# Enabling Real-Time Mobile Cloud Computing through Emerging Technologies

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# Preface

This book contains a collection of tutorial and research articles related to real-time Mobile-Cloud Computing, which is the state-of-the-art computational infrastructure for running advanced mobile applications. When the *real-time* constraint is placed on mobile applications, every possible resource surrounding these devices is stretched to its limits: Even to merely offload the application to the cloud, mobile devices have to meet certain computational, storage, and memory requirements. The communication network must be fast enough to handle reasonable data rates during this offloading process. Additionally, even the definition of the term *offloading* is a topic of research. This book is meant for graduate-level students who are pursuing research directions in advanced mobile-cloud computing. Faculty members who are interested in this research field will also benefit significantly from this book. To understand the motivation behind this book in a lot more detail, let's look at the evolution of mobile cloud computing.

Using an analog mobile phone two decades ago that weighed more than a kilogram (probably half of which was the battery), I welcomed every generation's improvement on mobile phones that made them lighter. It also was equally important that I could use the phone for two, three, or four hours without having to charge it. If a mobile phone's battery lasts for two hours, it hardly qualifies to be called *mobile*, whereas, being able to use it for a full day without charging it makes it a useful mobile device that can be enjoyed throughout one's entire day. An average user had his/her priorities in weight and battery life two decades ago, since these two were the limiting features within that time frame.

All of this started changing a decade ago when things started shifting from these big bulky analog phones to digital ones that you could carry inside your pocket throughout the day. In my mother language Turkish, a cell phone is still called a *pocket phone*, having its origins in this era. I wouldn't be surprised if similar terms are associated with cell phones in other languages. Digital phones owed their success to more sophisticated digital data encoding techniques as well as the progress of VLSI technology that afforded IC (chip) designers to cram more transistors into these chips. More transistors meant more processing, allowing increasingly more sophisticated digital encoding, which in turn yielded higher communication rates. Once you could put a sufficient number of transistors into a device, the device could do much more than just phone calls. I specifically remember Blackberry introducing a device that is capable of receiving and sending emails a decade ago. Right after this, my wife and I purchased a Palm Treo device that could also have *Calendar* and *Contacts*. This is the time frame when *Personal Digital Assistants* (PDAs) were separate handheld devices, not associated with *phones*. I remember a company selling a GPS attachment for our Palm Treo units. I bought one, and was ready to use it despite its messy connection cables and bulkiness. I could just never get it to work stably. I guess this technology was *too* soon. I returned it. This shows how receptive I was - as an average user - to new functionality that could be built-into my phone and could improve my life.

Despite such unsuccessful attempts as the external GPS functionality I just mentioned, the introduction of the PDAs and added functionality inside the phones sparked an avalanche of interest within tech enthusiasts and business folks that wanted to use these devices for business functions: as a calculator, email device, storing contacts, or whatever else you could introduce at a reasonable price. To be able to perform these functions, Palm and Blackberry had to incorporate a *Radio Processor* (or B*aseband Processor*) and an *Application Processor* into these devices. The Radio Processor was responsible for the *phone call* functionality, implementing the previously mentioned sophisticated data encoding and communication. Application Processor, on the other hand, was responsible for turning the phone into a computer (almost). It was only a matter of time when the Application Processor became sophisticated enough to turn this device into a full-blown computer, and was eventually accompanied with his sister: *Media Processor*, which was responsible for heavy-duty signal or image processing. For this to materialize, a lot of simultaneous progress was needed in different fields: VLSI technology had to advance to a point where hundreds of millions of transistors could be built into the Application and Media Processor chips, and, major advances in Computer Architecture were needed to make sure that, this device could operate at a very low (1W or 2W) power budget, while delivering the computation that these applications needed. Battery technology didn't advance as fast as the previous two, but a deeper understanding of the Lithium Ion rechargeable batteries a allowed more intelligent usage of them, which in turn increased battery life.

