What elements of the technical, economic, and policy factors influence the use of texting in electronic healthcare applications?

by Suzana Brown

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirement for the degree of

Masters in Science

for

The Interdisciplinary Telecommunications Program

October 2012
This thesis entitled:

What elements of the technical, economic, and policy factors influence the use of texting in electronic healthcare applications?

written by Suzana Brown

has been approved for the Interdisciplinary Telecommunications Program

______________________________

(Sharon Black)

______________________________

(Frank Barnes)

______________________________

(Katie Siek)

Date November 6, 2012

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

IRB protocol # 12-0024
Suzana Brown (Masters of Science, Interdisciplinary Telecommunications Program)

What elements of the technical, economic, and policy factors influence the use of texting in electronic healthcare applications?

Thesis directed by Scholar in Residence Sharon Black

With explosion of availability and use of mobile phones, in particular in developing countries, they are becoming a new platform to provide health care services. One of services on mobile phones, text messaging, is widely used in healthcare. Compared to voice text messaging has an advantage in unfavorable conditions, such as the edge of coverage, because it requires only several seconds of strong signal to transmit. The influence of telecommunications policy on its adoption is evaluated by interviewing experts from seventeen developing countries. Several obstacles to adoption are identified but no strong regional division found. Comparison of a specific application that uses text messaging, blood glucose monitoring for diabetics, to a traditional healthcare solution is evaluated in three different regions by performing a cost/benefit analysis. The regions are chosen because of different pricing schemes for text messaging. The sensitivity analysis on the assumptions of the model helps understand the factors better.
# TABLE OF CONTENT

## INTRODUCTION

1.1 Significance

1.2 Research question

1.3 ICT in healthcare

1.4 Technical requirements

1.5 Communications patterns

1.6 References:

## REVIEW OF LITERATURE

1. A Review of Related Literature for International Comparison
   1.1 Analytical Studies
   1.2 Pilot Studies

2. Review of literature on Short message Service (SMS)
   2.1 Reliability of SMS
   2.2 Transmission Delay
   2.3 Congestion
   2.4 Security and Quality of Service

3. mHealth Literature
   3.1 Medical Applications
   3.2 Surveys
   3.3 Pilot Studies
   3.4 SMS in mHealth

## TECHNICAL CHARACTERISTICS OF SMS

1. Introduction

2. GSM

3. SMS Architecture

4. Methodology
   4.1 Test Setup
5.1 Introduction 76
5.2 Health indicators 76
5.3 Description of Methodology and Data Analysis 78
5.4 Analysis 82
  5.4.1 Telecommunications technology 82
  5.4.2 Telecommunications policy 85
  5.4.3 Economic aspect of telecommunications 87
  5.4.4 Public health and mHealth adoption 89
5.5 A discussion of implications 92
5.6 Conclusion 94
5.7 References 95
Appendix 1 98
  Summaries of answers from African countries 98
Appendix 2 99

6 CONCLUSION 103
6.1 Summary of results 103
6.2 Future Work 105

Table of Figures
Figure 1.1 Factors important in the use of texting in healthcare ................................................................. 5
Figure 3.1 Path of a standard mobile voice call .......................................................................................... 35
Figure 3.2. Path of SMS message ........................................................................................................... 36
Figure 3.3. Equipment configuration for all tests .................................................................................... 37
Figure 3.4 Spectrum analyzer measuring the time it takes to send an SMS. ............................................. 39
Figure 3.5 Spectrum analyzer screen with measurement of a superframe. ............................................... 39
Figure 3.6. Cumulative distribution function of air interface delay for 60 character SMS message. ....... 43
Figure 3.7. Cumulative dist. function for 60-char. air interface delay ..................................................... 44
Figure 3.8. Weak signal fit .................................................................................................................... 45
Figure 3.9. Strong signal fit .................................................................................................................. 46
Figure 3.10. Mobility fit ...................................................................................................................... 46
Figure 4.1 Schematic of diabetes monitoring system .............................................................................. 56
Figure 4.2 Dedicated medical equipment cost and the annual cost/patient for diabetes ....................... 63
Figure 4.3 Break-even cost and the annual cost/patient ........................................................................ 66
Figure 4.4 USA adoption rates, percentage savings and total B-C ...................................................... 67
Figure 4.5 Latin America adoption rates, percentage savings and total B-C ......................................... 68
Figure 4.6 India adoption rates, percentage savings and total B-C........................................................................... 69

Table of tables
Table 3.1 Air interface delay ................................................................................................................................. 40
Table 3.2 Delays for 60-character message at two signal strengths ................................................................. 41
Table 3.3 Delays for 160-character message at two signal strengths ............................................................... 41
Table 3.4 Voice call setup and 60 character air interface delay ......................................................................... 42
Table 3.5 Delays for 60-character message, stationary and mobile ................................................................... 42
Table 3.6 GSM Model Parameters Determined From Data ............................................................................... 47
Table 3.7 Weibull Model Parameters Determined From Data ........................................................................... 47
Table 4.1 Overall Cost of Diabetes in 2011 ......................................................................................................... 59
Table 4.2 Possible Adoptees ................................................................................................................................. 60
Table 4.3 Cost/Benefit (transmission costs only) ............................................................................................... 62
Table 4.4 Maximum cost of dedicated equipment ............................................................................................. 63
Table 4.5 Break-even cost per text message ...................................................................................................... 65
Table 4.6 C/B with present SMS cost, cost of SMS to breakeven and maximum cost of medical equipment ...... 66
Table 4.7 Benefit – Cost with preprocessing option .......................................................................................... 70
Table 5.1 Economic and health indicator for represented countries ................................................................. 80
Table 5.2 Averages and deviations within and between regions ....................................................................... 81
Table 5.3 Mobile penetration and answers of respondents .............................................................................. 83
Table 5.4 Common themes in answers ............................................................................................................. 92
Introduction

Developments in information and communication technologies (ICTs) have changed the way people communicate by enabling transmission speeds and breadth of coverage never seen before. In healthcare, ICTs are providing a variety of new applications that will also change the way people view health services. The old way of “seeing” a health provider is changing and some health services are now available at a distance. Over the past 100 years, the health of the world’s population has been improving but unevenly with a gap between developed and developing countries growing larger [1]. The new ICT developments are promising to provide a tool to health practitioners and populations to improve the health outcomes in developing countries in particular. The purpose of this thesis is to look at one of the ICTs, Short Message Service (SMS) or text message, and the factors that influence its use in healthcare applications.

1.1 Significance

There is growing recognition that in the Information Age, the potential of economic growth depends heavily on the quality of human resources more than ever before [2]. “Biological embedding”, a term used for the quality of the social and physical environment children grow up in, produces neural sculpturing that in some cases influences competence and coping in the children for the rest of their lives. That in turn produces a certain quality workforce which determines the development of a nation [2]. In addition, poor health reduces a country’s measurement of development known as Gross Domestic Product (GDP) per capita by reducing both labor productivity and the relative size of the country’s labor force [3].

The average life span of people around the world increased slowly but steadily in the second half of the 19th century and then increased markedly in the 20th century. Economic historians and demographers still debate the genesis of these changes, but they increasingly point to rising incomes (and resulting improvements in food availability and sanitation) as the major cause of declines in 19th-
century mortality rates, and to the discovery of the germ theory of disease, a better understanding of
cygiene, and the development of antibiotics and vaccines for the decline in the 20th Century [3]. In the
21st century, use of telecommunication technology could be the factor that could contribute to a further
increase in the average life span, improvement in health, quality of life, and increase in productivity.
Since the gap in life span and public health between developed and developing nations is still
considerable [3], the developing nations have the most to gain from the improvement in the health of
their work force.

Several telecommunications services are available, including the data transmission service
known as SMS or text messaging. One major advantage of texting is that it is inexpensive compared to
other telecommunications services. On average the price of a text message is one half the price of one
voice minute postpaid, and one quarter of one minute prepaid [4]. The SMS protocol has its limitations
and the major one is that the size of the message is limited to 160 characters. As such, SMS presents a
platform for health applications that require only small amounts of data.

Academic and industry interest in the field is growing. In Chapter 2 I review 32 academic papers
that investigate the use of texting in healthcare applications. The growth of medical apps industry in the
US is even more dramatic. For example, in the US in 2012, the smart phone applications for diabetes
increased by almost 400 percent [5].

Compared to the populations in developed countries, such as the US, the populations in
developing countries have worse health outcomes; significant exposures to harmful effects; and are
subject to sluggish responses in health systems. Mobile technologies could: 1) provide real time data; 2)
improve access to large portions of population in pull and push direction and 3) enable health officials to
improve their response times. Based on these strengths, I postulate that the use of telecommunications
services in healthcare in developing countries will grow; in particular texting will become important for healthcare applications.

1.2 Research question

In order to support that claim I investigate which elements of technical, economic and policy factors impact the use of texting in healthcare applications. I ask the following research question:

“What elements of the technical, economic, and policy factors influence the use of texting in electronic healthcare applications?” I focus on the conditions in developing countries and rural areas of developed countries mostly because texting or SMS with its availability and low cost is a natural choice where other services are unavailable.

I investigate the above question by evaluating three aspect of the issue.

- From the technical perspective, I evaluate delay and reliability of SMS compared to voice. To that extent I investigate the behavior of each service in unfavorable conditions, such as weak signals at the edge of coverage. In weak signal environment delays are longer and reliability is lower. The importance of weak signal environment is that it represents conditions in developing countries and rural areas.

- Second aspect is the economic feasibility of texting in healthcare applications. I investigate that by evaluating the economic advantage of a specific electronic application that uses SMS to transport information, blood glucose monitoring for diabetics, by performing a cost/benefit analysis. I perform sensitivity analysis to assumptions and calculate the effect of preprocessing on the results.

- I evaluate telecommunications policy that promotes and inhibits adoption of texting in electronic healthcare applications. I investigate that by interviewing seventeen telecommunications professional from developing countries. In the process I identify the issues and discover several obstacles to adoption.
There is extensive literature in the space of electronic applications for healthcare which is presented in Chapter 2. However there are still gaps in knowledge, in particular there are not many papers looking at all three factors, technical, economic and policy, and their impact on the use of texting in electronic healthcare applications. To identify the elements of those factors I use analytical models, experimental data, and interviews of experts. I examine large number of elements but based on the above methods I consider only some and investigate their significance.

The thesis is organized as following. Chapter 2 outlines a review of the previous done research in the following areas: 1) influence of telecommunication policy on ICTs adoption in healthcare, 2) SMS applications, 3) mHealth in general, and 4) specifically SMS in mHealth. Chapter 3 researches: 1) technical characteristics and operation of SMS, 2) behavior of SMS on the edge of coverage, 3) comparison of SMS and voice in those conditions. Chapter 4 presents: 1) an example of blood glucose monitoring; 2) performs cost/benefit analysis for introduction of ongoing monitoring using electronic devices that use SMS for data transmission; 3) compares cost/benefit results across three regions: US, Latin America and India; 4) sensitivity analysis by varying assumptions; and 5) effect preprocessing has on cost/benefit. Chapter 5 analyses policy impact by presenting: 1) the state of telecommunications and healthcare in 17 different countries; 2) qualitative interview results from 17 telecommunications professions from those countries; and 3) obstacles to adoption and policy that promotes it. Chapter 6 concludes.

Figure 1.1 represents the order in which I investigate the three factors and their elements important in the use of texting in healthcare.
The following section underlines the importance of ICTs in healthcare, introduces new terminology: telehealth and mHealth; and categorizes different mHealth applications.

### 1.3 ICT in healthcare

The healthcare sector worldwide uses ICTs in two ways: 1) to supplement the existing services or 2) to offer new services to providers and patients. Examples of supplemental services include: collecting data electronically on prevalent diseases, using telecommunications for sharing knowledge among health providers and/or with the public, utilizing text messaging for reminders to patients about medication and appointments, and computerized access to centralized health records. Examples of new services that did not exist prior are: remote health monitoring via a portable devices that the patients wear, surgery performed under supervision of a specialist using real-time video conferencing.
The term “Telemedicine” is defined by the American Telemedicine Association (ATA) as the use of medical information exchanges from one site to another via electronic communications to improve patients’ health status [6]. In contrast, the term “TeleHealth” includes telemedicine plus the components of “education” and “prevention” [6]. Due to this breadth and generality, the term teleHealth is used throughout this paper.

With the explosion of the worldwide availability and use of mobile phones, especially in developing countries where the healthcare sector experiences serious staff and medicine shortages, mobile phones are becoming a new platform to provide healthcare services. In recent years, mobile phones are becoming an important tool in TeleHealth, and another new term is -- “mobileHealth” or “mHealth” [7]. mHealth is defined as the practice of medicine and public health that makes use of mobile telecommunications devices to provide care [7]. In the last five years, a plethora of companies and research institutions have been working to produce different services and devices connected to mobile phones that offer health services.

At present, the most popular medical applications for mobile phones are:

- ongoing tracking of medical information from a patient
- enable health professionals to have instant access to patients’ medical records
- send reminders and other health information to patients
- gather information of health conditions in remote locations, and
- provide specialist health consultations to remote locations

In developed countries, the healthcare sector is primarily looking at mHealth as a way to reduce cost of existing services and to provide specialized care to rural locations where it would not be otherwise feasible. Examples of mHealth in developed countries are:

- monitoring – blood glucose, pressure, postop monitoring
• adherence – medication, appointments
• communication with healthcare provider – Skype, email
• health apps on mobile devices (diet, fitness, lab tests, meds)

The diseases in developed countries that are successfully treated using mobile devices include diabetes, heart conditions and problems arising with aging populations.

In developing countries the healthcare issues include:

• healthcare workers located in cities, away from rural areas
• scarcity of medical equipment and medicine, and
• sizable health issues: HIV, malaria, malnutrition

At the same time, the mobile phone industry is partnering with both the public health institutions and the medical sector to provide mHealth to the poorest and most remote regions of their countries.

In this thesis I concentrate on one type of application that uses texting and that is monitoring. One type of monitoring relates to monitoring patients vital signs, but it could also be tracking medication and vaccines. In later chapters I use an example of monitoring mostly because it has been already successfully implemented in many developed countries. In that sense I postulate that developing countries with a successful example from the developed countries, will implement monitoring as one of the first applications.

1.4 Technical requirements

From the telecommunications perspective, these different solutions in developed and developing countries have the same technical requirements with the most important being:

• Size of message (bandwidth requirement)
• Latency (delay)
Latency addresses reliability versus timeliness, which depends on the frequency of monitoring. For example, when tracking data trends timeliness is not as important. On the other hand for life treating conditions timeliness is critical. Different telecommunications services support those requirements. SMS is reliable but not necessary timely. In addition, for health education, healthcare availability, or non-urgent distance consultation the timeliness is not essential. Bandwidth requirement depends on the size of messages. SMS is appropriate for small information transport, up to 160 characters. Large bandwidth is a more important issue for applications such as video consultations.

In Chapter 3, I examine technical capabilities of SMS and establish its performance at the edge of coverage. The importance of that assessment relates to issues of networks in developing countries which have the following problems:

- poor coverage
- base station outage
- congestion

The above issues produce conditions that are unfavorable for transmission and can be modeled by varying and low signal strength for mobile phone communication with a base station.

Where does SMS fit to satisfy technical requirements of health applications in developing countries? The protocol supports delivery confirmation option which in the US means confirmation that a message reached SMS Center (SMSC). In other parts of the world end-to-end confirmation is available. SMS can be defined as store and forward technology with reliable but not timely process. Problems with
timeliness are more likely to be present when the communication is between two mobile stations because:

- the receiving mobile station (MS) is turned off
- the receiving MS is out of coverage

When the communication is between mobile station and reliable end device (stationary server) it eliminates many issues because it concentrates only on one side being out of coverage. In good coverage, defined in GSM system as the power corresponding to \(-105\) dBm, it takes only a several (5-8) seconds to transmit a text message via an air interface.

1.5 Communications patterns

One last issue that I will discuss in this chapter is the communications patterns between different agents regarding medical information. Understanding that will determine which communications pair gets the highest return on investment.

Communications occur between the following agents:

1) healthcare worker and healthcare worker
2) healthcare worker and patient
3) individual collecting data about their own health, personal health record
4) medical device to medical device
5) patient to patient, inter-patient interaction
6) healthcare worker or patient to pharmacy
7) patient to crowd (crowd sourcing)
8) clinic to public health officials
9) patient or healthcare worker to information storage device
The above pairs have different telecommunications requirements but they are beyond the scope of this analysis and present valuable extension of this work. One example worth mentioning is two communications. For example, healthcare worker to healthcare worker is most likely to be a two way communication. Texting might not be the best solution for a conversation because of the limitations of characters parties can use and possible latency in delivery.

Another issue with SMS is the security of data transport. The security issue of texting and medical information is topic of many papers in the literature but it is outside the scope of this research.
1.6 References:


2 Review of literature

Consistent with accepted research techniques, I review the existing literature in several related areas prior to selecting the research question for this thesis. The review of literature is divided into several sections: 1) a review of literature analyzing the impact of telecommunications policy on the ICT adoption in health sector; 2) a review of literature of the technical characteristics of SMS; 3) a review of literature of issues in mHealth.

