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Mobile Cloud Computing Service Models: A User-Centric Approach

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Abstract: Together with an explosive growth of the mobile applications and emerging of cloud computing concept, mobile cloud computing (MCC) has been introduced to be a potential technology for mobile services. MCC integrates the cloud computing into the mobile environment and overcomes obstacles related to the performance (e.g., battery life, storage, and bandwidth), environment (e.g., heterogeneity, scalability, and availability), and security (e.g., reliability and privacy) discussed in mobile computing. This paper gives a survey of MCC, which helps general readers have an overview of the MCC including the definition, architecture, and applications. The issues, existing solutions and approaches are presented. In addition, the future research directions of MCC are discussed.

Keywords: Mobile Cloud Computing, Offloading, Mobile Services.

I. INTRODUCTION

Today, the Internet web service is the main way we access information from fixed or mobile terminals. Some of the information is stored in Internet clouds, where computing, communication, and storage are common services provided for Internet users. In the non-distant future, many of our queries will be beyond the current Internet scope and will be about the people, physical environments that surround us, and virtual environments with which we will be involved. With the Internet environment improving, mobile phones are overtaking PCs as the most common web access entities worldwide by 2013 as predicted. Current mobile devices have many advanced features such as mobility, communication, and sensing capabilities, and can serve as the personal information gateway for mobile users. However, when running complex data mining and storing operations, the computation, energy, and storage limitations of mobile devices demand an integrated solution relying on cloud-based computation and storage support. As a result, a new research field, called mobile cloud computing (MCC), is emerging.

In MCC, a mobile entity can be considered as a physical mobile device or a mobile computing/storage software agent within a virtualized cloud resource provisioning system. In the latter view of the cloud system, a software agent's main functionality is the mobility associated with software codes. In other words, mobile cloud applications may migrate or compose software codes in the distributed MCC resource provisioning environment. Mobile cloud services will Account for delay, energy consumption, and real-time entity presence, information caching capabilities, networking and communication connectivity, data protection and sharing requirements, and so on. By achieving these features, we are actually able to create a new world composed of both physically networked systems and virtualized entities that are mapped to the physical systems, preserving and in some cases extending their functions and capabilities. MCC distinguishes its research focuses on tight interaction between, and construction and integration of, the cyber physical system (CPS) and cyber virtual system (CVS), in which the CPS is immensely composed by computational and physical smart and mobile entities, and the CVS is mainly formed by cloud-based virtualized resources and services. Recent developments in augmented reality (AR) have demonstrated some of the application capabilities of MCC.

This article first focuses on a comprehensive study of existing MCC service models, and then a user-centric MCC service framework is presented. The rest of this article is arranged as follows. We summarize current mobile cloud service models based on the role of mobile devices. We illustrate the current representatives according to the different service models previously defined. We state the transformation from the traditional Internet cloud to the mobile cloud and highlight features of MCC. The future research directions of MCC are proposed, focusing on a new user-centric service model and corresponding application scenarios. Finally, we conclude this article.

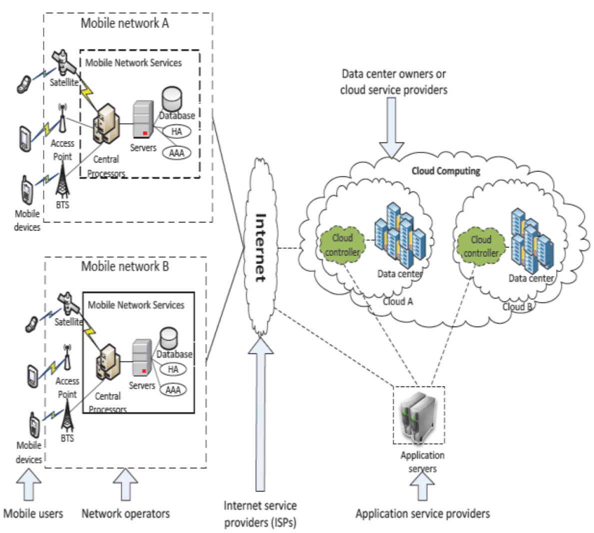
II. BACKGROUND STUDY

A. What is Mobile Cloud Computing?

"Mobile Cloud Computing at its simplest refers to an infrastructure where both the data storage and the data processing happen outside of the mobile device. Mobile cloud applications move the computing power and data storage away from mobile phones and into the cloud, bringing applications and mobile computing to not just smart-phone users but a much broader range of mobile subscribers". Aepona describes MCC as a new paradigm for mobile applications whereby the data processing and storage are moved from the mobile device to powerful and centralized computing platforms located in clouds. These centralized applications are then accessed over the wireless connection based on a thin native client or web browser on the mobile devices. Alternatively, MCC can be defined as a combination of mobile web and cloud computing [6], [7], which is the most popular tool for mobile users to access applications and services on the Internet. Briefly, MCC provides mobile users with the data processing and storage services in clouds. The mobile devices do not need a powerful configuration (e.g., CPU speed and memory capacity) since all the complicated computing modules can be processed in the clouds.