The term *smart phone* originates in this era, when mobile devices could perform so many different functions that, they even started communicating with their user to improve Human-Computer Interaction (e.g., the Siri on the iPhone and many similar implementations in other brands).We are now in an era where these smart phone devices are an indispensible part of human life, connecting us to the internet and social networks. The breakneck speed in application development put almost every imaginable application in the market which can be inexpensively purchased and run on smart phones and the next natural question is: what do we go from here ? The previous half decade has seen an explosion of research interest in answering this question. With very stable and fast connections to the internet backbone, smart phones' capabilities were no longer limited to their own hardware. One parallel development effort aimed to take advantage of an emerging concept: *the cloud*.

When the internet connection speeds of smart phones reached a threshold and became increasingly more affordable through the introduction of faster data connection standards such as 3G, 4G, and LTE, it became possible to augment the capabilities of smart phones with the vast resources residing in large scale datacenters (the cloud). This synergistic coupling, *Mobile-cloud computing*, marked a new era in the development for smart phone applications. Using Mobile-Cloud Computing allowed using less capable smart phones to perform highly sophisticated functions, partly making the capabilities of the smart phone itself less relevant. Additionally, offloading parts (or all) of a mobile application to the cloud could save precious battery life. More excitingly, Mobile-Cloud Computing could allow smart phones to run applications that they could never run themselves in the foreseeable future, due to the limitation of their resident hardware.

Mobile Cloud Computing is in its infancy, much like the smart phone itself was a decade ago. Much research effort will be devoted to making it a usable computational and resource sharing model in the following decade. There will be missteps and major success stories. One thing that is for sure: its continuous progress will never stop. Using Mobile-Cloud Computing, combined with the future communication standards such as LTE Advanced and 5G that aim much higher data rates than what is available today, it will be possible to run applications that will never be possible to run on mobile devices alone. Such applications are extremely resource intensive (computation, memory, and storage-wise) and may require access to real-time data that is only resident in the cloud. One such family of applications, ones that utilize Real-time Mobile Cloud Computing, is the focus of this book. A good representative example of this application family is *Real-time Mobile-Cloud Face Recognition*, which initially motivated the authoring of this book. The family of resource-hungry mobile applications are not designed to extend mobile applications to the cloud, but rather, they are designed as mobile-cloud applications right from the start, since it is not possible to run them solely on mobile devices.

This book contains a total of 12 tutorial and research chapters which describe new and innovative mobile applications and provide supporting surveys to understand the operating characteristics of these applications. The applications described in this book are resource-hungry in different ways: Some of them require an extensive amount of processing power, RAM (short-term memory) or flash/hard disk storage (long-term memory). Some require access to an enormous amount of data that is updated in real-time. Such a quantity of data (e.g., Peta bytes) is far beyond the capability of any single device to process or handle, including smart phones (*i.e., Big Data*). All of these challenges introduce many research directions to make these exciting applications a reality. Solutions to these challenges span multiple disciplines in Electrical Engineering and Computer Science, and is the primary focus of this book. The chapters of this book are organized as follows:

Chapter 1 describes a concept system for remote health monitoring of cardiac patients outside a healthcare organization. Four separate components of this system are described in detail: The bio-sensor component of the system involves the design of custom advanced sensors that are capable of detecting proteins such as Troponin, Myoglobin and CRP, that are essential for advanced cardiac patient monitoring. The custom circuit interface for these sensors is detailed and the operational characteristics are described. Communication interface of the system uses standardized communication components found in mobile cloud computing (e.g., cloudlet), while an integration to the emerging Internet-of-Things (IoT) infrastructure is also described in terms of the concentrator-cloudlet co-operation. Finally, the authors aim at formulating a new visualization mechanism for cardiac data that can provide summarized information over the duration of the long-term health monitoring. This is aimed at remedying the shortcomings of the short-term, in-hospital ECG recordings that only provide limited information about the evolution of the patients' health condition.

