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CLOUD-ASSISTED MOBILE AUGMENTATION

"Computers don't introduce order anywhere as much as they expose opportunities."

2.1 INTRODUCTION

People are becoming more and more dependent on hand-held devices for the fulfillment of their computation needs. The load, as well as expectations from mobile devices, have increased drastically because of their handiness or portability. On the contrary, mobile devices fail to accomplish the expectations of the users due to the limitation of resources. Mobile devices can perform very well if accompanied by a large amount of resources which is not practically feasible. However, the emergence of the cloud has proved to be very beneficial for the mobile devices as they can utilize the cloud resources located in remote locations to perform heavy resource-intensive applications which were otherwise not feasible to perform. Mobile cloud computing (MCC) has given rise to various concepts such as load sharing, remote execution and cyber foraging to boost the computing capabilities of mobile devices. These concepts are implemented by running resource-intensive applications of mobile devices on their respective surrogates which are present in the cloud. Cloud computing can be seen as a computing model providing resources to mobile devices on an on-demand basis along with ensuring some factors like elasticity, availability, low cost and security. The adoption of cloud-based resources has increased or in other words, augmented the capabilities of mobile devices. The amalgamation of cloud computing and mobile augmentation concepts gave rise to cloud-assisted mobile augmentation (CMA). CMA is a cutting-edge technology that provides augmentation of mobile resources by leveraging the concepts of cloud computing in the context of mobile computing. It can be seen as a computing model that enhances the capabilities of mobile devices by allowing these devices to augment

- *Decision-making Engine:* It is responsible for taking necessary actions related to the augmentation technique. There may be scenarios where we may have data related to our requirements, but we don't know whether to adopt augmentation approach or not. Decision-making engine helps us by making that decision for us.
- *Resource Scheduler:* The scheduling of resources on the mobile end as per the task requirements is done by the resource scheduler. It is responsible for distributing the resources at the mobile end and leaving rest of the task for the cloud end for execution.
- *QoS Management:* This block holds the responsibility of maintaining the quality of service being provided to the mobile user whether augmentation takes place or not.
- *Monitoring and Profiler:* The execution of the task and its performance is continuously monitored by this block and results are submitted to decision-making engine which can later on decide whether to change the course of actions for performing a task or not.
- *Communication Handler:* Message passing and communication between different blocks and components within a mobile device are handled and maintained by the communication handler. It ensures continuous communication between devices.
- *Analyzer and Optimizer:* With respect to the progress of task execution, a certain set of factors are monitored by the monitoring and profiler block. Results generated are analyzed by this block in order to perform any optimization, if possible.
- *Synchronizer:* While following any CMA based approach, it is necessary that the mobile device stays synchronized with the cloud at all times. It is the duty of the synchronizer block to maintain that synchronization between both the ends.

The building blocks address specific functionalities for any CMA model to work. Isolation is maintained between different blocks which means that these building blocks are independent of working of one another.

For instance, during the process of augmentation, the local application data and the remote application data need to be synchronized to ensure reliability. This function is performed by the synchronizer building block. The decision-whether to adopt augmentation or not is taken by the dsecision-making engine. Analyzing the resources required for

- *Energy Resources:* Mobile devices are energy hungry devices which need a continuous level of the battery to carry on the execution of their ongoing processes. Manufacturers are making compact, handy and lightweight mobile devices which restrict the amalgamation of high capacity batteries with them. Moreover, there is also a risk of battery explosion associated with every mobile device. With small and light batteries, this hazard can be handled but with large capacity batteries, such kind of hazards can turn out to be catastrophic for human lives. Thus, considering the user safety, installation of heavy batteries in mobile devices is avoided. At present, the battery demand of mobile devices is handled by using a lithium-ion battery which lasts soon if the device is performing prolonged computations. Researchers are trying to increase the battery life by reducing the energy overhead spent on OS, hardware, application requirements, networks, etc. Coming to the concept of CMA, in the absence of long-lasting batteries, the processes and applications can be run on cloud thereby saving the battery level of mobile devices. The battery of mobile device will be consumed only in the communication between cloud and the mobile device; the rest of computation is performed and handled by the cloud itself. CMA has also proved to play a major role in enhancing mobile and omnipresent computing.
- *Local Storage:* Mobile users face shortage of storage space on their hand-held devices. They demand huge storage space so that they can easily roam around with a large amount of digital data in their hands. Digital content such as audio, video, contacts, images, videos, files, etc., require a huge storage space whereas mobile devices, on the other hand, have small space available on them; usually a few gigabytes. Moreover, available storage space in the mobile devices is predominantly occupied by running services like applications, system files, music and video files. Such kind of issues usually leads to a deceleration in the adoption of mobile devices. Adoption of CMA approach has the potential to help the users facing this problem. CMA adoption will leverage the cloud to solve the problem of storage space. Cloud offers its users with a view of unlimited storage capacity and users can thereby use this space to store their huge amount of personal data with less overhead charges.
- *Visualization Capabilities:* Mobile devices usually have a lower screen resolution as compared to tablets, desktops, laptops, etc. Moreover, mobile device screen visualization capabilities are bound