B. Architectures of Mobile Cloud Computing

From the concept of MCC, the general architecture of MCC can be shown in Fig. In Fig. mobile devices are connected to the mobile networks via base stations (e.g., base transceiver station (BTS), access point, or satellite) that establish and control the connections (air links) and functional interfaces between the networks and mobile devices. Mobile users' requests and information (e.g., ID and location) are transmitted to the central processors that are connected to servers providing mobile network services



Mobile Cloud Computing (MCC) architecture.

Fig1. Mobile Cloud Computing (MCC) architecture.

Here, mobile network operators can provide services to mobile users as AAA (for authentication, authorization, and accounting) based on the home agent (HA) and subscribers' data stored in databases. After that, the subscribers' requests are delivered to a cloud through the Internet. In the cloud, cloud controllers process the requests to provide mobile users with the corresponding cloud services. These services are developed with the concepts of utility computing, virtualization, and service-oriented architecture (e.g., web, application, and database servers).

III. EXISTING SYSTEM

A. Current Mobile Cloud Service Models

Current Internet clouds have been broadly classified in three service models: infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). They are classified according to the layers of virtualization. However, due to the involvement of both CPS and CVS, MCC's service models are more appropriately classified according to the roles of computational entities within its service framework, where the classification of MCC service models can use the roles and relations between mobile entities and their invoked cloud-based resource provisioning. Based on this view, existing MCC services can be classified into three major models: mobile as a service consumer (MaaSC), mobile as a service provider (MaaSP), and mobile as a service broker (MaaSB). These MCC service models are illustrated in Fig. 3.1, in which arrows indicate service processing flows from service providers to service recipients.

MaaSC is originated from the traditional client-server model by introducing virtualization, fine-grained access control, and other cloud-based technologies at the initial stage. Mobile devices can outsource their computation and storage functions onto the cloud in order to achieve better performance and more application capabilities. In this architecture, the service is one-way from the cloud to mobile devices and mobile devices are service consumers. Most existing MCC services fall into this category.

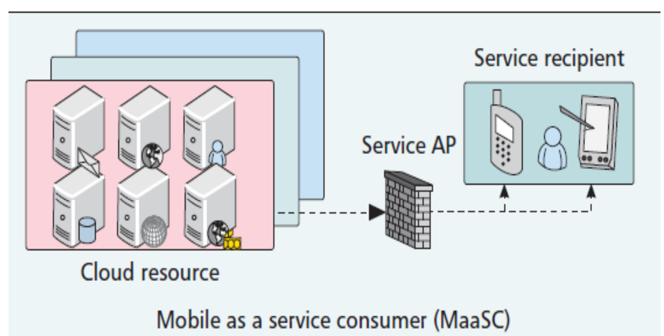


Fig2. Mobile as a Service Consumer

MaaSP is different from MaaSC in that the role of a mobile device is shifted from a service consumer to a service provider. For example, with onboard sensors (GPS module, camera, gyroscope, etc.), mobile devices are able to sense data from the devices and their neighboring environment, and further provide sensing services to other mobile devices through the cloud. In Fig3, consumers receive services provided by both the cloud and mobile devices. The types of services provided by mobile devices are diverse based on their sensing and processing capabilities.

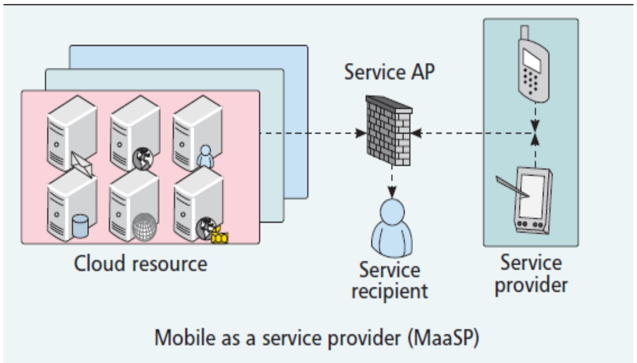


Fig3. Mobile as a Service provider.

MaaSB can be considered as an extension of MaaSP, where MaaSB provides networking and data forwarding services for other mobile devices or sensing nodes. MaaSB is desired under some circumstances because mobile devices usually have limited sensing capability compared to sensors that are dedicated for specially designed functionalities and sensing locations. For example, mobile phones can be used to collect users' physical activities. MaaSB extends the cloud edges to mobile devices and wireless sensors. Thus, a mobile device can be configured as a gateway or proxy providing networking services through various communication approaches such as 3/4G, Bluetooth, and Wi-Fi. Moreover, the proxy mobile device can also provide security and privacy protections to their interfaced sensors.