Chapter 2 provides an extensive survey of Military Tactical Communications and Networking (MTCAN). To summarize, MTCAN algorithms and protocols are similar to Mobile Ad Hoc networks (MANETs), however, they are distributed to introduce robustness and scalability and to eliminate single points of failure. Authors provide a survey of the TRACE (Time Reservations using Adaptive Control for Energy efficiency) family of protocols that have been developed at the University of Rochester, through the financial support of Harris Corporation, RF Communications Division, which is a leader in MTCAN. The protocols that are surveyed in the chapter include SH-TRACE (Single-Hop Time Reservation using Adaptive Control for Energy efficiency), MH-TRACE (Multi Hop Time Reservation using Adaptive Control for Energy efficiency), NB-TRACE (Network-wide Broadcasting through Time Reservation using Adaptive Control for Energy efficiency), MC-TRACE (Multi Casting through Time Reservation using Adaptive Control for Energy efficiency), MMC-TRACE (multi-rate multicasting), AR-TRACE (adaptive redundancy), CDCA-TRACE (Cooperative node balancing and dynamic channel allocation with Time Reservation using Adaptive Control for Energy efficiency) and U-TRACE (Unified TRACE). the authors conclude by providing future research directions.

Chapter 3 provides a survey of the technologies, infrastructure components, and research leading to the formation of an emerging cloud-based service: Sensing as a Service ($S^2$aaS). In this new service offering, any mobile device that is connected to the internet can be a part of the *sensing network*. Wireless Sensor Networks (WSNs), mobile phones, and other emerging Internet-of-Things (IoT) devices can contribute their local data to an application that aggregates this information with the intent to provide a much more comprehensive version of this data (i.e., a globalized or much more expanded version). This data can be used to provide statistics or sensing results to all (or some) of the contributing nodes. Since the only limitation for the mobile devices is a form of connection to the sensing network, and, clearly, the willingness of a node to contribute all of part of the data, the sensing network could be extremely flexible. Finally, the global authority for the application is in the cloud with almost no resource constraints, especially as compared to the contributing small nodes. This could be used to perform resource-intensive analytics on the received data, thereby opening the door to a set of exciting applications and service offerings. However, this form of a sensing network introduces significant challenges such as privacy concerns and reliability of the acquired data. This chapter provides a survey of the techniques to deal with such challenges.

Chapter 4 introduces a remote health monitoring system where a patient's vitals are being monitored in his/her house and the results are being transmitted to the cloud. An algorithm running in the cloud detects potential hazardous health conditions, such as abnormal cardiac function and warns the doctor in real-time. During the execution of this algorithm, the acquired patient medical data is transmitted from the patient's house into the cloud and it is processed in the cloud. The results are transmitted into the doctor's tablet. This chapter primarily focuses on the privacy of the data during the transmission. An emerging encryption technique, called Fully Homomorphic Encryption (FHE), is used to encrypt the data that is being transmitted. However, this type of encryption causes significant expansion of the data and is highly computationally-intensive to process. Traditionally, circuit-based solutions are used in conjunction with FHE by turning each *computation* into a *circuit*. This circuit is implemented using FHE building blocks to yield the final result. A different approach is introduced in this chapter which uses a *Branching Program*. In their approach, each Yes/No decision (such as a patient has a health hazard vs. does not have a health hazard) is formulated as a Branching Program, which has a True/False answer. This Branching Program can be solved using FHE building blocks. While this limits the applicability of FHE to a restricted set of medical computations, authors report a 20x speed-up in the overall execution time for certain useful medical applications.

Chapter 5 introduces a computational infrastructure where multiple smart phones contribute their computational power to an application. This concept, termed *Volunteer Computing,* allows computationally-intensive applications to be run by a set of distributed mobile devices that are owned by volunteers that *opt-in* to the computational network. Authors break down the approaches into major categories that are defined by the volunteering entity: 1) Server-driven mobile-distributed computing approaches surveyed in this chapter are a) prime-number research, b) text search; π value estimation, c) distributed hash-cracking, d) distributed multimedia search, e) dynamic life-cycle assessment of a building, and f) DNA sequence matching. 2) User-driven approaches are a) speech-to-text, b) face detection and collaborative photography, c) collaborative file download, and d) testing of the cloudlet formation algorithm. 3) Mobile Volunteer Computing approaches include a) scientific research projects, b) protein structure predictions and multiple other ones. The authors conclude with a summary and provide pointers to future research directions.