2.1 A Review of Related Literature for International Comparison

International comparison chapter is based on grounded theory and in grounded theory the review of literature is supposed to be of the related literature since the conclusions are based on data and not on any particular theory. This literature is diverse and comprises two types of studies: 1) analytical studies; 2) studies that evaluate pilot projects.

2.1.1 Analytical Studies

In a 2006 infoDev report Chetley [1] describes the major constraints and challenges faced in using Information and Communications technologies (ICTs) effectively in the health sector of developing countries and the emerging trends in technologies that are likely to shape ICT use in the health sector. From this, Chetley draws seven broad conclusions about the use of ICT in the health sector: 1) keep the technology simple, relevant and local; 2) build on what is there; 3) involve users in the design; 4) strengthen capacity of the effective ICT; 5) introduce better monitoring and evaluation; 6) include diverse communication strategies in the design of ICT projects; and 7) continue to research and share learning about what works, and what fails. Chetley’s conclusion is that there is no single solution that will work in all settings so he gives guidelines for customized solutions.

In 2008 Rodrigues [2] wrote an article that emphasizes the need for the following five things when applying technology to healthcare: 1) standardization of information exchange, 2) establishment of national policies about e-Health?, 3) the awareness of how humans use technology and the skill
development to better use technology, 4) equitable access to technology for all residents, and 5) security and privacy in the e-Health system. Rodrigues states that these five points are critical for the adoption of e-Health in developed countries. He finds the most important to be the government involvement in establishing national polices.

In comparison, in developing countries, Rodriguez finds that the health sector authorities are not taking full advantage of ITC developments [2]. In particular in developing countries there is significant resistance to change in certain professional roles, and thus, with the introduction of ICT in healthcare, the traditional structures and hierarchies are disrupted and change resisted. Another problem in developing countries is the lack of information about projects, methodologies, and technical solutions. Demonstrating the cost-effectiveness of new technologies in developing countries is especially challenging, since well-designed and randomized controlled trials are not feasible mostly because of the cost. The sporadic attempts to evaluate e-Health projects led by the World Health Organization (WHO), mostly in the Latin America, provide limited data.

2.1.2 Pilot Studies
In a 2011 Lemaire et al. [3] presents various mHealth pilot projects and discusses issues with their sustainability. Lemaire and his collaborators conclude that for governments to create an enabling environment for scale up, mHealth must be mainstreamed into existing healthcare structures and national health authorities’ policy. Additional recommendations include: 1) identify innovative ways to incorporate other mobile services using cross-sectorial approaches; 2) identify a sustainable and scalable business model that is applicable for large-scale implementations; 3) build partnerships with the private sector after a successful pilot phase; 4) perform social marketing; 5) empower users through the mobile phone technology, particularly women.
In a 2009 Maumbe, et. al. [4] completed a study on factors affecting the adoption of ICT for health service delivery in Namibia. The authors examined ICT use in health service delivery to patients in the Khomas and Oshana regions of Namibia. The study interviewed 134 patients and 21 health service providers. The results on individual ICT use identified: 1) personal privacy, 2) functional literacy, 3) ICT cost, 4) education, 5) age, and 6) positive perceptions about ICT applications in improving health services as statistically significant factors for adoption by both rural and urban patients in Namibia.

The above are just a few examples of the pilot projects described in the literature. In the section below I present literature on issues with SMS.

2.2 Review of literature on Short message Service (SMS)

2.2.1 Reliability of SMS

A major problem in sending Short Message Service (SMS) or text message is locating a receiving mobile station (MS). Jiang presents a study [5] on reliability, cost and delay performance of SMS delivery using different paging and retry methods. The study defines reliability of SMS delivery as the probability that a SMS message is successfully delivered to its recipient, while the cost of SMS delivery is defined as the total traffic (control and message data) in forward control channel per SMS delivery. Finally, the delay of SMS delivery is defined as the time from the first SMS attempt of delivery to the successful delivery. The most significant factor in the delay is the time-out for retry. A reasonable definition of a good SMS delivery method is that the recipient receives its SMS message with high reliability, minimum cost, and minimum delay. However, it is difficult to meet all of the three requirements so there is room for tradeoffs.

To assess the impact of these tradeoffs Jiang [5] analyses four SMS delivery methods: 1) the system directly broadcasts SMS messages to all the cells in the system; 2) the system first pages the zone where the mobile unit registered last time and if found delivers SMS message to the cell; 3) the
system pages the cell where the mobile unit registered last time, if the page fails, then it pages the whole zone; 4) if the SMS delivery to the current cell fails, SMS delivery area is expanded to the adjacent area.

Concerning reliability, Jiang’s analysis also allows for the impact of non-SMS system factors, such as the mobile user having his/her mobile phone powered off. He defines this as the “normalized reliability”, which is the success probability given that a recipient MS is turned on. This probability is appropriate because if the station is power-off, there is no way to improve the reliability of SMS delivery by paging and retry. Method 1 (broadcast to all cells) has the highest reliability and the lowest delay, however, at the expense of high cost. Method 3 (page the last cell and then the zone) has the lowest cost. If the cost is important consideration Method 3 is a good choice but the tradeoff is the lowest reliability of all 4 methods. The reliability of Method 4 (cell first, adjacent area next) is slightly less than that of Method 1, but with significantly lower cost. Method 4 is recommended for cases when both, the costs and reliability, are important. The delay performance of the last two methods (3 and 4) is at the same level. If the timeliness of SMS is not very important, the difference between those two methods can be ignored by designers.

Jiang’s study [5] also shows that as the number of retries increases, the reliability improves, but with it the cost increases too. If the loads in the forward control channels are not heavy, it is possible to use more retries with Method 4, with one of disadvantages that a few SMS may have a long delay. Overall conclusion of the study is that different delivery methods are available depending on the objectives of the system.

Another study [13] by Liu Pu proposes a new SMS-based protocol, which is designed with the mechanisms of reliable transmission and information encryption, for the home network and reliable remote control. The protocol contains two modules: reliable transmission module and information
encryption module. For the encryption it proposes the shared key using Diffie-Hellman algorithm. Authors apply this new proposed protocol for controlling home network gateway, which is designed to manage and share home resources.

2.2.2 Transmission Delay

In a study [6] Hui-Nien Hung et al. look at the transmission delay and derive the distribution of SMS delay based on 40,000 data points obtained from commercial operations. The authors use both parametric and nonparametric fitting methods to derive the distributions of the SMS round-trip delay. They consider normal, gamma, log-normal, and Weibull to approximate the distributions of the delay.

Another approach is a nonparametric fitting method, using a random number generation to capture the function behavior and simulate models for SMS delivery. The findings are that the transmission delay distributions are not symmetrical, have heavy tails and cannot be approximated by the normal distribution. Same can be said for truncated (from 1 to 150 seconds) gamma, log-normal, and Weibull distributions. Only the Cauchy (fat) tail fits the measured data. The conclusion is that the truncated distributions can only be used to roughly model transmission delays but not for precise estimation.

Another study [9] by Chwan-Lu Tseng et al. evaluates an application for agricultural data acquisition that employs GSM-SMS for data collection. The application uses SMS because of its low power solution, wide GSM coverage, SMS capability to save messages, and group broadcast functions of the system. Authors conducted delay measurements and one of them was sending SMS message through SDCCH channel. The message was 60 bytes and it took on average 3.2 seconds for the message from a mobile unit to reach SMSC and then MSC. Then they proceed to measure end to end one way data transmission delay, from a field monitoring platform (FMP) to remote host platform (HCP), and find out that it is 10-15 seconds. The round trip time is 35 seconds, which is a bit more than the double of one way but that includes 6 seconds for generating data. In another measurement, the average time of
a SMS message to any receiving endpoint ranged from 10 to 20 seconds. The accuracy of data transmission via SMS was 100%, retransmission rate was only 2.73% and data loss rate 0.66%.

A different study [10] by Collesei at el. explains that network delay depends on the length of the SMS message. For example, a message of 60 bytes (68 characters), that is sent either via SACCH or SDCCH, in an average radio propagation conditions, it will require 3.2 seconds before the message reaches a SMSC and can be routed to its destination. If the propagation conditions are extremely favorable, it will require only 2.9 seconds.

In a paper on suitability of SMS for emergency warnings [8] Pries at el. measured the message delay and packet loss in the German public GSM network. There were several different scenarios, in the first one 400 SMSs were sent a minute after each other. In these scenarios, there were no lost messages and the mean delay was 9.95 seconds. The second scenario compares two operators in the busy hour traffic. There was a significant difference in the mean delay, for one operator it was 6.3 seconds and for the other it was 9.9 seconds. Again no messages were lost. In the next scenario, the mobile phone was switched off while the message was sent and then the phone was switched on. The message was received in less than 45 seconds. Finally, the authors address their main goal and that is sending bulk messages as a warning to public about disaster. Even with 20 messages as a bulk, the delay increased significantly with some messages delayed up to 40 seconds. Addressing the most demanding locations, like Washington DC and New York City, with the average number of subscribers per sector of 3600 and 18000, respectively, the time required to warn population with the present system would be 14 and 71 minutes. The paper suggests a way to improve the time by using paging channels.

2.2.3 Congestion
A study [7] by Prieto et al. discusses a policy based congestion management for SMS gateway. The authors divide SMS service into two classes: guaranteed (person-to-person) and non-guaranteed
(bulk). The authors propose a policy based approach to congestion in the Enterprise Messaging Gateway (EMG) which differs from an extensively studied congestion problems in the context of IP routers. The differences are the following: SMS message is a single packet so the problem is not a flow based problem; SMS gateway (SMSG) is a node in an overlay network and its service rate varies on each port depending on the state of neighboring SMSGs. The policy balances two strategies, maximizing the throughput and minimizing the losses from dropping the messages. The authors propose a quantitative parameter that is the maximum allowable dropping percentage of bulk messages (since they are in the non-guaranteed class). The policy is dynamic and permits the EMG to manage the tradeoff between high throughput and low loss rate of non-guaranteed class messages.

2.2.4 Security and Quality of Service

A paper [11] on the quality of service (QoS) for SMS in GPRS/UMTS network by Jun Zheng at el. looks at an optimal buffering scheme taking into account the QoS requirements on both new and forwarded messages. This application is an extension of SMS that combines text, pictures and animations, called MMS, and it is used over the new high bandwidth wireless network, one of which is GPRS. The authors develop an analytic model based on one-dimensional continuous time Markov chain. Numerical results demonstrate that the optimal buffering can be achieved by the proposed methodology.

The state of security for SMS in mobile devices [12] is discussed by Garza-Saldaa at el. The authors are concerned with non-conventional applications of SMS in which private information is sent, such as health or payment information. They present 24 applications using SMS mostly because of its low cost and large acceptance. Their conclusion is that the most applications demand integrity of data, which prevents information change. Two other important forms of security for SMS are authentication and encryption. Previously suggested system of storing a public key on the SIM card is considered insecure with a better way of generating public and private key.
Finally, all the above papers reference a tutorial on SMS in GSM network [14], which presents an overview of the building blocks of GSM networks and then the SMS network and protocol architecture.

The section below looks in more depth at mHealth or teleHealth studies, and it ends with specific application of SMS in health solutions.

2.3 mHealth Literature

2.3.1 Medical Applications

A study [15] by Rao at el. evaluates video compressions for diagnostic level of quality in medical applications and bit rates that will assure the medical fidelity criteria. The authors use flexible algorithms for compression in the region of interest (ROI) with different compression in the background of the video. Limitations on bit rate require compression ratio larger than a certain minimum value. On the other hand, a requirement for diagnostic quality of a medical video is a compression ratio smaller than a critical value. The authors attempt to reconcile the two and test their algorithm using medical experts. Their conclusion is that it is possible, with a flexible compression algorithm, to reduce a bit rate to 500 kbps and still achieve a diagnostic level of video quality in the ROI.

Another study [16] by Bendtsen at el. evaluates the WHO suggestion to incorporate screening and brief intervention (SBI) into the daily routine of primary health care (PHC) for risky drinkers. It specifically excludes heavy and dependent drinkers and pays attention to only risky drinkers. A risky drinker in Sweden (where this study is performed) is someone who drinks more than 4-5 standard drinks (12 grams of alcohol per drink) one or more times a month. One reason the authors site for computerized self-referred evaluation is that family doctors are neither trained nor feel comfortable asking patents about drinking alcohol if they came for unrelated issue.
In the experiment touch screen computers that patients perform self-evaluation were located in local clinics. Patients performed the test either on their own or referred by the office stuff. Respondents received a personalized written feedback forms out the kiosk after completing the test. The respondents were followed up 3 months later. The results suggest that there is no difference between self and staff-referred respondent's behavior change. On the other hand, the net change from risky to non-risky drinking was larger than expected, 50 - 60% [16].

Misic at el. consider interconnection between IEEE 802.15.4 beacon-enabled network cluster and IEEE 802.11b network [17]. This scenario is important in healthcare applications where IEEE 802.15.4 nodes comprise patient’s body area network (BAN) and are involved in sensing health-related data. The authors are particularly interested in delays as the number of patents increases. They develop a probability distribution of packet service and wait time and show that the distribution cannot be characterized using the first two moments and that for accurate estimate it is necessary to have the whole distribution, in particular to estimate the delays at the receiver end.

2.3.2 Surveys

A study [18] by Oh at el. find 51 unique definitions of eHealth with a range of themes, but no clear consensus about the meaning of the term eHealth. They identified two universal themes (health and technology) and six less general (commerce, activities, stakeholders, outcomes, place, and perspectives). The widespread use of the term eHealth suggests that it is an important concept, and that there is a tacit understanding of its meaning. This compendium of proposed definitions may improve communication among the many individuals and organizations that use the term.

A paper [29] by Cubic at el. talks about the Session Initiation Protocol (SIP). It defines SIP as: “SIP is request-response application-layer protocol that provides the capability to: determine the location of the target end point, determine the media capabilities of the target end point via Session Description
Protocol (SDP), determine the availability of the target end point, establish a session between the originating and target end point, and handle the transfer and termination of calls.” So SIP makes delivery happen wherever the recipient might be. The path SIP messages take is independent from the message itself, which means that SIP messages do not add traffic to mHealth server. They present different scenario cases, and one they emphasize is an emergency alarms to patient's family and friends. They also include the mashup application of tele-monitoring and video/audio conversation between patient and doctor.

Papadopoulos presents a proof of concept for a small network involving patients on two islands, Cyprus and Chios, communicating with a hospital in Athens [19]. The project involved patients who are at “risk”, elderly and patients with chronic disease. It also monitored post-surgery patients. The platform consisted of patient's peripheral systems, PCs or laptops, wrist bands that collect bio-signals, wireless weight scale, software and app for medical monitoring, two-way radio USB communications device with 200 meters radius. All the information was stored at a remote centralized database that collects and tracks patient's data (SQL type database). Network consists of nodes that are research institutions and hospitals and 4 rural centers on Islands. Each node is connected to appropriate router via an Ethernet link running TCP/IP protocol. The network ensured broadband communication between Cyprus and Greece for transmission of audio-visual content. The uploading of measurements (heart rate, weight) is achieved by GPRS or ADSL. The audio-video interaction was achieved via ADSL with a speed of 1.024 Mbps upload and 512 kbps download for the connection to the research hospitals, which author considers sufficient for monitoring and teleconferencing. On the patient premises, the connection was 512 kbps upload and 128 kbps download, which author considers sufficient for monitoring. Since the hospital is the end point for all the calls, it is good that they have a wider pipe on their end. The patients do not communicate with each other but all of them talk to the hospital.
The platform maintained required security of data via HTTPS SSL, network firewalls, authentication and application firewall. Only six post-surgery patients participated in the home care trial. The author evaluated the platform from the perspective of technical metrics and user acceptance. He found that on the technical metric a failure rate was less than 1%, data was easily transmitted securely, and it maintained the integrity. Users surprisingly welcomed the platform. Post-surgery patients slowly used it less and less as they got better. In another paper the same author states that patients do not perceive immediately benefit of the mobile health apps since they are provide more prevention than cure. Conclusion was that this platform was low cost; it is easy to use and is well received. Finally, the system had positive impact on the health of participants.

In a different study [21] Choi et al. classify telemedicine technology into a store and forward and a two-way interactive tele-vision. They list a long list of formats and standards in medicine in general, with codes and procedures. They list three major areas for improvement in telemedicine: the definition is too broad; lack of standards; and increase in collaboration between the information technology and telecom industries. Their contribution is the emphasis on the importance of standards. The paper also talks about PAN but they call it Patient's Area Network (not personal area network which is a usual use of this acronym), and about smart room that monitors the patient's vitals.