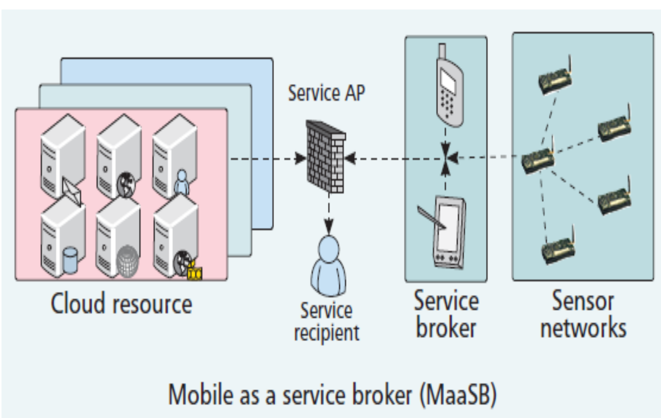


Fig4. Mobile as a service Broker

B. Existing Mobile Cloud Applications

We summarize existing MCC services and applications in Table. We discuss four major MCC service types and corresponding representatives. Each service or application can be categorized into one or multiple service models. MaaSC is the most common MCC service model because most existing mobile devices are still restricted by their computation and energy capacities. As an example, clonecloud provides computation task offloading service for mobile devices. In this case, the mobile device is the service consumer since it only benefits from the service provided by the cloud rather than providing services for other users.

	MCC services and applications	Service models		
MCC service types	Representative approaches	MaaSC	MaaSP	MaaSB
Mobile cloud computation	CloneCloud [3]	√		
	MAUI [4]	√		
	ThinkAir [5]	√		
Mobile cloud storage	Dropbox, Box, iCloud, GoogleDrive and Skydrive [6]	√		
	WhereStore [7]	√		
	STACEE [8]	√	√	
Security and privacy	CloudAV [9]	√		
	Secure Web Referral Services for Mobile Cloud Computing [10]	√		
	Zscaler [11]	√		
	Google Wallet [12]	√		
Context awareness	An Integrated Cloud-Based Framework for Mobile Phone Sensing [13]		√	√

Fig5. MCC services and applications.

1. **Mobile Cloud Computation:** Computation task offloading is a demanding feature for mobile devices relying on Internet clouds to perform resource intensive computation tasks. Partitioning computation tasks and allocating them between mobile devices and clouds can be very inefficient during the application runtime considering various performance metrics such as energy consumption, CPU usage, and network delay. How to efficiently and intelligently offload the computation tasks onto the cloud is one of the main research issues of MCC. CloneCloud and MAUI are two pioneer projects in this area. Both can automatically offload computing tasks to the cloud. CloneCloud serves as an application partitioner as well as an execution runtime environment that allows unmodified mobile applications to seamlessly offload parts of the executions from mobile devices onto a cloud server. The offloading decision is made by optimizing execution time and energy usage for mobile devices. In contrast to CloneCloud, MAUI allows modifying offloading applications at the coding level to maximize the energy saving of mobile devices. Thinkair [5] demands dedicated virtual machines (VMs) in clouds as part of a complete Smartphone system, and removes the restrictions on applications/inputs/environmental conditions by using online method-level offloading.
2. **Mobile Cloud Storage:** Storage capacity is another constraint of mobile devices. There are many existing storage services for mobile devices, such as Dropbox, Box, iCloud, Google Drive, and Skydrive [6]. Besides manually uploading the files or data onto the cloud, one desired feature of mobile cloud storage services is the automatic synchronization between mobile devices and the cloud. Multimedia data generated by mobile devices demands a

stable and highly available storage solution. This is the reason why many Smartphone operating systems natively implant the multimedia data synchronization feature (iCloud for iOS, Skydrive for Windows Phone, Google Drive for Android, etc.).

Moreover, mobile users' behavior data, such as location traces, browsing history, personal contacts, and preference settings, need to be kept in a reliable and protected storage space. Most existing commercial cloud storage solutions are built on a centralized data center, which is appropriate for Internet clouds. Storage mobility has gradually become a current research focus. WhereStore [7] is a location-based data storage solution for smartphones. It uses filtered replication (a filter expressing the set of data items that are likely to be accessed in the near future) along with each device's location history to distribute data items between smart phones and the cloud. STACEE [8] proposes a peer-to-peer (P2P) cloud storage where mobile phones, tablets, set-top-boxes, modems, and networked storage devices can all contribute as storage within these storage clouds. It provides a P2P cloud storage solution and addresses the storage issue for mobile users as a quality of service (QoS)-aware scheduling problem.