Chapter 6 details a new cloud-based service model called Acceleration as a Service (AXaaS). Authors base the conceptualization of this new aaS model on the acceleration capability of a cloudlet. To speed-up mobile-cloud applications, such as real-time face recognition, it is known that, a cloudlet can be placed locally within the WiFi reach of a mobile device, providing a fast and dedicated link to the cloud. The significant difference between a traditional cloudlet and what is prescribed in this chapter is *where* the cloudlet is placed. Rather than the standard model where a user owns a cloudlet, *renting the cloudlet* is suggested. The best entity for renting the cloudlet is determined to be the Telecom Service Provider (TSP). The TSP can rent a cloudlet through a monthly fee, which eliminates the need for the user to own or upgrade such a device. Since it is very expensive to shuttle data back and forth between mobile devices and the TSP, one important research challenge is to determine which parts of the code require computational speed-up (i.e., *acceleration*). The significant research challenge in such an infrastructure is *what to accelerate* using the TSP. This is analyzed by the authors through code profiling. It is determined that, a very limited library of functions, such as Fast Fourier Transform (FFT) and Basic Linear Algebra Subroutines (BLAS) are sufficient as acceleration points. Merely accelerating these two API functions provides drastic overall application speed-up, thereby creating a TSP service that the users are willing to pay for. A business ROI analysis is also provided from the standpoint of the TSP and the user.

Chapter 7 provides a framework for generalized privacy-preserving medical cloud computing. Running medical applications in the cloud offers a healthcare organization significant cost savings by being able to outsource the storage and computation of medical data to a cloud operator. However, this implies that, the breach of the medical data during cloud computing could result in a violation of Health Information Portability and Accountability Act (HIPAA) and is not acceptable. Authors propose to use Fully Homomorphic Encryption (FHE) to operate on the medical data that is stored in the cloud. While the storage of data can preserve privacy by using traditional encryption algorithms such as Advanced Encryption Standard (AES), no computation can be done on AES-encrypted data. On the other hand, FHE-based encryption allows both storage and computation in a privacy-preserving fashion, since the cloud cannot observe the data that it is computing. However, FHE-based computation and storage are substantially more costly than their AES-counterpart. Authors formulate a mechanism where some non-computationally-expensive medical computations can be performed in the cloud, such as minimum/maximum/average heart rate computations during remote patient monitoring, as well as the detection of certain cardiac health hazards such as Long-QT syndrome (LQTS). A detailed analysis is provided for each step of these computations.

Chapter 8 provides a survey of hardware and software support for Virtual-Machine (VM) based mobile-cloud application offloading. Mobile offloading concepts are briefly surveyed and the areas where VMs can help are determined. Advantages and disadvantages of virtualization are explained in detail. This is followed by a survey of software support including virtualization approaches, hypervisor types, Operating System support, as well as existing VM types. A survey of hardware assisted virtualization is also provided which details the Instruction Set support that is resident in three popular manufacturers' CPUs: Intel, AMD and ARM. Hardware assisted virtualization allows the virtualization of memory, I/O, and the CPU cores. Challenges in virtualization are listed such as the security and overhead of virtualization. A summarized discussion of GPU virtualization is also provided.

Chapter 9 is a practical and theoretical tutorial on network latency measurement. The author provides an extensive set of latency measurements provided by his research team. These measurements are done in a PlanetLab environment which is a network of volunteering academic institutions. A detailed discussion of how to repeat these experiments is also provided through a brief introduction to PlanetLab. Based on the measured data, author draws conclusions about what the distributions of the global latency values are. Latency is an important performance-limiting factor for mobile-cloud applications as it determines the speed at which a mobile device can access the cloud. The intuitions and practical measurements provided in this chapter are, therefore, an important guide to designing real-time mobile-cloud applications.

Chapter 10 focuses on the business aspects of running highly resource-intensive applications in the cloud and the cost of outsourcing such applications into the cloud. A list of the operating costs for the three popular cloud operators (Amazon, Google, and Microsoft Azure) are provided. These operators charge fees based on a) storage, b) computation, and c) network traffic. The analysis provided in this chapter breaks the application costs into these three categories and associates metrics for each one of these parameters. This analysis is not trivial in that, cloud operators provide a vast array of options based on commitment levels (in terms of time duration). Authors suggest the best choices for these options based on the characteristics of two resource-intensive applications: 1) a remote health monitoring application using Fully Homomorphic Encryption to perform privacy-preserving medical cloud computing, and 2) real-time mobile-cloud face recognition. Both of these applications are analyzed in terms of their functional characteristics and their resource demands are determined. These results are converted to a monthly operating cost in the cloud for three different cloud operators.

