m-Science

Sensing, Computing and Dissemination

Editors: E. Canessa ▪ M. Zennaro

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Editors: Enrique Canessa and Marco Zennaro

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Foreword

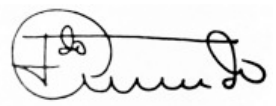
The Abdus Salam International Centre for Theoretical Physics (ICTP) has been a unique institution for over 45 years. It is an example of efficient support to the developing world by concrete long-term actions that improve the level of science and technology in all countries, rather than short-term unsustainable help often offered with minor positive impact in those societies over the years.

ICTP actively participates in educating and supporting scientists in developing countries through its programmes, conferences, schools, affiliated centres, networks and visitors. Its impact cannot be measured only by numbers (over 100,000 scientists from more than 180 countries) but in the qualitative change in the careers of many scientists worldwide with the corresponding positive effect on their societies. Its goals are two-fold: to perform top quality research in selected scientific fields and promote science in developing countries—in particular, fighting against the increase of diaspora of highly qualified professionals from the developing world.

By the same nature of its mission, ICTP needs to be up-to-date with the latest scientific and technological developments in the world. In particular, the increasing expansion of on-line education is of utmost importance for the ICTP mission since it allows us to reach a much larger number of scientists who have better and better access to Internet. As an example, the Science Dissemination Unit (SDU) of ICTP developed the award winning system EyA ("Enhance your Audience"). This is a web archive of audio/video presentations with synchronized slides of digital lectures delivered at the many ICTP workshops and, conferences and particularly for the five one-year Diploma Courses offered at ICTP in basic physics and in each of its four main research areas: high energy, cosmology and astroparticle physics, condensed matter and statistical physics, earth system physics and mathematics. The system is particularly suitable to follow blackboard lectures and is accessible even at low-bandwidth environments. Thousands of lectures can be found at the website www.ictp.tv that has already had hundreds of thousands of visits from all around the world.

Consistent with its mission, ICTP has the tradition of making the latest developments and practical technologies of particular interest to developing countries, available to all. The free book: "Wireless Networking in the Developing World" (www.wndw.net) is a successful example with several millions of downloads in a relatively short period of time.

Following this tradition, ICTP considers that the uses of new technologies, especially the new "mobile devices", are of particular interest in order to nurture scientists and to disseminate science around the world. It is a pleasure for us to offer free this new ICTP book on "m-Science: Sensing, Computing and Dissemination". We very much hope that this book will help many scientists and engineers worldwide to have access and actively contribute to this rapidly developing field.



Prof. Fernando Quevedo
ICTP Director

About this Book

Credits

This book was prepared for the ICTP Workshop on "Mobile Science: Sensing, Computing and Dissemination" held in Trieste, Italy in 2010, organized by the Science Dissemination Unit.

Editors

Enrique Canessa is a PhD Physicist working as a Scientific Consultant at ICTP. His main areas of research and interest are in the field of Condensed Matter and scientific software applications, with particular focus on disseminating science to and within Developing Countries using open source and state-of-the-art rich-media technologies.

Marco Zennaro received his Engineering degree in Electronics from the University of Trieste, Italy. He is currently working as a Scientific Consultant at ICTP in projects involving wireless sensor networks, multimedia and Open Access.

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The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

Science Dissemination Unit

Book Overview

Mobile technological tools are being used today to collect basic information in the health, world climate, geophysics, ecology, and other sectors to exchange information, and to access scientific computing among many services. The potentialities of this mobile technology need to be spread out on a larger scale in the academia in particular, and in the society as a whole so that its benefits can become widely accessible for further development. This is an issue that needs more attention and promotion, especially in less developed areas of the world[1].

Today, the majority of new generation phones can access the web in some way. There is evidence that mobile web access is also growing fast in developing countries. According to the ITU-International Telecommunications Union, there are billions of mobile phone subscribers around the world outpacing fixed-line Internet users, with more than 1,000 new users added every minute. More than 59% of them live in developing countries, making mobile phones the first telecommunications technology in history to have more users there than in the developed world. Mobile phone shipments grew to 930 million units in the past year. Cell phone usage in Africa is growing almost twice as fast as any other region and jumped from 63 million users two years ago to 152 million in 2009 (see, http://eprom.mit.edu/whyafrica.html). On the other hand, the possibility of connecting with a low-cost notebook (like Netbooks) to the Internet via broadband UMTS networks at low subscription prices is growing world-wide. While this is a proxy for actual mobile usage, it is nonetheless an indicator that mobile access is also rapidly increasing in the scientific environment.

Data forecasting indicates that in only a few years half of the planet's population will have access to the Internet through a

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[1] Based on an article published by the Editors on i4d (July - Sept 2009, p.37)

mobile device (cell phones, laptops, etc.) This means that a majority of the world's population will access electronic contents via their mobile devices. And this means that international organizations like the ICTP in Trieste and others around the world need to think about what this means for their scientific community and its online users (as, for example, for the new participants of the on-line ICTP diploma courses at www.ictp.tv also accessible via mobiles).

We define in this book **Mobile Science** (or "**m-Science**" in short) as the term that comprises sensing, computing and dissemination of scientific knowledge by the use of mobile devices. This book aims to engage the scientific community, engineers and scholars worldwide in the design, development and deployment of the newest mobile applications.

In the chapter "The Internet, Mobile Computing and Mobile Phones in Developing Countries", the author looks at the development and influence of two major technologies introduced in the last 50 years. These are the Internet and mobile phones. Originally the technologies were separate but now they are merging. This is driven to a large part by the support for Voice over IP on the Internet and the emergence of smartphones which enable mobile computing and take increasing advantage of the Internet. These developments are quickly reaching an increasingly large fraction of the world's population. They are becoming a regular part of everyone's daily lives both in the developed and developing world.

The chapter "Towards a Societal Scale Scientific Instrument" begins to explore some of the primary challenges to building a societal scale scientific instrument. It is by no means exhaustive. Instead, the authors discuss their own work in the context of the larger problem of societal scale sensing. They aims to provide a starting point for researcher, developers, activists, scientists, health workers and politicians, to consider how to start collecting data now, how to interpret and manage those data, and to hint at what might be on the horizon. As such, this book and this chapter cover a wide range of topics, and are intended for readers from different backgrounds. The authors cover the various stake holders for a societal scale sensing system, the goals and challenges of mobile sensing, achieving accuracy and precision using low cost devices, and and survey activity inference, privacy, privacy and energy issues.

“Data Gathering with Mobile Phones” is another interesting chapter of the book. Organizations engaged in fundamentally different activities share the same need for accurate and timely field data. Filling out paper forms, sending them back and transcribing them is a slow and cumbersome process that delays information availability and potentially crucial decisions. Data collection with a mobile phone has the potential to dramatically improve any service that relies on accurate and up-to-date information. The more time-critical the information, and the more remote the location, the more organizations have to gain from a mobile phone based solution. Nokia Data Gathering is a solution that helps organizations to collect field data on critical issues using mobile phones instead of paper forms, PDAs or laptops. Whether helping to prevent disease outbreaks, building a census or tracking agricultural stock levels, Nokia Data Gathering has saved time and money for organizations around the world while also improving information accuracy.

The wide availability of cellular telephones equipped with CMOS cameras (and of digital cameras directly exporting JPG files) opens many opportunities for inexpensive, portable photometric measurements. Spectrophotometry makes more sense to students when they can see light change intensity when passed through a sample than when they can only see equations, sketches, or the output of a computer screen or meter. Better yet, they can learn the concepts of dynamic range, stray light, saturation, digitization error, order overlap, and dispersion more easily by seeing the phenomena than by only hearing of them. In the chapter “Cell Phone Spectroscopy in the Classroom” the authors report the construction and give the hardware, software, and laboratory instructions for a diffraction spectrograph/cell phone (or digital camera) array detector suitable for high school and college students.

The chapter "A Blocks Language for Mobile Phones" introduces the "App Inventor for Android". This is a new visual programming environment for building mobile apps. With App Inventor, you program by piecing together blocks that represent the phone's functionality. Because it's like putting together a puzzle, even those with no programming experience can use App Inventor to create mobile apps. This chapter introduces App Inventor, illustrates its features through the development of a No Text While Driving app, and tells three stories of how university students used App Inventor to create apps with a real-world impact.

The "Mobile Application Development with Python" chapter introduces you to Mobile Python (better known as "Python on Symbian" or "PyS60"). If you are the one who has never developed on mobile platforms, this chapter serves as a getting started tutorial for you. If you have already worked on other mobile platform, this chapter enables you to use the powerful Python runtime for development and to build/prototype mobile applications rapidly. Besides serving as a "getting started" guide, the chapter also explains briefly about the user interface (UI), telephony, messaging, multimedia, camera, sensors and location tracking, with simple code examples.

The need for mobile phone applications in Africa is discussed in the chapter "Middleware for Grid Computing on Mobile Phones". The low Internet penetration and lack of electricity in the rural areas of the developing countries of Africa make the use of computer-based solutions a big challenge. Yet there is a direct need of such applications in these areas. Luckily, most of these countries have reported impressive adoption levels of mobile phones, a phenomenon that is now creating a paradigm shift; computing is slowly moving from the traditional PC to the phone. Coincidentally, advancements in the smartphone technology have produced such powerful gadgets that can ably compete with PCs of the 21st century. Today, for less than US$ 400, one can acquire a smartphone equipped with; 1000MHz clock speed, 512MiB (ROM +RAM), access to several types of data networks (CSD, HSCSD, GPRS, EDGE), and Wireless local-area network (WLAN) among other features. With this kind of new computing power, computer analysts/programmers can now develop both scientific and commercial applications to address numerous challenging facing poor people in the developing countries of Africa.

3rd Generation (3G) mobile data access has significantly improved data connectivity for users accessing information and data on-the-go. However, relatively poor 3G connection latency (and on occasion, poor WiFi connection latency) can still be a hurdle in developing scientific data access applications that provide fast data access and a good end user experience. In the chapter "Data Encapsulation and Mobile Access to the Protein Data Bank" the authors propose the use of EXIF data fields within JPEG images to include protein structure coordinate and other protein data for delivery to end-user applications. They also describe the development of proof-of-concept mobile application developed for the Symbian platform that utilizes these images to provide mobile access to PDB data.

"Supercomputing on a Cell Phone" is becoming also possible as anticipated in a chapter with this title. New software that runs on a smart phone can approximate in seconds computations that would take a supercomputer hours. The software works for problems whose form is known but whose particulars aren't; slider bars allow users to set the values for which they want the problems solved.

On the other hand, the chapter "Mobile Social Network in a Cultural Context" examines the guanxi-embedded mobile social network in China. By focusing on three concrete case studies with 56 in-depth interviews, including New Year text message greetings, mobile social networks for job allocations among migrant workers, and mobile phone rumours, this study observes that mobile social networks are a way that Chinese people cultivate, maintain and strengthen their guanxi networks. Embedding the reliability of guanxi, the message spreading via mobile communication always enjoys high credibility, while mutual obligation contributes to the explosive growth of the messages within mobile social networks under special circumstances, such as during festivals and holidays and social disturbances. This circulation in turn increases both the dissemination and credibility of messages, and rumours. The characteristics and strength of mobile social network in China therefore emanate not only from Information and Communication Technologies, but also from the socio-cultural source - guanxi - deeply rooted in Chinese society.

In the chapter “Use of Mobile Devices in Self-managed Learning” the authors present results sustaining the proposal that mobile devices are more effective as learning tools if they are used to learn with them rather than through them. In addition, the authors demonstrate that in order to get the most out of innovation in educational technology in the deployment of m-Learning, it is important to design more innovative strategies that are geared toward active learning by taking advantage of the students’ proclivity to engage with technology. The authors expose an experience of identification of learning gains in Physics and Mathematics at undergraduate level demonstrating that mobile learning can foster learning when integrating it in a planned manner. They focus on the evolution of Tecnológico de Monterrey Mobile Learning Model during the 2008- 2010 period.

The chapter “m-Learning in Sri Lanka” concludes the book with a case study discussion. Thanks to the high literacy (the highest in Asia –and lately to an average computer literacy estimated to be rising at an annual rate of 15%), open, distance and mobile learning programs, that are especially relevant in the higher education sphere, found in this country a prosperous environment.

“Introduction

m-Science

Enrique Canessa and Marco Zennaro
ICTP, Italy

"Scientific thought is the common heritage of mankind". This simple and profound sentiment, often expressed by the founder of the International Centre for Theoretical Physics (ICTP) and Nobel Prize winner Prof. Abdus Salam, has inspired the Centre since its inception in 1964 in the northern Italian town of Trieste. That was the same year when Nelson Mandela and seven others were sentenced to life imprisonment in South Africa, when the Beatles had 13 singles in Billboard's Hot 100 at the same time, and when Cassius Clay beat Sonny Liston in the World Heavyweight championship. In the same year, the number of telephones in the world reached 160 million, and on August 1st, NASA announced that the new Syncom II communications satellite had been used successfully to transmit voice live between the U.S. and Africa. Science in those days was closely embraced by the cold war.

The generation of physicists of Prof. Abdus Salam's time could never have imagined a mobile communication technology which today is expanding so fast, that by 2015, billions of people will have access to communications and information services. In fact, no innovation has spread so rapidly in history as the mobile phone. Today, more than 80% of the world's population is covered by fast GSM mobile networks. As a result, we are closer than ever to live in a world where everyone can be connected. This ubiquitous connectivity will certainly have deep implications on the scientific community of academia in general, and on international organizations like the ICTP.

As the examples in this book demonstrate, people are using mobile technology in powerful new ways to carry out scientific research, and to share results and to disseminate knowledge in affordable ways. For example, mobile phones are being used to gather scientific data from remote and isolated places that would be impossible to retrieve by other means. Scientists, acting alone or in groups, are starting to use mobile devices and web-based applications to systematically explore interesting scientific aspects of their surroundings ranging from climate change to earthquake monitoring. This mobile revolution enables new ideas and innovations to spread out more quickly and efficiently.

Mobile technology and Internet access open up also amazing educational opportunities. With m-Learning, students can also take advantage as learning is now freed from the restrictions of location. Students and teachers benefit from new educational methods using rich media and instant communication at a distance. Learners become more numerous, learning becomes more exciting, and teaching becomes even more rewarding.

Simply put, we shall define here **Mobile Science** (or "**m-Science**" in short) as the term that comprises sensing, computing and dissemination of scientific knowledge by the use of mobile devices. This include (i) data gathering, (ii) the analysis and process of data, and (iii) the access to on-line services and applications directed to nurture scientists and scholars (such as mobile access to e-Journals, podcasts, web lectures and webinars, virtual conferences, mobile collaboration tools, m-Learning, etc).

The worldwide interest in science has grown since Prof. Salam's pioneering efforts in the sixties. Based on information extracted from the Web of Science (Thomson Reuters) database of scientific publications spanning from 1980 to 2009, the world's scientific production has grown from about 400,000 to 1,200,000 publications in the last three decades. This increment of interest in science, together with the recent technological developments in mobile technologies, is making m-Science a completely new field of interest and research development.

Let us look forward to continue Salam's vision and hope that his laudable wish will be fostered and further established with the help of mobile technologies in use around the globe. This book humbly aims to create awareness within the existing scientific community on the huge possibilities ahead, as well as to motivate a new generation of learners, scholars and scientists to participate in the new challenges of m-Science.

The Internet, Mobile Computing and Mobile Phones in Developing Countries

R. Les Cottrell
SLAC National Accelerator Laboratory
Stanford University, USA

1. Internet History and Trends

1.1 Brief History of the Internet

In the 1950's and early 1960's most networking was between a few stations on dedicated links or leased lines (e.g. terminals connecting to a mainframe). In the 1960's DARPA funded research on packet networks led to a proposed architecture followed by a contract to BBN which in 1969 resulted in the first Internet (then known as ARPAnet) connection between UCLA and the Stanford Research Institute. By the end of 1969 there were four hosts on ARPAnet. By January 2009 there were over 600 million Internet hosts [1]. By the end of 2009 this corresponded to 1.8 billion Internet users or over 25% of the world's population [2].

1.2 Original Goals

When one considers the current challenges for the Internet it is important to understand the original goals. It was built as:

• a collaboration of global proportions with no central management (c.f. the phone system);

• it was non-proprietary (c.f. IBM's SNA or DECnet or Xerox XNS);

• it provided for best effort including recovery from losses and pipelining (e.g. the Transmission Protocol Protocol (TCP) one of the core protocols of the Internet Protocol Suite) but with no hard guarantees;

• with simple black boxes (i.e. routers) that did not retain detailed information from individual flows;

• packets inside envelopes, layers that were independent of one another so a mid-layer would not know if a lower layer was wireless, satellite, copper, fibre etc. (c.f. purpose designed networks such a TV broadcast networks, and the telephone network);

• there was little focus on security, in fact as Vint Cerf has said [3]: if it had focused on this it may never have happened;

• in many ways it was an experiment to connect mainframes and the people involved wanted to make it work.

1.3 Today's Challenges

Some of today's challenges include:

• the limited address space of ~4 billion that is estimated to run out in 2012 [4] and, despite many stop gap measures, the consequent need to migrate an operational network to a new protocol with about 3.4 x 10^38 addresses;

• the effective use of broadcast and multicast;

• security, e.g. name service vulnerabilities require digital signatures to prevent poisoning, lack of tools for strong authentication and identification, spam, viruses, Trojan horses, denial of service attacks, naive browsers and users, organized crime, state sponsored intelligence gathering – this contrasts to the original collaborative nature of the researchers;

• the need to support mobile computing, i.e. we no longer need to just connect up mainframes but now we have smartphones that move from cell to cell, satellites that can only send data at certain times etc., so there is the need:

  • to change IP addresses (today this can look like a hi-jack so one needs to establish trust) as one moves around,

  • to introduce concepts of persistence and presence,

  • to support quality of service, mesh and sensor nets, delay and disruption tolerance, the ability to continue a session from where it left off (n.b. there is no true session layer [5] in TCP/IP that would support this),

  • to support self organized nodes discovering one another and join, but how does one prevent a bad guy joining, how does one maintain trust (think of a military outpost being over-run and bad-guy acquiring the device and so can join).

1.4 Today's Expectations and Utilization

The expectations of the Internet today are:

• Ubiquity: Internet is accessible from businesses, homes, hot spots, cyber cafes, airlines, available on cell phones;

• Robustness: it is a critical business requirement, cuts such as the Mediterranean fibre cuts [6] result in loss of revenue and severe disruptions;

• High performance: the required speeds have moved from supporting simple text terminals, to email, the web, music/voice and video requiring orders of magnitude increases in performance.

The use of the Internet has become ingrained and has changed the way people interact, for example:

• No longer do salesmen come door to door selling shelves full of encyclopedias, rather one uses search engines such as Google, online dictionaries, Wikipedia etc.;

• The written word is increasingly enhanced/replaced with graphical images, sound clips, and videos. In fact, according to Cisco, video will grow at a 48% [7] Compound Annual Growth Rate (CAGR) from 2009 to 2014;

• Social networking has taken off with applications such as Facebook (dethroned Google as world's most popular web site [8]), Twitter and the like;

• Freedom of information (freedom of the press no longer belongs only to those who own the presses): via Google, blogs, photos, video (YouTube), Twitter, wikileaks [9] - for example street demonstrations, and/or police brutality are often reported first by individuals;

• Intellectual property, e.g. the music industry's protective stance, or how much does say Facebook or Google know about you, who your friends are, where you live, where you work, from the searches made, or mining all the emails etc.

• Mobility: smartphones bring mobility to the Internet user (see below).

2 Mobile/Cellular Phones

2.1 History

In December 1971, AT&T submitted a proposal for cellular service to the Federal Communications Commission. This was approved in 1982. The project to create the first handheld mobile phone (called the DynaTAC8000X) was started by Motorola in December 1972 and took until 1983 and $100 million in development costs to get to market. It weighed in at 2 pounds, offered just half an hour of talk time per re-charge and sold for $3,995 [10].

The 1st generation mobile phones in 1983 were analogue and used the 824-894MHz frequency range. Each carrier was assigned 832 frequencies, 790 for voice and 42 for data. The voice channel was 30KHz wide and each channel had 2 frequencies (one for transmit, one for receive) separated by 45MHz. This would accommodate 395 voice channels and 21 control channels in a cell.

The 2nd generation (2G) phones added compression and can fit 3-10 times more channels in the frequency range. There are 3 competing technologies:

• Frequency Division Multiple Access (FDMA) where each call uses a separate frequency. This is inefficient and mainly used in analogue phones;

• Time Division Multiple Access (TDMA) where each cell uses a certain portion of time on a given frequency. This provides three times the capacity of analogue and is used by the Global System for Mobile communications (GSM). GSM has encryption for security and uses the 900MHz and 1800MHz frequency bands in Europe, and much of Asia and Africa. Unfortunately it uses 850MHz and 1900MHz in the US and Canada since the 900MHz and 1800 MHz were already in use. So one may need a tri- or quad-band phone when travelling.

• Code Division Multiple Access (CDMA) where each call uses a unique code and spreads the call over the available frequencies. It uses GPS for timing.

The 3rd generation (3G) mobile phone technology was designed for smartphones and data. In particular it increased the bandwidth and transfer rates up to 3Mbps (i.e., 15 seconds for a 3 minute song) c.f. 144kbps for 2G phones, and accommodated web applications, audio and video files. There are several access protocols including CDMA (based on 2G CDMA), UMTS (Universal Mobile Telecommunications System) whose most common form is wideband CDMA, and Time-Division synchronous CDMA.

The 4th generation (4G) is the name given to the next generation of mobile devices such as cell phones. At the time of writing (July 2010), there isn’t an agreed upon industry standard as to what constitutes 4G mobile, so it tends to be a marketing term. There are two main contenders: Worldwide interoperability for Microwave Access (WiMAX) [11]; and Long Term Evolution (LTE) [12]. They:

increase data speeds (e.g. 100Mbps down, 50Mbps up); enhance security; enable carrying High Definition TeleVision (HDTV); they are intended for Internet use on computers also; they do IP packet switching only and support IPv6.

• WiMAX began testing in Baltimore in 2008,

• LTE began testing 14 December 2009 in Stockholm and Oslo.

2.2 How Cell Phones Work

The crucial development for cell phones was the use of multiple cell sites and the ability to transfer calls from one site to the next as the phone travelled between sites. The first commercial automated cellular network was launched in Japan by NTT in 1979. Bell Labs developed the modern commercial cellular technology in 1984, employing multiple centrally controlled base stations (cell sites) each providing service to a small area (e.g. 10 sq miles). The signals between the base station and mobile phone are deliberately kept low power so the same frequencies do not spill into non-adjacent cells and so the frequencies can be re-used (see Figure 1).

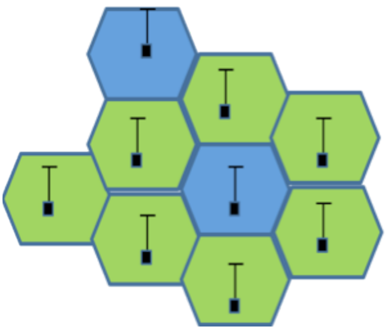

Figure 1: Conceptualized cell

Figure 2: AT&T Cell Phone Tower at SLAC

The base station typically consists of a tower (sometimes disguised) with climbing rungs, and a lightening arrester, as shown in Figure 2. At the top are antennas facing three 120 degree sectors. The number of antennae per sector depends on the number of technologies and frequencies covered. The antennae are connected by large coax cables to the small buildings at the base. These buildings contain the radio equipment, batteries and some form of temperature control. Then there is a source of power and an uplink to carry signals to and from the Mobile Telephone Switching Office (MTSO) that controls the base station and handles phone connections. Typically each carrier has an MTSO in each city. In addition there is usually a small GPS antenna on the tower to enable time synchronization.

When the mobile phone is powered on the phone listens on its control channel for the SID (System Identification Code, a 5 digit number unique to each carrier). The phone compares the received SID with that in its memory and transmits a registration request to the MTSO which tracks the phone location to see which cell it is in. The MTSO picks a frequency pair and tells the phone and relevant base station over the control channel. The base station and phone connect up on the frequency pair. If the SID on the control channel does not match the phone's SID then the phone knows it is roaming. The MTSO of the cell you are roaming in contacts the MTSO of your home system. The home MTSO confirms the phone's SID is OK. All this happens within seconds. Beware roaming can be expensive and if you want to roam internationally you may need a phone with multiple technologies.

2.3 Mobile Phones Today

Today's mobile phone/smartphone is one of the most intricate devices used daily. It may provide: compression, Analogue to Digital Converters (ADCs); Digital Signal Processor (DSP); a radio with hundreds of channels; a microphone and earpiece; a camera; sophisticated power management and a battery; an accurate clock; a microprocessor (e.g. today's iPhone has a 1GHz processor); Read Only Memory (ROM); flash memory (iPhone can support 32GBytes); touch sensitive colour display; some kind of keyboard; and with 4G speeds of up to 1Gbps; etc. If we compare the IBM

Stretch supercomputer [13] of the early 1960's with today's smartphone we can see we have come a long way:

• The smartphone is much smaller, i.e. it fits in the hand versus 2500 sq. feet;

• The smartphone weighs 5 oz. versus 40,000lbs;

• The smartphone uses 10,000 times less power;

• The smartphone is a thousand times faster at 1/100,000th of the cost.