A survey paper by Muller et al. [22] presents seven different telemedicine projects in Germany. It gives only an overview of the technology used and attempts to evaluate the projects. The patients are people with chronic heart failure and the goal is to avoid hospitalization. The limiting factor is the missing Internet access in primary care practices. All patients have electronic medical records with protected passwords. One thing in common is that all patients are contacted directly via telephone. Another concern that is addressed is educating patents about their health condition. The authors
evaluate the device-based telemedicine programs and find out that they are more cost efficient than the standard practice even after they account for the additional cost of the devices. The goal is shortening the length of in-patient hospital stay. At the patient’s end the data is transmitted using Bluetooth device to a central monitoring device. The central monitoring device transmits to the health facility using landline. Problem with comparison of results is nonexistent standardization. Another challenge is that teleMedicine services are not reimbursable by the insurance. For a sounder conclusion the authors call for the health-economics evaluation.

Another survey [23] of e-Health by Gustafson at el. specializes on applications for managing chronic diseases. In particular the survey looks at Randomized Controlled Trials (RCT). RCT is when study participants are randomly assigned to one or more treatments or a control group so that the basic characteristics are kept equivalent. Papers are obtained from web sites: Web of Knowledge and PubMed. They had to address ICT, chronic disease and monitoring and management.

Results of the paper survey: 1) number of studies increased over time; 2) of 34 studies, 21 used computer, 9 land-line, 3 mobile phone; 3) 10 studies addressed AOD (alcohol and other drugs), 7 management of diabetes, 3 cancer, 4 heart diseases, 5 smoking, 2 depression, 1 chronic headache, HIV, high blood pressure and chronic lung disease. Effectiveness, 29 of 34 found positive effects, 1 weak effect, 2 close response and 2 no effects. Further conclusions, not many smart phone studies, most effect comes from push intervention (when device initiates response).

Authors from this survey suggest: Move away from clinical settings (efficacy studies) to real world settings (effectiveness studies). Compare technology in different settings and find out what makes a difference. Increase the speed of studies so that it does not take so long while the technology is changing so fast. Two main conclusions, researchers are beginning to understand requirements for
producing high-quality smart phones and ICTs. Second, there is a need for addressing cost effectiveness of technology.

Zhang at el. [24] propose the use of a hybrid combining 802.11 and 802.16 telecommunications wireless standards. The standards differ in their QoS and priorities. WLAN (802.11) operates in unlicensed and WiMAX can do both licensed and unlicensed spectrum. The study talks about 802.11e protocol and different priorities it assigns, from highest to lowest -VOIP, video, best effort, background traffic. The authors suggest hybrid that will ensure the transfer of data with compatible QoS. The negotiating process between 802.11 and 802.16 happens as a bargaining game and it is based on the total utility of service. For WLAN connections the admission control is a zero-sum game between two networks, WLAN AP and the WMAN BS. The concern is a seamless handover and the paper presents an example of one whole network with BAN, WLAN and WiMAX core. Finally, it gives examples of teleMedicine applications that can be offered using the proposed hybrid.

In a paper [25] Pandian at el. talk about PSM (personal status monitor) deployed in the army in the 1990s. The wrist watch like device includes sensors of solder’s vital signs. Then the system uses VSAT network architecture, with satellite having a dedicated bandwidth and a more secure connection compared to the other communication technologies. The network they propose uses GSAT satellite in the C-band, and it is a single hop network. The local network uses WLAN of 2.4 GHz and 802.11g standard. It supports speeds of 54 Mbps and range of 200-400 meters. The clients form a distributed network, accommodating Video conferencing using Microsoft NetMeeting (a form of VoIP).

The results report delay in data transmission of 2 seconds for VSAT and less than a second for WLAN. Authors make a statement that the telemedicine system needs to be based on open system architecture. They recommend their system as reliable and inter-operable with any other IP based communication.
Ziadlou et al. survey [26] looks at different tele-medicine applications but it separates them using the type of the medicine practiced, tele-radiology, pathology and so on. The authors talk about the telecommunications methods separately, and do not connect the issues. When talking about application of telemedicine to crisis situations, it makes a couple of points. Tele-medicine in crisis needs to have redundancy using multiple paths of communication. It also isolates communications within organization and between organizations.

Wisely et al. [27] look at the IP networks with the intelligence at the edge, and with the bandwidth as the primary differentiator. Because Ad-hoc and personal area networks (PAN) are becoming more common as users create networks in their homes and form closed user groups authors claim that 802.11b is wholly unsuited to provide a cellular voice service. They discuss two main issues: user mobility and end-to-end QoS. They propose an intelligent middleware to address those two issues.

They foresee mobility on a node level and also on the whole sub-network level, as the sub-network moves. PAN networks will be not be only ad-hoc but include cellular and wireless access capabilities. A key feature of flexibility is applying polymorphic concept to radio access layers. Intelligent radio access layer contain single interface, multiple methods, and late binding techniques. In mobility management, issue is seamless mobility between heterogeneous sub-networks. Whole sub-network is one roaming node. IP micro mobility protocols provide fast seamless mobility, reduce round trip delay and eliminate the end-to-end registration signaling. For hierarchical tunneling, each foreign agent maintains a location base. They have many ideas for QoS and suggest various extension to protocols like RSVP and passive reservation around the node's current location. Finally, they define middleware as a software layer that resides between the application layer and lower layers and shields applications from heterogeneity of platforms.
2.3.3 Pilot Studies

In a paper [28] about the Cameroon Mobile Phone SMS (CAMPS) Trial, Mbuagbaw et al. explain the setup wonderfully but then there are no results presented. The authors discuss only the way the experiment will be conducted without actually writing about the results. They plan to compare two groups, one receiving SMS reminders and one not, otherwise identical. It seems like the perfect comparison, too bad we do not know what happened.

2.3.4 SMS in mHealth

A study [30] by Cole-Lewis et al. reviews current research on the effect of text messaging in the realms of disease prevention and management. Possible topics for disease prevention studies included physical activity, nutrition, risky sexual behavior, smoking, and adherence to preventive health measures. Options for conditions for disease management studies included diabetes, asthma, hypertension, and HIV. Seventeen papers representing 12 studies (5 disease prevention and 7 disease management) were included. 3 out of 12 studies found insignificant effect of the primary outcome and produced inconclusive results. In the rest of the 9 studies, 8 found evidence to support the effectiveness of text messaging as a tool for behavior change in disease prevention and management. Authors also noted that 4 of the 12 studies failed to isolate the effect of the text messaging as a telecommunications technology. 9 countries are represented in this review, but it is problematic that only one is a developing country, given potential benefits of such a widely accessible, relatively inexpensive tool for health behavior change.

Dunbar et al. [31] studied the feasibility of an automated two way messaging system to improve adherence, participants received multiple short daily messages designed to remind, educate, encourage adherence, and solicit responses concerning side effects and self-reported adherence. Twenty-five participants remained in the study for a median of 208 days, receiving 17,440 messages and replying to
14,677 (84%). Participants reported missing one or more doses on 36% of 743 queries and reported medication side effects on 26% of 729 queries. Participants expressed high satisfaction with the messaging system and reported that it helped with medication adherence. The results from the study suggest that it is feasible to use an automated wireless two-way messaging system to communicate with HIV-positive patients over an extended period of time.

Tahat designed a low-cost mobile patient monitoring system that uses SMS and MMS [20]. Patients ECG and temperature are monitored, collected by a micro-controller, sent to a cell phone via a Bluetooth transceiver. The phone communicated the information to the cell tower and ultimately to doctor's mobile phone or a PDA. The system uses either SMS or MMS for transmission.

Finally, Lester at el. study the effects of a mobile phone short message service on antiretroviral treatment adherence in Kenya [32], and found that patients who received SMS support had significantly improved ART adherence and rates of viral suppression compared with the control individuals. The authors conclude that mobile phones might be effective tools to improve patient outcome in resource-limited settings. The conclusion is based on the results that adherence to ART was reported in 168 of 273 patients receiving the SMS intervention compared with 132 of 265 in the control group. Patients were randomized by simple randomization to a mobile phone short message service (SMS) intervention or standard care. Patients in the intervention group received weekly SMS messages from a clinic nurse and were required to respond within 48 h. This conclusion is one of many that mobile phone can be an effective tool in adherence programs.
2.4 References


http://www.ehealthstrategies.com/files/Commonwealth_MOH_Apr08.pdf


http://www.igi-global.com/article/international-journal-healthcare-delivery-reform/2173


3 Technical characteristics of SMS

3.1 Introduction

Short message service (SMS) is one of the most popular mobile data services. The International Telecommunications Union (ITU) recently reported: “The total number of SMS sent globally tripled between 2007 and 2010, from an estimated 1.8 trillion to a staggering 6.1 trillion. In other words, close to 200,000 text messages are sent every second.”[1]

SMS has been proposed for a number of time-sensitive applications such as infrastructure monitoring [2], sensor data collection [3], medical patient monitoring [4], and 911 emergency communications [5]. SMS is designed for text messaging, an application which is asynchronous and delay tolerant. The FCC has proposed SMS as an additional method of contacting emergency services via 9-1-1 [5].

When using texting or SMS for medical applications, several technical aspects of the cellular phone service are critical. These include: 1) how strong a signal needs to be for a text to be transmitted? 2) how long does an SMS occupies the air interface? 3) under what conditions will a text get through but a mobile voice call will not? and 4) do these quantities change if the phone is stationary or moving? As the literature study in Chapter 2 indicates, only a handful of limited studies on these topics had been conducted or at least published. Thus, laboratory tests answering the above questions are presented here. The performance of SMS in unfavorable conditions, in this case weak signal conditions, is relevant for the developing countries since their coverage is spotty and the signal often weak.

The purpose of this chapter is to study this popular form of communication in a lab setting and present results of four different time measurements tests it takes to transmit an SMS between the mobile phone and the base station, which we denote the air interface delay. The chapter is organized as follows. It first presents the measurement setup technique. Second, it reports data for a variety of
conditions; these conditions vary the size of the SMS, the signal strength, and whether the sender is fixed or mobile. Third it reports a delay model and technique for estimating the model parameters. With these parameters it is possible to characterize the distribution of the delays better that in the literature presented in Chapter 2 section 2.2. A better characterization of SMS delay distribution would provide a method to assess the suitability of SMS in variety of applications. The performance analysis of SMS in unfavorable conditions, as it is the edge of coverage, presents a support for using SMS as a mode of communication in conditions common in developing countries.

For the purpose of this testing I use GSM phones because of the worldwide popularity of the GSM standard and convenience of accessing the network facilitated by SIM cards. While the model developed is specific to GSM, similar models can be developed for other standards such as CDMA 2000. Details of GSM system are explained in the following section.

### 3.2 GSM

The main system used in developing countries is Global System for Mobile Communications (GSM) and it is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe technologies for digital cellular networks. GSM is an open, digital cellular technology used for transmitting mobile voice and data services. GSM supports voice calls and data transfer speeds of up to 9.6 kbps, together with the transmission of SMS [6].

GSM operates in the 900MHz and 1.8GHz bands in Europe and the 1.9GHz and 850MHz bands in the US. GSM services are also transmitted via 850MHz spectrum in Australia, Canada and many Latin American countries. The use of harmonized spectrum across most of the globe, combined with GSM’s international roaming capability, allows travelers to access the same mobile services at home and abroad. GSM enables individuals to be reached via the same mobile number in up to 219 countries. Terrestrial GSM networks now cover more than 90% of the world’s population [6].
One of the key features of GSM is the Subscriber Identity Module, commonly known as a SIM card. The SIM is a detachable smart card containing the user’s subscription information and phone book. This allows the user to retain his or her information after switching handsets.

3.3 SMS Architecture

In a cellular telephone system, the location of a mobile station (MS) is determined by a registration and paging process over control channels. SMS messages are transported via those control channels. A voice call is set up using a control channel to communicate with the tower but as soon as the base station establishes that the request is for a voice call it transfers the call to a traffic channel. The mobile switching center (MSC) controls multiple base transceiver stations (BTS). The MSC also handles functions such as registration, authentication, location updating, handovers and routing to roaming subscribers. There are at least three databases it has access to: the Home Location Register (HLR) that keeps detailed records of each subscriber in the MSC network; the Visitor Location Register (VLR) keeps record of subscribers who have roamed into the jurisdiction of the MSC from other networks; Authentication Center (AuC) authenticates each subscriber that attempts to access the network.

Each vendor’s SMS is based on the capability of a digital cellular terminal to send and receive alphanumeric messages [7]. The short messages can be up to 160 characters in length and can be sent concurrently with voice traffic. When a subscriber is not on a voice call the SMS utilizes the stand-alone dedicated control channel (SDCCH) but while the subscriber is on a call it uses the slow associated control channel (SACCH) [7].

The payload length of SMS is limited by the constraints of the signaling protocol, precisely 140 octets. Short messages can be encoded using a variety of alphabets; the default in GSM is 7-bit alphabet. This leads to the maximum individual short message sizes of 160 7-bit characters [11].
The path of a voice call from one MS to another MS differs from a path SMS takes. Fig. 3.1 is a diagram of a standard mobile voice call. The main difference is that the MSC sends the SMS message to a SMS center (SMSC) and if the recipient is in the same network it is delivered directly. If the recipient is in a different network it goes via a Gateway as pictured in Fig. 3.2.

Figure 3.1 Path of a standard mobile voice call
Figure 3.2. Path of SMS message

The air interface delay can be computed from the first principles by examining the GSM protocol in [11]. However, there are considerable vendor and operator specific parameters. Further, as we will show, channel errors introduce significant variability to the delay and it is precisely this variability which we wish to characterize. Therefore we found this measurement approach useful.

3.4 **Methodology**

In this section we present the experimental setup and test methodology.

3.4.1 **Test Setup**

The testing took place inside of the Pervasive Communication Lab inside the Engineering Center at the University of Colorado. The basic setup is shown in Fig. 3. The mobile phone is a Telit EVK2 GSM Developer’s board with a SIM card for an AT&T/Cingular network. This is connected to a Larsen Special remote mobile antenna through a S.M. Electronics SA3550S manual step attenuator (0-3000 MHz, 0-50dB in 1 dB steps). An Anritsu Spectrum Master MS2721B spectrum analyzer is connected to the mobile phone and antenna through a 20dB attenuator and a Mini-Circuits 15542 Splitter.
The Federal Communications Commission (FCC) Spectrum Dashboard website was used to determine the GSM spectrum available and licensees for the test site in Boulder, Colorado. The SIM card used for testing carried the Corr Wireless brand, but they were not listed as having licensed spectrum in the area, which indicated they were reselling service from another carrier. As GSM in the United States was known to operate in the cellular bands around 850 MHz and in the PCS band around 1900 MHz, the Spectrum Dashboard was used to determine the exact frequencies licensed in Boulder. A series of test calls were placed and the spectrum analyzer was used to detect activity in these GSM bands. Multiple calls were used to verify that spectrum in the range of 824 – 835 MHz and 845 – 846.5 MHz were used for the reverse link (phone to BTS) and 869 – 880 MHz and 890 – 891.5 MHz were used for the forward link (BTS to phone), licensed to AT&T/Cingular wireless. Unless noted otherwise, all measurements were taken on the reverse link.

The Telit board was programed to send text messages, and then queried for the received signal strength (RSSI). Tracking the RSSI enabled the path loss to be tuned to specific repeatable received power levels.

The 20dB attenuator reduced the signal from the mobile phone board to within the operating range of the spectrum analyzer. This path was tested and calibrated using a signal generator and the spectrum analyzer. The path was found to have approximately 30 ±1 dB of overall attenuation with the
step attenuator connected but set to 0. At this setting, the base station signal strength is strong. The variable attenuator allowed the signal level at the phone to be varied between this strong level to a level that did not allow communication. The spectrum analyzer was placed in zero span mode so that the packet transmissions from the mobile phone could be recorded over time.

3.4.2 Definition of measured quantities

The two quantities we measure are the air interface delay for SMS and the air interface delay for a voice call setup time. The connection setup when viewed on a spectrum analyzer appears as a series of spikes, one for each packet in the exchange. Air interface delay for sending SMS is measured on the spectrum analyzer from the beginning of the first spike (initial RACH message) to the end of the last spike, as pictured on Fig 5. Voice call setup time is defined as a time elapsed from the moment of dialing to the moment when the landline begins ringing; this point in time was noted in the spectrum analyzer trace, and the setup time was measured from the first spike to the ring time. This measurement includes human reaction times to mark the ring time and the error is estimated to be 0.1 seconds or less. We used a landline as the called party to eliminate additional air interface time necessary for calling a mobile phone.

We measured performance at both strong and weak signal levels. The level of cut-off attenuation where a call or SMS could not be placed was found empirically. Reducing the attenuator by 1 dB was enough to enable a call or SMS connection. The measured signal level at this attenuation was -109dBm and denoted a weak signal. A strong signal was 12 dB higher (-97dBm).
3.4.3 First test setup - various message sizes

In the first test we intend to establish a baseline for the time delay of SMS and evaluate messages of different sizes. The sizes of the messages we use are 1, 60, and 160 characters. Those sizes present the full range of SMS message sizes. They are all measured with a strong signal.
3.4.4 Second test setup – 60 and 160-character messages at different signal levels
This test is designed to evaluate the effects of low signal strength—such as when a mobile phone signal is obstructed or at the edge of coverage—on the ability to connect a call with the device. Measurements were made under the weak signal conditions and compared to the previous results with strong signals.