Chapter 11 provides a technical and practical tutorial for understanding and running face recognition, which is a good representative case for resource-intensive mobile-cloud applications. The theory behind this application is described by breaking the application into three of its distinct execution phases: Face Detection, Projection, and Search. The theory behind these three different phases is detailed and the steps required to run this application on commodity computers using the OpenCV library are provided in a tutorial format. By following the steps that are provided in this chapter, other researchers in resource-intensive mobile-cloud computing can easily run face recognition using freely available open source tools.

Chapter 12 provides a practical view to the expected characteristics of mobile platforms. The author is a retired USG officer who brings a practical view to the importance of these parameters in generalized radio communication and draws conclusions from his practical experience. Availability (Ao) is explained as one of the most important parameters and the details are provided in regard to Ao and its effect on radio communication.

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# Chapter 1

# Conceptualizing a Real-Time Remote Cardiac Health Monitoring System

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## ABSTRACT

*In today's technology, even leading medical institutions diagnose their cardiac patients through ECG recordings obtained at healthcare organizations (HCO), which are costly to obtain and may miss significant clinically-relevant information. Existing long-term patient monitoring systems (e.g., Holter monitors) provide limited information about the evolution of deadly cardiac conditions and lack interactivity in case there is a sudden degradation in the patient's health condition. A standardized and scalable system does not currently exist to monitor an expanding set of patient vitals that a doctor can prescribe to monitor. The design of such a system will translate to significant healthcare savings as well as drastic improvements in diagnostic accuracy. In this chapter, we will propose a concept system for real-time remote cardiac health monitoring, based on available and emerging technologies today. We will analyze the details of such a system from acquisition to visualization of medical data.*

## INTRODUCTION

Conventional tests to assess the risk of cardiovascular diseases (CVD) involve clinical history, physical examination and electrocardiogram (ECG), which are highly observational and relatively insensitive (Petr, et al., 2014; Prasad, et al., 2013; Saul, Schwartz, Ackerman, & Triedman, 2014; Vatta, 2009). Although the pathology of CVD starts at earlier stages than it is observable by conventional methodologies, there

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# Chapter 2
# Energy Efficient Real-Time Distributed Communication Architectures for Military Tactical Communication Systems

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## ABSTRACT

*For military communication systems, it is important to achieve robust and energy efficient real-time communication among a group of mobile users without the support of a pre-existing infrastructure. Furthermore, these communication systems must support multiple communication modes, such as unicast, multicast, and network-wide broadcast, to serve the varied needs in military communication systems. One use for these military communication systems is in support of real-time mobile cloud computing, where the response time is of utmost importance; therefore, satisfying real-time communication requirements is crucial. In this chapter, we present a brief overview of military tactical communications and networking (MTCAN). As an important example of MTCAN, we present the evolution of the TRACE family of protocols, describing the design of the TRACE protocols according to the tactical communications and networking requirements. We conclude the chapter by identifying how the TRACE protocols can enable mobile cloud computing within military communication systems.*

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# Chapter 3
# Sensing as a Service in Cloud-Centric Internet of Things Architecture

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## ABSTRACT

*Sensing-as-a-Service (S2aaS) is a cloud-inspired service model which enables access to the Internet of Things (IoT) architecture. The IoT denotes virtually interconnected objects that are uniquely identifiable, and are capable of sensing, computing and communicating. Built-in sensors in mobile devices can leverage the performance of IoT applications in terms of energy and communication overhead savings by sending their data to the cloud servers. Sensed data from mobile devices can be accessed by IoT applications on a pay-as-you-go fashion. Efficient sensing service provider search techniques are emerging components of this architecture, and they should be accompanied with effective sensing provider recruitment algorithms. Furthermore, reliability and trustworthiness of participatory sensed data appears as a big challenge. This chapter provides an overview of the state of the art in S2aaS systems, and reports recent proposals to address the most crucial challenges. Furthermore, the chapter points out the open issues and future directions for the researchers in this field.*