The Apple iPhone jump-started smartphone adoption when it was announced in June 2007. As of early 2010 Nielsen Data [14] showed 23% of mobile users in the first quarter of 2010 had a smartphone compared to 16% in the second quarter 2009 and it is predicted that one billion people will own a smartphone by 2013 [15]. The main smartphone features used in the last 30 days, according to the Nielsen Data [14] reported in June 2010, were: text messaging; mobile Internet; email; downloading applications; multi-media messaging (e.g. picture messaging); game downloads; location based services (GPS). The biggest use in terms of bandwidth is probably downloading video clips, and YouTube is estimated at 30-50% of actual mobile traffic. For example, downloading an iPhone 2 minute 720p video of 4*MBytes at 1Mbps takes 6 minutes [16] and this is already becoming unacceptably slow. Such utilization is already stressing mobile providers' back-haul networks. This in turn is driving providers such as AT&T and Verizon to new support models. These include:

• Limits on amount of data transmitted, e.g. 200 MBcost $15/month, 2GB costs $25/month, 65% users use < 200MB/month, 98% use < 2GB/month, and only WiFi for video chat;

• Abandoning of network neutrality [17], i.e. charge more for better service;

• Drive to provide 4G services such as LTE and WiMAX. These may come for tablets before smartphones since supporting data only is easier than supporting multiple smartphone modes.

Other features that are showing up or are likely to show up in smartphones include: accelerometers, biometric sensors for fingerprint readers, GPS, gyroscopes, haptics (e.g. for keyboard feedback), pico projectors and pressure sensors [18].

2.4 Concerns

2.4.1 Security

With the capabilities now being built into mobile phones, we can expect to see a growth in malware and spyware aimed at them. Information Technology (IT) departments are not ready to fully support the new Operating Systems, yet smartphones may have access to sensitive corporate data. Users will need training to know to turn on encryption (e.g. SSL—Secure Sockets Layer, VPNs—Virtual Private Networks) for private data being sent from the smartphone, and to exercise caution, when browsing the Internet or accepting email enclosures, to avoid contamination. In addition there is a need for anti-virus, anti-malware apps, firewalls etc.. This is not only the case for corporate work but will be increasingly so for mobile payments (see below). Further smartphones can easily be lost. Thus one needs the ability to safely and remotely wipe the contents of a mobile phone.

2.4.2 Links to Cancer

Though there have been lots of studies, the links between mobile phones and cancer caused by the Radio-Frequency (RF) radiation is inconclusive. The main source of RF is produced by the phone's antenna and the closer to the head the higher the exposure. The measured metric is the Specific Absorption Rate (SAR). An SAR of < 1.6 watts/kg of body weight is considered safe by the Federal Communications Commission (FCC). The SARs for manufactured phones vary from 0.1 to 1.59 watts/kilogram [19].

The other source of radiation is the base station itself. The worst case ground level power density is 0.01W/sq cm. This compares with the average energy over entire earth/day (excluding clouds) of

~250W/sq cm, i.e. the electromagnetic energy from the sun is 25,000 times that of a cell phone tower [20].

2.4.3 Others

- Lack of attention leading to trips and falls, driving errors etc.
- Lack of consideration for others
- Locating emergency phone calls is more complex
- Privacy: use of multilateration to locate cell phone, remotely turning on microphone to listen to conversations.

2.5 Mobile Phones and Developing Regions

Cellphone towers are very costly (e.g. $120K-500K), typically take 9 months to 3 years to build including acquiring the permits and construction, and take 20 or so people with diverse skills (planning, design, construction, electrical, and electronic, RF, safety). However, compared to the infrastructure needed for landline phones (cables to each house) they are extremely effective. Thus we see developing nations leapfrogging wired phones increasingly in favour of mobile phones. For example Africa has 21% mobile phone penetration versus 9% for land lines [21].

The growing saturation of the market in the developed world means for example, in Western Europe, Japan and Hong Kong there are already more than one mobile phone per capita. On the other hand the under-developed world as illustrated in Figure 3, has room for growth. The strongest market growth for mobile phones is expected to be in the developing world in particular in Brazil, Russia, India and China.

Other factors that make the under-developed world attractive for growth are the low cost of labour, and the youth of the population. The low earning capacity will make the initial attraction be towards simple mobile phones costing less than $100 and given the power situation long battery life and alternate power supplies such as from a solar or a bicycle [22]. Some of the applications are also simple such as providing a flashlight or FM radio. Low cost smartphones with open operating systems are also entering the market which will assist in their deployment in developing countries.

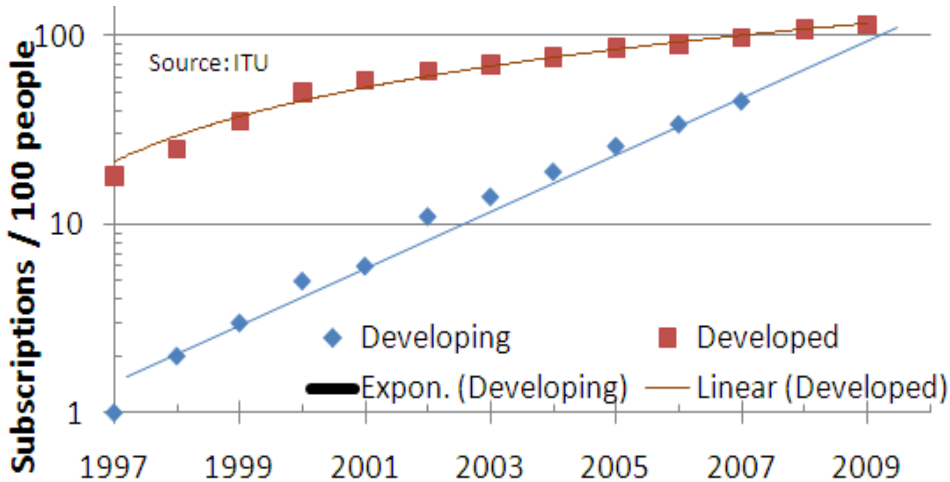

Figure 3: Mobile phone subscriptions per 100 people in the developed and developing world.

On the other hand a potentially very important mobile phone application, especially in the developing world, is mobile payments. In this, mobile operators, often in partnership with banks, card issuers and mobile payment service providers are looking to offer mobile payment service. The number of users is forecast to grow to 490 million by the end of 2014 [23].

2.6 Other Mobile Devices

Other mobile devices besides cell phones that are relevant to our discussion include: satellite phones, WiFi capable computers and phones, and tablet computers such as the iPad [24]. We are not considering short range devices such as cordless phones, or BlueTooth capable devices, or Citizen band radios or pagers.

2.6.1 Satellite Phones

There are several satellite phone services [25], we will only mention a few.

Inmarstat was founded in 1979. It originally provided large fixed installations intended for use on ships, but has only recently started to enter the market of hand-held phones. The company operates eleven satellites with another planned for launch in 2010. Coverage is available on most of the earth's surface, notably excepting Polar Regions.

The Iridium project consists of a (66 active plus spares) group of satellites in low earth orbits orbiting from pole to pole and designed to provide satellite phone coverage over the entire earth. Satellites communicate with neighbouring satellites on 10 Mbits/sec links. The satellites were launched in 1997-8. Each satellite can accommodate up to 1100 concurrent phone calls. In February 2009 a defunct Russian satellite crashed into and destroyed an Iridium satellite. It was replaced with a spare. This was the first recorded satellite-satellite collision [26]. A big user is the US Department of Defense. Typical uses include: maritime, aviation, government, the petroleum industry, scientists, explorers, frequent world travelers, and catastrophes such as the Haitian earthquake. Phone calls are expensive costing several dollars/minute. It is an essential component of South Pole communication which starting in 2006 has a total bandwidth of 28.8kbits/s. There are also stand-alone data logging units such as on buoys used for a tsunami warning system.

AT&T has recently introduced the Terrestar system [27]. The satellite was launched on July 1st 2009. It covers the US. The AT&T service uses hybrid phones that switch from cellular service to satellite when cellular service is not available. The phones cost about $800 and typically look like a Blackberry. The monthly charge is $5.0 on top of the mobile phone service charge. The satellite calls are $0.65/minute.

2.6.2 WiFi Capable Devices

WiFi is the utilization of the IEEE 802.11 technology that uses the unlicensed 2.4, 3.6 and 5.0 GHz frequency bands for wireless local area network devices. Use of the unlicensed radio frequency spectrum means it may encounter interference with other devices such as microwave ovens, security cameras, Bluetooth devices, cordless phones etc. It is used in personal computers, video game consoles, mobile phones and is typically used to connect to the Internet. Besides its use in office and homes it is also available for public access at “hot spots” such as airports, coffee bars, hotels, restaurants etc. There are also examples of cities such as Sunnyvale, California and many university campuses that provide WiFi access across their domain. Typically access to the end device is made through a wireless connection to a Wireless Access Point (WAP) that in turn has access to the Internet. There is also an ad-hoc computer to computer mode that can be used to communicate between the computers. A typical 802.11b or 802.11g WAP has a range of ~100ft indoors and 300ft outdoors. Outdoor ranges can be increased up to several kilometres by the use of directional antennas. Setting up a WiFi network optimally can be tricky due to RF obstacles such as walls, bad client drivers, heavy channel utilization, overlapping WAPs, interference from other devices etc. Due to its reach requirements, WiFi has fairly high power requirements making battery life in mobile laptops and phones a concern. Since WiFi is basically a broadcast medium, security can be a concern and there are encryption standards to combat this.

The latest WiFi communication standard is 802.11n [28] which was finalized in September 2009. It increases the raw data rate from 54 Mbits/s up to 600 Mbits/s by the use of four spatial streams at a channel with frequency of 40 MHz. It also increases reliability, the coverage predictability, and is more efficient so less battery power is needed.

WiFi enabled mobile phones are becoming increasingly important and the number of phones shipped with WiFi increased from 92.5 million in 2008 to 129.3 million in 2009 [29]. According to an ABI Research study the number shipping will exceed 500 million by 2014 when 90% of all smartphones will have the technology.

3 The Internet and Mobile Phones

3.1 Growth

Looking at Figure 4 we can see that the number of fixed wired phones worldwide has peaked and is starting to fall off. The number of mobile subscriptions on the other hand continues to grow exponentially and passed the number of fixed phones in 2001. By 2011 it is predicted that the number of mobile subscriptions will equal the world population. At the same time the number of Internet users worldwide is also growing exponentially, though at a slower rate than the mobile subscriptions. At the current rate the number of Internet users will equal the world's population around 2019. The move to mobile computing is such that according to the ITU (International Telecommunication Union), in 2008 mobile access to the Internet exceeded desktop computer based access.

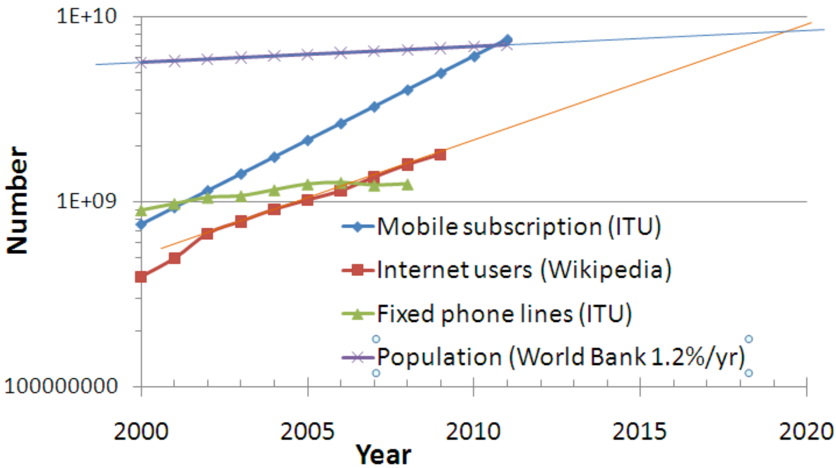

Figure 4: Population, Mobile subscriptions, Fixed phone lines, and Internet users this century

For phones this is leading to the demise of the once ubiquitous phone numeric keypad to be replaced QWERTY type keyboards such that by 2015 less than 50% of mobile phones will contain keypads [30].

3.2 Performance

The Internet performance results below are obtained from the PingER [31] project. PingER is a joint project led by SLAC [32], part of Stanford University near San Francisco with partners at NUST/SEECS [33] in Islamabad, FNAL [34] in Chicago, and ICTP [35] in Trieste. It uses the ubiquitous Internet ping [36] facility to actively measure Internet end-to-end Round Trip Times (RTT), losses etc. It has over 50 active monitoring hosts in 22 countries that, every 30 minutes, monitor almost 800 sites in 164 countries that between them contain over 99% of the world's Internet connected population. Figure 5 shows the PingER deployment in July 2010. The data goes back the start of 1998 so besides the current state of the Internet it contains much valuable historical data.

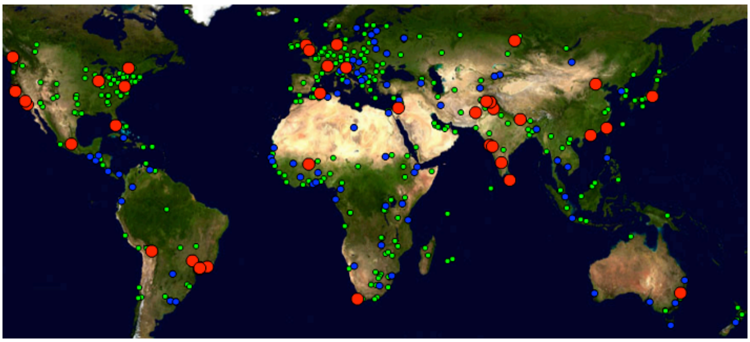

Figure 5: PingER deployment in July 2010. Red dots represent Monitoring sites, blue dots are Beacon sites and green dots are Remote Sites.

Besides measuring RTT and losses it is possible to derive other useful metrics such as: unreachability (the monitored host does not respond to any pings), jitter [37], TCP throughput [38] and the Mean Opinion Score (MOS) [39].

3.2.1 Derived TCP Throughput

The derived TCP throughput to the world as seen from SLAC is seen in Figure 6.

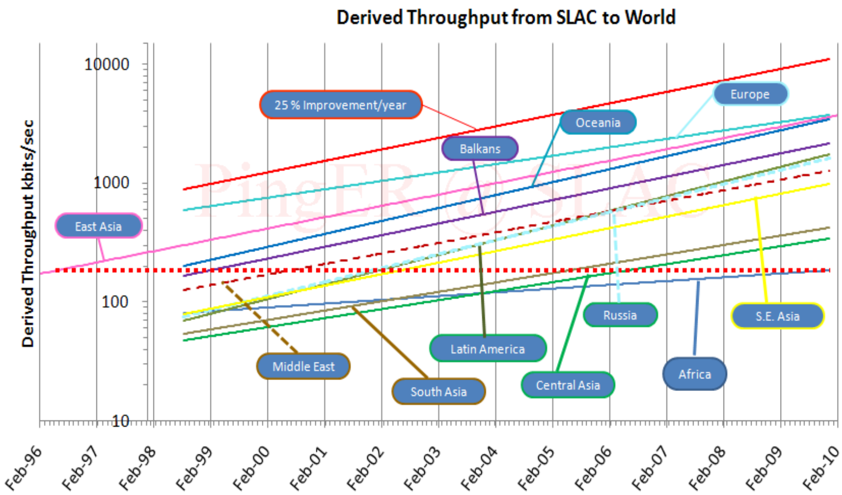

Figure 6: Derived Throughput from SLAC to regions of the world 1998-2010.

The red line is to guide the eye and shows a 25% improvement per year or roughly an order of magnitude in 10 years. It is seen that in terms of throughput performance, the world is divided roughly into three domains:

1. The best performing regions: Europe, East Asia, Australasia and N. America (not shown here since the measurements are made from SLAC within N. America and thus are distorted since the derived throughput is inversely proportional to the RTT)

2. A middle tier: Latin America, Russia, Middle East and South East Asia;

3. The most poorly performing regions: South Asia, Central Asia and Africa.

The red dotted line is to assist in showing how many years (almost 14) Africa is behind East Asia. What is worse is that Africa is falling further behind each year. After 10 more years at the current rates of improvement, East Asian sites would on average have 75 times more throughput than the average African site.

Looking in more detail at the derived throughput quality indicator (y axis) versus the number of mobile phones per capita (x axis) with population being represented by bubble size, regions by colour as a function of country for 2007 we get the bubble plot in Figure 7.

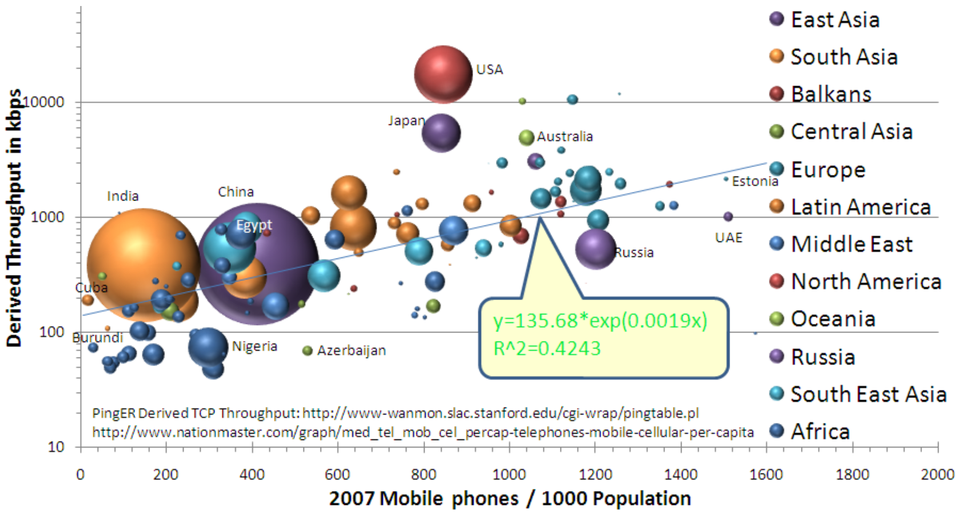

Figure 7: Derived TCP Throughput vs. mobile phones per capita.

There is seen to be a positive correlation (R2 = 0.4243) between the derived throughput and mobile phones per capita. Thus countries with good Internet throughput connectivity tend to have more mobile phones per capita. Though the markets for mobile phones in India and China are huge, it can be seen that the number of mobile phones per capita is low so the potential for growth is huge.

3.2.2 Mean Opinion Score (MOS)

The MOS provides a measure of the perceived quality of audio reception, and is thus very valuable for measuring phone call quality. It can be derived from the RTT, losses and jitter all of which are available from the PingER measurements. MOS values range from 1 to 5, with 5 being perfect reception, and 1 is the lowest perceived audio quality. Values of 4 and above are good, 3-4 is fair, 2-3 is poor etc. Typical values for Voice over IP (VoIP) [40] are 3.5 to 4.2 [41]. Values for the MOS derived from PingER measurements to regions of the world can be seen in Figure 8.

It is seen that N. America, Europe, E. Asia and Oceania have been fair to good all this century. Russia, Latin America and the Middle East improved dramatically in 2000-2001 as many of the sites moved from satellite to land-lines. South Asia and Central Asia are now just about usable. The latter is confirmed by personal experience, since SLAC can now hold regular VoIP meetings with SEECS/NUST in Pakistan using Skype [42]. Though the quality is poor, it is usable. A more serious inhibitor is the reliability of the connection due to power outages in Islamabad. Africa's performance on average is well below the limit for VoIP calls from SLAC.

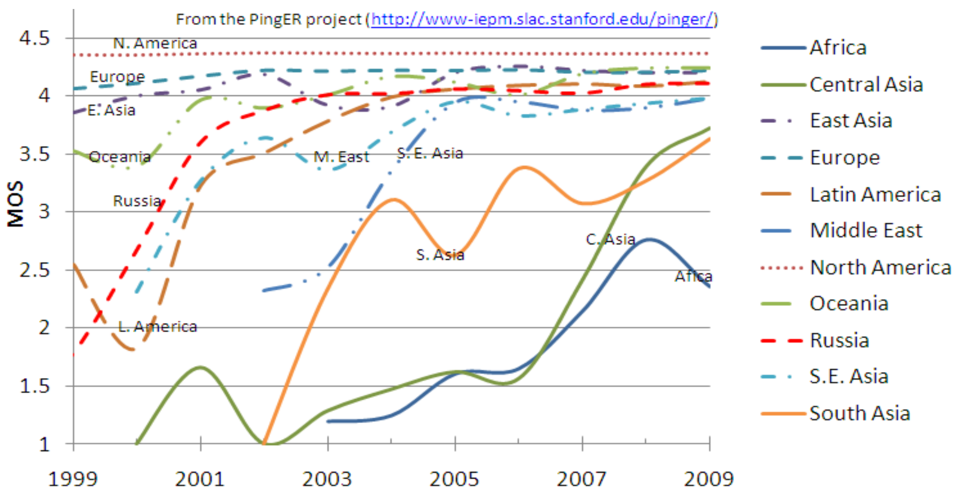

Figure 8: MOS measured from SLAC to regions of the world.

Looking in more detail at the MOS values (y axis) seen from SLAC for 2009 as a function of country (bubble), region (color), population (size of the bubble) and number of mobile subscriptions per 1000 population (x axis) we get the bubble plot seen in Figure 9.

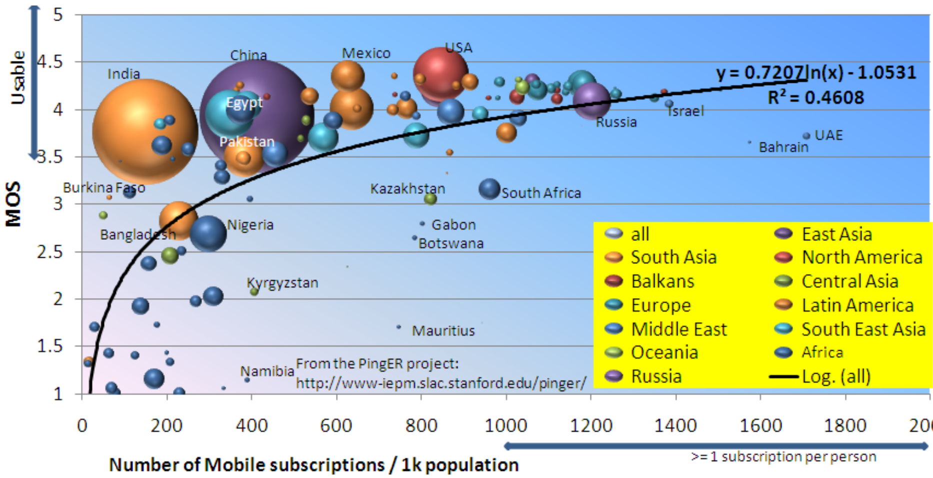

Figure 9: Worldwide Country MOS seen from SLAC vs. mobile subscriptions per 1000 population.

It is seen that Internet connectivity to most countries and in particular those with the larger populations is usable for VoIP. This is encouraging given the increasing dependence on VoIP. Many African countries (blue) including Nigeria and South Africa fall below the threshold though the Mediterranean African countries such as Egypt have acceptable performance. Several developed or developing countries such as Russia, several European countries, and some Gulf states already have over 1 mobile phone per capita. There is a medium strength positive correlation (R2 = 0.46) between the MOS and the number of mobile phones per capita.

4 The Digital Divide

"The digital divide refers to the gap between people with effective access to digital and information technology, and those with very limited or no access at all. It includes the imbalance both in physical access to technology and the resources and skills needed to effectively participate as a digital citizen" from Wikipedia [43]. There are many digital divides including those associated with: age of population; city vs. rural population; the rich vs. the poor; and our main interest that associated with regions of the world. For the current purposes we consider the Internet performance as

measured by the derived TCP throughput compared with two UN development indices.

4.1 Human Development Index (HDI)

The UNDP Human Development Indicator (HDI) [44] measures the average achievements in a country in three basic dimensions of human development:

• A long and healthy life, as measured by life expectancy at birth

• Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary and tertiary education gross enrollment ratio (with one-third weight)

• A decent standard of living, as measured by GDP per capita (or Purchasing Power Parity (PPP) in US$).

A bubble plot of the HDI vs. TCP throughput is shown in Figure created using the PingER motion chart application [45].

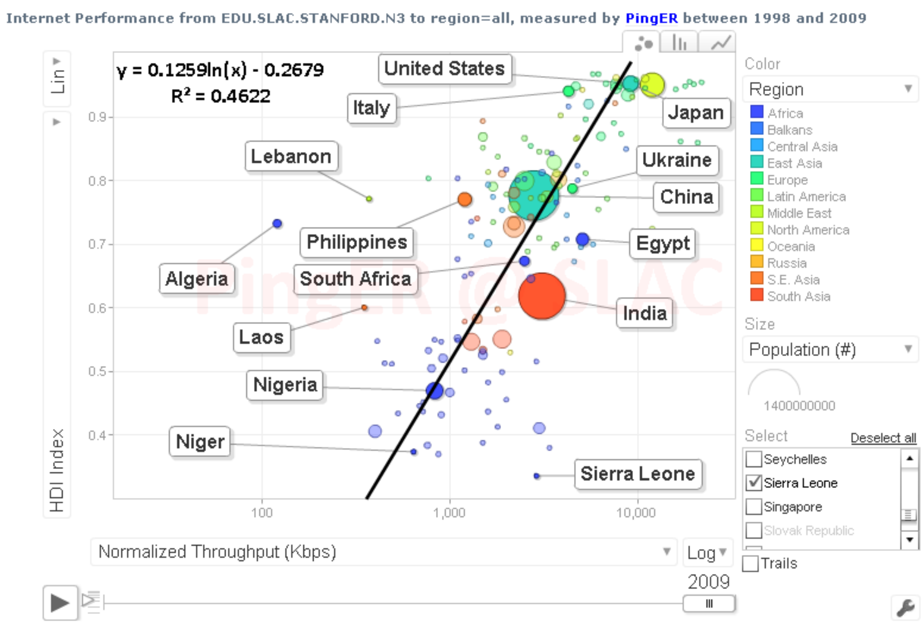

Figure 10: Comparison of PingER derived throughputs seen from N. America to various countries and regions versus the HDI.

