Mood-fatigue analyzer: towards context-aware mobile sensing applications for safe driving," in ACM Workshop on Middleware for Context-Aware Applications in the IoT, 2014.
65. X. Hu, J.-q. Deng, W. Hu, G. Fotopoulos, E. C.-H. Ngai, Z. Sheng, et al., "SAfeDJ community: situation-aware in-car music delivery for safe driving," in International Conference on Mobile computing and networking, 2014, pp. 363-366.
66. B.-G. Chun, S. Ihm, P. Maniatis, M. Naik, and A. Patti, "Clonecloud: elastic execution between mobile device and cloud," in International Conference on Computer systems, 2011.
67. S. N. Srirama, C. Paniagua, and H. Flores, "Croudstag: social group formation with facial recognition and mobile cloud services," Procedia computer science, vol. 5, 2011.
68. R. K. Ganti, F. Ye, and H. Lei, "Mobile crowdsensing: current state and future challenges," Communications Magazine, vol. 49, 2011.
69. W. Song, B. Wang, Q. Wang, Z. Peng, W. Lou, and Y. Cui, "A privacy-preserved full-text retrieval algorithm over encrypted data for cloud storage applications," Journal of Parallel and Distributed Computing, 2016.
70. M. D. M. L. Ruiz and J. Pedraza, "Privacy Risks in Cloud Computing," in Intelligent Agents in Data-intensive Computing, ed: Springer, 2016.
71. D. Hoang and E. Lawrence, "An Active Grid infrastructure for elderly care," Journal of telemedicine and telecare, vol. 14, 2008.
72. Google App Engine. Available: www.appengine.google.com
73. Microsoft Windows Azure. Available: www.azure.microsoft.com
74. AWS Developer Tools. Available: http://docs.amazonaws.cn/

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