## INTRODUCTION

The Internet of Things (IoT) paradigm denotes the pervasive and ubiquitous interconnection of billions of embedded devices that can be uniquely identified, localized and communicated (Aggarwal, C., Ashish, N. & Sheth, A., 2013). Sensors, RFID tags, smart phones, and various other devices are interconnected in a scalable manner in the IoT architecture. Application areas of IoT are various such as healthcare, smart environments, transportation, social networking, personal safety and several futuristic applications such as robot taxi (Atzori, A., Andlera, L. & Morabito, G., 2010; Miorandi, D., Sicari, S., De Pellegrini, F.

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# Chapter 4
# Secure Health Monitoring in the Cloud Using Homomorphic Encryption:
## A Branching-Program Formulation

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## ABSTRACT

*Extending cloud computing to medical software, where the hospitals rent the software from the provider sounds like a natural evolution for cloud computing. One problem with cloud computing, though, is ensuring the medical data privacy in applications such as long term health monitoring. Previously proposed solutions based on Fully Homomorphic Encryption (FHE) completely eliminate privacy concerns, but are extremely slow to be practical. Our key proposition in this paper is a new approach to applying FHE into the data that is stored in the cloud. Instead of using the existing circuit-based programming models, we propose a solution based on Branching Programs. While this restricts the type of data elements that FHE can be applied to, it achieves dramatic speed-up as compared to traditional circuit-based methods. Our claims are proven with simulations applied to real ECG data.*

## INTRODUCTION

Software as a Service (SaaS) provides an excellent alternative to any corporation looking to simplify their IT infrastructure. By renting Software as a Service (SaaS), rather than purchasing, the responsibility of software upgrades, as well as the infrastructure to run the software are transferred to the provider of the software. Upgrades on the software could be done instantly, since new patches and code improvements

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# Chapter 5
# Volunteer Computing on Mobile Devices:
## State of the Art and Future Research Directions

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## ABSTRACT

*Different forms of parallel computing have been proposed to address the high computational requirements of many applications. Building on advances in parallel computing, volunteer computing has been shown to be an efficient way to exploit the computational resources of under utilized devices that are available around the world. The idea of including mobile devices, such as smartphones and tablets, in existing volunteer computing systems has recently been investigated. In this chapter, we present the current state of the art in the mobile volunteer computing research field, where personal mobile devices are the elements that perform the computation. Starting from the motivations and challenges behind the adoption of personal mobile devices as computational resources, we then provide a literature review of the different architectures that have been proposed to support parallel computing on mobile devices. Finally, we present some open issues that need to be investigated in order to extend user participation and improve the overall system performance for mobile volunteer computing.*

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# Chapter 6
# Selling FLOPs:
## Telecom Service Providers Can Rent a Cloudlet via Acceleration as a Service (AXaaS)

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## ABSTRACT

*To meet the user demand for an ever-increasing mobile-cloud computing performance for resource-intensive mobile applications, we propose a new service architecture called Acceleration as a Service (AXaaS). We formulate AXaaS based on the observation that most resource-intensive applications, such as real-time face-recognition and augmented reality, have similar resource-demand characteristics: a vast majority of the program execution time is spent on a limited set of library calls, such as Generalized Matrix-Multiply operations (GEMM), or FFT. Our AXaaS model suggests accelerating only these operations by the Telecom Service Providers (TSP). We envision the TSP offering this service through a monthly computational service charge, much like their existing monthly bandwidth charge. We demonstrate the technological and business feasibility of AXaaS on a proof-of-concept real-time face recognition application. We elaborate on the consumer, developer, and the TSP view of this model. Our results confirm AXaaS as a novel and viable business model.*