by the energy factors and manufacturing techniques which do not allow them to be of significant size and resolution. Different software techniques like screen switching, tabular sections, multiple desktops, accelerometer, verbal techniques, etc., are needed to avail the smart screen visualization on mobile devices. Conversely, all of these software techniques require intensive computations which, in turn, drain batteries of these devices. A possible alternative to this problem is to use CMA approach to augment the computing capabilities of the software based techniques which are required to enhance the visualization capabilities. The software-based techniques are then allowed to run on the cloud so that the mobile device experiences lesser shortcomings and runs only the results provided by the cloud.

- *Privacy, Data Safety, and Security:* While taking the advantage of online resources, mobile users can also make themselves more susceptible to online threats and security breaches. Cyber crime has increased tremendously in the recent times and attackers have their ways to breach the security guidelines and can thus easily harm the mobile user in various ways. Mobile users have their personal information online like bank information, personal data, online purchases, credentials, etc., which is prone to be attacked and the resource restrictions of mobile devices limit the implementation of complex techniques to ensure security. Mobile users can thus augment the capabilities of their devices to execute security checks on their data by using the CMA approach. The security levels can be checked by using software techniques which will be executed on the cloud itself.

2.3 DIFFERENT TYPES OF CMA

Augmentation is a process which focuses on enhancing the capabilities of a mobile device in terms of computational, communicational or data-intensive capabilities. The main aim of CMA is to augment the resources of mobile devices from every available aspect. Depending upon various different scenarios, we can classify augmentation into five types. These five major types of augmentation are explained below.

2.3.1 Primary Functionality Outsourcing

Computing-intensive software as well as applications such as voice recognition, natural language processing, etc., need a large amount of resources to function properly which is something mobile devices do it does not demand availability of the Internet at all times. Whenever the user is online, the states (local and remote) can easily be synchronized.

2.3.3 Mainline Augmentation

This type of augmentation lies in between the primary functionality and background augmentation. The user can execute the application in any way he wants to whether to use primary or background augmentation. The application works in a mixed manner under mainline augmentation. For instance, a running application can be sent to the background, can be invoked back again anytime the user wants to, and it can then be run in a synchronized way (primary functionality augmentation).

2.3.4 Hardware Augmentation

Hardware augmentation aims at augmenting the hardware capabilities of mobile devices. The major hardware resources that a mobile device possesses are CPU, memory, storage, screen and battery. Augmenting the hardware resources is a tedious task because of a number of challenges such as:

- First of all, enhancing resource capabilities of mobile devices like making large screens, using powerful processors, and a huge amount of storage accounts for an increase in heat, size and weight of the mobile device. Deploying these enhanced resources in mobile devices is difficult as it decreases the handiness of the device.
- Secondly, the applications drain a large amount of battery. Even when they run partially in the background, they consume a large amount of energy resources and thus demand of powerful long lasting battery arises. Making large, more capable long lasting batteries is difficult to deploy, and occurrence of any kind of haphazard event can lead to catastrophic loss.
- Moreover, an increase in hardware capabilities will increase the price and unlike stationary systems; the components of modern mobile devices are not upgradable.
- The user needs to buy a new device if he wants an upgradation of hardware components of its device. Therefore, in the absence of futuristic techniques and due to the above-stated reasons, the hardware augmentation progress turns out to be real slow and expensive.