As expected countries in Africa generally occupy the lower values in x and y, and North American, European countries together with Australia, New Zealand, Korea and Japan occupy the higher values of x and y.

4.2 Digital Opportunity Index (DOI)

The DOI [46] is a comprehensive metric made up of a composite of 11 core indicators that aims to track progress made in infrastructure, opportunity and utilization. A snapshot of the PingER motion chart for the DOI versus PingER's derived normalized [47] TCP throughput is shown in Figure 11.

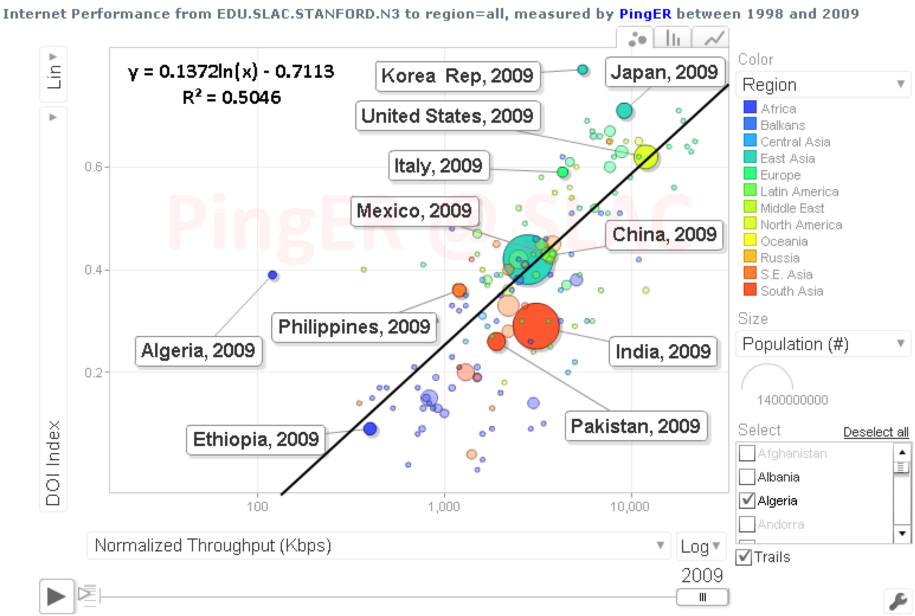

Figure 11: DOI versus Normalized derived TCP throughput

5 African Situation

As has been shown above the situation in Africa is dire, not only is it behind in most development measures, but up until now it has been falling further behind. To a large extent this is due to the large number of countries that had only Geo Stationary (GEOS) satellite connections. This results in large RTTs (over 400 ms) and is illustrated in the map of Africa shown in Figure 12.

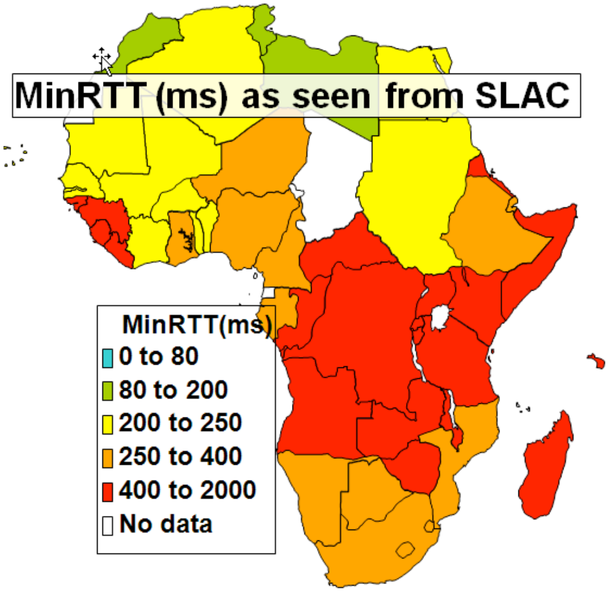

Figure 12: PingER minimum RTT to African countries as seen from SLAC as seen in 2008.

The countries with satellite only access are shown in red. It is seen that most of East and Central Africa had only satellite access at the start of 2009. At this time the only fibre to sub-Saharan Africa was the SAT3/SAFE [48] cable down the west coast of Africa. This was run by a consortium of state monopolies that had very expensive rates. The capacity of links between various regions of the world as seen in Figure 13 dramatically illustrates the very limited capacity available to Africa in 2009.

With the impetus of the World Cup in South Africa in 2010, and the vast underdeveloped (< 9% of the African population has Internet access [49]) African market (almost a billion people) several companies have rushed to install undersea fibre cables to African coastal countries and in particular the east coast of Africa. This is illustrated in [50] where it is seen that instead of there being a single cable of 340Gbits/s down the west coast of Africa, there are already or will be by the end of 2010, two cables down the east coast and three down the west coast. Not only does each of these cables have several times the capacity of the original SAT3/SAFE cable but now there is competition. Fortunately terrestrial fibre already existed, so inland countries such as Uganda and Rwanda already connected via Kenya to the Seacom cable by mid August 2009. The PingER monitoring data measured from ICTP in Italy was able to clearly detect the move from satellite to fibre as the minimum RTT dropped from 700ms to about 350ms to Uganda [51].

With the extra capacity, competition and the emergence of National Research and Education Network (NREN) bodies in Africa [52] that will enable collective bargaining, direct cross-border connections and a better understanding of what to do and whom to work with, it is hoped that the situation in Africa will improve dramatically for many African countries.

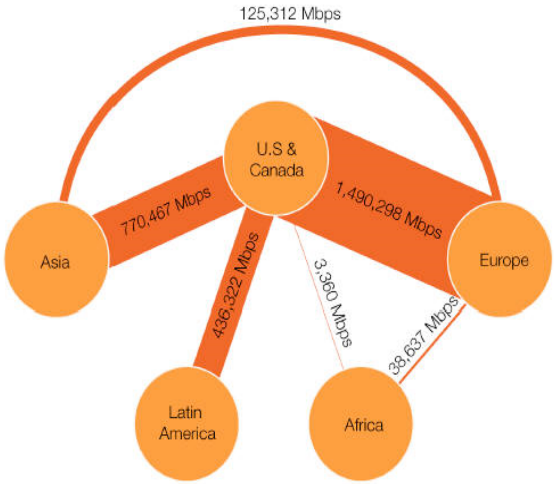

Figure 13: Internet interregional bandwidth.
Source: Telegeography research

Through there is much interest in expanding mobile phone services in Africa from companies such as India's Bharti Airtel, Vodaphone and France Telecom and there is still lots of room for growth (Africa has 300 million people lacking mobile phone access), the best customers already have mobile subscriptions. Thus the next steps will be to extend into poorer areas such as Niger where the per-capita GNP is less than $2/day. In addition, not only are there more operators per country than in say the U.S. and Europe, but also African customers are less tied to a service provider with more than 95% pre-paying rather than having a long term contract and 4-6% of subscribers switching operators per month [53].

6 Conclusion

The original Internet design has been outstandingly successful in bringing order to enable computers to communicate with one another. As the computers being connected become more ubiquitous, and their purposes increasingly diverse and mobile, the initial design is becoming increasingly in need of extending and improving. This is increasingly being driven by the mobile computing capabilities of smartphones which are rapidly growing out of the cellphone market and growing faster than other forms of computing. In many cases, cell phones are enabling developing regions to successfully leapfrog older technologies such as wired phones, and increasingly provide Internet connectivity. Unfortunately with this connectivity come many issues to do with security, privacy etc. that are only starting to be addressed.

When we look at how the Internet is performing worldwide we see big differences between developed and developing regions, even worse not only some regions such as Africa are many years behind, but also they appear to be falling further behind. At the same time in many areas the developed world is becoming saturated and so there is much attraction to the growth potential of developing regions. Despite the poorer performance of developing regions, nowadays most regions, with the major exception of Africa, have sufficiently good Internet performance to support VoIP. A big hope for Africa is that the impetus of the recent World Cup in South Africa has led to several undersea fibre optic cables being installed to countries on the East and West coasts of Africa. Not only are these the first cables to East Africa but in both East and West Africa there are now competing providers.

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“Sensing

Towards a Societal Scale Scientific Instrument

RJ Honicky
UC Berkeley, USA
Nokia Research Center, Berkeley USA

Eric Brewer
UC Berkeley, USA

Eric Paulos
Carnegie Mellon University, USA

1 Introduction

While industry analysts predict that cell phones will become the "next PC," we believe that the cell phone has the power to become something much more than a scaled-down, connected IO and processing device. In addition to these standard PC traits, a cell phone is situated in an environment, mobile, and typically co-located with a user. These traits make the cell-phone ideally suited to track and understand the impact that the environment has on individuals, communities, cities, as well as understanding how humans effect their environment.

By attaching sensors to GPS-enabled cell phones, we can gather the raw data necessary to begin to understand how, for example, urban air pollution impacts both individuals and communities. While integrating a sensor into a phone and transmitting the data that it gathers to a database is not very difficult, doing so at low cost, on a societal scale, with millions of phones providing data from hundreds of networks spread throughout the world makes the problem much more tricky.

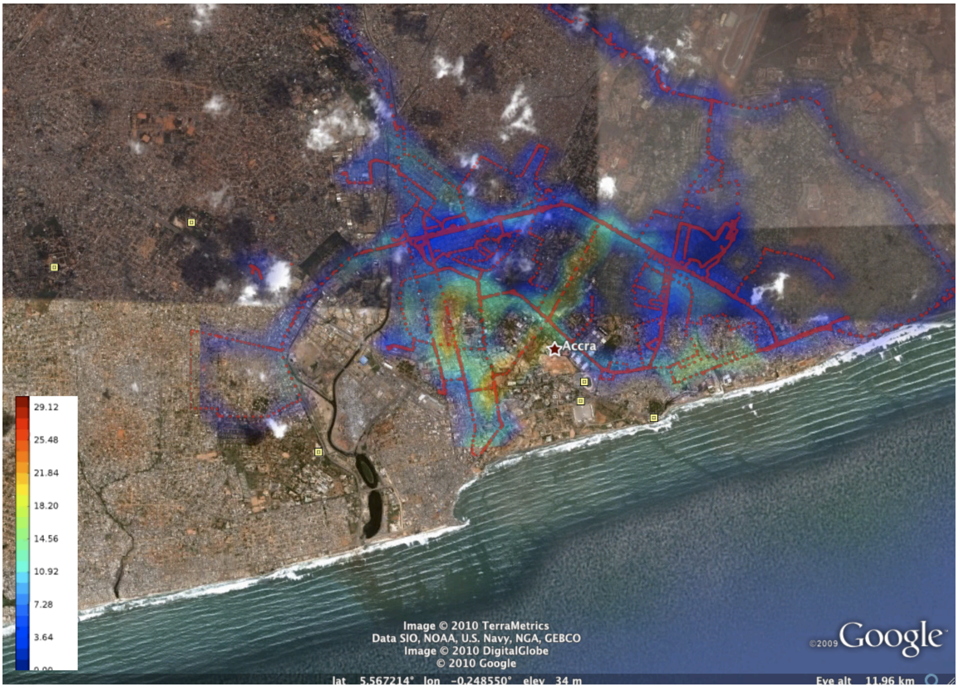

Figure 1: Carbon Monoxide data (red points) and interpolation (color heat map) gathered using sensors carried by taxis and students in Ghana, West Africa, on March 22, 2007. Images are overlaid on satellite imagery using Google Earth.

On top of the systems challenges, understanding the raw data gathered from a network of cell-phone-attached sensors presents significant challenges as well. Cell phone users are mobile, are unlikely to calibrate their sensors, typically put their phone in their pocket or handbag (thus obstructing the sensor from airflow), spend significant time indoors or in cars, and typically charge their phone at most once per day, often much less frequently. Even if users did calibrate their sensors, the very low-cost sensors we intend to use drift over time and environmental conditions. Without knowing the location of a sensing event, automatically calibrating the sensors in the phone, detecting the environment of the phone, and intelligently managing power (by sampling at the right times) the data gathered by the phones will be next to useless.

Integrating sensors into mobile phones, however, has several practical advantages. For many applications, the most significant challenges that face tradition wireless sensor networks are power management and network formation and maintenance. Of these, power management is greatly simplified (since users charge their phones regularly), and network formation is largely solved. Also, a dearth of real-world, practical applications has limited the number of “motes” (wireless sensor network nodes) that get manufactured, and thus the price of a mote remains relatively high. With the number of mobile phones sold in 2010 on track to surpass 1.2 billion [1], cell phones obviously have enormous economies of scale that will be hard to replicate in the near term. Thus the mobile phone platform has several significant advantages as a sensor that will allow relatively simple, and massive deployments.

The economics of mobile phones also provide a unique opportunity for developing countries in particular. Since mobile phones tend to first find markets in the highly industrialized world, and then secondary markets in less industrialized areas (either in the form of used devices or low priced overstock), if devices are manufactured with sensors integrated into them, they are almost certain to find their way to all corners of the globe.

Even today, the low cost of mobile phone-based computing offers the opportunity for scientists in developing regions with modest budgets to deploy sensing in their communities or areas of study. Integrating sensing into mobile phones is increasingly straightforward and commonplace, and an increasing number of examples abound.

The mobility of the phone also provides some important opportunities. At the expense of sampling a given location continuously, a sensor in a user’s phone can provide significant geographic coverage. Also, mobile sensors will be heavily biased towards locations in which people congregate, so for human-centric applications, sensing in mobile phones will often provide coverage exactly where it is needed most. In over-sampled locations, the precision of the sensing system can be increased by carefully averaging the readings from several nearby sensors (see Section 7). Also, sensors close to one another can be automatically calibrated, especially if there are some “ground truth” reference sensors also situated in the environment (see Section 6).

All these advantages point to a new opportunity: to build the largest scientific instrument ever built, consisting of millions or billions of sensors, aggregating data on an unprecedented scale. This instrument could be truly societal scale, reaching across economic, social, geographic and political boundaries, and illuminating the corners of human activity, how our environment affects us, and how we affect our environment.

This chapter begins to explore some of the primary challenges to building a societal scale scientific instrument. It is by no means exhaustive. Instead, we discuss our own work in the context of the larger problem of societal scale sensing. We intend to provide a starting point for researcher, developers, activists, scientists, health workers and politicians, to consider how to start collecting data now, how to interpret and manage those data, and to hint at what might be on the horizon.

As such, this book and this chapter cover a wide range of topics, and are intended for readers from different backgrounds. In this chapter, we present some technical and mathematical detail that may be difficult to follow for those without background in the subject, or simply may not be interesting to all of our readers. We hope that these readers will simply skip past the technical details to the larger arguments and observations about sensing in mobile phones, which we hope are equally interesting and valuable.

1.1 Active vs. Passive Sensing

In some cases, when using a sensor in a phone, we can imagine the user being explicitly involved in the sensing process, for example when using a micro-array connected to a phone in order to detect a pathogen in a blood sample. In other cases, for example when sensing ambient pollution of a large geographic and temporal area, the user might not even be aware of when the sensor is taking readings.

These two examples illustrate active vs. passive sensing, sometimes referred to as human-in-the-loop and human-out-of-the-loop sensing. Data gathered using active sensing tends to be very focused and specific to the user, whereas data gathered using passive sensing tends to be more global, and large scale. In this chapter we will focus on passive sensing, since this chapter focuses on achieving scale.

1.2 Users and Stakeholders

When we design a system, it is often useful to identify the users and stakeholders, in order to determine whether a design meet their needs. In this section we look at some of the primary users and stakeholders in a mobile-phone based sensing system.

We should note that although some of the stake-holders might use the data we produce for persuasive purposes, our goal in building a societal scale sensing system is explicitly not persuasive. We believe that the underlying information should be available to society, under an open and equal access system, and that the various stake holders can utilize those data for their own purposes. A microscope is intrinsically exploratory, rather than persuasive, and so too should a “mobiscope”. On the other hand, those with microscopes have more power in the form of information than those who do not, and so too with information from mobile sensing. Thus our commitment to open access.

Figure 2: A building housing generators for an ISP in Guinea Bissau. The closest generator was poorly tuned and exhausted into the room, causing dangerous levels of carbon monoxide to accumulate in the work area.

1.2.1 Individuals: *"What pollution am I being exposed to?"*

Personal exposure to pollution has increasingly become a primary health concern. For example, many urban areas publish pollen counts and air quality indicators for asthmatics, and other people with breathing difficulties, because of the direct correlation between atmospheric pollution and asthma related Emergency Room visits. The trend for people with older gas-powered appliances to install Carbon Monoxide sensors in the environment is another example of personal interest in exposure to pollution.

Figure 2 and Figure 3 illustrate the important impact that personal sensing can have on health and safety. While working in Guinea Bissau at an ISP datacenter, one of the authors briefly looked into a generator housing, where a poorly tuned generator was exhausting into the housing. Examining the log from a personal carbon monoxide sensor afterwards, we discovered that the carbon monoxide levels outside the room exceeded 300ppm, dangerously high even outside the room. For the safety of the technicians, the ISP immediately stopped using that particular generator until it could be tuned and properly exhausted. This is a perfect example of how personal monitoring leads to positive action for the individual and the community.

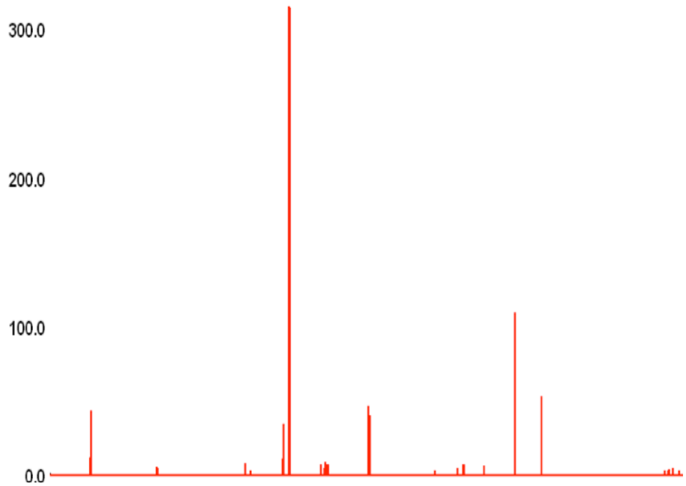

Figure 3: A personal log of carbon monoxide exposure during October, 2006. The 300ppm spike corresponds to standing in the doorway of the room depicted in Figure 2.

A project out of Dartmouth University, BikeNet, aims to provide these type of data to users with heavily instrumented bicycles. BikeNet bicycles use a 802.15.4-based local network to aggregate sensor data in a mobile phone, and then upload the data to a server. These data are analyzed, and can provide information about the “health” of a ride (including pollution exposure), and other computed metrics such as “fitness/performance” and also user-defined metrics such as “enjoyment” [2]. These data provide an important glimpse into what kind of in-context data users might be able to see about themselves, and suggests what users might do with them.

1.2.2 Policy Makers and Community Activists: *"What are the societal impacts of atmospheric pollution, and how can we mitigate them?"*

Individual interest in pollution extends, however, into the community, as well. Environmental justice groups are increasingly looking for ways in which to bring primary data to bear in their negotiations and confrontation with polluters and other stakeholders. Indeed, Jason Corburn asserts that a community's "political power hinges in part on its ability to manipulate knowledge and to challenge evidence presented in support of particular policies" [3].

The CommonSense project at Intel aims to provide a technology platform for personal sensing with the explicit goal of enabling community action, and supporting local policy-making. The CommonSense project works with community activists in West Oakland, near one of the country's busiest ports [4], and with the City of San Francisco to document pollution throughout the city using sensors mounted on street sweepers [5] (see Figure 4a), some data from which can be seen in Figure 4b.

Figure 4a: A sensing device mounted on a street sweeper in San Francisco as part of the Intel CommonSense project.

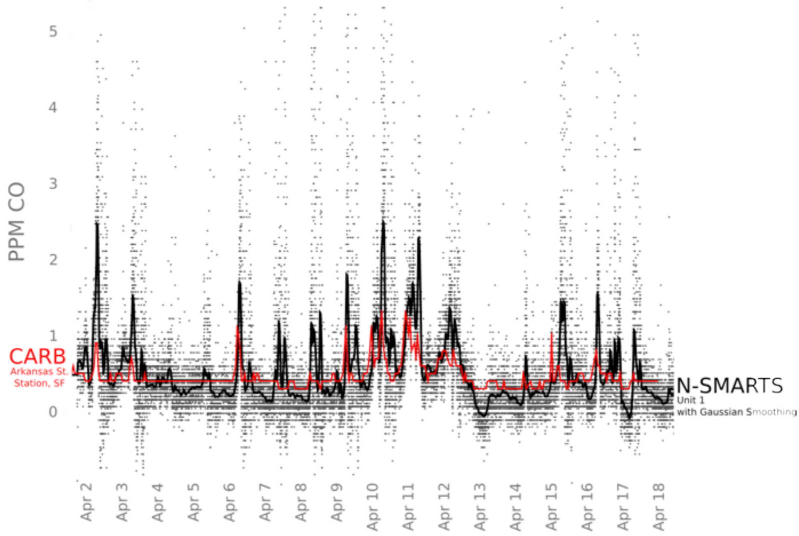

Figure 4b: Although the CommonSense street sweeper sensor is far less sensitive than the CARB CO sensor on Arkansas St. in San Francisco, it still tracks the ambient pollution levels recorded by the CARB sensor.

1.2.3 Atmospheric Chemists: *"How is pollution distributed, what are its sources, and how does it evolve"*

Atmospheric chemists study how pollutants and other chemicals evolve in our atmosphere. For pollutants like the nitric oxides (NO_X) and ozone (O_3), the life cycle of pollutants is very complex (these pollutants change from one to the other in a process that is poorly understood "in the wild"). For other pollutants, like carbon dioxide (CO_2), the chemical itself is relatively inert, but the presence of other pollutants can give us a hint as to the source of the CO_2. The work of an atmospheric chemist is to understand and classify the different chemicals in our atmosphere, how they get there, and how they inter-relate with one another.

To date, much of the work done by atmospheric chemists has used relatively high precision, high accuracy instruments, sparsely positioned throughout the environment. For locations not directly observed, chemists use models of dispersion and reaction in the atmosphere to predict the concentration of the chemicals.

Another common mechanism that gets more spatial coverage is to use vehicles instrumented with sensors, and move them through the environment. NASA has a special purpose DC-8 that allots "seats" for sensing equipment. The researchers provide an intake mechanism for their sensor that fit into a window frame in the plane and sample the air at high altitude. This mechanism allows researchers to observe the concentration of chemicals at high altitudes over a very large area. Because of the speed of the aircraft, the large area is observed over a relatively short period of time.

1.2.4 Epidemiologists: *"Who is being exposed, at what levels and how does that effect their health"*

At the end of the day, one of our most important concerns is how pollution impacts humans. Mobile sensing has the unique characteristic that it measures the pollution levels exactly at the locations where people are located. Not only does this enable us to track an individual's exposure, but this also means that samples will be concentrated exactly where people are concentrated. So if humans are our primary interest, then mobile sensing, in some sense, provides optimal spatial coverage.

It is also interesting to note that in conjunction with activity inference, an important ongoing research topic, we can begin to correlate activities (e.g. bike riding), with pollution exposure. Epidemiologists will also have a tool by which to correlate health outcomes to pollution exposure more directly, assuming the parties are willing to provide epidemiologists with identifying information.

1.2.5 Network Operators

Network operators, of course, need to be considered. Operators traditionally have taken a tightly controlled approach to the devices, applications and services, and have essentially viewed revenue going to third parties for phone based applications and services as "leaking revenue," particularly in American markets where devices are typically marketed by operators.

American operators have grudgingly ceded control of the phone in various ways as smartphones have generated huge revenue jumps for mobile operators and manufactures alike. Even as "unlimited" data plans become more prevalent, thus removing one important obstacle to getting data from the phone into the cloud, however, operators still exert significant control over what devices operate on their networks.

European and other global operators that primarily use GSM based networks, however, don't typically exert as much control over the devices that use their networks, so a hit product in Europe which has built-in sensing might be effective in persuading operators elsewhere to support phones with integrated sensors.

If operators are interested in some of the data that are collected for their own purposes (say, geographic signal strength information, for example), they might even be persuaded to subsidize sensor devices. Governments might also provide subsidies or legislative encouragement for operators to participate in building a societal scale sensor network.

1.2.6 Phone Manufacturers

Manufacturers are also key industrial players in building a large-scale sensor network. With razor thin margins on highly competitive and commoditized mobile phones, and a market that moves at a very fast pace, even minor increases to the bill-of-materials or engineering costs of a device must be offset by a clear increase in revenue and profit. This is a particularly difficult challenge for scaling a mobile sensor network.

One approach would be to pitch sensor-phones as a green initiative for the company. With increasing focus on environmental degradation and the accompanying health impacts, a sensor-phone might be seen as a way for a manufacturer to contribute towards improving environmental conditions, and thus as good marketing material.

Another approach would be to sell context awareness as an advanced feature in the top model phones, including pollution, humidity, temperature, noise levels, location, proximity to friends, and many other context-related measures. Considering the increasing importance of context awareness in general, monitoring one's own behavior and environment might be a good selling point for a mobile phone.

These ideas notwithstanding, there are many questions to be answered about how to convince manufacturers and ultimately consumers to bear the increased cost of integrating sensors into phones, regardless of how marginal those costs are.

2 The Goals of Mobile Sensing

Sensing in mobile phones has several aims. Of course, the primary aim is to provide data to the users. Part of this is to provide the raw data and/or aggregate data to the stake holders in a way that protects privacy while permitting collaboration and cross referencing as much as possible.