## INTRODUCTION

Consumer use of "smart" devices is rapidly increasing due to affordability and increasing wide area network (WAN) performance (Emarketer, 2014). As the capabilities of smart phones expand parallel to the improvement in the WAN performance, so do consumers' expectations for resource-intensive mobile applications. However, mobile devices are ill-suited to execute most these applications due to their hardware limitations. Computational offloading offers a way to augment mobile computation power,

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# Chapter 7
# Towards Privacy-Preserving Medical Cloud Computing Using Homomorphic Encryption

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## ABSTRACT

*Personal health monitoring tools, such as commercially available wireless ECG patches, can significantly reduce healthcare costs by allowing patient monitoring outside the healthcare organizations. These tools transmit the acquired medical data into the cloud, which could provide an invaluable diagnosis tool for healthcare professionals. Despite the potential of such systems to revolutionize the medical field, the adoption of medical cloud computing in general has been slow due to the strict privacy regulations on patient health information. We present a novel medical cloud computing approach that eliminates privacy concerns associated with the cloud provider. Our approach capitalizes on Fully Homomorphic Encryption (FHE), which enables computations on private health information without actually observing the underlying data. For a feasibility study, we present a working implementation of a long-term cardiac health monitoring application using a well-established open source FHE library.*

## INTRODUCTION

The Patient Protection and Affordable Care Act (US Government Printing Office) is one of the most significant government efforts to generalize the use of electronic medical records (EMRs) and to incentivize the development of innovative technologies that can help curb rising US healthcare costs. Cloud computing is a viable option to reduce healthcare costs associated with EMRs by outsourcing the storage of medical data to cloud operators (Amazon Web Services; Google Cloud Platform; Microsoft Windows Azure), however, Personal Health Information (PHI) privacy is strictly mandated by the Health Insurance Portability and Accountability Act (HIPAA) (US Department of Health and Human Services, 2014) and

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# Chapter 8
# Hardware and Software Aspects of VM-Based Mobile-Cloud Offloading

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## ABSTRACT

*To allow mobile devices to support resource intensive applications beyond their capabilities, mobile-cloud offloading is introduced to extend the resources of mobile devices by leveraging cloud resources. In this chapter, we will survey the state-of-the-art in VM-based mobile-cloud offloading techniques including their software and architectural aspects in detail. For the software aspects, we will provide the current improvements to different layers of various virtualization systems, particularly focusing on mobile-cloud offloading. Approaches at different offloading granularities will be reviewed and their advantages and disadvantages will be discussed. For the architectural support aspects of the virtualization, three platforms including Intel x86, ARM and NVidia GPUs will be reviewed in terms of their special architectural designs to accommodate virtualization and VM-based offloading.*

## INTRODUCTION

In the past decade, significant technological advances in the semiconductor technology have dramatically improved the computational and storage capability of handheld mobile devices such as smart phones and tablets. This enabled mobile devices not only to access a vast amount information instantaneously through fast communications networks, but also to perform ever more sophisticated computational tasks such as face and speech recognition, object detection and natural language processing (NLP) pervasively

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# Chapter 9
# A Tutorial on Network Latency and Its Measurements

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## ABSTRACT

*Internet latency is crucial in providing reliable and efficient networked services when servers are placed in geographically diverse locations. The trend of mobile, cloud, and distributed computing accelerates the importance of accurate latency measurement due to its nature of rapidly changing locations and interactivity. Accurately measuring latency, however, is not easy due to lack of testing resources, the sheer volume of collected data points, the tedious and repetitive aspect of measurement practice, clock synchronization, and network dynamics. This chapter discusses the techniques that use PlanetLab to measure latency in the Internet, its underlying infrastructure, representative latency results obtained from experiments, and how to use these measure latencies. The chapter covers 1) details of using PlanetLab, 2) the Internet infrastructure that causes the discrepancy between local and global latencies, and 3) measured latency results from our own experiments and analysis on the distributions, averages, and their implications.*

## INTRODUCTION

Internet latency is crucial in providing reliable and efficient networked services such as online retails (e.g., Amazon), multimedia streaming (e.g., Netflix), and social networking (e.g., Twitter). For example, Netflix runs its servers on the Amazon cloud in geographically diverse locations, and provides video streams from the server that can deliver the content to a client in the shortest time. In order to support this server selection in distributed computing, measuring accurate latency becomes extremely important. The trend of mobile computing like iPhone and Android-based smartphones only accelerates the importance of accurate latency measurement due to its nature of rapidly changing locations and interactivity. Accurately measuring network latency, however, is not an easy task due to lack of testing resources, the sheer volume of collected data points, the tedious and repetitive aspect of measurement practice, and