2.3.5 Augmentation Through Multiplicity

As the name indicates, multiple copies of the system image are used to run different processes in parallel. For a mobile device achieving augmentation through multiplicity, multiple types of data are handled and are processed simultaneously. This is beneficial when we need to make a decision for something where many options are available. We can select the best option by processing these system images in different scenarios. For instance, to execute a process, suppose we need to select the most optimum path among the n available paths. We can use the system image n times, to estimate the execution process cost for each system image. The most optimum process can then be selected based on the results.

2.4 TECHNOLOGIES UNDER CMA

Cloud-assisted Mobile Augmentation is largely achieved by implementing techniques relating to cloud computing. CMA is termed in a broader phase where it accounts for other technologies that augment the capability of the device. There are three major technologies that lead to the coining of this term 'CMA' as discussed below. All these three technologies focus on increasing and optimizing the capability of the mobile device by using other available resources. These technologies are concerned about the local resources of the mobile device and try to augment its capability as much as possible by leveraging resources at the cloud end. The only assumption with these technologies is that all the components and data related to the application are stored on the mobile device.

2.4.1 Load Sharing

Load sharing can happen when an entity, having a lot of workloads shares its load with another entity which is capable of handling that additional load. Mobile devices due to their low resource availability fail many times to handle the load of processes and applications that are running on them. The user demands the device to handle the load and hence, to upgrade the performance of the device, load sharing is done. The data related to the applications (which are considered for sharing) is sent to the nearest available resource. That resource calculates the results whether the sharing will be beneficial or not by accounting

2.5 WHY OR WHY NOT CMA

In the case of utilizing cloud resources, cloud-based mobile augmentation services have given advantageous results in most of the cases. Use of CMA has a number of significant advantages, among which some are discussed below:

2.5.1 Advantages of CMA

- *Empowered Processing:* A state of increasing virtual transaction execution per second and extending memory which influence the cloud-based mobile augmentation approach is called *empowered processing*. Smartphone developers are trying very hard to make mobile devices which can handle all kinds of compute-intensive mobile applications. Due to storage, CPU, resource, energy constraints, etc., mobile devices fail to achieve the need of the hour. Cyber foraging solved this problem for a wide number of mobile users. Even though the surrogates in augmentation process are able to serve the mobile users' demands, the denial of service or interruptions in providing quality service to mobile users may harm the user experience which, in turn, proves out to be disadvantageous to augmentation approaches. Cloud service providers while providing services, guarantee the availability of cloud resources along with a level of reliability. While benefitting from the cloud-based mobile augmentation process, mobile application developers do not bother to restrict their resource demand. Under the availability of cloud resources, they make applications with high demands to facilitate and please the user as much as possible. Talking of another side, latency, cost overhead, processing delay, etc., are the other factors which shadow the augmentation and cloud benefits.
- *Expanded Storage Capacity:* Mobile users nowadays want to use a large number of digital variant applications. These high resource-intensive applications need cloud storage and computing capabilities. Cloud computing offers a solution to this problem by providing the user with virtually unlimited storage space. The user can store as much data as he wants to store on cloud and can pay for it accordingly. Storing the information of these applications on the cloud makes the mobile user free of any responsibility. Mobile users can simply connect and use the application without bearing the headache of

- *Enriched User Interface:* Inability of mobile devices to provide their owners with visualization of high graphics leads to poor user experience. Cloud services can assist us with 2D or 3D visualization as they have the ability to perform complex, challenging tasks. Cloud servers can carry out complex visual tasks and can even compress-stream those visualizations to fit a mobile screen. This enriches the mobile device with high level complex visual effects which makes it capable of providing a better user interface.