3.4.5 Third test setup- Choreographed Mobility
The final set of tests is designed to evaluate the effects of mobility-induced fast fading when the signal is weak. We transmitted a 60-character message while moving the antenna in a choreographed manner [12] with one experimenter pacing back and forth on a path four meters long.

3.5 Results
Fig. 6 is a screen shot of the spectrum analyzer that shows the individual frames and the spacing of a GSM multiframe. This multiframe structure is characteristic for GSM and each grouping of three spikes represent two SDCCH with one SACCH in the middle. The standard multiframe length is 235.38 ms, as described by Redl et al. [11]. The measured value is 236 ms and is typical, thus our measurements are accurate to within a few milliseconds. Reported results are derived from at least 30 observations.

3.5.1 Various message sizes
For this test we compared the delay time of different size messages. We chose three messages sizes 1-character, 60-characters, and 160-character (the largest SMS size). The results are presented in Table 1.

<table>
<thead>
<tr>
<th>Message size</th>
<th>Average delay (sec)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 char</td>
<td>3.28</td>
<td>0.29</td>
</tr>
<tr>
<td>60 char</td>
<td>4.06</td>
<td>0.30</td>
</tr>
<tr>
<td>160 char</td>
<td>5.59</td>
<td>0.38</td>
</tr>
</tbody>
</table>
The longest message delay is only 1.7 times larger than the smallest message because most of the air interface delay consists of connection setup overhead. Thus, message size does not increase delay considerably.

3.5.2 Comparison of time delay of 60 and 160-character messages at different signals

For this test we compared messages of 60 and 160 characters at two different signals strengths. The strong signal is measured at -97dBm and the message is transmitted with 100% reliability. The weak signal strength is set at -109 dBm and the message is transmitted 82% of the time. The recorded time is only that of the successfully transmitted 60-character messages, and the results are presented in Table 2. In Table 3 we present time delay for the 160-character message.

Table 3.2 Delays for 60-character message at two signal strengths

<table>
<thead>
<tr>
<th>Signal level</th>
<th>Average delay (sec)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>-97 dBm (strong)</td>
<td>4.06</td>
<td>0.38</td>
</tr>
<tr>
<td>-109 dBm (weak)</td>
<td>4.49</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Table 3.3 Delays for 160-character message at two signal strengths

<table>
<thead>
<tr>
<th>Signal level</th>
<th>Average delay (sec)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>-97 dBm (strong)</td>
<td>5.59</td>
<td>0.38</td>
</tr>
<tr>
<td>-109 dBm (weak)</td>
<td>6.19</td>
<td>0.93</td>
</tr>
</tbody>
</table>

It is apparent that on the edge of coverage it takes longer to send a message of the same size, and more importantly that the standard deviation is approximately double for both the 60-character message and the 160-character message compared to the strong signal environment. The reasons for this extended delay are retries to establish a connection and layer two retransmissions.

3.5.3 Voice versus SMS on the edge of coverage

We measure call set-up time from a mobile phone to a landline, and the average time for call set-up is 3.69 seconds. Table 4 compares the setup time for a voice call with the air interface delay of a 60-
character SMS. Both are similar in length although for the SMS we only measure the time to deliver the SMS to the SMSC and not to the destination while the call setup measured the time to ring at the destination.

<table>
<thead>
<tr>
<th>Table 3.4 Voice call setup and 60 character air interface delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to set up</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Voice setup</td>
</tr>
<tr>
<td>SMS 60 char</td>
</tr>
</tbody>
</table>

Another test we conducted involved placing voice calls on the edge of coverage. We established a voice call and then increased attenuation to simulate a decrease in signal. The call lasted three minutes unless it was dropped. The majority of calls were not dropped (90%) but the RxQual, self-reported by the phone, was either six or seven, which implies Bit Error Rate (BER) of more than 6.4% or 12.8% respectfully [8]. Kemps, Beerends and Vary [13] show that values of the RxQual below four are desirable because at a gross BER of less than 1.6% (RxQual of four) almost all bit errors can be corrected by the channel decoder. Therefore the calls of RxQual six and seven that we observed are not an acceptable form of communication.

3.5.4 Choreographed mobility
Our final test was a choreographed mobility experiment as described by Rensfelt et al. [14]. We moved the antenna of the MS in a choreographed manner to simulate mobility and concurrently sent a series of 60-character messages. We started at a low signal with strength of -109 dBm and traced a path of approximately eight meters in random fashion. The results are presented in Table 5.

<table>
<thead>
<tr>
<th>Table 3.5 Delays for 60-character message, stationary and mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMS 60 char</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>stationary</td>
</tr>
<tr>
<td>mobile</td>
</tr>
</tbody>
</table>
As in the previous situations, the mean of the delay time of a mobile case increases slightly as compared to stationary, but the standard deviation quadruples. The large standard deviation implies that in realistic situations (when the sending device is moving) the time delay varies considerably.

### 3.6 Air Interface Delay Probability Model

The empirical cumulative distribution function for the 60-character SMS air interface delay is shown in Fig. 7 for the strong and weak signal case. Fig. 8 shows the empirical cumulative distribution function for the case of the mobile user. We observe that with the probability of 0.9, with strong signal, the delay of SMS messages will be under 5 seconds, with weak signal this delay will be less than 8 seconds, and in the mobile case this delay will be less than 6.5 seconds.

It has been shown [9] that the distribution of the delay is not normal nor well described by other common distributions. We instead take an approach based on knowledge of the SMS connection process. We consider the delay to be composed of four components. The first is a deterministic minimum time to deliver the message in the best case, \( t_{\text{min}} \). The second is a uniform distribution between 0 and \( t_s \), i.e. \( U \sim U(0, t_s) \), where \( t_s = 235.38 \text{ ms} \) is the multiframe duration. This accounts for the

![Figure 3.6. Cumulative distribution function of air interface delay for 60 character SMS message.](image-url)
random time between when the first RACH is sent and the assignment of the SDCCH. The RACH can fail due to collisions or not being received and this occurs with unknown probability \( p_r \). If a retry occurs, it happens after retry timeout \( t_r = 1 \text{ sec.} \) and this process can be repeated until successful. Thus, this third component is geometric, \( G \sim G(p_r) \). The last component is a function of the number of frames sent. The SMS message consists of \( n \) frames. Each time a frame is sent the transmission can be in error and require the frame to be resent with probability \( p_s \). Each of the \( n \) frames has to be sent and resent until they are successful. The number of attempts to send each frame is geometrically distributed and the total number of attempts to send all \( n \) frames is distributed as a negative binomial, \( B \sim NB(p_s, n) \). Thus if we let \( T \) be the random variable for the air interface delay, we get.

\[
T = t_{\min} + U + t_r G + t_s B
\]  

(1)

We note that we can estimate \( t_{\min} \) from the minimum time to send a message under strong signal conditions and we can similarly determine \( n \). The quantities \( t_s \) and \( t_r \) are known from the SMS protocol. The remaining quantities to determine are \( p_r \) and \( p_s \). For a given set of \( k \) air interface delay

---

**Figure 3.7. Cumulative dist. function for 60-char. air interface delay.**

![Cumulative dist. function for 60-char. air interface delay](image.png)
measurement, \( \{t_1, t_2, \ldots, t_k\} \), we compute the maximum likelihood values of the probabilities \( p_r \) and \( p_s \) using a grid search over possible values.

This approach was applied to the three data sets for the 60-character SMS air interface delay. The parameters of the model are shown in Table V. These parameters were used to plot the model cumulative distribution functions in Figs. 6 and 7. We see that this model provides a good fit to the empirical cumulative distributions. The fit for the strong signal and mobile scenarios is very good. The fit for the weak signal has more deviation, perhaps because a significant fraction of the transmission attempts (18\%) were unsuccessful and not include in the empirical data.

![Weak Signal Fit](image-url)

*Figure 3.8. Weak signal fit*
Figure 3.9. Strong signal fit

Figure 3.10. Mobility fit
Table 3.6 GSM Model Parameters Determined From Data

<table>
<thead>
<tr>
<th>SMS 60-char</th>
<th>$t_{\text{min}}$ (sec)</th>
<th>$n$</th>
<th>$pr$</th>
<th>$ps$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Signal</td>
<td>3.654</td>
<td>13</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Weak Signal</td>
<td>3.654</td>
<td>13</td>
<td>0.49</td>
<td>0.20</td>
</tr>
<tr>
<td>Mobile</td>
<td>3.654</td>
<td>13</td>
<td>0.38</td>
<td>0.22</td>
</tr>
</tbody>
</table>

As a comparison we consider a Weibull-based model distribution. The Weibull-based model is

$$T = t_{\text{min}} + W$$

(2)

where $W \sim W(\lambda, k)$ is a Weibull distribution with scale and shape parameters $\lambda$ and $k$. The Weibull is a general distribution that can help identify if the data follows some standard distributions. We fit the Weibull to the excess delay beyond $t_{\text{min}} = 3.5$ sec. This is smaller than the value in Table V. Delays as small as 3.654 sec were observed. With (2), since the probability of a 0 excess delay is 0, a small gap was necessary to get a valid fit. We note that such heuristics are not necessary in using (1). The resulting parameters are shown in Table VI. The shape parameter close to $k = 2$ suggest that the Rayleigh distribution is the best fit.

Table 3.7 Weibull Model Parameters Determined From Data

<table>
<thead>
<tr>
<th>SMS 60-char</th>
<th>$t_{\text{min}}$ (sec)</th>
<th>$\lambda$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Signal</td>
<td>3.5</td>
<td>0.86</td>
<td>2.01</td>
</tr>
<tr>
<td>Weak Signal</td>
<td>3.5</td>
<td>2.31</td>
<td>1.66</td>
</tr>
<tr>
<td>Mobile</td>
<td>3.5</td>
<td>1.97</td>
<td>2.04</td>
</tr>
</tbody>
</table>

We explore the goodness of fit between these models and the empirical distribution. To that goal we devise Q-Q plots comparing our GSM-based model distribution with the Weibull-based distribution. The result for weak signal, strong signal, and mobility are shown in Figures 3.9, 3.10 and 3.11, respectively. In all three cases (strong and weak signal, and mobility case) our model is closer to the experimental data than the Weibull as determined by its closeness to the 45 degree line. Note in particular that the fit is significantly better in the tail of the distribution which is important for modeling extreme excess delays.
3.7  **Analysis**  

The purpose of this study was to characterize the SMS air interface delay and compare this to the mobile voice call setup time. We considered four different scenarios.

The outcome of the first scenario, measuring the time delay of three SMS messages of different sizes, is that the overhead of an SMS message is large and the time delay of the smallest message (1 character) to the largest message (160 character) is 1:1.7. This test also established an expected longest time of delay for the longest message at 6.8 seconds in an environment with a strong signal.

The above measurements are conducted at a strong signal, defined as a reliable service, in this case -97 dBm. We then tested 60 and 160-character messages at a weak signal, defined as unreliable service, in this case -109 dBm. For both message sizes the time delay in a weak signal is longer primarily due to retries and layer two resubmissions. Both messages take an average of 10% longer in the weak signal scenario. More importantly, the standard deviation doubles in both cases, and now, with the probability of 0.9, the longest message takes 7.8 seconds to transmit.

Finally, we compared mobile voice to SMS, stationary and mobile. In the stationary case, the time to set up a voice call from a MS to a landline averaged 3.7 seconds. In the same situation, the time delay of 60-character SMS is 4.06 seconds.

In the case of mobility, the situation changes a bit. Because the standard deviation increases considerably, it will take at most 8.6 seconds to send a 60 character message, with the probability of 0.9. A mobility scenario in a weak signal environment is the most realistic but the most complicated case. Parameters such as RxQual have to be taken into account. The tendency of the network to keep the call open even with RxQual above four (where a channel decoder cannot correct the errors) means a call will not be dropped but the quality of the connection could be insufficient for meaningful communication. Further research is required to establish a comparison between mobile voice calls and SMS.
For each test we sent at least 30 text messages and conducted two different scenarios in each test, and we performed 4 tests, the total number of text messages was approximately 300. This is not as large as the field study discussed by Hung et al. [9] which had 40,000 messages but the results of our lab tests are compatible with the larger field studies.

3.8 Conclusion

I study an air interface time delay of GSM SMS messages. The length of the message does not increase the delay more than a factor of two. On the edge of coverage, where a signal is weak, the delay increases by an average of 0.5 seconds for both 60 and 160-character messages. Also, the standard deviations grow much larger, implying less reliability on the edge of coverage. The GSM protocol-based delay distribution model proved to fit the empirical data well. Future work will undertake testing using other standards for mobile communication and compare the results to the findings using GSM. The data and models presented here will assist researchers, government agencies, application developers, and system operators among others in analyzing the performance of SMS in time-sensitive applications. SMS is particularly useful in rural and developing areas due to its availability, low cost, and robustness, and well suited to systems and applications which are mindful of the benefits and limitations of the protocol.
3.9 References


testbeds, experimental evaluation and characterization, ACM, New York, NY, USA, 63-70.
DOI=10.1145/1860079.1860091 http://doi.acm.org/10.1145/1860079.1860091
Chapter on Cost/Benefit Analysis

4.1 Introduction

During the last decade, 2000-2010, the use of mobile phones has exploded and by 2010 an estimated 4.6 billion individuals are carrying mobile devices [1], out of an estimated 6.9 billion people in the world [2]. With this growth of mobile devices, “mobile health” or “mHealth”, has also emerged. mHealth is a term given to the various ways mobile devices are being used to collect health data and transmit that information among medical personnel, caregivers, and researchers. mHealth has huge potential to enhance the information available to health professionals to improve decision-making, to increase the quality of healthcare, to educate patients, and to promote healthy lifestyles. In addition, mHealth devices can assist patients in the detection and management of their health conditions and adherence to treatment. Given the enormous reach of mobile devices and other modern communication, mHealth significantly expands access to healthcare to more people, even in remote areas.

The scope of mHealth benefits depends on the economic development level of a particular region or a country. In more developed locations, with better health systems, mHealth is a tool that allows medical professionals and patients to access medical information more efficiently than from traditional paper records and in some cases to enable real-time access to information. For example, when ongoing monitoring of vital signs is required, medical professionals can monitor the patient and prescribe treatment, without having to be in the same location as the patient. In rural areas of the United States and in most developing countries, the main benefit of mHealth is the sharing of scarce medical resources resulting in the decentralization of healthcare. With mHealth each medical provider can reach and treat more patients with greater efficiency and effectiveness than in the past.
In this chapter I develop one extended example involving the treatment of diabetes mellitus. Diabetes is a metabolic disease that is associated with high or low blood sugar, either because the body does not produce proper levels of insulin or because cells do not respond the insulin that is produced. One of the distinctive characteristics of diabetes is that for many patients, a regimen of monitoring blood sugar levels and adjusting blood sugar with insulin injections is the therapy of choice. Traditional care for diabetes requires the patient to prick her finger, gather a blood sample, and test her glucose level using litmus paper strips. In contrast, telecommunications technology now enables ongoing monitoring of a patient’s glucose levels through adhesive “patches” without pricking the finger, and the technology enables the transmission of information to the patient, her physician, and to parents and caregivers, if appropriate. Record keeping is also continuous and automatic, thus more accurate, providing more reliable information for the patient and her physician.

At present we are in a phase of rapid innovation and dissemination of new telecommunications technologies. It is reasonable that attention is focused on the technical aspects of these new developments and on the excitement produced by innovations that change what is possible. However, a policy analysis should be much more practical and must include considerations of what is most beneficial and economically prudent. An important component of policy analysis is to determine the relative benefits and costs of new technologies, in the context and at the time when they will be implemented. Under many conditions, an inspiring new technology does not increase social welfare because it is still too expensive, or possibly because it is not reliable enough to provide a consistent benefit. In the case of mHealth technologies, there are subtle relationships between local telecommunication expenses and local benefits that make the answer to the question of whether to implement new technologies uncertain.
My goal in this chapter is to outline a general framework for cost/benefit analysis of a new mHealth application. I will use current best estimates for cost and benefit parameters. Of course, I expect those “inputs” to the analysis to change with time, even in the locations I have selected for the present model analysis. But, the general framework should continue to be applicable, with new updated parameters. In addition, if preprocessing of the data is performed on a local device and information is sent only if a change is detected the assumptions about the frequency of the data transfer will change considerably.

I will perform a model cost/benefit analysis for one mHealth solution, blood sugar monitoring, and find the rate of return on an investment (ROI) in this new technology. I test an assumption that the mHealth solution will provide a positive benefit and compare the estimated benefit with the cost of providing that solution. In order to test if the telecommunications cost associated with mHealth solution affects the outcome I choose three different regions/countries with a considerable burden of diabetes and different cost associated with sending the data. The countries are the US, India, and Latin America and the Caribbean.