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# Chapter 10
# Operational Cost of Running Real-Time Mobile Cloud Applications

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## ABSTRACT

*This chapter describes the concepts and cost models used for determining the cost of providing cloud services to mobile applications using different pricing models. Two recently implemented mobile-cloud applications are studied in terms of both the cost of providing such services by the cloud operator, and the cost of operating them by the cloud user. Computing resource requirements of both applications are identified and worksheets are presented to demonstrate how businesses can estimate the operational cost of implementing such real-time mobile cloud applications at a large scale, as well as how much cloud operators can profit from providing resources for these applications. In addition, the nature of available service level agreements (SLA) and the importance of quality of service (QoS) specifications within these SLAs are emphasized and explained for mobile cloud application deployment.*

## INTRODUCTION

Cloud is the platform of multiple servers over a widely disbursed geographic area, connected by the Internet for the purpose of serving data or computation (Bansal, 2013). Mobile Cloud Computing (MCC) can be described as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (Shanklin, 2014) from mobile devices. MCC therefore refers to both the applications delivered as services over the Internet and the hardware and system software in data-

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# Chapter 11
# Theoretical Foundation and GPU Implementation of Face Recognition

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## ABSTRACT

*Enabling a machine to detect and recognize faces requires significant computational power. This particular system of face recognition makes use of OpenCV (Computer Vision) libraries while leveraging Graphics Processing Units (GPUs) to accelerate the process towards real-time. The processing and recognition algorithms are best sorted into three distinct steps: detection, projection, and search. Each of these steps has unique computational characteristics and requirements driving performance. In particular, the detection and projection processes can be accelerated significantly with GPU usage due to the data types and arithmetic types associated with the algorithms, such as matrix manipulation. This chapter provides a survey of the three main processes and how they contribute to the overarching recognition process.*

## INTRODUCTION

Humans have the innate skill to continuously gather complex information from another person's face. While it comes naturally to us, it is really quite the feat to be able to do something as simple as recognizing individuals based on a quick gaze over a face. What may differentiate individual faces are inherently subtle variations in features such as skin, skeletal structure, hair and lips. Humans can do this with ease at any angle, most lighting, at a massive scale with a high degree of accuracy.

Computers have a comparatively difficult time with face recognition, even today. At a basic level, in order to recognize faces, a computer must first be able to determine which objects from an image are actual faces. It must then gather enough information by analyzing multiple image fragments to develop patterns associated with a face which may be presented in a variety of aspects and lighting conditions.

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# Chapter 12
# Reach to Mobile Platforms and Availability:
## A Planning Tutorial

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## ABSTRACT

*This chapter is practical system planning tutorial for internetworks that include radio-WANs. Author is retired USCG officer with both operational and program planning experience. In second career, author taught 'plowshares into swords internetworking' at the graduate level. The coaching herein reflects operational, planning, and academic experiences. Considering mobile communications requires adjusting some assumptions and working knowledge from a wholly wired internetwork. The advent of radio – the necessary means to mobile – entails changes in topology, capacity and nature of the media (shared). Further, the extension of the internetwork to mobile usually means rather overt embracing of mission critical applications.*

## INTRODUCTION

It was a dark, stormy and windy night. The weather service had forecast the 100 knot windstorm correctly and the fishing fleet had all scampered for port and were getting safely tied up. Except for one trawler, with a crew of three, who, as it turned out, pushed luck about an hour too far. As the wind built the Coast Guard established a communications watch, which meant radioing the fishing boat crew every half hour. Further, as the storm built, most of the crews at the lifeboat stations and air station had returned to duty, whether expressly called or not.

As the storm built further, trees started falling and electrical power went out for large swathes of the Oregon coast. The fishing boat was making maddeningly slow progress toward Cape Arago and safety in its lee.

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