Apart from the advantages we discussed, CMA's success is still restricted because of the various disadvantages. Some of these disadvantages are discussed briefly as:

2.5.2 Disadvantages of CMA

- *Dependence on the Performance Oriented Networking Infrastructure:* In order to fulfill the inter-domain communication necessities, CMA advances in the direction of networking infrastructures. These networking infrastructures include two categories, wireless and wired networking infrastructures. In wireless domain, CMA aims for achieving the goal of computing anywhere, anytime, from any number of devices. For this, CMA requires a certain level of performance with respect to factors like reliable, fast, performance oriented, robust and high bandwidth wireless communication. Whereas in wired communication, speedy and dependable communication base is mandatory in order to facilitate migration (can be live) of computation and heavy data to the cloud-based resources in the affinity of the mobile user.
- *Disproportionate Communication Operating Cost and Traffic:* In today's trending world, the number of mobile users is increasing drastically. These users require the utilization of cloud resources for carrying outintensive computational tasks. This dissipation of cloud resources by a large number of mobile users leads to increase in data traffic. CMA operations like mobile computation offloading or cyber foraging, data storage, data retrieval, live migration, etc., are the leading factors which account for the increased traffic and packet loss. The management of such irresistible traffic turns out to be challenging when seen in the context of wireless communication. As a result, we observe degradation in functionality and performance of applications which results in overall degradation of user experience.
- *The Complexity of Application Development:* Increasing competition in the mobile application market has made application development

a bit more demanding. Mobile application developers need to be well aware of various platforms in order to make their applications popular and successful. Developers need to acquire extensive knowledge about fields like interfaces, data structures, languages, interfaces, cloud OS, etc., so that they can amalgamate cloud resources to the mobile devices. Understanding and imposing such complex criteria impose a financial burden on the mobile application developers. This leads to decreasing the success of CMA-based mobile applications.

- *Paid Infrastructure:* Cloud service providers charge mobile users based on the utilization of their cloud resources, i.e., pay per usage. Mobile users reimburse their according to the service level agreement conferred with the cloud service provider. This acts as an incentive for the cloud service providers who provide the users with appropriate resources along with their maintenance. In certain circumstances, mobile users demand specific functionalities like local execution, transfer of their data, QoS, etc., for which they have to pay additionally, thereby resulting as a disadvantage.
- *Inconsistent Cloud Policies and Restrictions:* Cloud service providers impose certain policies and restrictions for controlling the quality of service being provided to the mobile users. They impose these restrictions by using some intermediate applications (bulk loader, GAE, etc.) between the cloud resources and the mobile users. These restrictions and policies are implemented by cloud service providers, and they may subject to change. This is a major challenge for the augmentation of mobile devices. Hence, it is mandatory to revise policies and restrictions in order to comprehend intense mobile computing and for meeting the MCC requirements.
- *Service Negotiation and Control:* Most of the policies and cloud-based agreements are not negotiable, and they may change over time as per the convenience of the cloud service provider. On the other hand, mobile cloud users need to negotiate and act in accordance with the terms and conditions of the cloud service provider. In the absence of a third party authority, mobile cloud users are not certified with providing them a service level of performance and service oriented commitments.

2.6 CLOUD MODELS BASED ON MOBILITY

Cloud-assisted mobile augmentation basically tries to augment or enhance the computing capabilities of resource constrained mobile

- *Proximate Immobile Computing Entities:* This model comprises stationary systems which are nearby located in the vicinity of the mobile user. These computers are generally located in public places like shopping complexes, airports, restaurants, eating outlets, etc., and are thus easily available to the mobile users for use. As per the observations, it has been observed that these computers do not perform any heavy computations. They just play music or play advertisements and simply perform the light computation based tasks. Most of these systems sit idle and may even have the connectivity to the Internet. Thus, they facilitate the nearby mobile users by providing them with abundant resources so that they can perform their heavy computations on these systems. These resource-rich systems prove to be very advantageous to the resource-constrained mobile devices. The architecture of proximate immobile computing entities is also distributed due to the varying locations of these public systems. Proximate immobile computing entities provide a moderate level of computing heterogeneity, availability, scalability, computing flexibility, power efficiency, resource intensity, execution performance whereas they lack in terms of complexity, sensing capabilities, execution latency, communication latency and maintenance complexity.
- *Proximate Mobile Computing Entities:* This cloud model comprises the mobile computing devices like tabs, highly equipped smartphones, and minicomputers, etc., which are in the vicinity of the mobile clients. These devices act as servers for the nearby mobile users who can benefit from these devices. The mobile devices on both sides (server and user) have mainly ARM-based devices and mobile OSs. This largely solves the problem of heterogeneity in hardware, software, and platform between mobile devices. The available devices or servers have unutilized resources most of the time which can be utilized by the nearby mobile devices. This utilization of nearby resources increases the security risk among the users. This poses a major threat to confidential information of the mobile user which can be accessed by another unauthorized person. Apart from providing low security, trust and communication latency, proximate mobile computing entities perform well in case of sensing capabilities, computing heterogeneity, computing flexibility.
- *Hybrid (Converged Proximate and Distant Computing Entities):* Such kind of clouds are modeled on the basis of an idea