3. Security and Privacy: Security related services aim to provide data security protections through the cloud. The security of mobile devices can be enhanced under the help of cloud security mechanism including cloud-based secure proxy, remote anti-virus, remote attestation, and so on. CloudAV advocates such a cloud-based security model for malware detection for end hosts by providing antivirus as an in-cloud security service. Secure web referral services enable antivirus and antiphishing services through the cloud. Referral services depend on a secure search engine to validate URLs accessed by a mobile device to prevent mobile users from accessing phishing websites. Zscaler is one of the most well-known commercial cloud-based security companies, providing policy-based secure Internet access for mobile devices. It provides a comprehensive cloud-based security solution including three main components: ZEN (proxy), central authority (CA), and Nanologs server (log server). Various cloud-based security services are built based on these components.

For example, the *ByteScan* service enables each ZEN to scan every byte of the web request, content, responses, and all related data to block malicious actions and data such as viruses, cross-site scripting (XSS), and botnets. The *PageRisk* service relies on the ZEN to compute a PageRisk index for every page loaded and enables the administrator to control content served to their users based on an acceptable risk evaluation. The *NanoLog* service enables administrators to access any transaction log in real time. An increasing number of security features can be enabled in the cloud, in which a reliable and secure connection between a mobile device and the cloud is the main challenge for this type of solution. Google Wallet [12] was developed on a cloud-mobile dual trust root model, where the cloud is in charge of the application-level security such as credit card transactions and user credential management, and the Google Wallet enabled mobile device is protected by strong trust computing elements on the board to prevent malicious attacks on mobile devices.

4. **MCC Context Awareness:** Nowadays, a smart mobile device usually serves as information gateway for mobile users involving various personalized activities such as checking emails, making an appointment, surfing the web, locating some interesting spots, and analyzing personal behavior data based on data mining and machine learning. For example, in [13], each mobile device has a dedicated mobile cloud engine (MCE) including three modules: decision module, publish subscribe module, and context awareness module. The decision module handles and regulates the transactions among the different parts of the MCE. The publish subscribe module is responsible for establishing the data flow between the mobile application and the MCE. Finally, the context awareness module provides context information to the application. The state-of-the-art solutions lack a unified approach suitable to support diverse applications while reducing the energy consumption and providing intelligent assistance to mobile users.

IV. PROPOSED SYSTEM

A. Transitions from Internet Clouds to User-Centric Mobile Clouds

Current MCC Issues and Transition Directions From the service point of view, current MCC service providers and their customers (i.e., mobile devices) are clearly defined. Most existing computing models are similar to the traditional client-server service models. Several issues with existing MCC services are explained and the expected transition characteristics are also discussed below.

1. Symmetric MCC service model: Most current MCC service models are asymmetric. As shown by the examples presented in Table 1, mobile devices are usually considered as clients of cloud services. The service (e.g., computing and storage services) direction is mainly unidirectional, from the cloud to mobile devices. With the increasing capability of mobile devices, mobile devices can also collaboratively execute the applications' tasks.

Moreover, the virtualized environment should provide intelligent feedback to physical devices to adjust their behaviors or actions in order to provide better virtualized services. This virtualization-feedback loop model demands a symmetric MCC service model; that is, both mobile devices and the virtualized cloud are service providers as well as clients at the same time.

2. Personalized Situation Awareness: In the current complicated mobile cloud environment, data sources could be diverse (e.g., a mobile device, the environment, or a social network). Sometimes, a single data source is not sufficient to support MCC applications in the cloud; moreover, data collected from heterogeneous networks might be unstructured or unclassified. For example, in the physical world, there could be multiple networking interfaces and services that are available to a user's device (a wireless sensor network, social network, vehicular network, personal and body area network, etc.). The cloud should be able to get data from different source networks and then cluster them together to make the data structural and readable in the future. Thus, more work is expected to construct situation awareness services that can be personalized according to individual users in the virtual environment.

3. User-centric trust model: Most current cloud trust models are centralized: all mobile entities need to trust the cloud service provider. Storing private data in the cloud environment is a big hurdle for most mobile cloud applications. It is desirable to establish a distributed or decentralized trust management framework within the virtualized cloud system to address the privacy concerns of mobile users. In the physical world, the virtualized resource could be hosted in either public or private clouds that are tailored according to users' preference. This requirement demands that the current centralized cloud be transferred in a distributed or decentralized fashion. For example, including mobile users' computing and storage resources into the mobile cloud infrastructure without requiring (or even allowing) administrative privilege can significantly reduce the privacy concerns of mobile users.

B. User-Centric Mobile Cloud Computing

The next-generation MCC applications demand tight integration of the physical and virtual functions running on the mobile devices and cloud servers, respectively. Moreover, due to the mobility of mobile users and changes in the application running environment, the MCC application functions are not fixed on their running hosts. An illustrative vehicle traffic management example is shown in Fig6, in which a vehicle may request video capture (VC) functions from other vehicles directly (the dashed line) or through a centralized video fusion function to get a holistic view of the entire road intersection. In this example, the VC providers are not fixed and are selected by their location.