4.2 mHealth solution - Tracking glucose level

4.2.1 Technical system
Blood glucose monitoring is a way to test the glucose concentration in the blood. The procedure is particularly important in the care of diabetes mellitus. A traditional blood glucose test is performed by drawing blood from a finger, then applying the blood to a chemically active disposable ‘test-strip’ [3]. Different systems use different technology, but most measure an electrical characteristic, which they use to determine the glucose level in the blood [3]. The results are recorded, and usually entered into an electronic data base.

Healthcare professionals advise patients with diabetes to monitor their blood glucose level regularly [3]. Most people who have Type 2 diabetes perform daily tests while diabetics
who use insulin (all Type 1 and some Type 2 diabetics) test their blood sugar level more often (sometimes up to 10 times per day), both to assess the effectiveness of their prior dose and determine their next insulin dose [3].

The technology for measuring blood glucose is constantly changing and with it the standards of care for diabetic people. The majority of the new electronic glucose tracking systems have software that provides users with ability to download results to a computer [4]. This information can then be used, along with professional medical consultations, to improve the management of diabetes. The glucose meters usually require a connection cable, unless they are plugged directly into the computer [4].

On the other hand, the mHealth solution for blood glucose monitor determines blood glucose levels on an ongoing basis (every couple minutes). One proposed electronic system, pictured in Figure 4.1, consists of:

- a disposable glucose sensor worn under the skin and replaced every few days;
- the sensor sends information to a monitor, in this case called an insulin pump, worn around the waist by a patient, that displays blood glucose levels continuously;
- the insulin pump either sends information directly through the cellular system or uses patient’s mobile phone to unload the information to a secure server accessible from the physician’s office [4];
- alarms that alert patients of hypoglycemia or hyperglycemia are often programmed into the system, so that a patient can take a necessary corrective action, which is important in cases where she does not feel symptoms of either condition.

While this technology has its limitations, studies have demonstrated that patients with ongoing glucose monitoring are able to better manage their condition, experience oscillations in
glucose less frequently, and are better able to reduce their glycosylated hemoglobin levels [5] [6].

An example of an electronic and ongoing blood glucose monitoring system is presented in Figure 4.1.

Figure 4.1 Schematic of diabetes monitoring system

4.2.2 Impact of diabetes

In order to understand the social impact of this particular medical condition in the US, I examined the data released on January 26, 2011, by the American Diabetes Association (ADA). ADA states that there are a total of 25.8 million children and adults in the United States, about 8% of the population, who have diabetes [7]. The number of diagnosed patients is 18.8 million people; undiagnosed is 7.0 million people; and pre-diabetic is 79 million people. In 2010 alone, 1.9 million new cases of diabetes are diagnosed in people 20 years and older [7]. Perhaps the most alarming fact in the ADA study is that in 2010, 79 million people in the U.S. were pre-diabetic and will eventually develop the condition and require treatment. The main cause of this increase is life style factors, such as diet, obesity, and smoking (diabetes is also caused by
genetic and non-life-style medical conditions, but the rates of these forms of diabetes are not increasing). The ADA calls this a “Diabetes Epidemic.”

The same agency estimates the Cost of Diabetes to be $174 billion per year or about $6,744 per person per year [7]. The total yearly cost in the United States includes:

- $116 billion in direct medical expenses
- $58 billion in indirect costs (disability, work loss, and premature mortality)

Diabetes can cause far-reaching health complications such as kidney damage, neuropathy (nerve damage), sleep apnea, stroke, so the health expenses of people with diabetes are larger than regular population. After adjusting for population age and sex differences, the ADA study further calculates that in 2010 the average annual health expenses of a person with diabetes is 2.3 times higher than for an average person without diabetes [8].

In June 2009, in response to the rising numbers of current and anticipated diabetic patients and the burgeoning costs to treat them, the Food and Drug Administration (FDA) gave a 510(k)\(^1\) clearance to a wireless remote monitoring system, HealthPAL, developed by MedApps. HealthPAL is a small, portable dedicated device that MedApps uses to collect data from wirelessly connected glucose meters, blood pressure monitors, pulse oximeters, and weight scales [9]. The data is then sent over a secure server to an online portal, for example Microsoft’s HealthVault or Google Health, for patients and physicians to view [9]. In my analysis I consider HealthPAL as a model case for calculating cost and benefits of the implementation.

---

\(^1\) Section 510(k) of the Federal Food, Drug, and Cosmetic Act requires those device manufacturers who must register to notify FDA, at least 90 days in advance, of their intent to market a medical device.
4.3  Traditional care versus mobile health

4.3.1  Diabetes in three regions

Different regions around the world represent different costs and benefits parameters, and I perform illustrative cost/benefit calculations for the US, Latin America, and India. There are several reasons why I consider these three regions:

- they are similar in geographic size;
- they each have a significant number of diabetic patients, in relative and absolute terms;
- the amount the disease costs to each society is considerable.

Special interest in the present analysis is the fact that the telecommunications cost associated with the electronic solution of blood glucose monitoring differs greatly across the three regions. This allows me to assess the cost of sending a text message containing medical information on the cost/benefit results.

4.3.2  Number of persons with diabetes

The estimated numbers of the diabetes patients for 2011 for the three regions separately and jointly are:

- In the US 25.8 million people, about 8% of the population [7].
- In Latin America and the Caribbean there is an estimated 25.1 million people with diabetes, or 8.7% of the adult population [11].
- The largest number of people affected by diabetes resides in India and the total is 40 million, which is 3.3% of the Indian population [16].
- All three regions have 90.9 million diabetic patients or 1.3% of the world population.
4.3.3 Cost of diabetes

In 2011, the diabetes cost in the US is estimated to be $174 billion (both direct and indirect) [7], which amount to $6744 per patient/year.

The data available for Latin America and the Caribbean is from 2000, the total annual cost associated with diabetes was estimated at $65 billion (direct $10; indirect $54 billion) [10]. On the other hand, in 2011 Latin America and the Caribbean had an estimated the health care expenditure for diabetes of $20.8 billion (only direct expenses) [11]. An average inflation rate for the last 10 years in Latin America is 9% [12]. Different countries in Latin America had different inflation rates over the last ten years, so I based my estimate on Brazil’s rate because Brazil has the highest incidence of diabetes in Latin America and it is one of the largest countries [11]. In order to calculate the total expense of diabetes I take the indirect expense from 2000, which was $54 billion and adjust it for inflation ($54 billion * (1.09^{10})) obtaining an indirect expense of $128 billion in 2011 prices. That way the total diabetes cost in 2011 (direct and indirect) in Latin America is $148.8 billion, which is $5928 per patient/year.

India has published the cost for the year 2004, and the total diabetes cost (direct and indirect) for that year was $333/person [14]. Assuming no substantial changes and adjusting to 2011 prices by using an average inflation rate of 7% [15] we obtain an estimate of $500 per patient/year.

Table 4.1 Overall Cost of Diabetes in 2011

<table>
<thead>
<tr>
<th>Region</th>
<th>Total expenses</th>
<th>Diabetic Patients</th>
<th>Cost/Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>174 billion</td>
<td>25.8 million</td>
<td>$6744</td>
</tr>
<tr>
<td>Latin America</td>
<td>148.8 billion</td>
<td>25.1 million</td>
<td>$5928</td>
</tr>
<tr>
<td>India</td>
<td>20 billion</td>
<td>40 million</td>
<td>$500</td>
</tr>
</tbody>
</table>
4.3.4 mHealth adoption

To estimate a pool of possible adoptees of mHealth technology, I consider 25.8 million patients with diabetes in the US, with an estimated 12% who use insulin regularly [4], which gives us approximately 3 million potential adoptees of the new glucose tracking technology. From that pool I assume a 20% adoption rate which is 600,000 possible beneficiaries.

In Latin America, the available data is for the year 2000 when one in 15 million people with diabetes took insulin. Applying the same percentage to 25 million patients in 2011, we get an estimate of 1.6 million potential adoptees. Assuming the same 20% adoption rate gives us 320,000 possible beneficiaries.

Only 1.2 million diabetic patients use insulin in India [17], and with the same 20% adoption rate there are 240,000 possible beneficiaries.

Table 4.2 Possible Adoptees

<table>
<thead>
<tr>
<th>Region</th>
<th>Diabetic Patients</th>
<th>Insulin Users</th>
<th>Adoptees (20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>25.8 million</td>
<td>3 million</td>
<td>600,000</td>
</tr>
<tr>
<td>Latin America</td>
<td>25.1 million</td>
<td>1.6 million</td>
<td>320,000</td>
</tr>
<tr>
<td>India</td>
<td>40 million</td>
<td>1.2 million</td>
<td>240,000</td>
</tr>
</tbody>
</table>

In section 4.5, termed Sensitivity Analysis, I vary the adoption rate and evaluate the effect on the outcome.

4.3.5 Benefits of mHealth diabetes monitoring application

I make an assumption that an effective and reliable new mobile device for measuring blood sugar level will improve public health and as a consequence reduce the cost per diabetic patient who adopts it by 10%. Reducing cost of diabetes is a social benefit because the total cost of diabetes per year is not only a burden to patients but also to health insurers, employers, and
the society in general. The cost reduction will come from allowing doctors to have more accurate and timely information about each patient’s blood sugar levels that should help prevent serious complications through preventative treatment. Another benefit is providing patients with better knowledge of their body reactions to diet and giving them more tools to control the disease. I calculate the benefit using numbers from Table 4.2 (adoptees) and 10% savings on the total number of cost per patient in Table 4.1.

- In the US that will be around $400 million/year (600,000 * $674).
- In Latin America, the cost savings would be around $190 million/year (320,000 * $600).
- In India we have the total saving at $12 million/year (240,000*$50) for 240,000 adoptees.

In section 4.5 I again vary the above assumption of 10% and present combination of the rate of adoption and the savings.

4.3.6 Telecomm Cost

On the other hand, there are expenses for implementing mobile technologies for diabetic care. Cost of cell service in the US is the highest in the world at $53/month, which translates to $636/year. I consider 10% of that cost to be dedicated to medical service using SMS, which is sufficient to send short information about the glucose level. That cost would be $64/patient/year. In the US most plans have unlimited SMS but using the 10 messages per day for 365 days it is 3650 messages and that translates to 2 cents per message. For 600,000 users that would cost $38 million for mobile phone service. Again the preprocessing of the data would make a significant impact on the number of SMS sent.

SMS cost in Latin America is high, on the order of 10 cents per message [13]. If diabetic patent sends 10 messages per day it adds up to $1.00 a day. That is yearly cost of $360 (which is
substantial, given income levels in Latin America). For 320,000 adoptees that would be $150
million/year.

The cost of SMS in India is 2 cents/message (or 20 cents per day); sending 10 messages a
day for 240,000 patients will cost $17.5 million.

If the collecting device has software that will preprocess the data and sent only the
information that represents a change in patient’s health, the number of SMS messages
transported will be considerably smaller and consequently the cost significantly lower. The
analysis of such situation is the outside of the scope of this paper.

In the cost/benefit calculation I did not include a dedicated medical device cost
(electronic glucose meter and transmission device) but only the recurring telecommunications
cost for the service. Nevertheless, it is sufficient to gain an insight about this mHealth option
that incorporates 10 text messages a day given the assumptions of the model. Table 4.3
summarizes results of cost/benefit for the three regions.

Table 4.3 Cost/Benefit (transmission costs only)

<table>
<thead>
<tr>
<th>Region</th>
<th>Benefit/year</th>
<th>Telecomm Cost/year</th>
<th>Benefit - Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>$400 million</td>
<td>$38 million</td>
<td>$362 million</td>
</tr>
<tr>
<td>Latin America</td>
<td>$190 million</td>
<td>$150 million</td>
<td>$40 million</td>
</tr>
<tr>
<td>India</td>
<td>$12 million</td>
<td>$17.5 million</td>
<td>-$5.5 million</td>
</tr>
</tbody>
</table>

In addition, I calculate the maximum cost of dedicated medical equipment for mHealth
and assuming the telecommunications cost is zero. Table 4.4 presents the results of that
calculation.
Table 4.4 Maximum cost of dedicated equipment

<table>
<thead>
<tr>
<th>Region</th>
<th>Benefit/year</th>
<th>Adoptees</th>
<th>Max Cost of Equipment/year/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>$400 million</td>
<td>600,000</td>
<td>$666</td>
</tr>
<tr>
<td>Latin America</td>
<td>$190 million</td>
<td>320,000</td>
<td>$593</td>
</tr>
<tr>
<td>India</td>
<td>$12 million</td>
<td>240,000</td>
<td>$50</td>
</tr>
</tbody>
</table>

Figure 4.2 Dedicated medical equipment cost and the annual cost/patient for diabetes

Figure 4.2 is a visual representation of the maximum dedicated medical equipment cost per patient. The relationship is linear against the cost of diabetes per patient.

4.3.7 The Model

To understand the calculations I present a general model for computing the cost and the benefit.

Total Cost is calculated using the following equation:

\[ C = (N_m \times C_m + C_e) \times N_s \]
With the notation as following:

\( N_m \) – number of text messages sent in one year because of the disease

\( N_a \) – number of adoptees

\( C_m \) – cost per text message

\( C_e \) – cost of dedicated medical equipment

Total Benefit is calculated by the following equation:

\[ B = N_a \times S \]

Notation as following:

\( N_a \) – total number of adoptees

\( S \) – expected percentage in cost reduction per adoptee from mHealth solution

4.4 Analysis

The difference between the benefit and the cost for implementing the mHealth solution for glucose monitoring in the US, Latin America and India is presented in Table 4.3. We can derive several conclusions.

1- For applications that perform monitoring and send information that utilize text messages multiple times a day, it makes more economic sense if patients have calling plans that include unlimited texting. One reason is that the telecommunications cost is predictable, and another that as the number of messages increases the cost per message decreases.
In regions where the cost per text message is high, as in Latin America, and number of required messages per application high, many initiatives based on text messaging will prove to be non-economical.

Even though India has low cost per message, the total cost exceeds the benefit for applications that use 10 text messages per day. There are several reasons for that:

- the number of insulin users in India is small;
- the cost of traditional care is low;
- even with low cost for texting, the number of text messages sent in a year is large and the cost adds up.

To better understand the surprising impact of text message cost on the overall social benefit, I calculate the break-even point for each region. The results are presented in Table 4.5. This calculation is also useful in that it tells us when to reconsider the possibility of introducing the new technology, on the basis of the “signal” in the cost of message transmission in a meaningful, per message metric.

<table>
<thead>
<tr>
<th>Region</th>
<th>Cost/Patient</th>
<th>GDP/Capita</th>
<th>Cost as % GDP/Capita</th>
<th>Break-even text cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>$6744</td>
<td>$48,398</td>
<td>14%</td>
<td>18 cents</td>
</tr>
<tr>
<td>Latin America</td>
<td>$5928</td>
<td>$11,770</td>
<td>50%</td>
<td>16 cents</td>
</tr>
<tr>
<td>India</td>
<td>$500</td>
<td>$3,693</td>
<td>14%</td>
<td>1.4 cents</td>
</tr>
</tbody>
</table>

The chart below (Figure 4.3) presents the relationship between the cost of diabetes and the break-even cost of text message, for this specific case of mHealth. The line has the same
slope as the maximum dedicated equipment cost since they are both looking at the same quantities but from different perspectives.

**Table 4.6** summarizes all three results: cost/benefit with the present cost in all three regions; breakeven cost of SMS; and the maximum cost of the dedicated medical equipment.

<table>
<thead>
<tr>
<th>Region</th>
<th>B-C (present SMS cost)</th>
<th>Break-even SMS cost</th>
<th>Max Cost of Medical Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>$362 million (2 cents)</td>
<td>18 cents</td>
<td>$666</td>
</tr>
<tr>
<td>Latin America</td>
<td>$40 million (10 cents)</td>
<td>16 cents</td>
<td>$593</td>
</tr>
<tr>
<td>India</td>
<td>-$5.5 million (2 cents)</td>
<td>1.4 cents</td>
<td>$50</td>
</tr>
</tbody>
</table>

With the present SMS cost only the US would draw considerable gain in implementation of mHealth solution. The difference between cost and benefit in Latin America is positive but nowhere as large as in the US. In India the difference is negative indicating that the mHealth solution would not be at all beneficial. Breakeven SMS cost in the US is nine times larger than the present cost indicating that the SMS cost is not a critical cost in mHealth implementations.
In Latin America it is 60% larger than the present cost, which is a variation that could influence adoption in some countries in the region. Finally, in India 30% lower cost would make this mHealth implementation break even.

The cost of dedicated medical equipment for this mHealth solution is similar in the US and Latin America but in India is ten time lower. This suggests that further research is necessary to produce low cost medical equipment for electronic blood glucose monitoring.