comes to design and implementation of further phases of CMA implementation. The decision-making factors are categorized in five parts and are explained as:

- *Mobile Device:* In order to perform augmentation, local resources such as memory, CPU and storage form an important base for augmentation. Along with these native resources, energy is considered a critical resource due to the short lifespan of batteries. Maintaining a level of trade-off between device's battery and the energy consumed by augmentation approaches is important. Even the communication ability like 2G, 3G, and Wifi are important for the offloading process. All these bounds are subject to decide whether to adopt for augmentation or not.
- *Contents:* The nature of content which is considered is also crucial for taking the decision of augmentation. Attributes such as the granularity of code, code size, data type, data volume, etc., all play an important role. For example, local processing can be done in the case of latency small sensitive data whereas in the case of big volumes of sensitive data, processing as well storage should be done at cloud end.
- *Augmentation Environment:* Augmentation largely depends on the communication ability via which major portion of tasks is carried out. The significant benefits of augmentation approach (low-cost, available, scalable) are drastically affected by the quality of communication which comes out to be intermittent, unreliable, risky in a number of cases. It thus becomes challenging to find a suitable communication method which can ensure factors like required bandwidth, congestion, latency delays, utilization, etc. These factors are important to ensure a good quality of service to mobile users who face restrictions due to their wireless communication medium when specifying remote servers at runtime. Augmentation approaches should be agile and dynamic in nature and allow any change to reflect instantly in the mobile environment.
- *User Preferences and Requirements:* There is a section of users which considers the Internet a risky place to carry out their tasks while some users demand to access cloud services via the Internet on the other hand. Therefore, mobile users should be able to adapt through the technical as well as through non-technical requirements while implementing augmentation approach. They should be able to customize their needs, and they can even improve their experience

by analyzing the available options and selecting the most appropriate one.

- *Cloud Server:* Cloud-based augmentation approaches when implied to mobile device tends to enhance its computing needs. Augmentation approach leverages the available cloud resources, and hence a large amount of its credibility and performance depend on the usage of cloud resources. Utilization of cloud resources while augmenting mobile devices gives tremendous results under various factors such as elasticity, cost-effectiveness, availability, vulnerability to attacks, reliability, performance, etc.

2.7.2 Limitation Factors

The level of performance of augmentation solutions keeps on varying due to several factors. These factors pose a limitation on the performance of augmentation solutions. Major factors among these are described below.

- *Heterogeneity:* Mobile cloud computing can be considered a combination of cloud computing, mobile computing, and networks. These three diverse domains enhance the level of heterogeneity to new heights. Although heterogeneity provides the mobile users a level of choice among various alternatives, but it also poses a great number of challenges and limitations to the CMA approaches. Different mobile platforms like iOS, android, Symbian, etc., have diverse hardware architectures and pose strong inhibition on portability of applications and data. While porting an application from one device to another, this heterogeneity poses a challenge. Hardware, cloud service, application, platform, etc., all of these factors come with heterogametic behavior and inhibits the interoperability in mobile cloud computing domain which, in turn, affect the augmentation benefits.
- *Data Volume:* The volume of data used in today's digital components is exponentially increasing. It severely affects the augmentation process. The present implemented technologies, and wireless communication is not up to the mark to match the pace of this huge amount of data. Storing such a huge data is often difficult and demands data partitioning and distribution. Storing such humongous data not only mitigates data integrity and consistency but also makes data management a significant need in MCC. This challenge thus impacts the efficiency of augmentation approaches.

provider. Whenever the communication link between the two parties is lost, the application is asked to perform locally on its respective device or is requested to initiate its augmentation again. Some processes prefer local execution as they cannot bear the communication costs, if once the link is broken. Therefore, due to the heterogeneous environment of communication, the demand for seamless connectivity becomes a challenge for successful augmentation of CMA-based processes.