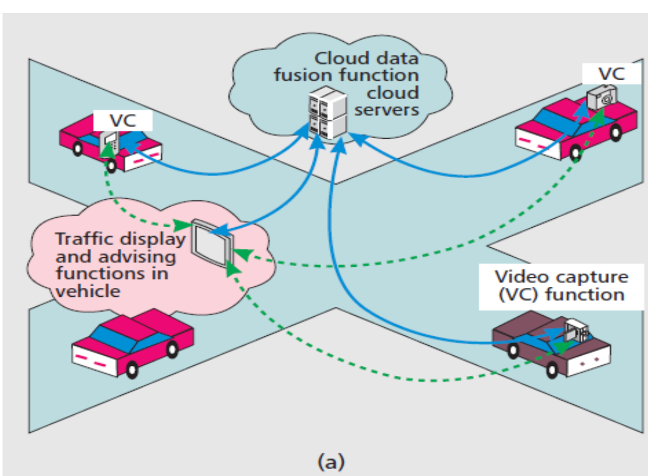


Fig6. MCC application scenario

Moreover, a VC function may not only be used for an individual vehicle; it can also be used for road traffic management, accident/hazard detection, and so on. The resources, including mobiles, cloud servers, and corresponding networking, that form an ad hoc cloud application running environment can be customized for each individual user; we refer such a customizable ad hoc cloud application running system as user-centric MCC.

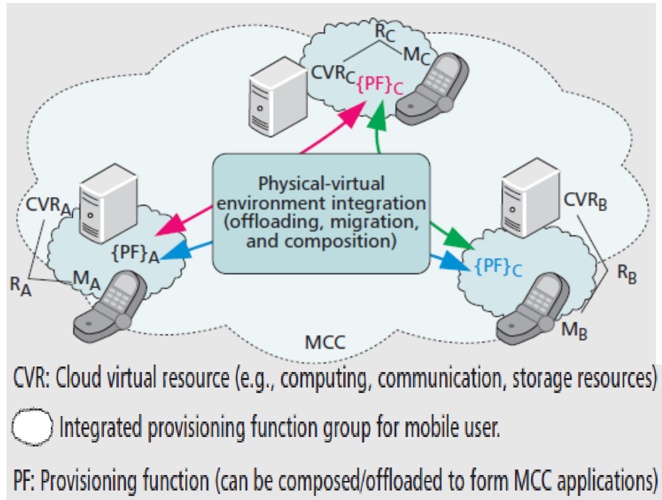


Fig7. User-centric MCC application model

The basic functions used to form this MCC application (VC, display, data fusion, etc.) are called provisioning functions (PFs). The user-centric mobile cloud application running environment can be further illustrated in Fig7, where mobiles (*MA*,*MB*, *MC*) and their responding cloud virtual resources (*CVRA*, *CVRB*, *CVRC*) construct a pair wise resource pool, *RX* = (*MX*, *CVRX*), including both physical and virtualized resources. *RX* represents user *X* constructing MCC applications formed by a set of PFs {*PF*} *X* running on local or remote resource pools. In this user-centric mobile cloud application running environment, a PF can be highly mobile, and composed and used by multiple applications at the same time.

C. Design Principles of User-Centric Mobile Cloud Computing

Future MCC should be reconsidered as a new service model, where mobile agents (i.e., both physical and virtual entities) and related resources collectively operate as mobile clouds that enable computing, storage, and networking capabilities, context awareness modeling, content discovery, and data collection and dissemination. To build future user-centric MCC based on the described concepts and requirements, mobile clouds should be shifted from the traditional Internet cloud by using the following principles:

• **Principle 1: User-centric:** MCC applications should be designed in such a way that a user can control their own data and activities with strong privacy and security protection.

Cloud resources should be collected and allocated according to mobile applications customized for each individual user.

• **Principle 2: Service-oriented application platform:** Due to the symmetric service model, every mobile node can potentially serve as an MCC service provider; thus, a service-oriented application platform is the natural choice for MCC.

• **Principle 3: Mobility efficiency:** MCC resources should be dynamically allocated and managed according to the need of mobile cloud applications. The mobility of MCC should be confined through a set of mobile cloud application constraints to maximize efficiency using a set of system performance evaluation metrics such as availability, computing power, storage, and their spacial-temporal boundaries.

• **Principle 4: Virtual representation:** MCC maintains a trusted, reliable, and accessible virtual representation for each user. The virtualized representation can be considered as an assistant for mobile users and performs actions such as sensing a user's daily activity to build the user's behavior and activity profiles, and delegate the user's activities in the virtual environment.