The raw data, however, are difficult to interpret for several reasons, outlined below (see Section 3), and so part of our aim needs to be to provide stakeholders with tools and allow them to interpret the data in a way which reflects the ground truth as much as possible. Our tools must also quantify our confidence about the data and our interpretation.

Finally, sensing in mobile phones, in particular, is unique in that it can amortize the cost of monitoring our pollution exposure and our environment over millions or billions of people. This is a critical distinction from other wireless sensor network technologies, which might be highly scalable, but lack capital because they are not driven by consumer demand.

Another point which cannot be emphasized enough; pollution monitoring and other sensing in mobile phones is almost optimally capital efficient. That is to say, everything we need to do mobile sensing is in the phone, except the sensors themselves. The marginal cost of adding the sensors themselves is essentially the only cost.

Thus, one of the primary goals of sensing in mobile phones is to amortize cost over millions or billions of people, and to maximize the capital efficiency of deploying sensors.

3 The Challenges for Mobile Sensing

Sensing in mobile phones confronts several important challenges. If these challenges are not addressed, we cannot hope to realize the benefits of a societal-scale sensing instrument. Instead, we will be limited to small, expensive deployments.

3.1 Energy

Often, in one way or another, challenges in the mobile phone domain boil down to energy. Sensing is no different. As phone processor speeds, network data rates and screen sizes push faster and bigger, the energy and power budgets in mobile phones becomes increasingly constrained. Not only are the increasing energy requirements of the hardware running up against the physical limitations of batteries, but the mobile phone chassis can typically dissipate a maximum of 3 watts of power, limiting the peak performance and peak concurrency for the mobile phone form factor. In these highly constrained circumstances, passive sensing must have a negligible impact on operating time[1].

This has several impacts on our sensing protocol. First, and most obviously, the act of sensing itself must take minimal energy. This includes operating the sensors as well as the sampling mechanism (the mechanism for exposing the sensors to the atmosphere in a controlled way). Secondly, we must be able to wake up at the

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1 "Operating time" is the time a device can operate before needing to recharge its battery. The term "battery life" is often used in this way, but actually refers to the time until a battery can no longer effectively hold a charge.

appropriate time, take a sample and go back to sleep quickly. This means that we will need to carefully control long start-up times to limit energy consumption, if they are necessary. Finally, following directly from the second point, we must be able to sample our location quickly: the long signal acquisition times for GPS are unacceptably expensive because they require significant processing power that will limit the reasonable duty cycle of our sensors to an order of once per hour or less. Fortunately, there is an elegant solution to this problem that we will discuss in detail below.

3.2 Cost

Of course, the cost of the sensors must also be low enough to have a minimal impact on the overall cost of the device. This must include any circuitry required to run the sensor, as well as the sensor itself. Fortunately, any sensing mechanism with a short bill of materials is likely to be affordable when manufactured in units of millions, assuming that the manufacturing process can be scaled that large. This includes almost any semi-conductor based technology, so we believe that mobile phones integrating atmospheric sensors will probably use semi-conductor based sensors. Since this is a relatively simple challenge that can most likely be addressed by large scale manufacturing, we will not discuss cost again, except in the context of other discussions.

3.3 Physical Space

The mechanical design of a phone has an enormous impact on its desirability, and therefore a direct impact on the profitability of a company. The size and weight of a phone will have a direct impact on a phone's desirability. A practical implementation of atmospheric sensing using mobile phones must therefore have a negligible impact on the devices' form factor. This means that the sensor itself, as well as the sampling mechanism, must be extremely small and light-weight. We will discuss the size of different sensor technologies in Section 4.

3.4 Calibration

All sensors require calibration, and cheap sensors (which are the only viable option for a mass produced sensor-phone) usually require relatively frequent calibration (e.g. every few weeks or months). Traditionally, calibration happens by exposing a sensor to at least two (for linear-response sensors) known concentrations of a substance. The sensor's response to these substances allow us to determine the bias (the sensor's response to clean air), and gain (the change in the response of the sensor as the concentration changes).

These factors are complicated by the fact that sensors are sometimes "cross-sensitive" to other chemicals, the humidity, temperature, air-flow rate and air-pressure of the environment, and that sensors may not respond linearly to changes in concentration. When a sensor is sensitive to one or more of these factors, calibration usually requires that the sensor be exposed to the cross product of these factors: e.g. we must record the response of the sensor at different humidities, temperatures, etc.

This type of calibration must be done in a highly controlled setting (e.g. a chemistry lab), by a trained specialist. It is not reasonable to expect millions of users to do this on their own or incur expense or effort to calibrate their sensors. Rather, we must figure out how the system can figure out the calibration of the sensors automatically, without user intervention. We will discuss calibration in Section 6.

3.5 Precision

Another consequence of using cheap, mass produced sensors is that they typically have low precision. On the other hand, in many popular locations, we will have highly dense sampling: lots of people will be in the same place, at the same time. If we are smart, we will be able to increase the precision of our system by averaging readings in an appropriate way.

3.6 Security and Privacy

Whenever information about people gets collected, security and privacy immediately become an important issue. If we want to convince users to provide us with their data en mass, they must trust that we will use the data for its intended purpose, and not to exploit them. They must also trust that we will handle their data in such a way that it won't inadvertently or intentionally fall into the hands of people who will try to exploit them. We will need to prove to users that their data will be properly handled, which we discuss in Section 9.

4 Sensor Technologies

In order to get a better handle on what kinds of sensors exist today, and what will exist in the near future, and the challenges associate with each technology, we will briefly discuss the main types of gas sensors we might consider for integration into a phone.

4.1 Electro-chemical

Perhaps the easiest to work with of the currently available technologies, electro-chemical sensors typically function by creating an electric current from a chemical reaction with the substance being sensed. They are often a type of fuel cell (similar to the high power hydrogen fuel cells being researched to replace batteries) that uses an electrolyte and catalyst specific to the substance being sensed. The sensor typically generates a very minuscule electric current (on the order of a few tens or hundreds of nano-amps), which can then be measured with sensitive electronics.

Electro-chemical sensors are reasonably well understood, and are commercially manufactured in a variety of shapes and sizes. Because the principle of operation relies on measuring an electric current generated by a chemical reaction, the more reaction that takes place for a given concentration, the more sensitive the sensors can be. Since the current generated by the chemical reaction is so small, the thermal noise and drift in the electronics measuring the current can impact the precision and accuracy of the measurements.

As a consequence, the larger the sensor, the more precise and accurate it can be. This obviously must be balanced with the size constraints in a mobile device. Unfortunately, the smallest practical sensors are typically around 1 cubic centimeter, which is rather large to integrate into a phone.

On the other hand, electro chemical sensors typically have a linear response over a wide range, are relatively sensitive, and require very little power to operate, since they are self powering. The device only needs to use power to amplify the signal from the sensor and actually take the measurement, and this circuitry can typically start up in a matter of microseconds, allowing for very fast sampling.

Although they are sensitive to extreme humidity, since the fuel cell can dry out or saturate with water (between 20% and 95% relative humidity is a typical operating range), electro-chemical sensors are typically reasonably insensitive to humidity in the typical humidity range of air (about 25% in the desert to 100% during rainfall). They do, however, need to be calibrated for humidity over their operating range. They also can be somewhat sensitive to temperature and air pressure, and need to be calibrated to these factors as well.

These characteristic make electro-chemical sensors a very attractive option for researching mobile sensing, but an unlikely candidate for ultimate integration into a mobile phone.

4.2 Spectroscopic

Spectroscopic sensors typically operate by observing which frequencies of light are absorbed by a particular gas in a controlled chamber. Since different types of molecules have different absorption bands (e.g. the molecule resonates at particular frequencies, thus absorbing a lot of the energy at that frequency), we can use a laser tuned to one or more of the absorption bands specific to a particular gas, and observe how much light in the absorption band transmits through the gas. The higher the concentration of the absorbing gas, the less light that gets transmitted.

Additionally, some spectroscopic sensors (sometimes denoted fluoroscopic sensors) operate by exciting a gas using a laser tuned to one or more of the gas' absorption bands. The gas then emits a photon at a lower wavelength and this fluorescent band of radiation can be detected, possibly in conjunction with the absorption band.

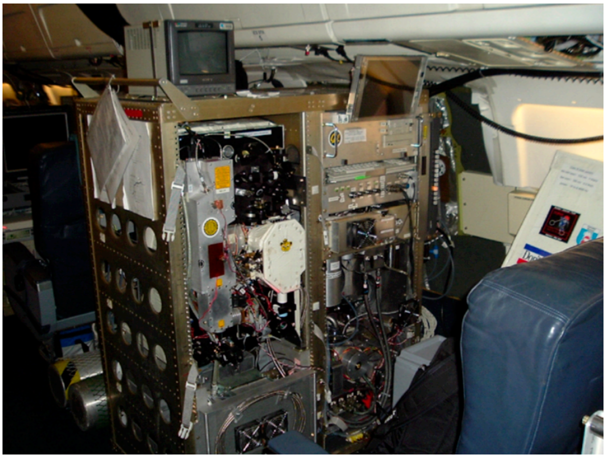

Figure 5: An extremely high precision spectroscopic NO_2 sensor mounted with an intake out the window of a DC-8. Photo courtesy of the Cohen Group at UC Berkeley.

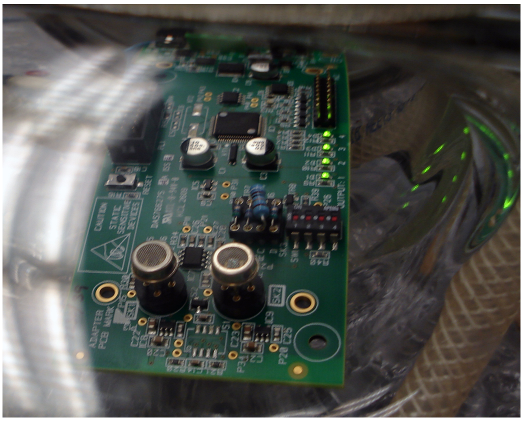

Figure 6: Two metal oxide ozone sensors (round, near the bottom) in the test chamber shown in Figure 9. Most of the volume of the sensor is the enclosure, and could be eliminated in a phone deployment. Photo by Virginia Teige.

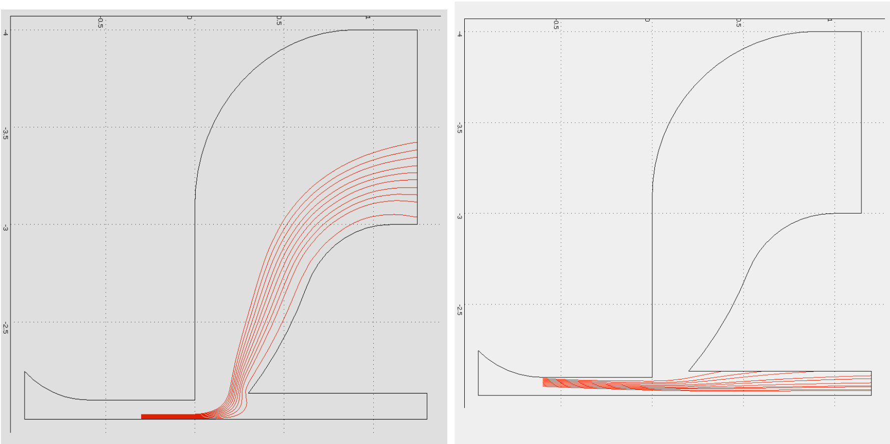

Figure 7: Calculated particle trajectories through the (simulated) impactor for (left) 0.5 μm and (right) 5 μm particles. Images reprinted from [32] with permission

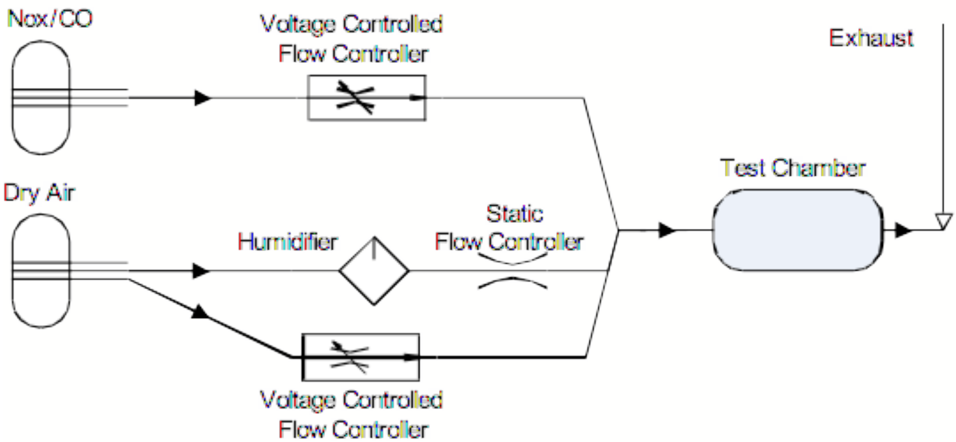

Figure 8: Poison gas, dry air and humidified air are mixed together using flow controllers, keeping flow rate constant, in order to precisely control the concentration of pollutants our sensors are exposed.

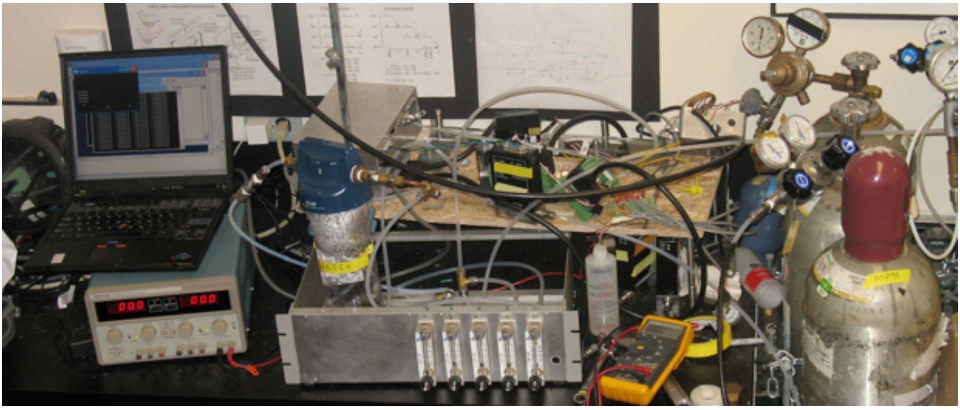

Figure 9: This setup has a small chamber that allows us to quickly change the concentration of poison gas in the chamber

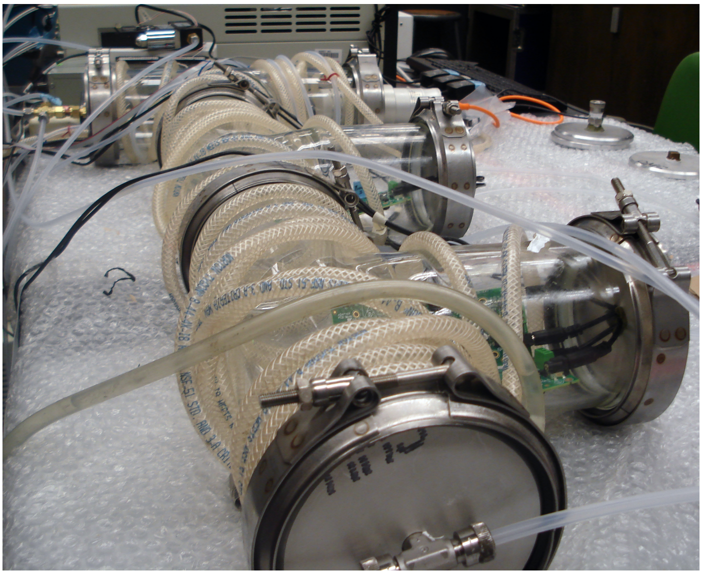

Figure 10: Another setup in our lab has a large chamber that allows us to test multiple large sensors simultaneously (Photo: Virginia Teige)

Spectroscopic sensors can be extremely accurate, and have the advantage that since they do not rely on a chemical reaction, they work for relatively inert compounds, such as CO_2. Some spectroscopic sensors are available off the shelf, they are also a popular choice for high precision sensing, since their principle of operation is relatively simple and they can be made extremely precise when precise components are used (see Figure 5).

On the other hand, while they can be made somewhat compact by using mirrors to increase the distance over which the laser travels, the size is still constrained to be large enough to permit the laser to travel over sufficient distance to excite a sufficient amount of the measured gas. These sensors are typically a minimum of a few centimeters long.

4.3 Metal Oxide/Silicon

Another common technology for portable sensing is metal oxide sensors. In this technology, a thin film of a metal oxide that is sensitive to a particular gas is deposited on a silicon substrate. There are many ways in which to construct a sensor using a metal oxide, a common one is to design the sensor in such a way that the resistance of the sensor changes as it is exposed to a particular gas. The change in resistance can be measured and translated to a change in concentration. This typically works best for reasonably reactive gasses such as NO_X, or Ozone, and less well for relatively inert gasses such as CO_2.

This method typically requires that the surface of the metal oxide be heated to a high temperature (say, 500C), so it requires a lot of power to perform a measurement. Fortunately, the heater can be pulsed on an off quickly, and the way that the resistance changes as the temperature changes can give more information about the gas that is causing the change of resistance. Gasses to which the sensor is cross-sensitive may also respond in different ways to the change in temperature than the primary gas, thus increasing the selectivity of the sensor.

Metal oxide sensors tend to be very sensitive to other environmental factors such as pressure, and flow rate (since flow rate can affect the surface temperature of the sensor).

Metal oxide sensors are available of-the-shelf, and are very small, but require extensive calibration. Accuracy as an absolute reference of gas concentration is difficult to attain, so they tend to be used in application where it is more important to detect a relative change in concentration. One such application is in automotive emission control.

One project in Berkeley affiliated with our research is exploring how to attain reasonable accuracy using very small, low-cost metal-oxide sensors. In this project, the researchers use a chamber in which they can carefully control gas concentrations, humidity and flow rate (see Figure 6). They are also examining how to exploit temperature measurements of the surface of the metal oxide sensors using a precise infrared sensor to detect and respond to changes of surface temperature, in order to reduce sensitivity to flow rate and ambient temperature.

4.4 MEMS

Micro Electro-Mechanical Systems or MEMS-based sensors mechanical devices are built using photo-lithography, the same technology used to build microchips. MEMS-based sensors share the advantage of extremely small size with other silicon/photo-lithography based approaches. There are many MEMS based sensors out there, and we will not try to survey the field, but rather discuss one technology affiliated with our research.

In this technology, a thin-film, bulk-acoustic resonator, or FBAR, is used to measure the concentration of particulate matter (PM or aerosol pollution) in the air. This is a particularly important application, since existing technologies for measuring aerosol pollution are very large, typically on the order of tens or hundreds of cubic inches. Manufacturing FBARs is a well understood process, because FBARs make good notch filters for high frequency radios, and so they commonly appear in mobile phones.

Thus the manufacturing process has already been well tuned for high volume and low cost.

An FBAR resonates at a very high frequency, say 1.6 GHz. If we can cause particles in the air to deposit on the FBAR, the weight of the resonator will change slightly, thus causing a change in its resonance frequency. We can measure that change of frequency and translate it into a concentration of aerosol pollution.

One way to cause a particle to deposit on the fbar is by inducing a thermal gradient over the FBAR using a heater. This technique is called thermal-phoresis, and is relative insensitive to the composition of the aerosol pollution. Other deposition methods (e.g. electro-phorsesis) have greater sensitivity to the composition of the particles, but lower power, and thus might be used to create a lower-power sensor that is sensitive to only certain types of aerosol-pollution (e.g. pollen).

In order to create a PM sensor specific to particles of a particular size (e.g. smaller than 2.5 microns), we can use various filtration mechanisms. One mechanism is inertial impaction, in which larger particles have greater inertia with respect to the viscosity of air, and thus follow a different trajectory than smaller particles. By carefully controlling the flow rate of the air, we can select for a particular size of particles (see Figure 7).

A controlled flow-rate, however, means a relatively high power air pump, which will have an impact on the total power of the sensor. Optimizing the power of the deposition and airflow mechanisms are therefore a subject of ongoing research.

5 Accuracy and Precision

Since manufacturers build mobile phones in very high volumes, typically with thin margins, cost will be a central issue. The question we need to ask is "how can we build a societal scale sensor using mobile phones, and using affordable technologies, so as not to significantly impact the desirability of the devices to the consumer."

Since the incremental cost of integrating a sensing into a phone is almost entirely in the sensing mechanism itself (including the mechanism for providing airflow), the cost of the sensor and airflow mechanism (given that they are suitably sized) will ultimately determine whether manufacturers will consider participating in building a societal scale sensor.

Unfortunately, there is often a tradeoff between the size of a sensor, and the precision and/or accuracy of that sensor. Since precision and accuracy ultimately determine the usefulness of data in a sensor or sensor system, the precision and accuracy of a sensing system become the fulcrum on which a sensing system pivots between feasibility and usefulness.

Precision and accuracy are two related but orthogonal concepts in sensing. Roughly speaking precision refers to the amount of information in a signal, (e.g. the number of bits that we need to capture a signal), and accuracy refers to the correctness of those bits (e.g. how closely those bits reflect ground truth). We can also understand precision in the context of "repeatability," or the extent to which different measurements under the same conditions produce the same results. These two concepts of precision, e.g. measurement resolution vs. repeatability, are essentially the same.

We can have a very precise, but inaccurate signal, in which the signal is very steady (in the short term), but is improperly calibrated (or has drifted over time). The sensor thus provides "bad" data, in which our information about ground truth is incorrect. We can also have an accurate signal that is imprecise, in which the noise of a signal makes it difficult to get a lot of information about ground truth, despite proper calibration. In the extreme, we might have a sensor that only gives us a single bit of information about ground truth, although we have a very high confidence that that single bit is correct.

Obviously, if the drift of a sensor can be bounded (as it often can), then we can make a sensor more accurate by reducing its precision, until the drift of the sensor falls within the bounds of the sensor's precision. Conversely, if we can characterize or somehow manage the drift of a sensor, then we can increase the precision of the sensor. Typically, however, we view drift as a longer term and somewhat deterministic process, and noise as a short term, and fundamentally random process, so our approach to mitigating problems with accuracy vs. precision are necessarily different.

Cross-sensitivity to other environmental factors such as humidity, temperature, pressure and other compounds in the air also contribute to inaccuracy. If we can characterize these cross-sensitivities, using calibration and modeling, then we can increase our accuracy without reducing our precision.

5.1 Noise Model

Although the noise in a sensor depends on the particular sensor, and the underlying technology, many sensors are dominated by thermal noise, and possibly, to some extent, shot noise (for extremely sensitive sensors). Shot noise is most accurately modeled as Poisson distribution, for less sensitive sensors (as in our cheap sensors) a Gaussian noise distribution for both thermal and shot noise is sufficient.

In order to study our devices and algorithms, we have built two testing chambers for exposing our devices to poison gasses at precise concentrations and under controlled humidity. Both chambers operate by diluting a known concentration of one or more poison gasses with clean, dry air, and clean humidified (at close to 100% humidity) air. To alter the concentration of the poison gas while keeping the humidity constant, the flow rate of the humidified air is kept constant while the rate of flow of the poison gas and clean air are simultaneously adjusted to keep the same total flow rate. Similarly, to adjust the humidity of the air while keeping the concentration of poison gas constant, the flow rates of the clean dry air and poison gas are both adjusted proportionately, while the rate of flow of the humidified air is adjusted to keep the total rate of flow the same (Figure 8).

The first chamber is a small chamber that permits the concentration in the chamber to change rapidly, thus allowing us to characterize temporal characteristics of the sensors such as response time (Figure 9). The second chamber is a larger chamber that has room for several large sensors, allowing us to characterize and experiment with larger sensors (Figure 10).

With these setups we can easily measure the noise in our sensor and circuitry, simply by placing the sensor in the chamber, flowing clean air, and examining the readings. As we can see in Figure 11, our sensor board output is very close to Gaussian.

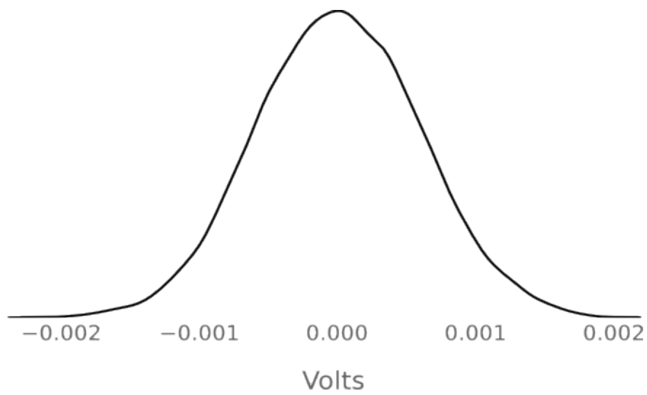

Figure 11: A kernel density estimate of readings taken while the sensor was exposed to clean air. This distribution closely approximates a Gaussian distribution.

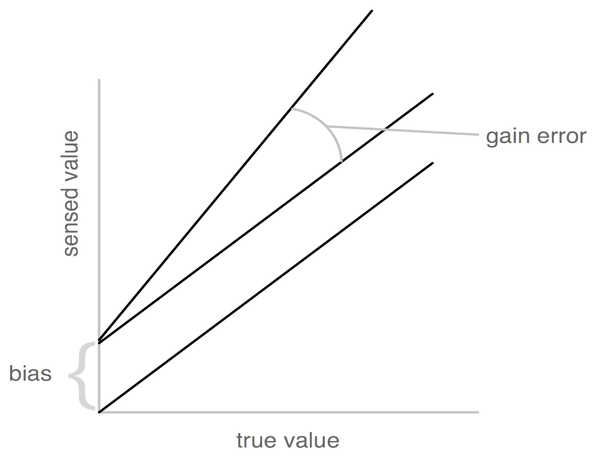

Figure 12: Gain and bias in a linear sensor

6 Calibration and Accuracy

Section 5 briefly explained the concepts of accuracy, precision and bandwidth. From that discussion, it should be apparent that if the calibration of sensors drifts over time, then the sensing system will become inaccurate. Without a reasonable mechanism for manually calibrating sensors in a societal scale sensor network, we must rely on the data themselves to calculate the calibration of sensors in the system without explicit user action.