- *Computing and Temporal Cost of Mobile Distributed Execution:* When complex resource intensive applications are executed on the cloud, there exists an overhead of computation and communication costs of migration. The sending and receiving results of the application between the cloud and the mobile device is another challenge for CMA based applications. This challenge is further intensified by the problem of seamless communication as discussed above. The distance between the cloud and the mobile device can be reduced by the use of local or proximate clouds which exist in near proximity of the user. These clouds can be interlinked to the actual cloud service provider and may service the mobile user on their behalf. This is only possible by having the knowledge of provider's performance, demands of the application and with some mechanisms such as resource discovery, resource allocation, service and consumer mobility management, etc. These efforts are necessary to enhance the CMA and its vision as well.
- *Autonomic CMA:* With the increase in adoption and implementation of CMA, the volume of user's data stored on the cloud is increasing rapidly. This high level of complexity can be dealt with by using the autonomic techniques, use of which can thereby decrease the level of complexity as viewed by the mobile user. Autonomic methods such as management, optimization, protection, etc., can be used for the ease of adaptation of the mobile user with any heterogeneous environment and also for dealing with their related complexities.
- *Application Mobility Provisioning:* In a CMA based approach, the mobile user, as well as the cloud service provider, are free to move anywhere when augmentation takes place. This free-to-moveability of both the parties makes code mobilitya challenge. Therefore, as compared with the traditional augmentation approaches, the code mobility is difficult to attain in CMA based approaches. Moreover, factors like service disruption, loss of connectivity, intermittency,

etc., result in a poor level of service user experience. The provisioning of code mobility or application mobility thus becomes a challenge for CMA based approaches.

2.9 SUMMARY

The smartphones which we use today somehow lack the resource requirements of resource-intensive applications. Cloud-assisted mobile augmentation provides a way to leverage the cloud computing concepts in order to optimize and enhance the computing resources for mobile devices. In this chapter, we discussed the techniques and concepts that eventually lead to the coining of term cloud-assisted mobile augmentation (CMA). We try to explain the reasons for going with or without CMA. Cloud models based on their mobility are also discussed in this chapter. The end of the chapter covers some of the recent works and future directions pertaining to CMA.

EXERCISES

1. How can you say that cloud-assisted mobile augmentation can be considered a superset of all the concepts which target to increase the capability of mobile devices?
2. Provide the scenarios where a mobile user should adopt for cloud-assisted mobile augmentation.
3. What are the responsible factors that lead to the adoption of term CMA?
4. What are the different types of CMA? Explain the differences between each one of them.
5. What are the technologies that constitute CMA?
6. Define the decision-making parameters and limitation factors with respect to CMA.
7. Discuss the various cloud models based on their mobility and also their relationship with CMA.
8. Discuss the future aspects for CMA.
9. Design a scenario where we can adopt an approach which falls under CMA.

GLOSSARY

Accelerometer: Proper acceleration, G-force, tilt and motion are measured by an electromechanical device called accelerometer.

Amazon EC2: Amazon Elastic Compute Cloud is used to provide services to users where they can spawn their own virtual instances on which they can run applications they desire with virtually unlimited storage capacity.

Bulk Loader: It is a command line utility which loads metadata into BEA Virtual Content Repository by scanning the directory structures where the content is stored.

Cyber Foraging: Cyber foraging is a term coined by M. Satyanarayanan in 2001. It is a technique to hamper the concepts of pervasive computing by allowing mobile devices to offload their resources hungry workloads on a nearby resource rich computational entity.

GAE: Google App Engine is a cloud-based platform used for developing and deploying applications on the data centers of Google. Developers are provided with their own sandbox where they can deploy their own custom built application. It is a prominent example of Platform as a Service (PaaS).

QoS: The quality of a service is a term which suggests that we can measure and improve the performance of a service by measuring parameters like transmission rates, error rates, downtime, etc.

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