D. Mobile as a Representer: A User-CentricApproach

The future mobile cloud service model should be delivered based on the principles illustrated. Besides previously presented service models (*i.e.*, MaaSC, MaaSP, and MaaSB), we present a new user-centric MCC service model called mobile as a representer (MaaR). The architecture of MaaR can be found in Fig.8.

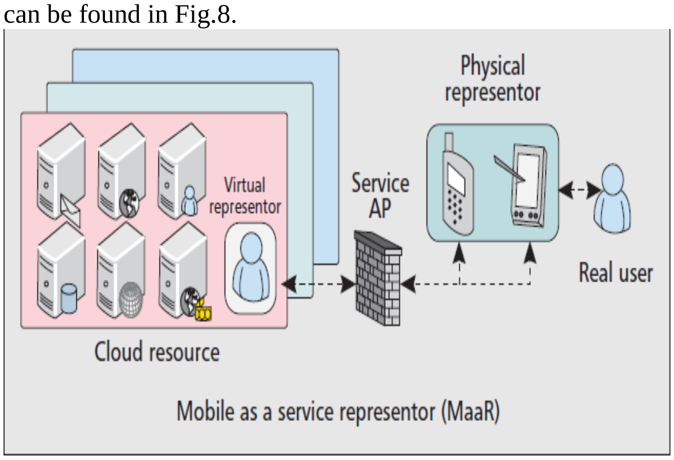


Fig8. Mobile as a Service Representer

In MaaR, each user can be represented by a virtualized entity in the cloud through his/her physical entity (i.e., mobile device). Users' behaviors and attributes can be collected from the real world (people, environment, or mobile devices) in real time and sent to their corresponding virtual entities in the cloud to perform further analysis and processing. Data mining and machine learning algorithms can be used to analyze a mobile user's situation and perform actions proactively. MaaR can be regarded as the next-generation MCC service model in that both physical systems and virtual systems are seamlessly integrated through virtualization technologies to provide services. In MaaR, the mobile devices and clouds are highly interactive, and as a result, the service flow can be presented as bidirectional arrows. In addition to helping mobile entities execute tasks more efficiently, MaaR is able to accomplish some tasks that are impossible to realize in current MCC architecture.

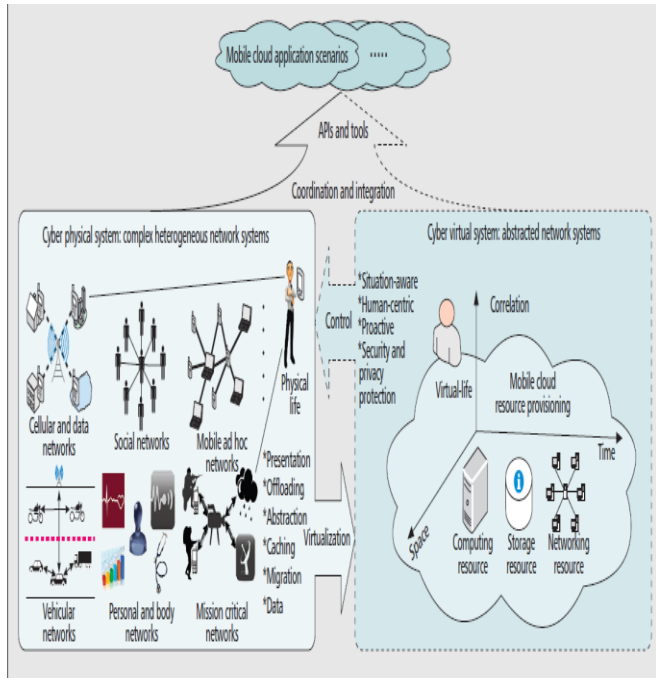


Fig9. A conceptual architecture of MaaR

MaaR model is presented to support the next-generation user-centric MCC services and applications. A conceptual architecture of MaaR is presented in Fig9. Where both CPS and CVS are integrated as a whole system.

In the CPS, heterogeneous networks coexist, and all these networks can be virtualized at the CVS by performing operations including presenting, offloading, abstracting, caching, migration and so on. All data with the spatial, temporal, and correlation information from the CPS will be submitted to the CVS. Among all these three types of information, correlation information is essential in that it helps to fuse different types of data together into a well formatted one so that the CVS can further perform context awareness, user-centric proactive, and security protection tasks. For example, the sensor network carries sensed data, while the social network collects and generates the social relationship data. The correlation information helps the CVS to generate sensing data with social attributes (e.g., personal data that is only accessible from a specific social group, like people in the user's friend list).