In this section we outline the background concepts pertaining to sensor calibration, and two mechanisms for automatic calibration of sensors. The first mechanism, called CaliBree, was developed by researchers at Darthmouth, and the second mechanism is our own research.

6.1 Gain and Bias

In the context of sensing, gain refers to the amount of change in the sensed value with respect to the change in the underlying, true value, and bias refers to the sensed value when the true value is zero. For linear sensors, gain and bias simply refer to the slope of line of ADC readings vs true values, and bias refers to the y-intercept of the line (see Figure 12).

Because gain error is, by definition, a percentage of the sensed value, it does not impact readings very much unless the reading is large. Bias is therefore a more important consideration in a system that measures ambient pollution: typically, ambient pollution has a very low concentration, so in order to achieve any realistic accuracy we must reduce the bias of our readings to a minimum. Furthermore, the gain drift of a sensor can often be bounded to a small percentage, further limiting the impact of mis-calibrated gain. For example, the gain of the electrochemical sensors that we use can drift no more than 5% per year, according to the data sheet [6].

With that said, we will first discuss our techniques for automatic calibration of sensor bias in a network of mobile sensors, and then we will expand the techniques slightly to calibrate for gain as well.

6.2 Problem Setup

In a network of sensor phones, with potentially millions of devices, we cannot reasonably expect people to invest their time or money into calibrating the sensors. The human must be out of the loop, so to speak. The system needs to exploit characteristics of the data to provide accurate information to the end users of the data without requiring action by the user.

Fortunately, people tend to congregate, and when they do, our sensor phones are likely to be close to one another. In that case, they should sense roughly the same value. If they don't, then there is likely a mis-calibration in one or both of the sensors that results in the sensors reading drastically different values (although some variation is expected, since the sensors are not in exactly the same location).

6.3 CaliBree

CaliBree is a self calibration algorithm for mobile sensor networks based on the idea of calibrating during very close rendezvous, in which the sensors are close enough to be exposed to a negligibly different environment [7]. CaliBree uses a weighted average of the difference between "ground-truth nodes," which have been recently calibrated, and mobile sensor nodes. The weight that gets assigned to the readings from a particular given rendezvous can be adjusted according to probability correspondence between the ground truth reading and the mobile node, the authors do not specify exactly how that correspondence is determined.

CaliBree makes an excellent start towards providing a calibration mechanism for a mobile phone-based sensing system, it makes some assumptions that we consider unnecessarily limiting. First, the assumption that the there are well-calibrated "ground-truth" nodes located throughout the environment is not scalable, particularly for developing countries. While it is likely that a few well calibrated sensors will exist in the environment, its is unlikely that many users will rendezvous with these sensors close enough for the mobile and ground-truth sensors to be in the same sensing environment.

Secondly, restricting the rendezvous region to an area in which the readings of the two sensors should be virtually identical discards useful information. Since readings from nearby locations should be correlated even if they are not close enough to be identical, we should be able use information from nearby locations, weighted by some distance metric.

Similarly, even if samples are not taken close enough in time to one another to be considered exactly the same, the correlation between the samples should be related to the time difference between the samples. We should be able to exploit that correlation.

Finally, CaliBree does not offer a good way to integrate heterogeneous sensors with varying accuracies, drift, etc. We imagine that many different phone models, with different sensors, plus higher accuracy instruments located in the environment will all provide readings to our societal scale instrument.

6.4 Automatic Calibration using Gaussian Processes

With these limitations in mind, we will now develop an algorithm based on Gaussian process regression, for inferring the bias of each sensor. This algorithm is capable of incorporate high precision and accuracy "ground-truth" nodes if they are available, and can exploit their increased accuracy to increase the accuracy of the system, but in no way relies on these "ground-truth" nodes to work. Instead, these algorithms rely on the opportunistic rendezvous between any sensors in the system, and the proximity of the rendezvous determines the amount of correlation that the system expects between two readings, and hence determines the amount of information that can be used for the sensors' mutual calibration.

The algorithm relies on two important assumptions. First, that the bias of the sensors in the system is distributed as a Gaussian. Secondly, the algorithm relies on the calibration event being done with information about all of the sensors. Whereas CaliBree is completely distributed, with calibration happening on the mobile sensor itself, our algorithm works in the cloud, using global information about all of the sensors in the system.

6.4.1 Gaussian Process Regression

Very briefly, a Gaussian process is a Gaussian distribution over functions, which essentially means that it is the continuous version of a multivariate Gaussian distribution. In place of a mean vector, we have a mean function, and in place of a covariance matrix, we have a covariance function, also often called a kernel function. Typical covariance functions give more covariance to points that are close to one another, so a Gaussian process essentially implies some amount of smoothness, depending on the particular covariance function used.

We can view a Gaussian process in terms of standard linear regression

$$f(x) = \phi(x)_T w + \varepsilon$$

When the number of dimensions of w goes to infinity, and we place a Gaussian prior over w, then we have a Gaussian process.

We define $K(X_1,X_2)$ as the matrix of covariances between the elements of vector X_1 and X_2. X is the locations of our observations, Y is the values of our observations, X_* is the locations of where we want to predict using our model, and σ_n^2 is the variance of the sensors (assuming for a moment that all of the sensors have the same variance), then we can infer the mean and covariance functions as

$$\begin{aligned} \bar{f}_* &= \mathrm{E}[f_* \mid X, y, X_*] = K(X_*, X)[K(X,X) + \sigma_n^2 I]^{-1} y \\ \mathrm{cov}(f_*) &= K(X_*, X_*) - K(X_*, X)[K(X,X) + \sigma_n^2 I]^{-1} K(X, X_*) \end{aligned}$$

This allows us to perform regression on non-uniformly sampled points.

Rasmussen and Williams provide an excellent introduction to Gaussian Processes, and their book is available online for free (although we feel that the hard copy is well worth the money for those who can afford it) [8].

6.4.2 Modeling Bias

Following from Rasmussen and Williams, to model bias, we first augment our x vector:

$$x = \begin{bmatrix} x_d \\ x_b \end{bmatrix},$$

where x_d is the previous x vector, representing the a single sample location, and x_b is a vector of indicators which are 1 if the sample came for sensor i, and 0 otherwise.

Next we change our model slightly as follows:

$$g(x) = f(x) + h(x)^T \beta$$

where f is our original model, and $h(x)=x_b$. Now, if we assume

a Gaussian prior over β:

$$\beta \sim \mathbb{N}(b, B)$$

then we can incorporate b and B into our model [9]:

$$g(x) \sim GP(h(x)^T b, k(x, x') + h(x)^T Bh(x'))$$

Plugging this into the prediction equations above, we get

$$\begin{aligned} \overline{g}(X_*) &= \overline{f}(X_*) + R^T \hat{\beta} \\ \operatorname{cov}(g_*) &= \operatorname{cov}(f_*) + R^T (B^{-1} + HK_y^{-1}H^T)^{-1} R \end{aligned}$$

where

$$K_y = K + \sigma_n^2 I$$

$$\hat{\beta} = (B^{-1} + HK_y^{-1}H^T)^{-1}(HK_y^{-1}y + B^{-1}b) \quad ,$$

$$R = H_* - HK_y^{-1}K_* \quad .$$

$\hat{\beta}$ can be seen as trading off between the prior and the data.

In the event we have information about the bias of any of the sensors, we can choose b and B to reflect that information. This might be the case if we have already calibrated them in the factory or lab, or if previous iterations of this algorithm have made an inference about the values of b and B. In that case, we use the equations above directly.

Next, here is how we can specify ground truth sensors: we can set b with the calibration information for each particular sensor, and set B with the variance on our prior information about b. Furthermore, if we have very precise sensors, then we can set the variance on the readings from those sensors to reflect that precision. We set the variance for those readings by setting the corresponding entries on the diagonal that corresponding to readings from the each sensor to the variance of the noise for that sensor.

In the case where we have no apriori knowledge about each β, we can let the covariance of the prior on β go to infinity, and hence we have that $B^{-1} \rightarrow 0$ (thus specifying a diffuse prior). In that case we can simplify to

$$\text{cov}(g_*) = \text{cov}(f_*) + R^T (HK_y^{-1}H^T)^{-1} R$$

with

$$\hat{\beta} = (HK_y^{-1}H^T)^{-1}(HK_y^{-1}y)$$

Thus b has no influence on our prediction, as we would expect from a diffuse prior.

Even if we don't have any "ground-truth" sensors in our system at all, we can still approximate the most likely bias value for all of our sensors. Assuming that the bias of the sensors are iid, then the maximum likelihood value of the ``true'' bias is the empirical mean of the inferred $\hat{\beta}$ values

$$\hat{\beta}_{ML} = \frac{1}{s}\sum_{i=1}^{s}\beta_i$$

This algorithm adds little computational overhead to our regression algorithm.

6.4.3 Inferring Gain

So far we have only discussed inferring bias, but we previously noted that gain is also sometimes an important contributor to sensor error. The algorithm presented above does not treat gain explicitly, a minor adjustment will allow it to do exactly that.

First, we should note that we want to calibrate gain and bias using different sensor readings. To calculate gain, we want to use the largest values possible, since large readings will be the least influenced by biased sensor readings, and thermal noise (in terms of a percentage of the sensed value). On the other hand, we want to use small readings to calculate bias, since small readings will be least influenced by gain error.

Thus, we can choose a cutoff, below which readings are used to calculate bias, and above which readings are used to calculate gain. Bias is calculated as above.

Next, we note that whereas in the case of bias, the per-sensor differential is additive, in the case of gain, the per-sensor differential is multiplicative.

$$g_{gain}(x) = f(x) \cdot h(x)^T \beta$$

Unfortunately, if we place a prior distribution over beta, then the distribution of g_{gain} will no longer be gaussian. We could optimize the likelihood of g_{gain} numerically, but that would be extremely computationally intensive, since each sensors in the system will introduce a new dimension to the problem, thus quickly making the problem intractable.

Note, however, that if we consider $\log(g_{gain}(x))$ then the problem once again becomes additive:

$$log(g_{gain}(x)) = log(f(x) \cdot h(x)^T \beta) = log(f(x)) + log(h(x)^T \beta)$$

If we consider, for analytic convenience, f(x) and h(x) to be drawn from log-normal distributions, rather than normal distributions, then the problem devolves to the same problem as the bias problem. This may appear to be a contrived solution to our problem, in practice the misspecification of the distribution may not turn out to make a significant difference on the gain inference. Since this trick makes the gain inference computationally tractable (whereas numerical optimization over thousands or millions of dimensions is not), it is worth exploring.

6.4.4 Experimental Results

Evaluating these algorithms under realistic circumstances is difficult, since they rely on a high density of mobile devices in some locations, and depend to some extents on user mobility patterns. We plan to evaluate these using several sensors "in the wild," under controlled mobility patterns, for the time being we have observed the algorithms effectiveness in laboratory and simulation scenarios.

Using the test chamber shown in Figure 9, we exposed four sensors to Carbon Monoxide over 25 minutes at concentration increments of approximately 25ppm, for five minutes at each, and keeping the relative humidity at approximately 50%. The raw readings from the sensors are show in Figure 13. Each of the four sensors has a slightly different gain and bias. We can see in Figure 14 that our algorithm effectively removes the bias when examining small values. In Figure 15, we can see that our algorithm also effectively removes gain error once the bias has been removed.

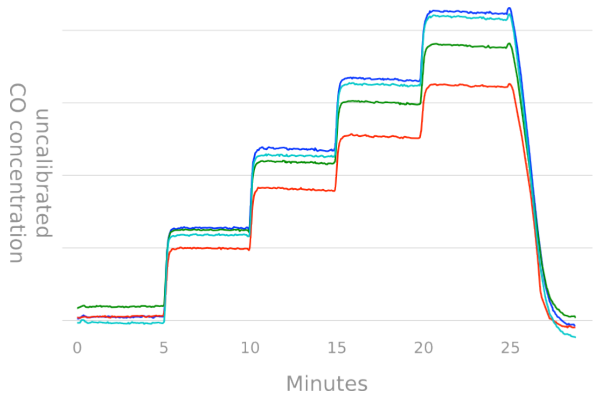

Figure 13: Uncalibrated sensor readings of four CO sensors in our poison gas lab chamber, under semi-controlled temperature and humidity.

One thing to note in Figure 15 is that when the sensors return to zero, they overshoot, and that the steps are not evenly spaced at 25ppm increments. This is probably due to their slow response to the sudden change in humidity and temperature versus the humidity and temperature of the ambient air. We can correct for this effect, and it will not impact the effectiveness of our algorithms, but it will require further sensor characterization. Regardless, the gain and bias calibration algorithm is clearly effective in making results between sensors repeatable.

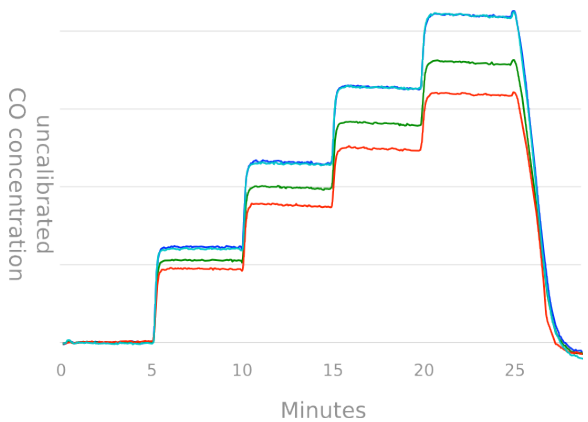

Figure 14: The same sensor readings after bias auto-calibration.

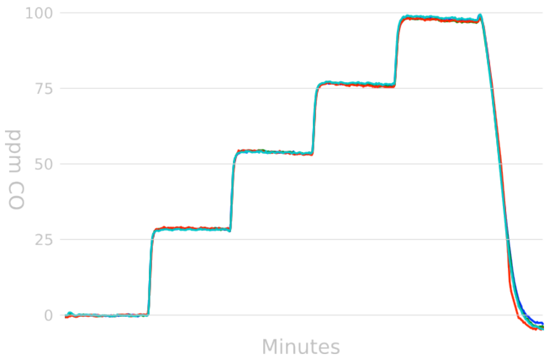

Figure 15: The same sensor readings after both bias and gain auto-calibration.

Of course, one of the important features of our algorithm is to allow for automatic calibration even when sensors are not exactly co-located. Figure 16 shows a simple experiment in which a function is sampled by two different sensors that are never co-located. The algorithm is able to infer their bias with reasonable accuracy, even with the signal to noise ratio is relatively low.

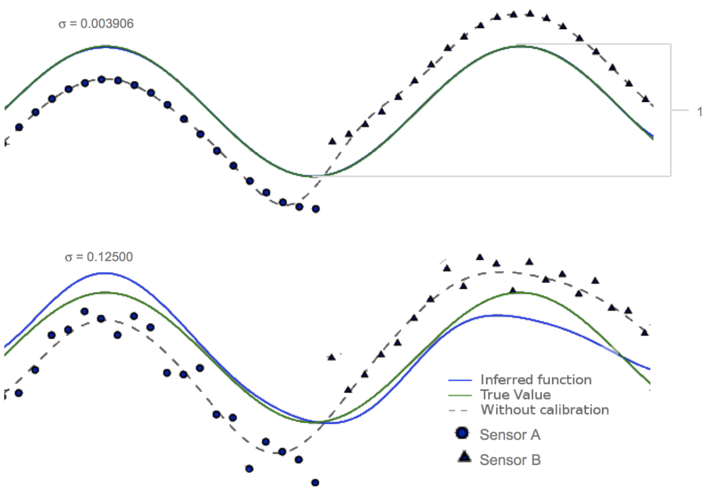

Figure 16: A simple simulation in which a function is sample by two biased sensors, under low and moderately high noise conditions. Even with moderate noise, our algorithms can infer the bias of both sensors with reasonable accuracy.

Our next step will be to do field trials to determine how much proximity is necessary in order to infer calibration.

7 Increasing Precision

Once we have calibrated our sensors, then we can exploit dense sampling by averaging. Gaussian process regression does this naturally. The diagonal of the estimated covariance function gives the variance of our estimate at each location. We can use the square root of this variance as our estimate of precision at that location. The rest of this section deals with our empirical and simulated validation of this principle, using our test chamber and electrochemical sensors.

7.1 Empirical Results

As the density of sensors at a given location increases, we can increase the precision of our system by super-sampling, and averaging. For sensors with Gaussian noise (which our CO sensors exhibit) sampling in the same location, we expect the variance of the signal to be C/n if we average the signals from n sensors with noise variance C. Note that when the noise is not Gaussian, the noise power will still decrease, but at a slower rate.

In Figure 17 we see an experiment with six sensors in a chamber in which we can control the concentration of CO. In this case, we stepped the concentration of CO by 0.2ppm increments over an hour, and observed the response of the sensors. The light dots show the response of one sensor, and the dark dots show the averaged response of six sensors. Clearly the noise variance has decreased.

Figure 18 show the variance of the signal versus the number of sensors averaged. The empirical results match the theoretical results closely!

7.2 Non-colocated Sensors

Using Gaussian process regression (GPR), we can also increase the precision of the system even when samples are not in the same location in space-time (a more realistic situation). The closer the samples are to one another, the greater the increase in the precision.

We should note that GPR is appropriate not only because the sensor noise is Gaussian, but also because the process by which concentrations of gas mix and vary is also often modeled as Gaussian [10]. Modeled this way, we have the sum of two Gaussians, which is itself a Gaussian.

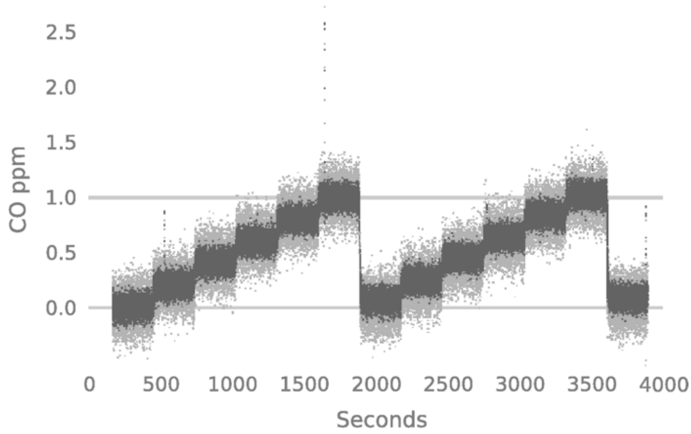

Figure 17: The signal from one sensor (light dots) and the average from six sensors (dark dots). Clearly averaging has decreased the noise power.

7.3 Gaussian Process Learning Curves

The amount that the precision of the system increases depends on the density of sampling. As the density of sampling increases, so does the precision.

To quantify this increase in precision for a given algorithm, it is typical to consider the ``learning curve'' of the algorithm. The learning curve shows the deviation of the true values of samples from the inferred function as the number of training examples increases for a given area. Sollich provides some reasonably tight analytical bounds on the learning curves for GPR [11]. In the future we will present an analysis of the learning curves under various model assumptions.

In Figure 19, we see simulation results in which the variance of the signal at a point decreases when nearby sensor's readings are also taken into account. In this simulation, we use a standard radial basis kernel, and the sensors are uniformly distributed within twice the scale of the kernel. This means that many of the points will be relatively far away from the point of interest, and will not contribute significantly to reducing the variance. Nonetheless, we can see that as the density near the point of interest increases, the variance decreases.

8 Inferring Activity

An important way in which we can add value and better understand the data we collect with sensor phones is by labeling the samples from sensor according to the activities and context in which the user takes the samples. By tagging samples as having been taken indoors or out-of-doors, while walking, running, riding a bike or driving, etc., we can answer questions about peoples exposure to pollution during these various activities and contexts. These labels will also assist in determining, for example, if a sample should be included in a map of outdoor air pollution.

There exists a large body of research on techniques and applications of mobile context and activity inference. Many researchers have examined utilizing accelerometers positioned in various locations on the body [12], and using a wide variety of inference algorithms [13, 14]. Studies have also focused on integrating data from other sensors such as audio and barymetric pressure [15], or location [16] to reduce the inference algorithm's reliance on sampling acceleration from multiple points on the body in order to give high precision, recall and accuracy. Accuracy rates are now typically reported at above 90%.

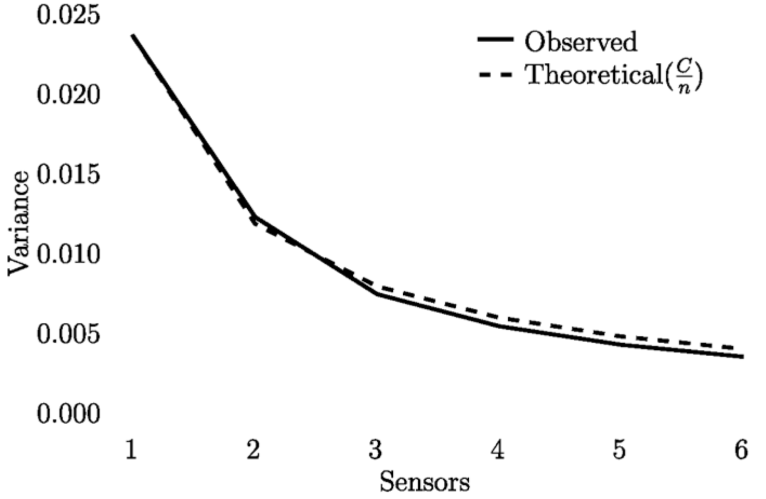

Figure 18: The noise power decreases as more sensors are averaged together, closely matching the theoretical prediction.

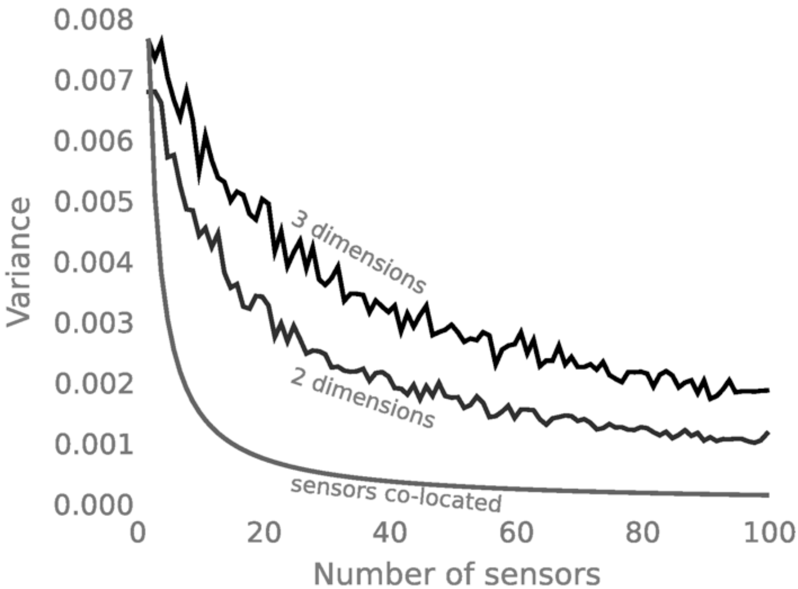

Figure 19: Simulated learning curves for two and three dimensional Gaussian processes as the density of sensors in an area increases.

As mobile phones have increasingly integrated accelerometers and other sensors, the focus of activity inference research has shifted towards inferring activity and context using phones or phone-like devices [15-18]. Transportation mode inference, in which an algorithm typically distinguishes between some subset of walking, biking [17-19], running, riding a bus, and driving, has become a common focus. Fortunately, these modalities are relatively easy to distinguish between, using acceleration data augmented with other sensor date, particularly location.

Energy consumption during activity inference is an important consideration, since some algorithms require high frequency sampling in order to be effective. Sohn et. al. examined using changes in GSM radio finger-prints to determine velocity, rather than energy-intensive GPS signal-tracking. Energy was the explicit focus for Wang et. al. [20], who found that by turning off sensors when they are not needed for a particular inference, they could extend the operating time of a Nokia N95 by up to almost 3 times versus leaving the inference sensors operating all of the time without sacrificing inference quality.

Finally, we should note that there are already many applications deployed that take advantage of activity and context inference in one respect or another. The Personal Environmental Impact Report uses location traces and transportation mode inference to give the user a report about the impact of their transportation choices [21]. Several health-monitoring applications use transportation mode as proxy for the level of activity of the user. For example, Ambulation helps monitor the activity level of elderly and disabled people [22], and UbiFit Garden is a persuasive application that encourages people to monitor and improve their activity level [23]. Finally, SenSay is one example of an application that tries to adjust settings like ringer volume on the phone based on the inferred context of the user.

The quantity of studies, application and research in the area of activity inference, along with the generally high accuracy of activity inference algorithms suggests that we can reasonably expect to label sensor readings with the users' activities.

9 Security and Privacy

Obviously, if we are asking users to submit data to the cloud for analysis, we need to ensure that users' data will not be used in an unauthorized or undesirable way. If users do not have confidence that their data will be used appropriately, they will not submit it. This is particularly true because we are asking them to submit location information: misuse or mishandling of location information can result in severe political, criminal and social consequences for users. For example, a government might arrest or otherwise intimidate everyone who was at a opposition political rally or protest, based on their location histories. Kapadia, Kotz and Triandopoulos provide a good overview of privacy issues in opportunistic sensing systems [24].