4.5 Sensitivity Analysis

In this section I vary the assumptions about the adoption rates and the savings. Previously I assumed that the adoption rate is 20% and the savings from mHealth solution is 10%. I am going to relax those assumptions and vary the adoption rate along with the savings rate and have several lines depicting their relationship. Figure 4.4 shows the relationship for the US.

**Figure 4.4 USA adoption rates, percentage savings and total B-C**

![Graph showing sensitivity analysis for USA adoption rates, percentage savings, and total B-C.](image)
In Figure 4.4 we can see that every combination of the adoption rate and the savings rate gives positive B-C. So the sensitive analysis does not change the previous conclusion that in the US mHealth for this example is economically feasible.

Similarly for all adoption rates in Latin America, the savings has to be above 5% for the B-C to be positive. Assuming 5% or higher savings is not unreasonable so I would say that for Latin America the previous results do not change.
For all adoption rates in India, the savings has to be above 15% for the B-C to be positive. In this case we gain the most insight with the sensitivity analysis. With the initial assumptions the B-C was negative and from Figure 4.6 we can tell that the savings have to be above 15% for that to be positive. Obtaining savings above 15% in India is significant savings implying that mHealth solutions might not be adopted in the near future in India.

4.6 Preprocessing

As mentioned in the introduction, this analysis is based on ongoing monitoring that sends on average 10 text messages per day. If the system has a preprocessing option that sends a text only when patient’s results are above a certain threshold the number of messages can be reduced significantly and the cost/benefit analysis will have different results. The cost would be significantly lower but the benefit will be the same, implying much high B-C result. Such implementation would make a significant difference for adoption in countries where the prices of SMS is high.
To analyze the effect on cost/benefit I will present one example. Let’s assume that instead of 10 messages a day the system with preprocessing sends only one message/day.

<table>
<thead>
<tr>
<th>Region</th>
<th>Benefit/year</th>
<th>Telecom Cost with preprocessing/year</th>
<th>Benefit - Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>$400 million</td>
<td>$3.8 million</td>
<td>$396.2 million</td>
</tr>
<tr>
<td>Latin America</td>
<td>$190 million</td>
<td>$15 million</td>
<td>$175 million</td>
</tr>
<tr>
<td>India</td>
<td>$12 million</td>
<td>$1.75 million</td>
<td>$10.25 million</td>
</tr>
</tbody>
</table>

In this example Benefit - Cost is positive for all three regions and considerably higher than in Table 4.7. As such preprocessing feature will have significant influence on adoption by bringing the cost down.

### 4.7 Conclusion

Before we replace traditional healthcare with mHealth solutions it is necessary to perform a cost/benefit analysis for each setting and to evaluate the efficiency of the proposed application. Here I explore the cost/benefit of a specific example of continuous monitoring of glucose level in diabetic patients. The recurring telecommunications cost in this case is a per text message cost. The cost/benefit analysis reveals that for three regions with significant numbers of diabetic patients and high healthcare costs, that in the US and Latin America the difference between costs and benefits is positive. In the US the difference is nine times larger than in Latin America mostly due to low cost per text message since in the US most plans have unlimited texting. In India the cost of text message is low but the benefit is also low, so the cost/benefit bottom line is negative. The maximum price of the dedicated medical equipment, another factor in the cost calculation, shows a linear relationship with the total cost/patient.
The biggest insight provided by the present analysis was the surprisingly impactful role of individual text message transmission costs across the three regions. The per message break-even analysis is a useful projection, as it tells us when to reconsider the blood glucose application as per message transmission costs drop, as they surely will.

Sensitivity analysis provides additional information. In the US for any adoption rate and savings percentage the B-C is positive. In Latin America, the savings has to be above 5% and in India it has to be above 15%. In the case of India the savings of 15% with the present cost of diabetes per patient would mean $150 per patient. Such savings seem rather large so we can say that India will not adopt electronic mHealth solution in the near future.

Preprocessing option makes considerable difference in calculations and by reducing number of sent messages it makes the discussed mHealth application more attractive.

Comprehensive cost/benefit analysis is just one tool that could be used to assess if a region is “ready” for an innovative mHealth solution. There are several factors playing a role but I identify two major ones for one particular solution, which uses a text message to transport the medical information to a central location where patients is monitored, they are: 1) cost per text message, and 2) the benefit it brings to a region, which depends on the number of the patients that will benefit from it relative to the social cost the disease presents to society.

Regarding the research question, we can say that economic feasibility of mHealth in this particular case is with qualifications. When the cost per text message is low even with high volume of text message transmitted daily the Benefit – Cost is still considerably high, and the mHealth application is economically feasible. In other countries with high cost per text message
the Benefit - Cost is negative and one option that I explore is to reduce cost by implementing preprocessing.
4.8 References


http://www.census.gov/ipc/www/popclockworld.html


http://www.diabetesdaily.com/wiki/Blood_glucose_monitoring


http://www.who.int/bulletin/Barcelo0103.pdf


http://www.tradingeconomics.com/inflation-rates-list-by-country


    http://www.indexmundi.com/g/g.aspx?c=in&v=71


5 Developing Countries and factors for mHealth adoption

5.1 Introduction

All over the world—particularly in developing countries where the health sector experiences serious shortages—mobile phones are becoming a new platform to offer health services. In recent years mobile phones have become an important tool in assisting people manage their health.

Prior research [2] [3] identifies telecommunications policy as one of the key elements in mHealth adoption. In order to test that hypothesis I interview telecommunications professionals from seventeen countries, and use grounded theory to explore the impact of telecommunications factors on mHealth adoption. The question is – if telecommunication technology, policy and regulation, and pricing structure, influence the adoption of mHealth in developing countries. I also seek to find if the above factors have different impact in separate regions of the developing world and for that purpose I group the countries into geographic regions. In addition, I postulate that two social factors have significant influence on mHealth adoption: 1) culture and attitudes of the population, and 2) state of health care, and explore their impact. Finally, I evaluate if the countries in my sample fall into regional groups based on economic and health indicators and if we can use those regional grouping for predictions.

5.2 Health indicators

Despite incredible improvements in health since 1950, the World’s population still faces a number of health challenges. For instance, one Billion people lack access to healthcare systems [4] [5]. 36 million deaths each year are caused by non-communicable diseases, such as cardiovascular disease, cancer, diabetes, and chronic lung diseases [4] [5]. In 2005, an estimated 17.5 million people died from cardiovascular diseases (CVDs), representing 30% of all global deaths that year. Over 80% of those CVD deaths occurred in low and middle-income countries. In 2008, some 6.7 million people died of infectious diseases, far more than the number killed in the natural or man-made catastrophes that make headlines.
For example, HIV/AIDS has spread rapidly, and for 2008, UNAIDS [5] [6] estimated that:

- 33.4 million people were living with HIV
- 2.7 million new infections of HIV were diagnosed that year, and
- 2 million deaths from AIDS occurred that year.

Another silent disease is tuberculosis, killing more than 1.7 million people each year, with 9.4 million new cases each year. Added to that, another 1.6 million people die every year from pneumococcal diseases\(^2\) including meningitis, pneumonia and sepsis, making it the number one vaccine-preventable cause of death worldwide. More than half of the victims are children. A third disease, malaria, causes some 225 million acute illnesses and over 780,000 deaths, annually. A fourth disease, measles, killed 164,000 people in 2008, mostly children under 5, even though an effective immunization costs less than $1 per dose and has been available for more than 40 years. These and other diseases kill more people each year than conflict alone [2] [6].

To evaluate a state of healthcare in a specific country, the World Health Organization (WHO) uses numerous indicators including: 1) malnutrition and its “stunting” impact on the height and weight of children, 2) child mortality, and 3) the number of physicians available to each 1000 persons in a country. Of these, the leading indicator for children’s health is malnutrition, and a key indicator of chronic malnutrition is the “stunting” of children’s growth. As growth slows down, brain development lags behind and as a result stunted children are more likely to learn poorly – impacting theirs and the country’s economic future. According to the child growth standards established by the WHO, about 178 million children globally are too short for their age. Additionally, recent estimates indicate that 115 million children under 5 years of age worldwide are underweight [3] [7], and the occurrence varies

\(^2\) The pneumococcus is a bacterium that causes serious infections like meningitis, pneumonia and sepsis. In developing countries, even half of those children who receive medical treatment will die. Every second surviving child will have some kind of disability.
among continents. Stunting rates among children are highest in Africa and Asia [3] [7]. In Africa, the number of underweight children increased from 24 million in 1990 to 30 million in 2010. In Asia, the number of underweight children was estimated to be even larger, at around 71 million in 2010.

Child mortality, which refers to the death of infants and children under the age of five, represents a second indicator of a country’s level of health progress. Child mortality worldwide is declining, with the total number of deaths of children under 5 years old dropping from 12.4 million in 1990 to 8.1 million in 2009 [2]. The level of mortality, however, remains alarmingly high in both low-income countries and certain regions of the world. In 2009, low-income countries around the world experienced 117 deaths per 1000 live births. This is compared to child mortality rates in the high-income countries of fewer than 5 deaths per 1000, and in middle-income countries, fewer than 10 deaths per 100 live births. In certain regions of the world, however, the numbers are even worse. Specifically in Africa, in 2009, the child mortality was 127 per 1000 live births [3] [7].

A third important indicator of the quality of healthcare in any country is the physician density per 1000 of the population, including both generalist and specialist medical practitioners. Medical doctors are defined as doctors that study, diagnose, treat, and prevent illness, disease, injury, and other physical and mental impairments in humans through the application of modern medicine [7] [8]. The physician density ranges from a high of 6.4 per 1000 in Cuba, through 2.67 per 1000 in the USA, to 0.019 per 1000 in Malawi [7] [8]. For the purposes of my research, when comparing regions and countries, I will be using two of the indicators most relevant to the state of healthcare: child mortality rates and physician density.

5.3 Description of Methodology and Data Analysis
The data in this study were collected through personal interviews in a convenient sample of 24 telecommunications and science professionals from 17 different countries who were attending a workshop held in February 2012 in Trieste, Italy. The interviewees have either Masters or Doctorate
degrees in telecommunications or related fields and have worked in the field for 5-10 years. The workshop was about sustainable wireless solutions. The attendees were carefully selected because of their background and interest to follow the workshop. In the interview, I asked them their opinion about the state of telecommunications technology, policy and mHealth adoption in their countries. The attendees came from seventeen countries, located on four continents. The countries included: Cameroon, Democratic Republic of Congo (DRC), Malawi, Gambia, and Tanzania in Africa; Peru, Colombia, Ecuador, Argentina, El Salvador, Nicaragua and Jamaica in Latin America; Albania, Ukraine in Europe; and India, Nepal, the Philippines in Asia.

I analyzed the data using Atlas.ti, qualitative data analysis software, commonly used in studies with interviews as primary sources. The interview data was open coded and then iteratively coded to identify themes. For the comparative analysis, I grouped the 17 countries into three regions: Africa, Latin America, and Europe/Asia. The grouping in geographical regions is motivated by my hypothesis, presented in the introduction, that countries in the same regions will have similar obstacle to mHealth adoption. The grouping is further motivated by the supposition that countries within a region would have similar economic and health care indicators. The third group, the Asia/Europe region, is small due to the distribution of participants, but the economic and healthcare indicators between them are similar and justify grouping them regionally. Those three regional groupings are presented in Table 5.1 that lists several economic and health indicators [24] from the represented countries.
In addition to raw data, Table 5.1 presents variations within a region, indicated by the number representing country’s deviation from the regional average. For example, Gross Domestic Product (GDP) of Argentina is twice the regional average (2.0 x Average). It is important to notice that there are substantial variations in GDP within a region, while the number of doctors per 1000 people, child mortality, and life expectancy do not vary as much. The life expectancy is the factor with the least variation of all three health indicators. That suggests that other factors than the previous three have significant influence on the life expectancy and keep it uniform within a region. Indeed World Health Organization (WHO) uses these indicators to assess the state of public health [26].

On the other hand, Table 5.2 contains averages and standard deviation within regions and between regions. The factor indicating country’s wealth, GDP, varies considerably within a region and between regions. That is also true for the number of doctors/1000. The other two health indicators vary

<table>
<thead>
<tr>
<th>Country</th>
<th>GDP (PPP) (Average)</th>
<th>Doctors/1000 (Average)</th>
<th>Ch. Mort./1000 (Average)</th>
<th>Life expectancy (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin America</td>
<td>$9,285 (Average)</td>
<td>1.4 (Average)</td>
<td>18 (Average)</td>
<td>74 (Average)</td>
</tr>
<tr>
<td>Argentina</td>
<td>$17,376 (2.0 x A)</td>
<td>3.15 (2.3 x A)</td>
<td>10 (0.6 x A)</td>
<td>77 years (1.0 x A)</td>
</tr>
<tr>
<td>Peru</td>
<td>$10,000 (1.0 x A)</td>
<td>0.92 (0.7 x A)</td>
<td>22 (1.2 x A)</td>
<td>73 years (1.0 x A)</td>
</tr>
<tr>
<td>Columbia</td>
<td>$9,998 (1.0 x A)</td>
<td>1.35 (1.0 x A)</td>
<td>19 (1.0 x A)</td>
<td>72 years (1.0 x A)</td>
</tr>
<tr>
<td>Jamaica</td>
<td>$8,727 (0.9 x A)</td>
<td>0.85 (0.6 x A)</td>
<td>14 (0.8 x A)</td>
<td>73 years (1.0 x A)</td>
</tr>
<tr>
<td>Ecuador</td>
<td>$8,317 (0.9 x A)</td>
<td>1.5 (1.1 x A)</td>
<td>20 (1.1 x A)</td>
<td>76 years (1.0 x A)</td>
</tr>
<tr>
<td>El Salvador</td>
<td>$7,429 (0.8 x A)</td>
<td>1.6 (1.2 x A)</td>
<td>20 (1.1 x A)</td>
<td>73 years (1.0 x A)</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>$3,147 (0.3 x A)</td>
<td>0.37 (0.3 x A)</td>
<td>22 (1.2 x A)</td>
<td>72 years (1.0 x A)</td>
</tr>
<tr>
<td>Africa</td>
<td>$1,416 (Average)</td>
<td>0.07 (Average)</td>
<td>71 (Average)</td>
<td>56 (Average)</td>
</tr>
<tr>
<td>Cameroon</td>
<td>$2,218 (1.6 x A)</td>
<td>0.19 (2.6 x A)</td>
<td>60 (0.8 x A)</td>
<td>55 years (1.0 x A)</td>
</tr>
<tr>
<td>Gambia</td>
<td>$2,018 (1.4 x A)</td>
<td>0.038 (0.5 x A)</td>
<td>70 (1.0 x A)</td>
<td>63 years (1.1 x A)</td>
</tr>
<tr>
<td>Tanzania</td>
<td>$1,689 (1.2 x A)</td>
<td>0.008 (0.1 x A)</td>
<td>66 (0.9 x A)</td>
<td>53 years (1.0 x A)</td>
</tr>
<tr>
<td>Malawi</td>
<td>$827 (0.6 x A)</td>
<td>0.019 (0.3 x A)</td>
<td>84 (1.2 x A)</td>
<td>52 years (0.9 x A)</td>
</tr>
<tr>
<td>Congo</td>
<td>$328 (0.2 x A)</td>
<td>0.11 (1.5 x A)</td>
<td>76 (1.1 x A)</td>
<td>56 years (1.0 x A)</td>
</tr>
<tr>
<td>Europe/Asia</td>
<td>$4,800 (Average)</td>
<td>1.2 (Average)</td>
<td>27 (Average)</td>
<td>72 (Average)</td>
</tr>
<tr>
<td>Ukraine</td>
<td>$7,077 (1.5 x A)</td>
<td>3 (2.5 x A)</td>
<td>8.5 (0.3 x A)</td>
<td>69 years (1.0 x A)</td>
</tr>
<tr>
<td>Albania</td>
<td>$7,781 (1.6 x A)</td>
<td>1.15 (0.9 x A)</td>
<td>15 (0.6 x A)</td>
<td>77 years (1.1 x A)</td>
</tr>
<tr>
<td>Philippines</td>
<td>$4,111 (0.9 x A)</td>
<td>1.15 (0.9 x A)</td>
<td>19 (0.7 x A)</td>
<td>72 years (1.0 x A)</td>
</tr>
<tr>
<td>India</td>
<td>$3,703 (0.8 x A)</td>
<td>0.59 (0.5 x A)</td>
<td>46 (1.7 x A)</td>
<td>76 years (1.0 x A)</td>
</tr>
<tr>
<td>Nepal</td>
<td>$1,328 (0.3 x A)</td>
<td>0.2 (0.2 x A)</td>
<td>44.5 (1.7 x A)</td>
<td>66 years (0.9 x A)</td>
</tr>
</tbody>
</table>
between regions more than within a region. Based on these findings, I use the regional grouping in the analysis only when considering health indicators and not the wealth of the country.