In MaaR, the CVS has three main types of provisioning resources: computing resource, storage resource, and networking resource. The user's virtual entity is represented by maintaining seamless communication between the CPS and the CVS, which also allows for establishing multiple personalized MCC clouds due to different application purposes. An MCC application is able to control integration of CPS and CVS through a well defined application programming interface (API) and MCC tools. The traditional

Internet cloud is one-way operational as users can only submit data from the CPS to the CVS, while it is possible to allow the CVS to further control the CPS functions in a highly adaptive and dynamic fashion based on the MaaR model. Besides physical data being virtualized to a virtual environment, the CVS can provide feedback and control functions in the CPS.

To enable the service-oriented application running environment, MaaR provides a personal on-demand execution environment for MCC (POEM) framework to achieve the user-centric MCC service running platform highlighted. POEM is a mobile cloud application execution platform that enables mobile devices to easily discover and compose cloud resources for their applications. For mobile resource providers, they may not even know what applications and who may call their provisioned functions beforehand. In this way, the mobile application design should not be application-oriented; instead, it should be functionality-oriented (or service oriented). To achieve these features, we can consider those PFs as the fundamental application components in the MaaR model, which can be composed by mobile cloud service requesters in runtime.

POEM takes a comprehensive approach by incorporating the OSGi-based service-oriented architecture into MCC. It treats the offloading as part of service composition, and as a result, the codes (or computation tasks) are considered as services provided by mobile devices and the cloud. In this way, offloading and migration operations can be multidirectional (i.e., among mobile devices and the cloud) compared to one directional (i.e., from a mobile device to the cloud) in previous solutions. Moreover, due to the popular Java-based OSGi framework, POEM can greatly improve the adoption of the SoA-based code reuse and composition for MCC.

V. APPLICATION ON MCC

A. An Application Scenario Based on the User-Centric MaaR Model

To better understand the proposed future MaaR model, we revisit the vehicular video sensing and collaboration example presented. We assume that MaaR service modules are already equipped on many users' smartphones. When user Alice is driving, her smartphone uses onboard sensors like a camera or GPS to detect her location, driving speed, and image/video captured on the road. The information can be collected and virtualized into the CVS to construct a virtual representation of the mobile device in the cloud for Alice, which is the essence of MaaR in that the virtual representer represents the real situation of the physical user. Practically, the representer is implemented through a set of software agents (i.e., OSGi bundles) on a dedicated VM allocated for Alice, where Alice has the administrative privilege on the VM to decide which data can be shared and protected (by encryption).

The dedicated VM is the application holder for Alice to incorporate various data processing models and functions for security, data mining, and intelligent situation-aware decision making that are personalized for Alice's use. In this model, the VM can be hosted in a public or private cloud as Alice chooses. User Bob may want to know the current traffic status around the bridge five miles ahead where Alice is driving. Users with MaaR services running on their mobile devices near the bridge can provide sensing functions (e.g., GPS, video/camera), which are searchable by Bob so that Bob's display function can call those functions in real time through either direct P2P connections or a centralized traffic monitoring function provided by a third party.

In addition to the presented video capturing usage of the application, MaaR services and applications can also maintain social diagrams for each user. For example, when Bob is driving in the area during lunchtime, the MaaR service representer of Bob can prepare for suggestions such as good nearby restaurants with high rates by Bob's trusted friends. Other suggestions may relate to Bob's daily activities and job functions according to his current location, and provide resources promptly when Bob needs them. These personalized suggestions are based on correlating the location and various sensed data by the MaaR service representor.

B. Other Applications of MCC

Mobile applications gain increasing share in a global mobile market. Various mobile applications have taken the advantages of MCC. In this section, some typical MCC applications are introduced.

1. Mobile Commerce: Mobile commerce (m-commerce) is a business model for commerce using mobile devices. The m commerce applications generally fulfill some tasks that require mobility (e.g., mobile transactions and payments, mobile messaging, and mobile ticketing). The m-commerce applications can be classified into a few classes including finance, advertising and shopping.

2. **Mobile Learning:** Mobile learning (m-learning) is designed based on electronic learning (e-learning) and mobility. However, traditional m-learning applications have limitations in terms of high cost of devices and network, low network transmission rate, and limited educational resources. Cloud-based m-learning applications are introduced to solve these limitations. For example, utilizing a cloud with the large storage capacity and powerful processing ability, the applications provide learners with much richer services in terms of data (information) size, faster processing speed, and longer battery life.

3. Mobile Healthcare: The purpose of applying MCC in medical applications is to minimize the limitations of traditional medical treatment (e.g., small physical storage, security and privacy, and medical errors. Mobile Healthcare (m-healthcare) provides mobile users with convenient helps to access resources (e.g., patient health records) easily and quickly. Besides, m-healthcare offers hospitals and healthcare organizations a variety of on-demand services on clouds rather than owning standalone applications on local servers.

4. Mobile Gaming: Mobile game (m-game) is a potential market generating revenues for service providers. M-game can completely offload game engine requiring large computing resource (e.g., graphic rendering) to the server in the cloud, and gamers only interact with the screen interface on their devices.