Besides the appropriate use of encryption and other standard information security practices, the dominant mechanism for ensuring privacy of users who publicly reveal information about themselves is called k-anonymity. k-anonymity is a mechanism for ensuring that at least k other individuals have the same publicly available identifiers [25]. The original work focuses on identifiers such as birthdate, gender and zip-code, but it has been extended to location histories as well by many researchers [26].

The concept of k-anonymity is both important for plausible-deniability, in which a person can plausibly claim that a location history does not belong to them, and also for foiling tracking attempts.

The k-anonymity mechanism has been extended in various ways in order to provide a more practical privacy mechanism. Xu and Cai propose a mechanism for setting k to a level that corresponds to the amount of anonymity a person requires by having them chooses locations in which they would feel sufficiently anonymous, and then inferring k based on density of people in those locations.

Hoh, et. al. use "virtual trip lines," in which traversals across pre-determined, non-sensitive locations are reported in lieu of location traces, for privacy enhanced traffic flow monitoring. This mechanism also allows the traversals to be aggregated semi-anonymously before reporting to ensure that at least k traversals are reported from the same location simultaneously, providing k-anonymity. The authors also increase privacy by distributing the aggregation process across two servers which would force attackers to compromise multiple systems in order to access sensitive information [27].

Although traffic flow is a linear process, whereas mobile sensing deals with unconstrained movement, the virtual trip line concept could be extended to regions of interest, where the aggregating servers would be informed when a device entered that region of interest.

Another important privacy protecting sensing system is AnonySense [28]. AnonySense provides an architecture for implementing privacy aware collaborative sensing applications, focused on real-time collaboration. AnonySense also uses k-anonymity as one of its privacy preserving techniques. AnonySense provides an interesting mechanism by which sensing tasks, which can require various levels of identification from the sensor, can be submitted to the mobile device. The mobile agent then chooses whether to accept the task or not, based on its own privacy requirements.

Researchers have made significant progress towards ensuring privacy of data by providing a degree of intrinsic anonymity in the way that location information is transmitted and aggregated, these mechanism all rely on a degree of trust in the infrastructure. Homomorphic encryption schemes allow un-trusted entities to perform arithmetic operations on encrypted data without access to the unencrypted data. Thus the data can be aggregated by un-trusted entities before the aggregate values are decrypted by a trusted entity, and can be made resilient to collusion by a subset smaller than a quorum. Cramer and Damgård provide a good overview [29]. These mechanism have been proposed for resource constrainted wireless sensor networks, and would be directly applicable [30]. This brings an additional degree of security to the data collection system.

10 Energy

When optimizing a system for energy consumption, we can either decrease the power used by the system, decrease the time that the system uses power, or both. The three-watt limit on power dissipation by a phone chassis not withstanding, instantaneous power is not a central issue for sensing in mobile devices, since sensors that could reasonably be integrated into a phone typically require orders of magnitude less power to operate. Nonetheless, if a sensor's power draw is reasonably high, then it needs to be operated very briefly in order to remain within an acceptable energy budget.

Sensors such as the metal oxide sensors mentioned in Section 4.3 fall into this latter category: since metal oxide sensors require a high power heater to operate, the heater should be pulsed just briefly enough for the temperature on the surface of the sensor to reach its operating temperature. Even at 70 mW, a 500 ms pulse would use about 2.6uAh, or 3.8mAh per day if we sample once per minute, 24 hours per day. Since batteries on phones typically have a capacity of 800-2000mAh, sampling the metal oxide sensor at a reasonably aggressive duty cycle would reduce the operating time by about 0.5%, or about 1.2 minutes for a phone with 4 hours of talk time. Of course, if we were smart about when we sampled, we would reduce that even further.

So reducing sample acquisition time is a key component of realistic energy consumption. One problematic sensor is the GPS. For a GPS to determine its position, it must sample the radio frequency at which the GPS satellites transmit (quick and low power), and then perform a search over a large parameter-space to lock onto the satellite signals (slow and high power). In order to sample quickly and reduce energy requirements for localization, the GPS can simply record the signal it receives from the GPS satellites, possibly pre-process them minimally, store them, and upload the recorded signal with the data samples. These data can then be processed in the cloud, and samples can be localized at minimal energy cost on the phone [31].

Of course, there is an energy cost to transmitting raw signal data as opposed to concise position information, so we must be careful to transmit those data at an appropriate time. For example, GPS signal data, or any other sensor data that is not time critical, can be stored until the phone is plugged into a charger, at which time, transmission energy is "free." If we have the flexibility to time shift in this way, then we can save significant energy. We believe that pollution data will generally not be time critical, and therefore can be uploaded at the energy-optimal time.

Another obvious, but important and practically difficult energy optimization is to actually turn off the sensing and support mechanisms when they are not being used. With multiple sensors sampling at different intervals, duty cycling the sensors and supporting hardware can become complicated. Wang et. al present a framework for managing that complexity, and report significant energy savings over both leaving sensors on continuously, and also over less careful control over sensor activity [20].

Finally we should note that for pollution sensing in particular, we will most likely need an active sampling mechanism. In order to ensure that the sensors in the phone quick get exposed to the atmosphere, we will probably need an air pump or another mechanism to create air flow around the sensor. Again, we will need to duty cycle the sampling mechanism to avoid significant energy consumption.

11 Conclusions and Future Work

In this chapter, we have explored some of the key challenges to building a societal scale scientific instrument by integrating sensors into mobile phones. There are many stakeholders and potential users, and a long list of challenges that need to be addressed before environmental sensing becomes a ubiquitous reality. In the context of these challenges, we have discussed our own approach to them, or highlighted others' important work towards solutions.

Clearly there remains a great deal to be done before we will be ready to deploy a large scale system. On the other hand, many of the individual components of a societal scale sensing instrument have been built: its just a matter to pick the right ones and putting them together. Much of the work we and others have done can be used and adapted today to build small to medium scale sensing systems, in the real world.

The next step for ourselves and others will be movement towards larger, real-world implementations, for which the data are actively serving real stakeholders. Although we can continue to refine and test algorithms and system designs using experimental implementations, we also need access to large mobile sensing data sets to understand how scale will affect our systems. As sensing and mobile processing continue to become less and less expensive, more integrated, and more ubiquitous, we hope that small, and eventually large scale sensing projects will increasingly be within reach of scientists in the less industrialized world, and that that accessibility will help bootstrap a truly societal scale network.

Acknowledgements

Thank you to Igor Paprotny for the MEMS images, Virginia Teige and the Cohen Group for sharing their photos (and their lab!), and Paul Aoki and Allison Woodruff, and the rest of Intel's CommonSense team (of which the author is a part), for sharing their time, effort, data and equipment.

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Data Gathering with Mobile Phones

Sanna Eskelinen
Nokia, Finland

1 Mobile Solution Speeds up Collection of Vital Data

Organizations engaged in fundamentally different activities share the same need for accurate and timely field data. Whether it is about efforts to monitor and fight outbreaks of malaria and dengue, track the stock levels of agricultural produce, improve people's access to water or conserve endangered species a significant amount of data need to be collected, analyzed and acted upon.

2 Benefits of Mobile Data Gathering

The use of mobile phones for data gathering is proliferating around the world. Especially in the emerging markets where availability and accuracy of data can be poor mobile data gathering has proved to solve many challenges with delays, costs and inaccuracy.

Speed. The primary benefit of mobile data gathering solutions is the speed at which information can be gathering from the field and analyzed. Mobile phones have the ability to transmit and time-critical data quickly; when ever within the coverage area of a mobile network.

By contrast, paper forms are usually collected and transported to a separate office location for manual data entry by another member of the organization. Transportation is rarely seamless, particularly in more remote areas. Delays often occur before and during transportation as well as afterwards, when the information awaits manual entry to the IT system.

Data accuracy. With data collected on mobile phones, the information only needs to be entered once removing the need for interpretation of hand-written data and potential mistyping of information when transferring information from paper to a computer system.

Reduced cost. The cost efficiency of a mobile based data gathering solution comes through many sources: reduced transportation, removal of duplication of work and error correction to mention few. There is also a cost of inaction – as time passes the decision-making environment changes and can result in organizations having to take a less favorable course of action. In the case of a disease outbreak or crop infestation, for example, delays can lead to significant human as well as financial costs.

Reduced environmental impact. Mobile data gathering minimizes the frequency and need for heavy load transportation and carrying papers in and out - especially at remote locations.

Usability. Mobile phones as a data collection tools offer convenience through their usability (mobile phone can easily be used while standing or on the move), size (easy to carry and keep safe), weight and battery longevity (especially important in the regions with lack of electricity). They offer also additional possibilities for example GPS location data and imaging. Additionally, since mobile phones can send data from many remote locations, collected data can be transmitted in near real-time for analysis.

3 Nokia Data Gathering History

Nokia Data Gathering program was born in early 2007 in response to inquiries from public, private and non-governmental organizations about the development of technological solutions which could be used on a global scale and which focused on the rapid and accurate collection of data from field research. This data could then be used by an organization for analysis and decision making.

Alternatives	Benefits	Disadvantages
Mobile phones	• **Fastest data transfer from remote locations** • GPS location data for each response • Greater data accuracy and security • No duplicated work • Lower transportation costs • Suitable for mobile use (standing/on-the-move) • Long battery life • Light, easy to carry • Easier to protect from theft and the weather • Need to invest only in one device	• Up-front investment • Technical training required
Laptops	• Faster data transfer than paper forms • No duplicated work • Improved data security • Portable	• Slower data transfer than mobile phones • Up-front investment • Heavy • Short battery life • Ill-suited to mobile use (standing/on-the-move) • Requires personnel to carry multiple devices • Difficult to protect from theft and the elements • Technical training required
Paper forms	• Low up-front investment • Easy questionnaire creation • Easy to use	• Slow • Transcription errors • Duplicated data entry • Transportation costs • Higher operating costs • Lack of data security • Risk of total data loss

Figure 1: Comparison of different data collection methods

After initial research the Community Involvement team at Nokia Institute of Technology in Manaus developed Nokia Data Gathering, a mobile system to improve the efficiency and accuracy of data collection in the field. The first project on Nokia Data Gathering was implemented in the Amazonas together with

Amazonas State Health Department (SUSAM) and the Health Vigilance Foundation to fight back dengue fever.

Since the first project, Nokia Data Gathering has been implemented around the world in different sectors. Since August 2010 the software has been offered as open source version to allow many more organizations to use it and modify it for their own specific needs.

4 Nokia Data Gathering Solution Overview

Nokia Data Gathering is a solution that helps organizations to collect field data on critical issues using mobile phones instead of paper forms, PDAs or laptops. Since mobile phones can send data from many remote locations, collected data can be transmitted in near real-time for analysis.

Nokia Data Gathering consists of two modules, server and mobile phone, to enable smooth information transfer from the survey administrators to the field workforce and vice versa.

Server: The Server Module is used to create and send surveys to mobile phones, receive interview results, administer users, devices, questionnaires and responses, map data using GPS-based data, and export data. The server can receive interview results in near real-time, provided the field personnel are within range of a mobile voice or mobile data network. Additionally, the server can be connected to a GSM modem to send messages and receive responses from the mobile phones of the field personnel.

Mobile Phone application: The Mobile Phone Module is the only part of the system that is visible to the field personnel. It is the software that appears on their mobile phone, presented as an easy-to-fill questionnaire.

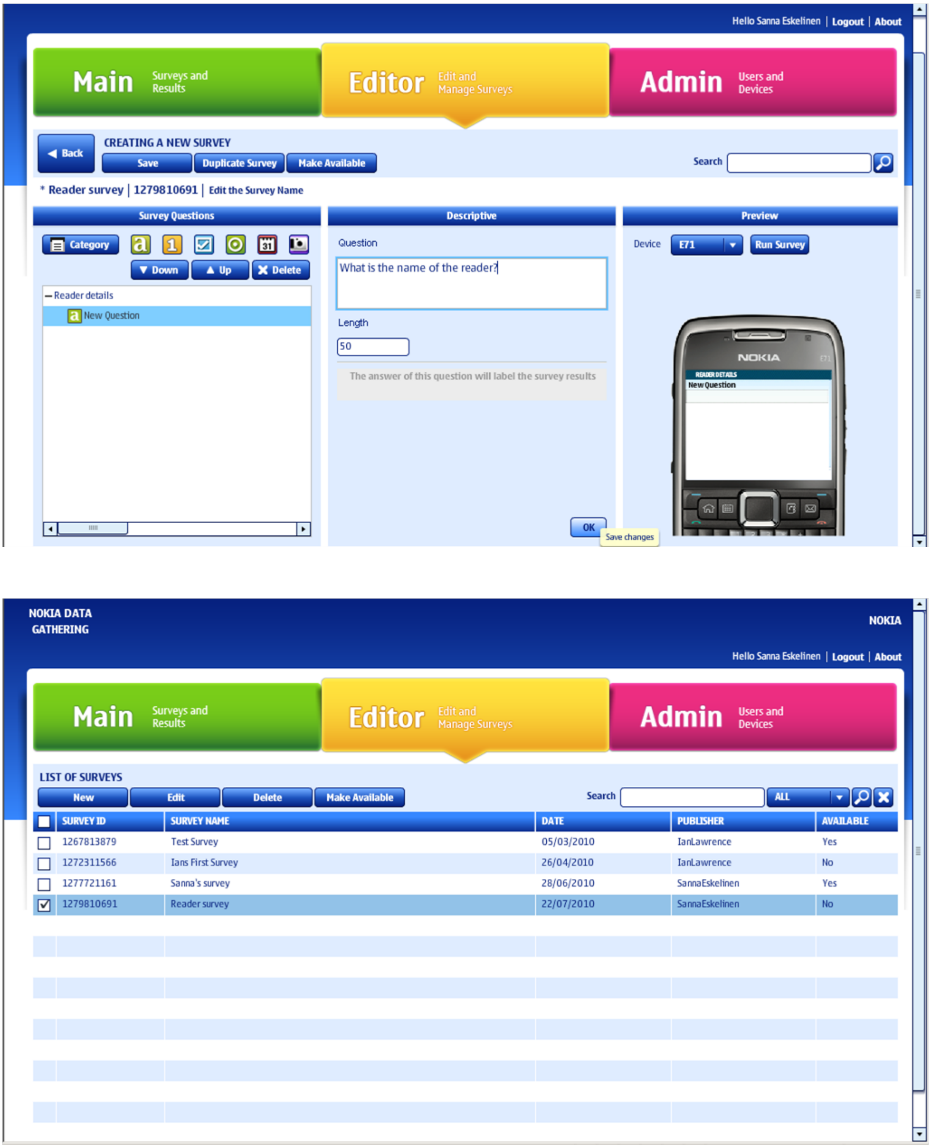

Figure 2: Example screens from Nokia Data Gathering server

Figure 3: Examples of Nokia Data Gathering mobile phone application

The process with Nokia Data Gathering begins with survey creation, which enables the production of tailored questionnaires. The questionnaires can then delivered to the field workforce wirelessly using a normal mobile telecommunications network. Having received the questionnaire(s) on their mobile phones, the field workforce can then use their phones to enter and store the responses to questions. The system also allows to geo-tag data with GPS location information, providing an additional layer of information and helping to validate data. Once the information is collected, solution enables them to send responses back for instant analysis, again via a mobile network.

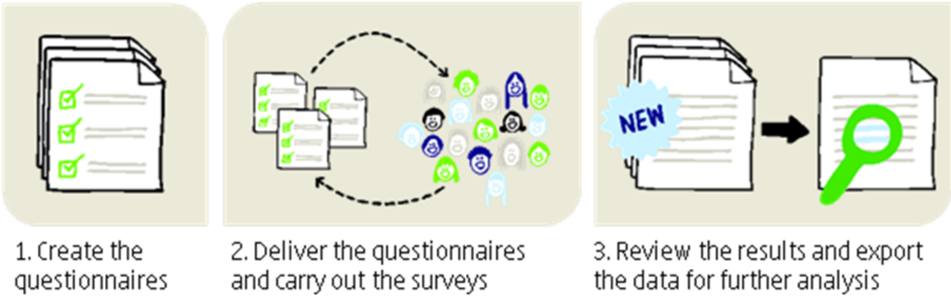

Figure 4: Nokia Data Gathering process

Compared to many other mobile based data collection tools, Nokia Data Gathering offers high usability (easy to use Java-based client), complete end-to-end system (including mobile and server modules allowing organizations to host their own server and have security in the knowledge that the data collected by them will remain in-house) and ability to map the results.

5 Nokia Data Gathering Projects

Since 2007 Nokia Data Gathering has been implemented around the world to helping to prevent disease outbreaks, building a mobile birth registration, tracking agricultural stock levels and more. When time is of the essence, it doesn't matter whether it is a public service or commercial operation; fast, accurate information is important for sound decision-making in every organization.

5.1 Fighting Back Dengue Fever in the Amazonas - Amazonas State Health Department and Health Vigilance Foundation

Every year hundreds of people die of dengue fever in Brazil. The disease is transmitted through mosquito bites and outbreaks spread quickly with devastating effects. Amazonas State Health Department (SUSAM) and the Health Vigilance Foundation (FVS) leverage Nokia Data Gathering to help fight the spread of this disease and increase the effectiveness of treatment.

During 2008, 3522 cases of the dengue were registered in Manaus. With the help of Nokia Data Gathering, during 2009 the number of cases was reduced dramatically to 245. That is 93% cut in the number of the cases! Nokia Data Gathering helped the health workers to do their jobs. It cut the steps in the process, made the process faster, and more accurate.

"The Secretaria de Saúde do Amazonas has a series of programs dealing with endemic diseases in the region, and Nokia's technology will help us to more rapidly identify and investigate the results and symptoms of the surveyed population. The transmission of immediately after the interviews improves agility, increases public safety and avoids manual filling-in of forms which is usually a difficult and time-consuming process". Agnaldo Costa, State Health Secretary of Amazonas State.

5.2 Improving the Care for Sponsored Children in Indonesia –World Vision Indonesia

Collecting information from tens of thousands of sponsored children on a regular basis is very labor and cost-intensive, yet crucial for both the donors and children themselves. With accurate and up-to-date information, immediate issues that might keep the children from being safe, healthy and going to school can be addressed quickly. Timely and accurate reports also lead to increased quality of service towards the donors, thus encouraging further funding.

Nokia Data Gathering will simplify the data collection process and reduce manual steps. This will lead to up to 48% savings on the time spent on and reduce operational costs of the data collection by 39%. Savings derived can potentially sponsor more than 16,000 children when Nokia Data Gathering is fully deployed across Indonesia. Efficiency improvement on data collection allows more efforts and time to be spent on activities that have direct and positive impact on the children.

"I'm excited with the new tool and perceive Nokia Data Gathering as a positive program that can speed up the process of taking the child's data at field level (Child Management Standard) and shorten the admin work in ADP (Area Development Program) office". World Vision Indonesia Field Officer in Pontianak, West Kalimantan, Indonesia.

5.3 Following up the Crop Production in the Philippines –Department of the Agriculture and WWF

Getting timely, relevant and error-free data from the field to the regional and central offices plays a crucial role in following up the crop production and ensuring sufficient levels of stock.

Department of Agriculture together with WWF have started tracking stock levels and market prices of agricultural produce using Nokia Data Gathering. Additionally damages caused by El Niño and other natural disasters are being monitored. Nokia Data Gathering has substantially shortened the cycle for requested field information enabling faster and more accurate decisions benefitting the agriculture producers nationwide.

"The Nokia Data Gathering solution will augment and eventually replace our data-gathering systems so we can concentrate on crafting programs and solutions to further boost farm yields despite the erratic weather patterns". Bernie Fondevilla, The Department of Agriculture Secretary.

References

For further reading, please visit:

http://www.nokia.com/datagathering

https://projects.forum.nokia.com/ndg

Cell Phone Spectroscopy in the Classroom

Alexander Scheeline and Kathleen Kelley
University of Illinois
at Urbana-Champaign (USA)

1 Introduction

Spectrophotometry is covered in every introductory text on quantitative analysis or instrumental analysis. Beer's Law can be quoted by nearly every student who has taken chemistry in the last half century. Yet it is our experience that students have only a weak understanding of the relationship between light intensity, transmittance, and absorbance, that they report absurd numbers of significant figures, and that they fail to grasp topics such as stray light, noise, dynamic range, linearity, saturation, and order overlap. Until recently, having students dissect photometric instrumentation was prohibitively time consuming and expensive. In the days of photographic photometry, film calibration and quantification of emission (let alone absorption) took endless hours of experimentation, dark room work, densitometry, and interpretation.

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For greater technical detail, see a successor publication: A. Scheeline, "Focal Point: Teaching, Learning, and Using Spectroscopy with Commercial, Off-the-Shelf Technology," Appl. Spectrosc., 64(9), 256A-268A (2010).
More info here: http://www.asdlib.org/onlineArticles/elabware/Scheeline_Kelly_Spectrophotometer/index.html

Photomultiplier tubes were delicate, required high voltage power supplies, and could only measure one wavelength at a time. Although semiconductor photodiodes were not so delicate and required only low voltage power, they required a current-to-voltage converting amplifier and readout electronics, and were difficult for students to understand. In recent years, diode array or CCD array spectrometers have provided full spectral coverage, but all of the optics and electronics are buried behind a computer screen. Student interaction with the measurement was reduced to a press of a (virtual) button, and the instrumentation for everything from computer-controlled chromatographs to cybernetic potentiostats became indistinguishable from a parametrically-intensive computer game. Direct sensing of measured quantities has effectively ceased.

Sometime during 2008, it occurred to the authors that cell phone cameras had become common among students. *"They're only 8 bit CMOS chips"*, was the initial thought. *"The signal-to-noise ratio will be terrible. Dark current is likely to be a problem. No one in their right mind would use such a poor detector for doing quality spectrophotometry".* In November, 2008, the authors had a double-take. If all these measurement problems were so blatant, wouldn't that make the concepts behind the problems easier to sense and learn than if one used a high quality detector and system? The result is reported in this chapter: an inexpensive array detector spectrometer useful for teaching the basics of visible absorption spectrophotometry and the concepts general to spectroscopy at all wavelengths. The students supply the detector, while the instructor provides all other parts, costing no more than $3 per group (2009 prices). After watching individuals, pairs, and triples of students use the parts, the authors believe that a team size of 3 is optimal, being big enough to have discussions, but small enough that all students get a turn to influence the engineering. This chapter reports work in progress. Comparative, statistically-validated student evaluation has not yet occurred. Bugs continue to appear in the software. And yet, the enthusiasm with which the cell phone spectrometer has been met by nearly everyone who has heard of it suggests that an early "roll-out" of the concept is warranted. As an Open Access/

Creative Commons publication, the authors solicits participation by the community in implementation, debugging, and evaluation of this pedagogical instrument.

The use of cameras in cellular telephones for optical spectroscopy has been previously patented [1].

2 Educational Goals and Methods

If successful, the student will be able to:

• List the components of a spectrophotometer and the order in which light traverses those components;

• Explain what a diffraction grating does, specifically including the concepts of dispersion and diffraction order;

• Explain what stray light is and explain how stray light decreases the quality of spectrophotometric measurement;

• Describe how a quality spectrophotometer would differ from the hand-made device.

The approach taken is, in essence, POGIL [2]. Students are given open-ended guidance as to how they might build the spectrometer. Typically, after a few minutes, the stimuli from the components cue the students as to what may be interesting or productive. To date, no student has reported an accurate, quantitative measurement. Yet, in discussion, it appears that they understand gratings, stray light, and dispersion more clearly than do students who have only heard of or seen pictures of the instrument components.

3 Scientific Background

Any text on analytical chemistry [3-6] covers the basics of absorption and fluorescence spectrophotometry. The central relationship is Beer's Law (or, for purists, the Beer- Lambert Law),

$$A = \varepsilon bC = \log_{10} T = -\log_{10} \frac{I}{I_0}$$

Where

A: Absorbance

T: Transmittance

ε: Molar absorptivity, L mol^{-1} cm^{-1}

b: Light path length through specimen, cm

C: Absorber concentration, mol L^{-1}

I: Intensity detected in the presence of sample

I_0: Intensity detected absent sample but with solvent present

Greater detail is contained in a vast literature, including discussion of spectrometer design [7], detectors [8], and measurement non-idealities [9-10]. A review of spectrometer instrument design is thus omitted here, though simplified discussions do appear in the "High School Teacher Module" and "Student Module" available at the link given at the beginning of this chapter. Critical ideas include how diffraction gratings function:

$$n\lambda = d(\sin\alpha - \sin\beta)$$

with

n: diffraction order (integer)

λ: wavelength (nm)

d: grating groove space (nm)

α: incidence angle of light on grating, measured counter-clockwise from grating normal

β: exit angle of observed, constructively-interfering light, measured counter-clockwise from grating normal

Low-granularity optical detectors (8-10 bit intensity digitization per pixel or channel) for chemical analysis have previously been employed [11-21]. Accepted practice is that charge-coupled arrays are employed for low-light-level applications (fluorescence, Raman, atomic emission), while diode arrays are used for absorbance measurements (including commercial instruments by Agilent, Ocean Optics, Stellarnet, and others). In the limiting case that readout granularity is the limiting noise source, the signal-to-noise ratio for concentration measurement is given by:

$$\frac{C}{\delta C} = \frac{-I_0 T \ln T}{\delta I (1 + T^2)^{1/2}}$$

For an 8 bit digitizer, $I_0/\delta I = 255$ or less. A plot appears in Figure 1.