Table 5.2 Averages and deviations within and between regions

<table>
<thead>
<tr>
<th>Region</th>
<th>GDP (PPP)</th>
<th>Doctors/1000</th>
<th>Ch. Mort./1000</th>
<th>Life Expectancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>All countries</td>
<td>$5700 ± $3900</td>
<td>0.95 ± 0.72</td>
<td>36 ± 28.5</td>
<td>68 ± 9.88</td>
</tr>
<tr>
<td>South America</td>
<td>$9300 ± $4300</td>
<td>1.4 ± 0.88</td>
<td>18 ± 4.49</td>
<td>74 ± 2.00</td>
</tr>
<tr>
<td>Africa</td>
<td>$1400 ± $810</td>
<td>0.07 ± 0.08</td>
<td>71 ± 9.23</td>
<td>56 ± 4.30</td>
</tr>
<tr>
<td>Europe/Asia</td>
<td>$4800 ± $2600</td>
<td>1.2 ± 1.07</td>
<td>27 ± 17.4</td>
<td>72 ± 4.60</td>
</tr>
</tbody>
</table>

The methodology employed to analyze the data is a form of qualitative research. Qualitative research analyzes the issue from multiple dimensions and layers, and attempts to portray the results in a multi-faceted form [7]. The study participants, telecommunications experts, did not always give answers that match the statistics available on the Internet or government published studies because those experts evaluate the situation in their own country from the insider prospective. Knowing details unavailable to outsiders, they can give us insight in the sentiment of the population. In particular, I use grounded theory [12] that begins from careful data analysis and through iteration develops a theory. Grounded theories are particularly useful when current theories about the phenomenon are inadequate or outdated [10]. The impact of telecommunications factors on the adoption of mHealth is a new topic with no proven theories. I adopted selective coding in which categories are combined as described by Corbin [11]. To that goal I group the interview questions into five separate modules: 1) telecommunications technology, 2) telecommunications policy, 3) economics, 4) health care environment, and 5) obstacles to adoption of mHealth in each country. From these groupings I attempt to determine the influence of each category on the mHealth adoption.

Before the interviews, I collected statistics about each country’s indicators presented in Table 5.1, and published data on mobile penetration in each country [14] [15] [16]. In some cases, interviewees did not agree with the statistics published by budde.com.au [28], an independent research
and consultancy company focused on the telecommunications market, and explained to me that in their opinion the published facts do not reflect the reality.

5.4 Analysis
To answer the questions about the influence of telecommunication technology, regulation and pricing structures on the mHealth adoption in developing countries, I follow the equivalent modules in the interview. The initial hypothesis is that telecommunications technology has a limited influence and that policy and regulation, and relative pricing of telecommunications services have considerable influence. In the interview’s last module I consider the influence on adoption of the two social factors: culture and state of healthcare.

5.4.1 Telecommunications technology
The answers about the telecommunications technology’s indicate that the participant’s perception of the telecommunications technology infrastructure in their country is not based on the indicators such as the mobile penetration per capita, and population/geographic coverage published by consultancies such as BuddeComm, but on how much the quality and availability of services in the country have improved. To prove that point, I compared the answers with the published facts on indicators such as mobile penetration. Mobile penetration is defined, in percent form, as the number of mobile phones divided by the number of citizens, however that number does not necessary indicated the percentage of people owning a mobile phone. In many countries some citizens own multiple phones so the penetration could be over 100%.

Almost all Latin American participants responded that the telecommunications infrastructure in their country is advanced and mobile penetration rates in those countries are either 100% or more. Only the Nicaraguan respondent was not satisfied with the telecommunications infrastructure in his country. Nicaragua has 71% mobile penetration which is the lowest in the Latin American sample. In Africa, all five interviewees noted that the level of telecommunications is good and constantly improving, while
the actual mobile penetration ranges between 20% and 80%. In both regions, the participants reported that rural areas have much worse coverage than urban areas, similar to the situation in developed countries [23]. For example, an interviewee from Peru answered: “Coverage is very good in main cities, but in rural areas the coverage is spotty.” In Europe/Asia region, Albania and Ukraine both have over 100% mobile penetration, but the participants did not find telecommunications infrastructure quality in those countries the same. Albanian interviewee noted that: “The country’s telecommunications operators can do better; all the companies give inaccurate information about prices.” The Ukraine interviewee reported that: “Telecommunications are as good as in developed countries.” Indian interviewee considers telecommunications infrastructure as improving, while in the Philippines is “as good as in developed countries.” The interviewee from Nepal reported that the country has very low mobile phone penetration rate but the telecommunications infrastructure quality in the cities is as good as in developed countries, although not in rural area.

For more detail Table 5.3 presents data on mobile penetration and answers of respondents.

<table>
<thead>
<tr>
<th>country</th>
<th>mobile phone penetration</th>
<th>perceived quality of telecomm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>150%</td>
<td>good coverage, bad service</td>
</tr>
<tr>
<td>Argentina</td>
<td>130%</td>
<td>good in cities</td>
</tr>
<tr>
<td>Cameroon</td>
<td>49%</td>
<td>average for Africa</td>
</tr>
<tr>
<td>Columbia</td>
<td>100%</td>
<td>decent compared to a developed country</td>
</tr>
<tr>
<td>DRC</td>
<td>24%</td>
<td>good</td>
</tr>
<tr>
<td>Ecuador</td>
<td>100%</td>
<td>very good</td>
</tr>
<tr>
<td>El Salvador</td>
<td>136%</td>
<td>very good</td>
</tr>
<tr>
<td>Gambia</td>
<td>92%</td>
<td>fairly good</td>
</tr>
<tr>
<td>India</td>
<td>65%</td>
<td>growing rapidly, mediocre</td>
</tr>
<tr>
<td>Jamaica</td>
<td>119%</td>
<td>excellent</td>
</tr>
<tr>
<td>Malawi</td>
<td>20%</td>
<td>average for Africa, improving</td>
</tr>
<tr>
<td>Nepal</td>
<td>45%</td>
<td>good in main cities</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>71%</td>
<td>mediocre for Latin America</td>
</tr>
<tr>
<td>Peru</td>
<td>99%</td>
<td>good only in main cities</td>
</tr>
<tr>
<td>Philippines</td>
<td>80%</td>
<td>as good as developed country</td>
</tr>
<tr>
<td>Tanzania</td>
<td>62%</td>
<td>decent for Africa</td>
</tr>
<tr>
<td>Ukraine</td>
<td>120%</td>
<td>as good as developed country</td>
</tr>
</tbody>
</table>
In summary, twelve of the seventeen respondents thought that the telecommunications infrastructure in their respective countries was either excellent or very good. Only five of the seventeen respondents considered their country’s telecommunications infrastructure not adequate including: Albania, Cameroon, Malawi, Columbia and Nicaragua. The Albanian participant’s opinion is not based on the fact that her country has very high mobile penetration (100%), but the other four countries have low mobile penetration. Cameroon has the highest Gross Domestic Product (Purchasing Power Parity) in the African sample, but it has a low mobile penetration rate (50%) presenting an example of the underdeveloped telecommunications market.

When asked to rank (in ordinal ranking) different telecommunications infrastructures, the interviewees from all seventeen countries reported mobile phones as the most utilized telecommunications form. Traditional landlines were listed as either the least used or second to the least used technology, just above the Internet. The Internet was frequently ranked as the least available telecommunications service, except in the Ukraine. The interviewee from the Ukraine stated that her country has a level of Internet service comparable to the developed countries. This statement is strong, but not without grounds considering that the World Bank ranks Ukraine in the top third of 150 countries (developed and developing) using a composite index based on four indices for the Knowledge Economy, with one sub-index being ICT infrastructure development which implies good Internet access [25].

5.4.1.1 Ranking mobile services

While ranking the various mobile services (ordinal ranking), the respondents from Africa noted that voice is the dominant service. In Latin America, voice and texting share the first place. All interviewees answered that texting is a popular service. For three Latin American countries, young people are the demographics that texts the most and in the other three Latin American countries it is the whole population. For all the countries in Africa, the population that texts the most are younger
people, school age population. Participant from countries like India report: “Texting is not that popular as it is used be. Nowadays it is used mostly in the urban areas by youngsters.” In the Ukraine, texting is not popular and Internet dominates telecommunications services. The countries where all demographics use text messaging are: Argentina, Ecuador, El Salvador, Nicaragua, Philippines, and Nepal. There are slightly more countries from the Latin America but based only on such a small sample it is hard to make a general statement.

In conclusion, according to the respondents’ opinion, the biggest influence on the telecommunications infrastructure quality is the improvement rate in the quality and availability of services in the country. Furthermore, in this sample of developing countries mobile voice and texting are the most popular service while Internet is lagging behind.

5.4.2 Telecommunications policy
In the second module, concerning telecommunications policies in each country, the interviewees were asked questions regarding the degree of competition in the telecommunications market and the government’s involvement in it. Interviewees from the three countries in Latin America reported that their telecommunications markets were not competitive: Jamaica, Nicaragua, and Peru. However, respondents from Argentina, Colombia, Ecuador, and El Salvador, noted that a high degree of competition existed, with significant government involvement in setting the policies. At the same time all seven Latin American interviewees thought that the government is making an effort in promoting further competition in telecommunications. In Africa, four interviewees, except Cameroon, reported that the market is competitive and gave credit to the government for promoting competition. In the Europe/Asia sample, respondents from all of the countries, except the Ukraine, considered their telecommunications markets competitive and gave their governments credit for promoting competition. The majority of the countries in my sample have competitive telecommunications markets so we cannot isolate competitiveness as an issue that influences mHealth adoption in the sampled countries.
Published reports [14] [15] indicate that only two countries from my sample do not have competitive markets: Cameroon and Nicaragua. Cameroon’s economic growth is lagging behind other countries in the region, and that influences the development of its telecommunications sector. In 2012, Cameroon has only two mobile service providers, MTN and Orange [14], while other countries in Africa have healthier competition in telecommunications [14]. The consequence of this restrictive telecommunications market structure is a mobile market penetration rate that is below the African average in particular when compared to other countries with similar GDP per capita [14]. Nicaragua has a weak regulatory structure and strong bureaucracy, so market liberalization is slow to be implemented. The country’s telecommunications market is a duopoly, with América Móvil’s Claro and Telefónica’s Movistar as the two providers [15]. This uncompetitive situation is contributing to a lag in quality and price in Nicaragua compared to the neighboring countries. Participants from India and Ukraine perceived their telecommunications market as non-competitive. Although the participant from India does not believe the telecommunications market in their country is competitive, the person is most likely influenced by the recent scandal regarding corruption in assigning mobile operator licenses [16]. In early 2012 the impact of the unfolding scandal over the awarding of 2G licenses in 2008 has weaken the Indian mobile telephone sector and influenced public opinion regarding government involvement in promoting telecommunications market competition. The cancellation of some 122 mobile licenses and the subsequent responses of the industry regulators is the key to the future shape of the mobile industry in India [16]. The competition in Ukraine is improving as alternative operators join the industry; however the incumbent remains the dominant player, with the regulatory environment more likely to improve once privatization of the incumbent is completed [17].

5.4.2.1 Medical data privacy and security

In this module I also asked participants if they thought the people of their country are concerned over privacy and security of their medical data. The majority were under impression that
people in their respective countries do not pay much attention to those issues. Twelve respondents said that their compatriots are not concerned about it. Respondents from Ecuador, El Salvador, Gambia, Tanzania, and Ukraine informed me that the people from their country pay attention to privacy and security, but it is not the top priority. The concern about privacy and security is slowly developing, but at this moment in time it is not as important in developing countries as it is in developed countries, in particular in the USA.

The conclusion from the policy section is that most countries in my sample have competitive telecommunications markets and that the residents from those countries are not overly concerned with privacy and security of their medical data.

5.4.3 Economic aspect of telecommunications

To evaluate the economic background, I asked respondents about the major economic problems in their countries. In Latin America the major economic problems are poverty, unemployment, and lack of government investment in communications. The African respondents listed corruption, poverty, and the lack of governmental policies to stimulate growth as the major economic problems. In Europe/Asia, the problems noted are corruption, poverty, and illiteracy. The top three economic challenges in all the regions are: corruption, poverty, and politics. These are the major problems that developing countries face regardless of location. Others worth mentioning are high taxes and lack of government investment. Overall, all participants think their governments are not doing enough to fight corruption and poverty.

Following up with questions about their government involvement in regulating prices in telecommunications, all African participants consider government an active player. Latin American participants are split half and half on the issues, and in Europe/Asia they think that the government is not regulating telecommunications. The majority of participants knew about their government’s involvement in telecommunications price regulation. The ones that did not think their government
regulates telecommunications prices are: Albania, Cameroon, India, Jamaica, Nicaragua, and Peru. Governments from those countries might not regulate prices but in India [16], Peru [18], and Albania [19] prices are driven down by the competition. Cameroon [14], Jamaica [20], and Nicaragua [15] have neither competitive market nor governmental regulation.

5.4.3.1 Call paying party

In the economics part of the interview I also asked participants who pays for the calls and the texts, all the respondents answered the same, only the calling party pays (CPP). On the other hand in the US, Canada and a few Asian countries both parties pay (BPP). Most of the world uses the CPP system, in which the caller pays the entire cost of the call, and their network pays the receiving network for terminating the call. The cost of calling is generally higher in BPP countries, and the usage is correspondingly lower. On the other hand, while the outgoing minute price has a significant impact on usage, the incoming minute price has a corresponding impact on penetration [15]. Specifically, under CPP it is affordable to purchase prepaid SIM cards and receive incoming calls for free, requiring little upfront financial commitment and allowing close control of costs. It is not surprising that in the majority of developing countries CPP is prevalent. All the participants came from countries that use the GSM systems, the most prevalent system in the world. Most GSM systems have prepaid SIM cards where the expense of the consumer is well-known and easy to predict. This fact is important for our study because in medical applications using mobile devices as platforms the existence of the CPP system could have significant influence on who initiates the communication, doctor or patient. In the system where only the calling party pays, from purely economic perspective patient is more likely to be agree to receive free calls and texts for a medical problem than to use mobile device for outgoing calls to report or track an issue. Particularly in low income or high price outgoing calls/texts countries such considerations should be incorporated into the mHealth practice.
5.4.3.2 Services ranked based on prices

Finally in the economics module, the participants ranked (ordinal ranking) the types of telecommunications services based on the cost. In the majority of countries, landlines are the cheapest but falling in use and in some African countries they never developed. World Bank report for Africa [27] cites that on average only 5% population is covered by landlines. As an interesting fact, the Ukrainian participant told me she does not know the cost of landlines because she has never had one. This mirrors the trend in the developed countries where the total number of landlines is steadily declining. In 2009, the Economist ran an article “If you want to save money, cut the cord” [13], giving evidence that most of the consumers in the developed world are canceling their landlines. Text messaging is right behind landlines as the second cheapest, and in some countries even the cheapest. Mobile voice is either second or third and in almost all the countries the internet is the most expensive form of telecommunications service.

In conclusion, most governments regulate telecommunications prices, and the cheapest are either landlines or text messaging. CPP system might determine mHealth applications which allow patients to receive calls/texts without extra expense.

5.4.4 Public health and mHealth adoption

The fourth module explores public health issues in each country with a sub-section on usefulness and obstacles to mHealth implementations. Public health issues vary, in Latin America they are poor provision of government health care and facilities, and health issues are various tropical diseases. In Africa, the main problem is a lack of doctors and medications, while the main diseases are HIV, malaria and lack of maternal care. The European respondents did not think their countries have any significant public health issues, and the respondents from the Asian countries cited malnutrition and dengue fever as the main public health problems. Diseases differ per region but almost all the countries in my sample have insufficient resources to address public health issues. Lack of doctors and supplies
are prevalent everywhere. TeleHealth initiatives are present in many countries but limited to isolated pilot projects most often based in a university hospital or institution. Six participants have not heard about any teleHealth projects in their own countries indicating that either the projects [21] [22] are not well publicized, not significant, or the participants were not in the target population. The majority of respondents expect their country to increase a role of mobile technology in public health, mostly because of the prevalence of the devices. It is significant to note that participants did not think that the telecommunications technology is sufficiently developed for healthcare implementations. Three respondents even considered mHealth a science fiction because they did not think the circumstances are in place yet.

5.4.4.1 Obstacles to mHealth

Obstacles to introducing mHealth fall in three major categories: cost, technology, and people attitudes. In Latin America the main issues are technology, people’s attitudes and insufficient government support. The same respondents in an earlier section perceived the technology excellent when considering the quality of service but not appropriate for mHealth. In Africa the obstacles are capacity of the network for advanced applications, resistance of medical community, and insufficient education of population. In Europe, it is the lack of political support. In Asia, it is lack of government support and inadequate awareness of population.

My hypothesis that telecommunications technology will not play a major role does not seem supported because in all regions respondents did not perceive the level of telecommunications technology to be adequate. However they often mentioned advanced teleHealth applications and did not connect mHealth with simple SMS reminders.