C. Other Practical Applications

1. Keyword-based Searching: An intelligent mobile search model using semantic in which searching tasks will be performed on servers in a cloud. This model can analyze the meaning of a word, a phrase, or a complex multi-phase to produce the results quickly and accurately.

2. **Voice-based Searching**: A search service via a speech recognition in which mobile users just talk to microphone on their devices rather than typing on keypads or touch screens

3. Tag-based Searching: A photo searching technique based on ontological semantic tags. Mobile users search only recall parameters that are tagged on images before such images are sent to a cloud. The cloud is used for storing and processing images for resource-limited devices. The current service is designed for the images stored on private cloud computing environment. In the future, it is expected to expand for searching images in a public cloud environment.

VI. ADVANTAGES OF MCC

1. Advantages of Mobile Cloud Computing

Cloud computing is known to be a promising solution for mobile computing due to many reasons (e.g., mobility, communication, and portability). In the following, we describe how the cloud can be used to overcome obstacles in mobile computing, thereby pointing out advantages of MCC.

2. Extending battery lifetime: Battery is one of the main concerns for mobile devices. Several solutions have been proposed to enhance the CPU performance and to manage the disk and screen in an intelligent manner to reduce power consumption. However, these solutions require changes in the structure of mobile devices, or they require a new hardware that results in an increase of cost and may not be feasible for all mobile devices. Computation offloading technique is proposed with the objective to migrate the large computations and complex processing from resource-limited devices (i.e., mobile devices) to resourceful machines (i.e., servers in clouds). This avoids taking a long application execution time on mobile devices which results in large amount of power consumption.

3. Improving data storage capacity and processing power: Storage capacity is also a constraint for mobile devices. MCC is developed to enable mobile users to store/access the large data on the cloud through wireless networks. First example is the Amazon Simple Storage Service which supports file storage service. Another example is Image Exchange which utilizes the large storage space in clouds for mobile users. This mobile photo sharing service enables mobile users to upload images to the clouds immediately after capturing. Users may access all images from any devices. With cloud, the users can save considerable amount of energy and storage space on their mobile devices since all images are sent and processed on the clouds. Flickr and ShoZu are also the successful mobile photo sharing applications based on MCC. Face book is the most successful social network application today, and it is also a typical example of using cloud in sharing images.

4. Improving reliability: Storing data or running applications on clouds is an effective way to improve the reliability since the data and application are stored and backed up on a number of computers. This reduces the chance of data and application lost on the mobile devices. In addition, MCC can be designed as a comprehensive data security model for both service providers and users.

For example, the cloud can be used to protect copyrighted digital contents (e.g., video, clip, and music) from being abused and unauthorized distribution. Also, the cloud can remotely provide to mobile users with security services such as virus scanning, malicious code detection, and authentication. Also, such cloud-based security services can make efficient use of the collected record from different users to improve the effectiveness of the services. In addition, MCC also inherits some advantages of clouds for mobile services as follows:

1. **Dynamic provisioning**: Dynamic on-demand provisioning of resources on a fine-grained, self-service basis is a flexible way for service providers and mobile users to run their applications without advanced reservation of resources.
2. **Scalability:** The deployment of mobile applications can be performed and scaled to meet the unpredictable user demands due to flexible resource provisioning. Service providers can easily add and expand an application and service without or with little constraint on the resource usage.
3. **Multi-tenancy**: Service providers (e.g., network operator and data center owner) can share the resources and costs to support a variety of applications and large number of users.
4. **Ease of Integration**: Multiple services from different service providers can be integrated easily through the cloud and the Internet to meet the users' demands.

VII. CONCLUSION

Mobile cloud computing is one of mobile technology trends in the future since it combines the advantages of both mobile computing and cloud computing, thereby providing optimal services for mobile users. According to a recent study by ABI Research, a New York-based firm, more than 240 million businesses will use cloud services through mobile devices by 2015. That traction will push the revenue of mobile cloud computing to $5.2 billion. With this importance, this article has provided an overview of mobile cloud computing in which its definitions, architecture, and advantages have been presented. The applications supported by mobile cloud computing including mobile commerce, mobile learning, and mobile healthcare have been discussed which clearly show the applicability of the mobile cloud computing to a wide range of mobile services. This article focuses on the introduction of MCC concepts and is tutorial in nature so that readers are able to have a holistic view of the current development of and vision for user-centric mobile cloud computing. We first provide a classification and representative achievements of current MCC service models. Then we discuss the transformation from the traditional Internet cloud to the user-centric mobile cloud by listing the issues for current MCC and presenting user-centric MCC and its design principles. Finally, a MaaR service model with an illustrative example is presented for achieving the user-centric MCC. Then, the issues and related approaches for mobile cloud computing (i.e., from communication and computing sides) have been discussed. Finally, the future research directions have been outlined.

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