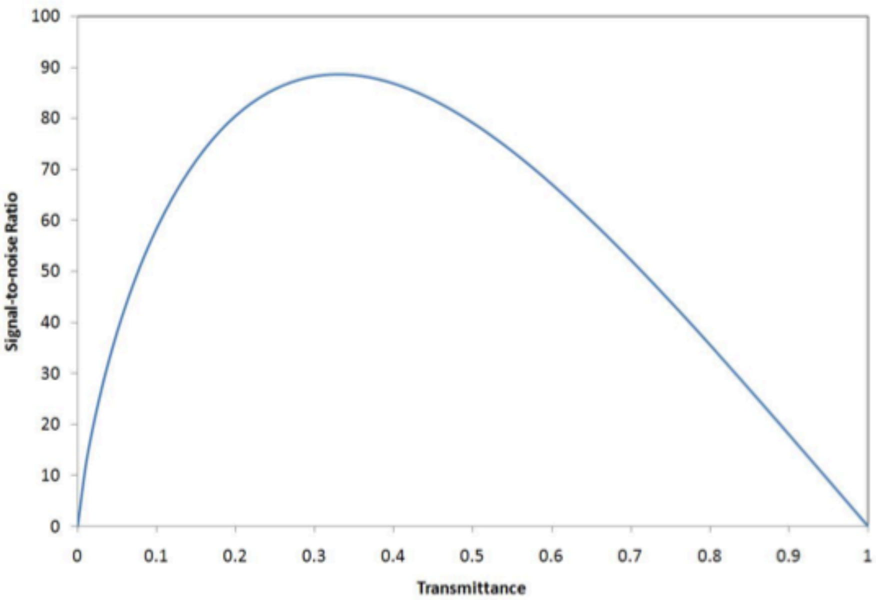

Figure 1: Signal-to-noise Ratio for an 8 Bit Digitized Photosignal. Assumptions include: I_0 is full-scale exactly, at A=∞, I = 0 (no stray light), and intensity is high enough and stable enough that no noise source other than digitizer resolution contributes to measurement uncertainty.

What is not obvious is that instrument alignment, actual use of digitizer range, and positional stability of the detector all overwhelm the influence of digitizer resolution for the open geometry employed here. One may thus ignore all the usual theory and mathematics prior to having students build instruments; they will discover measurement flaws without the burden of algebra in advance.

4 Components

Any camera that outputs a 24 bit JPEG file is adequate as a detector. Let the students bring whatever they have to lab. Their familiarity with their own cameras and cell phones obviates the need for instructors to document anything about the detectors, or even to know how to use them. When, in prior practice, has it been feasible to use instruments where the students were presumed to be technically more proficient than the instructors?

Every spectrometer needs a baseplate. A PDF file of a simple design is available at the link given at the beginning of this chapter. What it lacks in rigidity and sophistication is made up for by low cost. Any photocopier or printer can provide adequate replicas. Using heavy paper or thin cardstock has a slight advantage. The original drawing was made in Autocad 2004, and is linked at the beginning of this chapter.

The light source is a blue-LED-pumped fluorescent light source, dubbed a white LED (not to be confused with LEDs that are three independent emitters, one red, one green, and one blue). We have used an RL-5-W5020 device [22]. The output divergence angle, ±9°, is narrow enough to provide high intensity, while being narrow enough to confine most light to the area of the grating. Approximate output as claimed by the vendor is replotted in Figure 2. Output power is specified for a current of 20 mA which requires a drive voltage of 3.8 V. For simplicity, we instead use a CR2032 3V battery, commonly employed in remote keyless entry transmitters. The LED/battery combination results in a current of barely 2 mA, so output is only about 1/10 of the full power rating (see Figure 3).

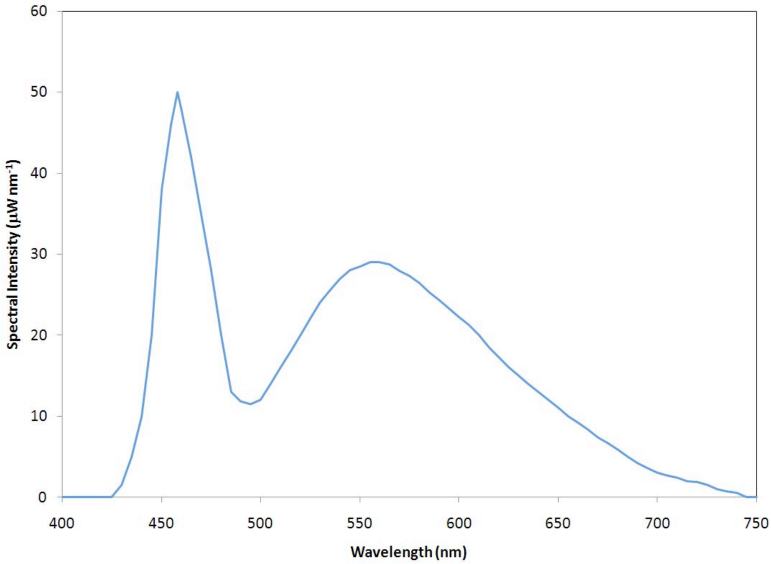

Figure 2: LED Emission Spectrum for 20 mA drive current. (replotted from Superbright LED website)

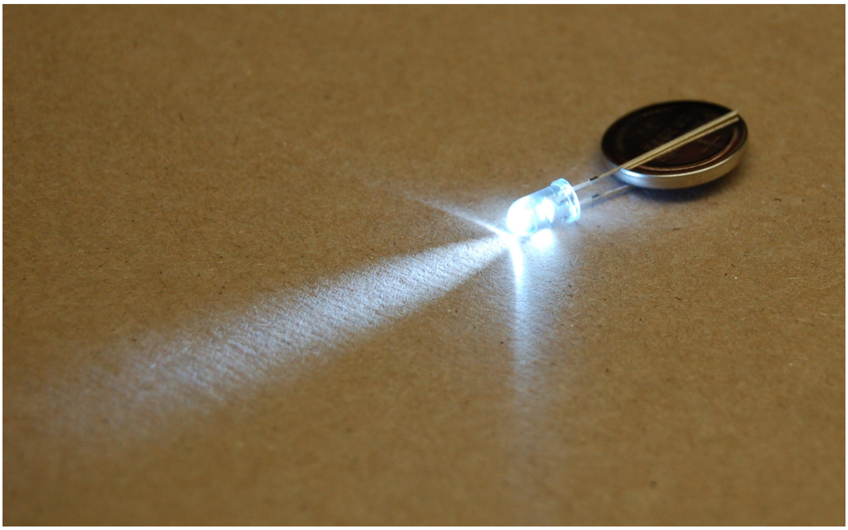

Figure 3: LED and Battery. LED diameter is 5 mm.

Plastic 1 cm square, 3.5 mL cuvettes are entirely adequate; they are opaque below 300 nm, but the light source only emits above

425 nm. Commonly available from most lab supply houses, 100 unit quantities are available at approximately $0.15 each.

Finally, one must obtain transmission diffraction gratings. Edmund Scientific Optics [23] is a convenient reseller. Edmund's stock number NT54-512 is a 500 line/mm grating available for $0.78 each in quantities of 80. An important reason that the spectrometer design and software are being shared through a Creative Commons license is in the hope that without the possibility of license fees or aggregator's markup, costs will remain low, allowing wide use. The assembled spectrometer (sans detector) is shown in Figure 4.

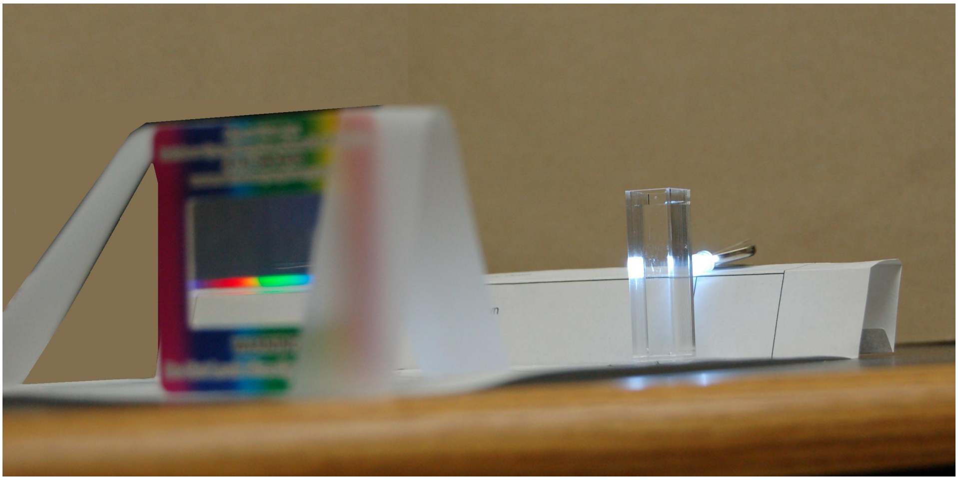

Figure 4: Assembled Spectrometer. LED, perched 1" above desk, shines through cuvette, aimed directly at grating, which in turn is braced with transparent tape. Spectrum and LED glare are unretouched (laboratory background removed for clarity).

5 Software

Cameras typically output JPEG files. Spectral measurement thus proceeds most easily if software can directly import such files, extract spectra, and manipulate the spectra into intensity, transmittance, and absorbance data. Data export to other software, such as spreadsheets, is also critical, as students will want to adjust for stray light or saturation once they realize the problems exist. One could, of course, use commercial graphics software to pre-process the images and commercial mathematical packages such as Matlab or Mathematica to do the manipulations, but this would subvert one of the goals, making data manipulation accessible to all students. We have thus made available both the source code and executable file for software to carry out the necessary processing. CodeGear RadStudio Delphi 2007 was employed, using IOComp's ixyPlot and related components. A version of the software that will run in a web browser (Java code) is being planned. It is obvious that a native cell phone application would be highly desirable. It is likely that a reader of this chapter can write such an application sooner than the current authors can! An impediment to native cell phone coding is the range of common operating systems (Windows CE Mobile, Symbian, Palm, Google/Android, iPhone/Linux, RIM/Blackberry, ...).

The software loads reference and sample spectra (I_0 and I respectively) from a directory of the user's choice; picture preview is not available inside the program, so the Windows "Thumbnail" function in Windows Explorer is helpful for selecting data. If files are too big to conveniently navigate in the image displays, Windows Paint is entirely adequate for making smaller JPG files, either by cutting out the desired data and making a new, smaller inset file or by "stretching" the file to some smaller footprint. Resolution must suffer from compression, but since we have not yet characterized system resolution we do not yet have data on this aspect of performance. If some user has a mercury penlamp or other line source, students could easily "play with" the parametric dependence of dispersion, resolution, and throughput. In any event, once spectra are loaded, one can use either typed-in pixel coordinates or a point and click mouse interface to tell the software where the useful spectral data appear, how many pixels high the integration area should be, and the range of wavelengths putatively covered by the extracted spectrum. Once the desired area is defined, plots of I, I_0, both on the same axes, T, and A can be rendered. Because one must assume that no two frames are taken with the same hand-held camera orientation, an algorithm to linearly interpolate $I(\lambda)$ applicable to the wavelengths of $I_0(\lambda)$ is included in the transmittance computations. Comma-delimited lists of all extracted and computed data are available once any have been plotted. One can then transfer the data to a spreadsheet, allowing improved data processing. For example, an average stray light level could be subtracted.

6 Audiences and Initial Experience

The cell phone spectrometer has been used three times as of this writing. First, a group of instrumental analysis students at the Faculty of Chemistry, Hanoi University of Science worked with the components. By fluke, two-dimensional "double axis" diffraction gratings were obtained, giving more complicated visual patterns that could be used easily since the software had no predetermined, assumed diffraction pattern to fit. Second, a group of high school teachers from Illinois were given the components and allowed to explore how a spectrometer so designed might fit into their classrooms. Finally, 26 high school students (mostly seniors, but at least 2 sophomores) in groups of three, attending a summer outreach program at Clark Atlanta University were given the components and some guidance in their use. In all cases, while there was a sequence of questions that could be followed, the students/participants were encouraged to ignore the writeup and proceed until they could obtain reproducible exposures at controlled dispersions so that absorbance experiments could be performed. At that point, "primary color" samples (Kool Aid for the high school teachers, $CuSO_4$ for students) were provided.

In all three cases, the classroom dynamics were the same. After a few minutes of confusion and intense questioning of the instructor, the idea of "playing in the sandbox" to optimize throughput, dispersion, exposure, alignment, stability, and so on "clicked." In place of a frenzied instructor, there was intense student-student interaction, with an occasional, "look at this!" as the photographic spectra started rolling forth. A few students never tried to engage the project for reasons unclear; those who stayed focused for at least 5 minutes generally completed assembly and were able to obtain pedagogically-significant data i.e. data that led them to understand one or more of the ideas previously listed.

For illustrative purposes, here are data obtained by this chapter's authors. A Nikon D50 camera, operating without flash, set for closeup focus, and aimed at the spectrum transmitted by water or 20 µM Methylene Blue, obtained f/4, 1/30 s exposures as shown in Figure 5.

Figure 5: Spectral Data for 20 µM Methylene Blue. Left spectrum: I_0. Right spectrum: I. Insets combined using Windows Paint. Line near the left end of the green part of the spectrum due to dirt on the grating. Note change in yellow part of spectrum due to MB absorption.

A screen grab of the spectra as processed by the software, showing raw intensity data, is in Figure 6. The green line across the spectra shows the region plotted, and the dimmer lines above and below the green central line show the range of pixels summed. Note that near reported wavelengths of 450 nm and 625 nm, the I_0 spectrum can be seen to saturate. Wavelength calibration can be seen to be terrible; methylene blue absorption is centered at 655 nm in a well-calibrated measurement, but turns up here at 590 nm (Figure 7). The reason for non-calibration is clear from the way the wavelength calibration is set; the user simply guesses which pixels correspond to the extreme wavelengths emitted by the LED and detected by the camera, with no knowledge of the red or blue cutoff of the sensor. If this were a "real" measurement, such arbitrariness would be unacceptable. Here, it helps make the case for careful calibration, for showing the effect of the spatial extent of the light source on dispersion and resolution. Saturation at blue wavelengths in both spectra and in red wavelengths for the reference spectrum illustrates dynamic range limitations. Because these spectra were taken in a darkened room, stray light is minimal. In a brightly-lit room as shown in Figure 4, stray light is also obvious.

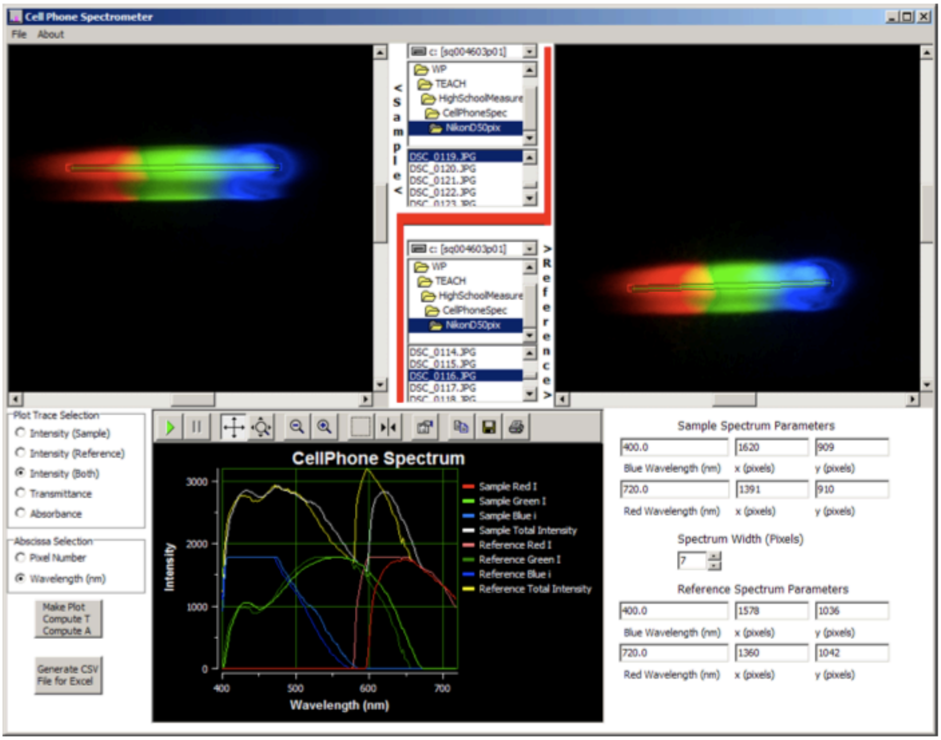

Figure 6: Screen Grab of Raw Intensity Data for 20 µM Methylene Blue.

The artifactual "absorbance" at blue wavelengths (<512 nm on the graph abscissa in Figure 7) makes the students question when Beer's Law fails due to the instrument as well as when chemistry may be involved. Is there a way to distinguish the two? Inexpensive cameras adjust exposure to avoid detector saturation; getting reproducible exposure is easiest when there is much stray light to fool the camera electronics, but of course this generates dynamic range and background subtraction difficulties. Students can explore the noise reduction due to signal averaging by varying the number of rows of pixels average to produce the raw spectrum. The lack of correspondence between I(λ) for any color sensor and the purported output of the LED naturally leads to discussion of quantum efficiency, throughput, and the fraction of generated light that actually reaches the detector. A mercury penlamp could be used to show wavelength range, resolution, and wavelength calibration (warning: such lamps typically produce substantial ultraviolet light; while brief exposure is unlikely to cause sunburn, eye protection is essential). The range of discussion that may come from this instrument is yet to be fully explored; in no case as yet have all students had convenient ways to offload their spectra to their laptops in real time. Emailing spectra to the instructor served as a proxy for full, real-time participation.

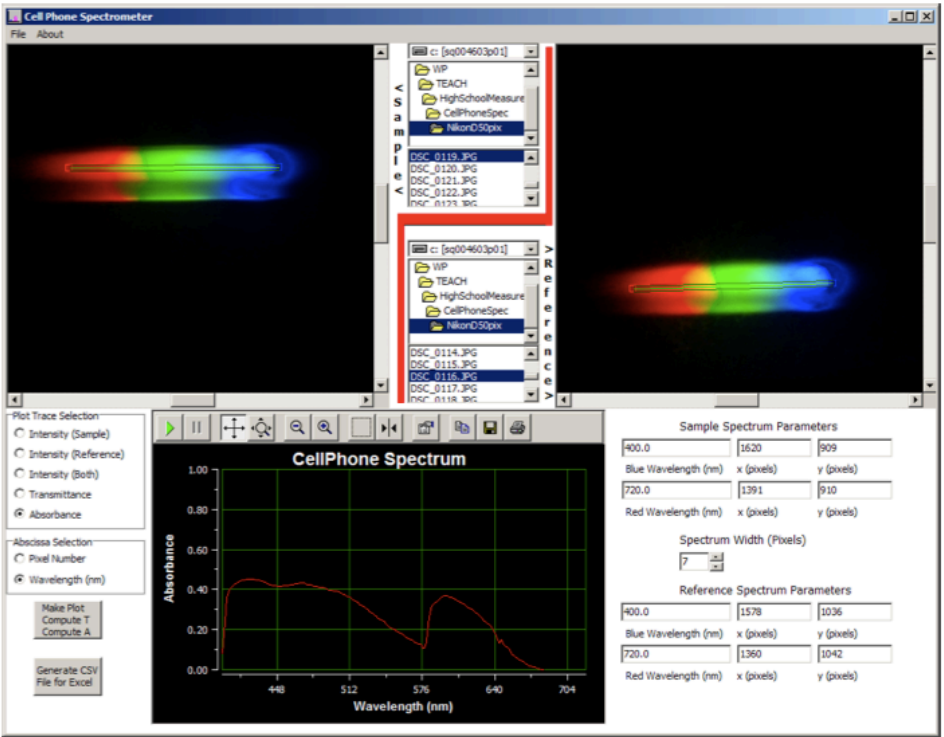

Figure 7: Absorbance Spectrum Corresponding to Figure 6.

7 Conclusion

While there has been no controlled testing of student learning with the home-made spectrometer compared to other approaches, decades of watching students and reading misguided exam answers, when contrasted with discussion during construction and use of the cell phone spectrometer, suggests that this highly visual, intentionally crude approach to teaching about spectroscopic instruments is more effective than any other approach the author has tried.

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“Computing

A Blocks Language for Mobile Phones: App Inventor for Android™

David Wolber
University of San Francisco, USA

1 Introduction

Point your phone at the sky, and Google's Skymap overlays information about the celestial objects in view. It is an example of how mobile technology is helping to bring science out of the classroom and lab and into the real world. The potential for science, and science-related apps, is unlimited.

Google's Skymap was created by expert engineers, as are all apps, as the mobile app frontier is open only to a select group, open only to that .0001% of the world who can program in Objective-C (iPhone) or the Java SDK (Android). Like the web a decade ago, the mobile app world is read-only, a medium where most are consumers, not producers, of information. If you have an idea for an app you needed to be a programmer, or be able to pay one. It's unfortunate that scientists, and artists and domain-experts in all disciplines, cannot manifest their ideas directly.

Fortunately, this closed world is in the midst of being opened to the masses. In July 2010, Google announced App Inventor for Android, an end-user tool for developing apps [1] The New York Times called it “Do-it-yourself App Creation Software” [2]. Salon.com referred to it as a “Hypercard” for the smart-phone [3]. Based on a blocks programming paradigm that had proven successful for kids, App Inventor dramatically lowers the barriers to becoming an app developer.

I taught App Inventor to university students during the 209-2010 school year as part of a Google pilot program for the language. The students, mostly humanities and business students fulfilling their math core requirement, built a variety of apps with App Inventor. They were highly motivated because they could create software for their most beloved device, the phone, and the apps they built could have an impact on the world and their lives personally.

The incredible experience I had with these students leads me to believe that App Inventor will have a major impact on all disciplines and particularly science. You can now take an idea and within a couple of hours turn it into an interactive prototype and even a complete app that interacts with sensors and information sources on the web. This chapter introduces App Inventor, illustrates its features through a sample app development session, then discusses the real-world impact of some of the apps developed by students.

1.1 A Blocks Language for Mobile Phones

App Inventor is a visual, drag-and-drop language for building mobile apps on the Android platform. You design the user interface and components of an app using a web-based graphical user interface (GUI) builder, then specify the app’s behavior by piecing together blocks as if you were working on a puzzle. The tool is free to use and runs in the “cloud” so is accessible from any browser.

The blocks language provides a low-threshold entry to programming. The elimination of most typing dramatically reduces the frustrations beginners have with syntax, the blocks use color and visual cues to help avoid problems, and only some blocks lock into place, further eliminating the possibility of error.

The blocks language paradigm has been proven successful for end-user programming, that is, opening up software development to a much larger pool than just computer scientists. It first gained popularity in the Lego Mindstorms robot programming environment [4]. More recently, the Scratch language [5,6] was introduced as a way for kids to create animated stories on the web. Because of its easy to use blocks language and burgeoning community site for sharing programs, developers have built and uploaded over a million programs on the Scratch site.

With App Inventor, Google engineers have applied this same blocks language paradigm to general-purpose mobile app development. The App Inventor language targets the full functionality of an Android device. App Inventor blocks do things like process incoming SMS texts, interface with the GPS location sensor of the phone, scan barcodes, and talk to web APIs.

Of course a tool that lets anyone program a mobile phone or tablet has generated a lot of excitement. When Google announced its invite-only, beta version in July 2010, they received an overwhelming number of requests—the months following were spent preparing the server infrastructure for this huge user base that had emerged. The potential is there to bring a whole new class of "end-user" programmer into the mix, changing the mobile world from a read-only one where app development is limited to hardcore programmers, to a read-wrote mobile world where anyone can create new apps or customize existing ones.

1.2 "Hello World" in Java, Scratch, and App Inventor

A visual drag-and-drop blocks language helps beginning programmers get past the initial stages of learning programming. So does motivation. To illustrate these issues, let's take a look at an initial example that might be taught to a beginner in a traditional language, Java, and the blocks languages Scratch and App Inventor.

1.2.1 Java Beginning Sample

With Java, the prototypical first example is Hello World:

```
class HelloWorldApp {
        public static void main(String[] args) {
        System.out.println(”HelloWorld!”);
        }
}
```

As anyone who has taught Java to beginners knows, this sample, or any beginning Java sample, is problematic. Because of its object-oriented nature and syntax, even the simplest example has a lot packaging. Just about every term used in the “Hello World” sample—“class”, “public” “static”—is indecipherable to a beginning student. Beginners are not developmentally ready to learn any of it, and the teacher must wave his hand and move on.

The second issue with beginners and the Java sample is motivation. If the beginner can figure out how to run the above program, they get to see “Hello World” displayed in a terminal screen, not exactly the most inspirational event.

1.2.2 Scratch Beginning Sample

Scratch targets kids and has had great success because you can create fun animated apps almost immediately, like in this Whirling Butterfly introductory tutorial from the Scratch site [7].

To program in Scratch, you drag blocks from the left panel to the middle scripts panel. Within minutes you can create an animated story with characters and behavior you can modify. Such a startup is incredibly motivating, especially for kids, and is a big reason for Scratch’s success.

Figure 1. Scratch's Whirling Butterfly

1.2.3 App Inventor Beginning Sample

Now consider the following App Inventor blocks, which I use as an initial sample in my App Inventor courses (This sample will be expanded later):

Figure 2. App Inventor's SMS Texting Auto-Response

This sample auto-responds to a text received by the phone, sending back the text, *"I'm driving right now, I'll contact you later".* It's the first version of an app one of my students created in Spring of 2010.