Even though the majority of countries have liberal telecommunications policies and competitive markets, the respondents did not think government would support mHealth applications.
Health insurance coverage varies around the world. In Latin America government offers coverage to working people but the care is poor with long wait time for non-urgent medical issues. In Africa again government offers insurance to working people and the care is rather poor. Ukraine has good health care and universal coverage while Albania has no health insurance at all. Nepal has no health insurance but India has universal care. In the Philippines only the working people have health insurance. In all the countries there are private insurances available but few are able to afford them. I asked the respondents their opinion about possible effectiveness of mobile phones in health applications. Everybody universally thought that it would help bring care to the rural areas but considered it far future, almost science fiction. This is surprising given the education of the respondents which might indicate that the conceptual leap of using mobile phones to communicate with friends and family to communicate with healthcare professionals and health data collection is hard even for highly educated telecommunications professionals in developing countries. Access to health insurance could be a reason that influences attitudes towards mHealth. Only two countries, Democratic Republic of Congo and Albania, informed me that people have no health insurance at all. All others countries have health insurance for the working population and all of those respondents have health insurance provided by their university or company. A few of them told that the health insurance is decent: Colombia, Ecuador, Gambia, India, and Ukraine.

Finally, only one out of seventeen respondents has ever seen a health application on a mobile phone. One reason might be that the majority of widely accessible mobile health applications are designed for smart phones and all the respondents came from countries with low adoption of smart phones due to the high cost of data plans and devices themselves. Another reason might be that mobile health applications are not yet as popular in the developing countries as in the developed countries and as such not affordable.
In conclusion, lack of medical personnel is prevalent in all the countries in my sample, while health insurance is available in the majority of the countries, but only to the working population. The perceived obstacles of mHealth are cost, technology, and people attitudes.

5.5 A discussion of implications

Table 5.4 Common themes in answers

<table>
<thead>
<tr>
<th>Factor</th>
<th>Common themes in answers</th>
<th>Connections between factors</th>
<th>Influence on adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>technology</td>
<td>improvement good service quality</td>
<td>competition = good service and low pricing</td>
<td>not developed for mHealth</td>
</tr>
<tr>
<td>policy</td>
<td>promotes competition</td>
<td>government supports competition</td>
<td>no political support for mHealth</td>
</tr>
<tr>
<td>pricing</td>
<td>texting cheap</td>
<td>alternatives emerging</td>
<td>pricing drives applications</td>
</tr>
<tr>
<td>health care</td>
<td>lack of medical personnel and supplies</td>
<td>needs improvement particularly in rural areas</td>
<td>many problems to be solved</td>
</tr>
<tr>
<td>people attitudes</td>
<td>no conceptual leap using mobile phones for health</td>
<td>present in all countries</td>
<td>promote education</td>
</tr>
</tbody>
</table>

Table 5.4 summarizes common themes in answers, connections between factor, and their influence on mHealth adoption. The themes provide a background to explain interconnection between factors and their influence on adoption.

For the telecommunications technology - according to the respondents’ opinion, the biggest influence on the telecommunications infrastructure quality is the rate of improvement, and service availability in the country. The majority of the respondents were satisfied with the telecommunications technology quality in their respective country. On the other hand almost all of them considered the technology to be undeveloped for medical applications. That seems like a contradiction and one of possible explanations is the inability of respondents to make a conceptual leap from using mobile phone for social and business conversations to health support. In this sample of developing countries mobile voice and texting are the most popular service while Internet is lagging behind. Implications are that
mHealth applications based on texting and voice will lead the way with Internet applications being introduced later.

The telecommunications policy aspect reflects that competition is not an issue that I can explore using this data because majority countries in my sample have competitive telecommunications markets from the perspective of respondents and the published reports. On the other hand, in the experience of the respondents there is no political support for mHealth.

From the economic aspect most governments regulate telecommunications prices, and the cheapest are either landlines or text messaging. Pricing structure has considerable influence on the popularity of a mobile service; in particular unlimited plans for texting are driving the extensive use of texting service. Text messaging is inexpensive in all the countries in my sample and can be a resource for mHealth applications.

The healthcare aspect reveals that the lack of medical personnel is prevalent in all the countries in my sample, while health insurance is available in majority of countries but only to working population. The listed mHealth obstacles are cost, technology, and people attitudes. One implication is that government has to promote mHealth in particular and educate public on the capabilities of mobile devices in health. People’s attitudes and lack of health care are issues worth exploring further.

One of the factors that I did not consider initially, but identified in the interviews is that the CPP system is prevalent in the developing countries. This might have implications of who initiates the call or sends the text in medical applications utilizing mobile services. In a developing country where budgets are tight a call or a text from a nurse or doctor are more likely to be accepted as a part of the mHealth deployment than patients calling or texting back.
Finally, health indicators such as life expectancy and child mortality are comparable within a region such as Africa or Latin America while GDP varies considerably. The implication is that something else than the GDP influences those two health indicators.

5.6 Conclusion
Regional comparison based on seventeen developing countries in this sample provides us with some evidence about the influence of telecommunications technology, policy and pricing. All the participants in the interviews perceived improvement in telecommunication technology as a good service quality, whether is that or not. All but two governments in these seventeen countries promote competition and prices of text messaging are low compared to other services. Major health issues stem from the lack of medical personnel and supplies, while all the respondents foresee possible use of mobile technologies as a way to alleviate some of health problems. However that will require government involvement on the level of promotion and education of population. Regional grouping does not suggest that countries from different developing regions have different problems.
5.7 References


Appendix 1
Summaries of answers from African countries

Cameroon – infrastructure average, ranking: mobile phones, Internet, landlines. Mobile penetration is around 50% but even illiterate people use mobile phones. Texting is cheap, smart phones rare. Landlines are nonexistent, people have to wait long to get one. It has regulatory body since 1998, one of few countries in Africa left with only two competing mobile networks, MTN and Orange. Prices high, regulation does not promote competition. http://www.researchandmarkets.com/research/31335b/cameroon_teecom

On economic level taxes are high and there is not promotion of small business, country depends on agricultural export.

Texting cheaper than mobile voice, telecom improved economy but not enough.


This conference is hosted by the Cameroonian Health Informatics Society (CAHIS). CAHIS is the national platform for health activities in Cameroon; it is a member of the International Medical Informatics Association (IMIA) and Pan African Health Informatics in Africa Association (HELINA).

Potential problems of telemedicine adoption will be with the local community, people would need education on how to use the technology for health. Health care is poor, long wait for doctors, working force has subsidy for health insurance. No smart phones and smart phone apps but more feature phones and SMS for health.

Democratic Republic of Congo (DRC) – is a large country but it has a decent infrastructure, satellite links for international communication, one operator has an extra-long microwave backbone of 4000 km. Landlines nonexistent, mobile phones have penetration of 24%, voice most popular but texting too for values added services like short codes. Telecom market is competitive, 5 operators, government promotes competition and imposes interconnection. Issues with health doctors are not skilled and medical care is not good. No telehealth initiatives but huge potential because country has good cell coverage. Obstacles to telehealth are insufficient network capacity for bandwidth hungry applications, no fiber yet. Health care poor and there are no any health apps.

Malawi is a very poor country with average but improving telecom infrastructure. Mobile penetration is low 20% but the interviewee thought that it is much higher because he lives in a town and in urban areas penetration is considerably higher. He showed me his cheap feature phone that looked like a kid's phone in the US. Voice is the most popular service but SMS is right behind. Telecom market is
competitive and government encourages and promotes it. The economic growth has been strong until recently when political problems emerged. Texting is the cheapest service. Medical problems are malaria, HIV, fever. In the health care sector there is lack of doctors and medications. The interviewee himself is involved in 3 telemedicine projects, one of them a long distance link that connects 3 medical institutions. The biggest obstacle is the acceptance of technology by doctors. He has health insurance and medical apps are in the experimental phase.

**Tanzania** has a decent coverage in urban areas but not rural. The country is poor with the lowest doctor per capita ratio. Mobile penetration is 62% and mobile voice is the most popular service. Texting is not particularly popular and the telecom market is competitive with government support. The country is growing slowly, fighting corruption, health issues like malaria, maternal health and HIV. There are several telehealth projects but they are regional and never took off. Obstacles for telehealth in Tanzania are underpaid doctors and expensive technology.

**Gambia** has very good telecom coverage and high mobile penetration of 90%. Mobile voice is the most popular service and texting is not that popular, only among younger population. The telecom market is competitive with 4 providers and government involvement in regulation. The country is poor with fast telecom growth but slow overall economic growth. 95% calls are prepaid and landlines are still in use but the Internet access is very low. Texting is cheaper than voice but not as popular. Disease that is the public health issues is malaria, especially for pregnant women. There are some Gates foundation projects to fight it. Also some pilot studies with WiMax for telemedicine demonstration in teaching hospitals. The biggest obstacle for telemedicine will be cost. Health care is socialized but not great, and there are not many smart phones.

**Summary of Africa**

- Telecomm infrastructure decent and improving in all 5 countries
- Mobile penetration ranges between 20-80%
- Mobile voice and SMS have the same usage
- Internet present only in big cities and in infancy
- SMS not as popular as I expected given that it is cheaper than other telecom services

**Appendix 2**

Interview questions for participants in the “Sustainable wireless solutions for Environmental Monitoring” at the International Center of Theoretical Physics, February 2012.

**Introduction:**

My name is Suzana Brown and I am writing a thesis for a Master of Science degree in Telecommunications from the University of Colorado located in Boulder, Colorado, USA. The topic I am researching is: “the use of text messaging to provide health services in developing countries.”
As part of my research, I am asking people from various countries general questions about the use of mobile telecommunications in health services in their countries. I would like you to answer the questions about your country related to major obstacles for the use of telecommunications in health care. I have divided the questions into six modules: general, technology, legal/regulatory, economics, public health and responder’s information. I would sincerely appreciate your answers.

I will do my best to obtain basic information about your country prior to the interview but you are welcome to correct me if the information is not accurate or not up to date.

Module 1 - General:

1. What is the name of your country? ______________________
2. Level of literacy? _____________________ (Find online prior to interview as a reference)
3. Life expectancy ______________________ (Find online as a ref.)
4. Child mortality ______________ (Find online as a ref.)
5. GDP per capita ____________________(Find online as a ref.)
6. Number of doctors per capita ____________(Find online)

Module 2 – Telecommunications:

1. In your opinion, what is the state of telecom infrastructure in your country in comparison to the developed countries?
2. Can you please provide ordinal ranking based on popularity of the following forms of communication in the country:
   - Traditional telecommunications services (landlines)
   - Mobile phones
   - Internet
   - Other
3. What is the penetration of mobile phones? (Find this online as a ref.) Do some people own multiple cell phones?
4. What is the most popular mobile phone service in your country? Voice? Texting? Data plan on a smart phone?
5. In particular is texting popular?
6. What demographics use texting the most?

Module 3 - Legal/Regulatory
1. Do you consider the telecommunications market in your country competitive?

2. To your knowledge, is the government promoting competition in the telecommunications sector?

3. Does your country have laws on consumer privacy and security? Are people in your country concerned about those issues?

Module 4 - Economics of telecommunications

1. What do you consider are the top two economic challenges in your country?

2. Is your government regulating prices in the telecommunications sector? (Find online as a ref.)
   - Yes
   - No

3. Who pay the charges for a mobile phone call? Is it the same for texting? Is it calling party only or do both parties pay?

4. Please use ordinal ranks for the telecommunications services based on their cost in your country?
   - Landline call
   - Mobile voice
   - Text messaging
   - Internet access

5. In your opinion, is telecommunication having a positive impact on the economic growth of your country?
   - Yes
   - No
   - Maybe

Module 5 - Public health issues and mHealth

- mHealth is a term used for the practice of medicine and public health, supported by mobile devices.
- teleHealth is the delivery of health-related services and information via telecommunications technologies.

1. What do you consider are the top two public health problems in your country?

2. To your knowledge are there any mHealth or teleHealth initiatives in your country?

3. Do you think mobile phones can be effective tools in addressing public health in your country?
4. What do you think would be the biggest obstacle to adoption of teleHealth in your country?

5. Can you please tell us about the cost of insurance and quality of health care in your country?

6. Are medical apps for smart phones popular in your country? Do you or would you use any?

Module 6 – Responder’s Information

1. Education ____________________________
2. Affiliation __________________________
3. What is your profession:
   a. Telecommunications engineer
   b. Scientist
   c. Government agency worker
   d. Other –
6 Conclusion

6.1 Summary of results

This thesis explores the area related to ICT implementation in healthcare, specifically the use of texting in healthcare applications. The primary research question is: “What elements of the technical, economic, and policy factors influence the use of texting in electronic healthcare applications?”

To research this question I focus on the following three aspects of the issue:

- The technical advantage of texting compared to voice in unfavorable conditions, such as the edge of coverage.
- The comparison of electronic solutions using texting with the traditional healthcare methods by performing cost/benefit analysis of the savings texting based healthcare application brings to a particular health issue, blood glucose monitoring by diabetics.
- Evaluating telecommunications policy and the elements that promote or inhibit adoption by interviewing experts from seventeen countries.

From the technical perspective I evaluate the performance of SMS by measuring the air interface time delay, which is defined as the time it takes to transmit a text message between the mobile phone and the base station. On the edge of coverage, where a signal is weak, the delay increases by an average of 0.5 seconds, about 10-12%, for both 60 and 160-character messages. However, for different setups the standard deviation doubles or triples, implying less reliability on the edge of coverage. The GSM protocol-based delay distribution model fits the empirical data well. The data and models presented will assist researchers, government agencies, application developers, and system operators among others in analyzing the performance of SMS in time-sensitive applications in unfavorable conditions. SMS is particularly useful in rural areas and developing countries due to its robustness to signal strength. One of the most useful attributes of SMS that I discovered in the lab
experiments is that it requires a very short (6-8 seconds) access to the air interface, so in situations when the coverage is spotty a few seconds are sufficient to send a message. SMS requirements of the air interface resources outperform other services like voice.

The policy aspect is informed by regional comparison based on seventeen developing countries in my sample. Fifteen out of seventeen countries have competitive telecommunications markets and prices of text messaging are low compared to other services. However the competitive telecommunications policy is not enough to promote the use of electronic healthcare applications. Majority of experts I interviewed thought that it will require government involvement on the level of promotion and education of population about benefits of mHealth applications to make a difference in adoption. In my sample major health issues steam from the lack of medical personnel and supplies, while all the respondents foresee possible use of mobile technologies as a way to alleviate some of health problems. Regional grouping does not suggest that countries from different developing regions have different problems as it comes to adopting mHealth.

Finally, before we replace traditional healthcare with mHealth solutions it is necessary to perform a cost/benefit analysis for each setting and to evaluate the efficiency of the proposed application. I evaluate a specific example of ongoing blood glucose level monitoring in diabetic patients, and compute the overall net benefit in three regions: Latin America, India and the US.

The most important insight from the cost/benefit analysis is the impact the individual text message cost has across the three regions. The impact shifts the introduction of the electronic blood glucose monitoring innovation from a positive benefit, in the United States where message transmission is relatively cheap, to a negative benefit in India, where transmission is relatively expensive. However, after performing sensitivity analysis to the
assumptions, I find that there are several factors playing a role in “readiness” for innovative solutions. I identify two major ones: 1) percentage of patients that adopt the mHealth solution, and 2) the benefit it brings to a region, which depends on the number of the patients that will benefit from it relative to the social cost the disease presents to society. Preprocessing of data is one way to control the cost by reducing the amount of data sent and decreasing telecommunications cost substantially.

Overall conclusion is that technically SMS performs well in unfavorable conditions so developing countries and rural areas could use it for a variety of healthcare applications. Competitive telecommunications policy is not sufficient; in addition governments have actively to promote mHealth. Finally, each situation should be evaluated from cost/benefit perspective to assess country “readiness” for innovative mHealth solutions.

6.2 Future Work
Future work will undertake testing on reliability of the cellular network in particular for time critical applications. A larger sample size for SMS testing could give a better validation of my distribution model. Testing SMS performance in different congestion situations will provide more information about performance variability.

Examining telecommunications policy for a wider base of developing countries will provide data sufficient for performing significance tests on influence of pricing structure on mHealth adoption. Interviewing more people within a country will provide better information of internal forces influencing adoption. Adding a better variability between countries, in particular adding more countries from Asia would expand the understanding of policy impact.
Comparing and contrasting the performance of SMS with GPRS, or IP based application, could provide insights into alternatives to SMS as a platform for medical applications.

It would be useful to employ another evaluation criterion that avoids the shortcomings of cost/benefit, such as multi-criteria analysis, to analyze the readiness of a country for mHealth solutions. Rather than a single score, or market value, multi-criteria analysis accepts and builds upon multidimensional set of objectives.

Finally, based on the above results, it is possible to develop a model that will look at the interplay between above factors and their elements and apply it to specific country studies. The model will provide a tool to decision makers (health policy and government officials, and businesses) to apply to their own country specific situations.