The blocks are understandable, like with Scratch. They also have meaning in the real-world. Students see it and immediately ask questions. *"Could you make it so the response sent back could be* *customized? Can you make it so the texts are spoken aloud? Can you write an app that let's people vote for something by text, like on American Idol?".*

1.3 Motivation and Learning

As a teacher, I know that such motivation translates into students wanting to learn and driving the learning process. I taught App Inventor as part of a Google pilot program during the 2009-2010 school year. The students built a wide variety of apps—"No Text While Driving", the app that auto-responds to texts, "Android Where's My Car", an app that records where you park your car so you can find it after a concert or ballgame, "Dating AppVice" a crowd sourcing app that allows you to ask people in the mobile web questions, "Broadcast Hub" an app that broadcasts information with SMS texts. They even built apps that talk to web services, e.g. "Droid Muni", which provides personalized information about when the next bus is coming, and "VenYou" an app that provides location-aware concert information. In seventeen years of teaching, I've never had an entire classroom of students work so hard and learn so much as in my App Inventor class.

Why is it so motivating? I think its because with App Inventor you're building something for that most beloved device, the phone, which for many of us is practically an augmentation of our very bodies. Another key is that the apps can interact with some very interesting technology like SMS texting, text-to-speech and GPS sensors. Perhaps most importantly, the apps, even a simple introductory one, can have an impact on the world and people's lives.

1.4 App Inventor and Science

App Inventor has great potential in terms of science education and dissemination. Scientists want a programming language that lets them do what they need and doesn't get in their way: App Inventor, because it is so easy to learn, provides exactly that. Furthermore, App Inventor provides access to technologies scientists care about —sensors for determining location, acceleration, and orientation, access to web information sources, and the ability to easily store data. Perhaps most importantly, you build mobile apps with App Inventor, so scientists can build apps that help them collect and use information in the field or lab.

The access to web information sources is of particular interest to scientists. App Inventor provides a component, TinyWebDB, which makes it easy to write apps that bring in information available in a web service, e.g. weather information. A number of App-Inventor-compliant web service APIs have been made available and it is relatively easy to create new ones for any data source [8].

App Inventor is also of great interest to scientists because of its open-source nature. Often software is open source more in theory than in practice, as actually replicating the source code and understanding it is overwhelming. With App Inventor, source blocks can be shared and understood. This facilitates wide-spread sharing, an example of which is discussed in section 4.

2 App Inventor Overview

The App Inventor programming environment has two windows: the component designer and the blocks editor. You can also plug a phone into the computer to view and test your app live during development.

The Component Designer is a fairly typical WYSIWYG tool for designing user interfaces—you drag out buttons, labels, and textboxes from a palette into a view, modify component properties like background color and width, and in general specify how the app will look. You can also drag out the non-visual components you'll need in your app, such as a Texting and Text-to-Speech components.

2.1 Components Types

App Inventor provides about thirty components separated into various palettes:

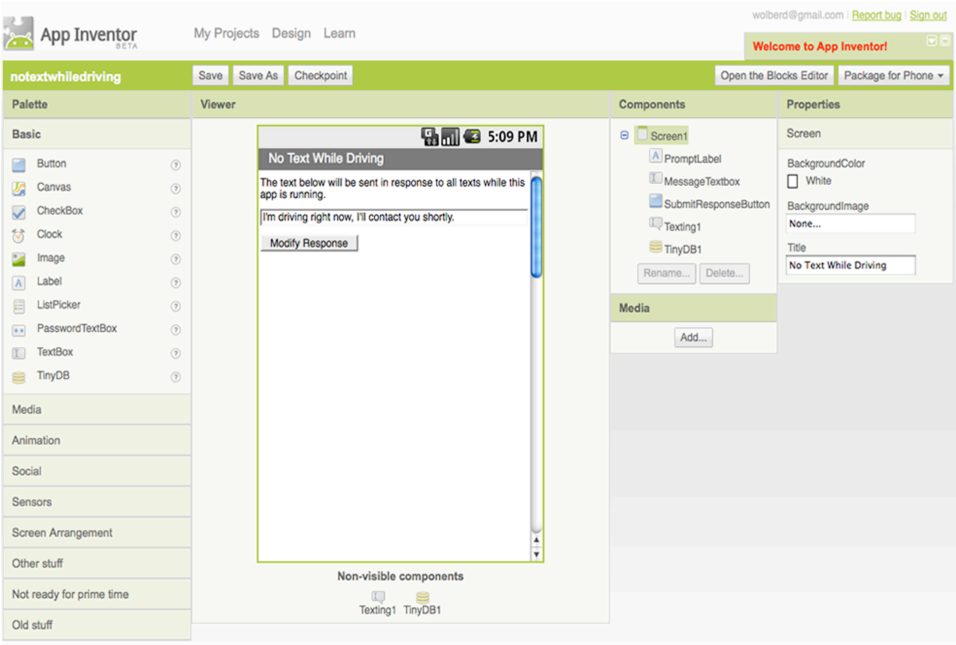

Figure 3. App Inventor's Component Designer

Basic—the user interface components like button, label, textbox, image, and canvas as well as a component for persistent storage (TinyDB).

Media—components for playing sound files and video, as well as a component for interacting with the phone's camera.

Animation—a ball and general image sprite, both of which have high-level functions for movement and object-interaction (e.g. Collision).

Social—components for making phone calls, processing and sending SMS text messages, interacting with the phone's contact list, and a sample API component that interfaces with Twitter.

Sensors—components for sensing the phone's location, orientation, and acceleration.

Screen Arrangement—components for organizing user interface objects on the screen.

Other stuff—a barcode scanner, text-to-speech and speech recognition components, as well as a low-level component, Activity Starter, for launching any Android app from your app (e.g. you can open a map to a location specified by your app).

Not read for prime time—components for interacting with the web and others, including GameClient for building multi-user apps and TinyWebDB which is used to talk to web services and databases.

2.2 Behavior Blocks

Once the components of the app have been specified in the Component Designer, the behaviors are defined in the Blocks Editor. The Blocks Editor has two palettes, one for built-in functionality separate from the components, and another, “My Blocks”, which contains blocks created for each component added to the app.

The built-in blocks allow you to do many of the things you do with a normal programming language, including defining variables and specifying conditional and iterative behaviors. The built-in blocks are separated into drawers:

Definitions—blocks for defining variables and procedures.

Text—text (string) functions, e.g. join, split

Lists—list functions, e.g,, addItem, selectItem

Math—math functions

Logic—logical operators

Control—if, ifelse, foreach, while

Colors—a palette of colors

The My Blocks section contains a drawer of functionality for each component that was added to the app. This adds to the concrete nature of the environment as the developer works with instances and not classes.

Each component has event-handler blocks, functions, and property setters and getters. So, for instance, a (SMS) Texting component has a MessageReceived event-handler block containing a hole that can be filled in with the function blocks that should be executed in response. It also has a function SendMessage, and blocks for changing or reading all of its properties.

2.3 Testing, Deploying and Sharing

App Inventor's live testing feature allows you to plug in a phone during development and interact with the app you are building live. This feature is to my knowledge the first of its kind and truly transforms the development process.

When you are ready to deploy the app, you can package it into and Android app .apk file and have the tool generate a barcode for it. The barcode appears on screen and you can then scan it on to your phone. You can also download the .apk file to your computer. Android provides an emulator, so if you do not have a device available you can develop apps and test them on the emulator.

Finally, you can generate source code (blocks) for an app that you want to share. A zip file is generated which can be shared and uploaded by another programmer for customization.

3 The "No Text While Driving" App

This section describes a real-world issue and an app-based solution devised by a university student—it is an extension of the first app described in Section 1. The story is a great example of how App Inventor can help transform an idea into a working prototype, and how this can potentially lead to a mass-produced app with great utility. It also illustrates how App Inventor provides easy access to the powerful features of Android—SMS text processing, database management, text-to-speech, and the location sensor.

3.1 No Text While Driving and Real-World Impact

In January 2010, the National Safety Council (NSC) announced the results of a study which found that at least 28 percent of all traffic accidents –close to 1.6 million crashes every year—are caused by drivers using cell phones and texting [9] Many states have banned cell phone use while driving altogether.

Daniel Finnegan was a student in a fall 2010 University of San Francisco App Inventor programming class. In brainstorming about a project for the class, Daniel thought about this driving and texting epidemic, and came up with an app that helps by reducing the urge to text back when one receives a text. He created the app, "No Text While Driving." The app responds to any arriving text with a response message such as, “I’m driving right now, I’ll text you back later.” The app even lets the user change the response for different situations—say if you’re going into a meeting or a movie.

When Daniel first introduced his idea, some in-class brainstorming resulted in a couple of great suggestions. First, it was observed that when you’re driving, the jingle of the texts coming in can kill you with curiosity—even if you know an app will auto-respond for you. Wouldn't it be great if you could hear the texts spoken aloud?

The other idea was this: you’re a house husband (or wife) home making dinner, and you’d like to know when your spouse will arrive home. Of course you don’t want to endanger him or her by having them answer your text while they’re driving, but you’d really like to know how far into that long commute they’ve progressed. The solution? Make use of the phone’s GPS capabilities and have “No Text While Driving” add the driver’s current location in the response text as well.

In the summer of 2010 I took Daniel’s “No Text While Driving” idea and developed it with the additional features as a tutorial on the App Inventor site [10] I also created a screencast on how to build it [11].

Figure 4. State Farm Announced No Texting and Driving App with Video

Some weeks later, State Farm Insurance announced an Android app called “On the Move”[12]. “On the Move” has functionality almost exactly the same as “No Text While Driving”. The service is free to anyone as part of State Farm’s updated Pocket Agent® for Android™ application.

“It is our hope that this widget will prevent crashes and save lives,” said Laurette Stiles, Strategic Resources vice president at State Farm. “This new service will help drivers manage the temptation to read or respond to text messages when they are behind the wheel. We wanted to make this widget available free-of-charge as just one of the ways we’re working to keep our roadways safe for drivers” [12].

I don’t claim that the State Farm app was inspired by Daniel’s No Text While Driving, though it’s possible it was. What is interesting about the story is that an app created in a beginning course, by a creating writing student, may have inspired this mass-produced piece of software. The question is possible because App Inventor has opened things up so that anyone with a good idea can quickly and inexpensively turn idea into a tangible—well, virtual—reality, an interactive app. Would State Farm have come up with their crash-reducing app if Daniel hadn't manifested his idea? Nobody can ever say, but there is no doubt that working versions of software have a much greater chance of inspiring people than an idea that never leaves the classroom or cafe!

3.2 Building "No Text While Driving"

This section demonstrates how to build "No Text While Driving", including the text-to-speech and location sensing capabilities. We'll build the app step-by-step, starting with the original auto-response. You can follow along and build the app with App Inventor, or just read along to get an idea for how App Inventor works. The reader is referred to [10,11] for a tutorial version of this app with more detailed instructions.

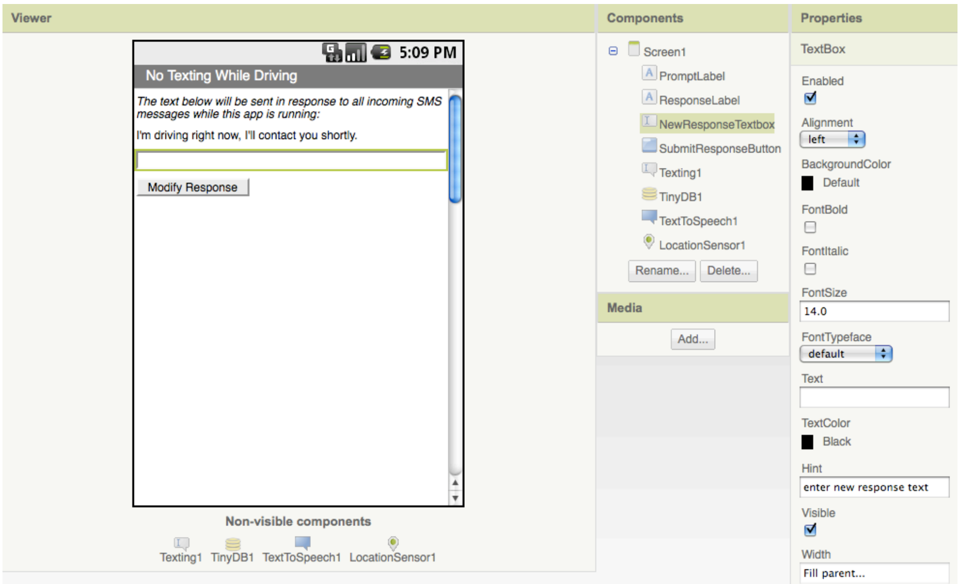

Figure 5. The Components of "No Text While Driving"

3.2.1 Designing the User Interface and Components

The user interface for NoTextWhileDriving is simple: it has a label that displays the current SMS message that should be sent in response to any incoming text, along with a text box and a button for submitting a change to that response. The app also needs four non-visual components: a Texting component, a TinyDB component, a Text-to-speech component, and a Location Sensor component, all of which appear in the "non-visual" component area. Here's how the app looks in the component designer once these components have been added in Figure 5.

3.2.2 Programming an SMS Auto-Response

For the auto-response behavior, you'll use App Inventor's Texting component. You can think of this component as a little person inside your phone that knows how to read and write texts. For reading, the component provides a "when Texting.MessageReceived" event block. You can drag this block out and place blocks inside it for whatever you want to see happen when a text is received.

To program the response text, you'll place a Texting.SendMessage block within the MessageReceived block. Texting.SendMessage actually sends the text—so you'll first need to tell the component the message to send, and who to send it to, before calling SendMessage

The blocks should look like in Figure 6.

The yellow boxes are comments—you add them by right-clicking on a block and selecting "Add Comment". You don't have to add these—comments are for decoration only and don't cause the app to behave differently.

How the Blocks Work. When the phone receives any text message, the Texting1.MessageReceived event is triggered. The phone number of the sender is in the argument number, and the message received is in the argument messageText. In response, the app sends a text message to the sender. To send a text, the app first sets the two key properties of the Texting component: PhoneNumber and Message. Texting.PhoneNumber is set to the number of the sender. Texting.Message is set to the text in ResponseLabel—in the component designer, this was set as a default to, "I'm driving right now, I'll contact you shortly." Once the Texting object's properties are set, the app calls SendMessage to actually send the response.

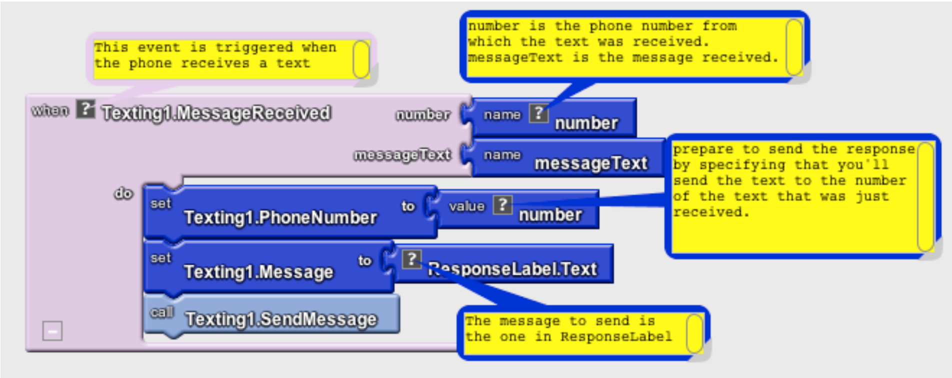

Figure 6. Texting.MessageReceived Event-Handler

3.2.3 Storing the Custom Response in a Database

The next behavior entails modifying the app so it stores the custom response message the user enters. When the user enters a text and clicks the Modify Response button, the app should 1) move the text the user has entered from the NewResponseText into the ResponseLabel, and 2) store the text in the phone's database.

The response text needs to be stored in the database because the user expects that data to be persistent. Persistent data is database data, like the information you enter when you modify your Facebook profile—if you change your status there, you expect that newly entered status to be the same when you exit Facebook and come back to it later. With the "No Texting While Driving" app, the user will have similar expectations: when he closes then re-opens the app he will expect the last response message he entered to be remembered by the system.

Data stored in component properties, such as the ResponseLabel.Text property, is transient data. Transient data is like your short-term memory, and the phone "forgets" it as soon as an app closes. If you want to remember something long-term, you have to transfer it from short-term memory (a component property or variable) to long-term memory (a database).

In many programming environments, you store data persistently using a database and the Standard Query Language (SQL). With App Inventor, you store data persistently using the high-level

TinyDB component. TinyDB provides two blocks: StoreValue and GetValue. The former allows the app to store a tagged piece of information into the phone's database, while the latter lets the app retrieve one.

Here are the blocks you'll need for transferring a newly entered response into the ResponseLabel and storing it in the database:

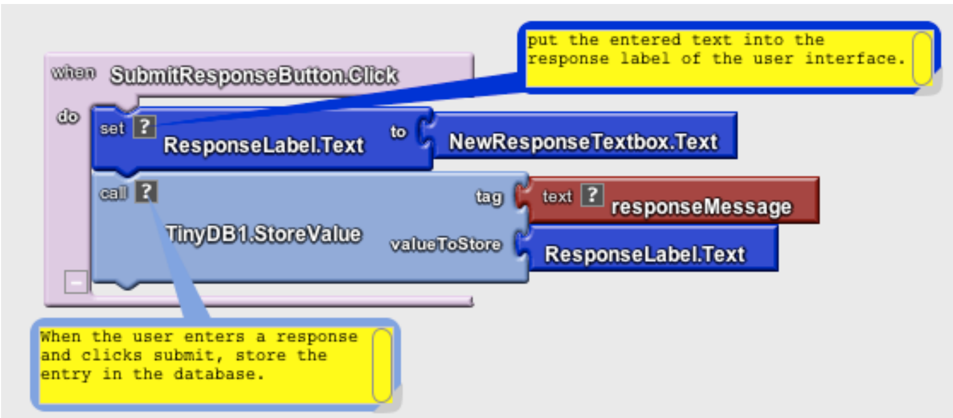

Figure 7. SubmitResponeButton.Click Event-Handler

How the Blocks Work. Think of the input forms you use—you first enter something in a textbox then click a submit button to tell the system to process it. The input form for this app is no different. When the user clicks the SubmitResponseButton, the SubmitResponseButton.Click event is triggered. The event-handler first copies (sets) what the user has entered in NewResponseTextbox into the ResponseLabel. Recall that ResponseLabel holds the message that will be sent out in auto-response, so it is imperative that the new custom message is placed there.

Next, the app uses TinyDB to store the text it just put in ResponseLabel into the database.

The text "responseMessage" is used as a tag to uniquely identify the information—later, you'll use that same tag to retrieve the message from the database.

3.2.4 Retrieving the Custom Response when the App Opens

The reason for storing the custom response in the database is so that, when the user closes then later reopens the app, that custom response can be loaded back into the app.

App Inventor provides a special event block that is triggered when the app opens: Screen1.Initialize. If you drag this event block out and place blocks in it, those blocks will be executed right when the app begins.

For this app, your Screen1.Initialize event-handler should check to see if a custom response has been put in the database. If it has, it should be loaded in using TinyDB's GetValue function.

Figure 8 shows how the blocks should look.

How the Blocks Work. When the app begins, the Screen1.Initialize event is triggered. The app calls the TinyDB1.GetValue with a tag of "responseMessage"—the same tag used when you stored the user's entry earlier. The resulting value is placed in the variable response.

The variable response is used so that the value returned from the database can be checked. If it has a length of 0, then there was no database entry with a tag of "responseMessage"—something that will occur the first time a user runs this app. But if the length is greater than 0, the app knows that a custom response has been stored previously, and the retrieved value can be placed in ResponseLabel which the user will see and which is used as the message for any response texts sent.

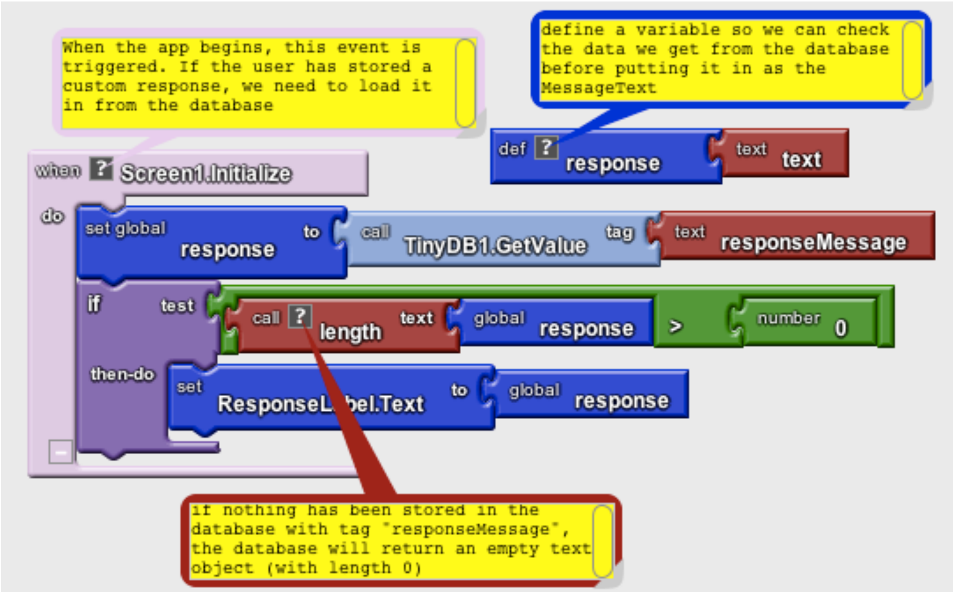

Figure 8. Loading in the previously stored response

3.2.5 Speaking the Incoming Texts Aloud

In this section, you'll modify the app so that, when a text is received, the sender's phone number, along with the message, is spoken aloud. The idea here is that when you're driving and here a text come in, you might be tempted to check the text even if you know you're phone is sending an auto-response. With Text-to-speech, you can hear the incoming texts and keep your hands on the wheel.

Android devices provide text-to-speech capabilities and App Inventor provides a component, TextToSpeech, which will speak out any text you give it. Note that here "text" is meant in the general sense of the word—a sequence of letters, digits and punctuation—and not just an SMS text.

In the Getting Started section of this app you were instructed to download a text-to= speech module from the Android market. If you didn't do so, you should do so now. Once the Text-To-Speech module is installed and configured as desired, you can use the TextToSpeech component within App Inventor.

The TextToSpeech component is very simple to use—you just call its Speak function and plug in the text you want spoken into its message slot. For instance, the following function call would speak, "Hello World":

For the No Texting While Driving app, you'll need to provide a more complicated message to be spoken, one that includes both the sender of the SMS text's phone number, as well as the message. Instead of plugging in a static text object like the red "Hello World" block, you'll plug in a make text block. make text allows you to combine multiple pieces of information into a composite text object.

You'll need to make the call to TextToSpeech.Speak within the Texting.MessageReceived event handler you programmed earlier. The blocks you programmed earlier handle this event by setting the PhoneNumber and Message properties of the Texting component appropriately and then sending the response text.

You'll extend that event handler in the following way:

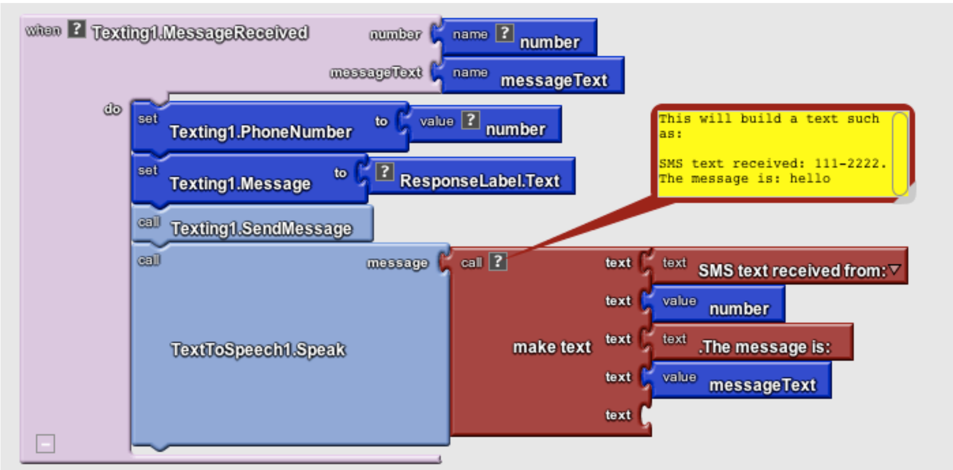

Figure 9. Speaking the Texts aloud

How the Blocks Work. After the response is sent, the TextToSpeech1.Speak function is called. You can plug any text object into the message slot of the Speak function. In this case, make text is used to build the words to be spoken. make text concatenates together the text "SMS text received from", the phone number from which the message was received (number), the text ".The Message is:", and finally the message received (messageText). If the text "hello" was received from the number "111-2222", the words "SMS text received from 111-2222. The message is hello." would be spoken.

3.2.6 Adding Location Information to the Response SMS Text

App's like Facebook's Place [13] and Google's Latitude[14] use GPS information to help people track each other's location. There are major privacy concerns with such apps, one reason being that location tracking kindles people's fear of a "Big Brother" apparatus that a totalitarian government might set up to track its citizen's whereabouts. Of course there are more personal concerns as well —many people are happy keeping there whereabouts private unless someone asks them where they are and they choose to answer.

Of course location information can be quite useful as well—one thinks of a lost child or hikers lost in the woods. Within the context of, "No Text While Driving", the "driver" location information can be used to convey a bit more information in response to incoming texts. Instead of just sending back, "I'm driving", the response can be something like "I'm driving and I'm at 3413 Cherry Avenue". For someone awaiting the arrival of a friend or loved one, this extra information can allow them to plan accordingly.

App Inventor provides the LocationSensor component for interfacing with the GPS functionality of the phone. GPS stands for Geographical Positioning System. Besides latitude and longitude information, the LocationSensor also will provide the current street address, making use of Google Maps information to do so.

The LocationSensor doesn't always have a reading. For this reason, care needs to be taken to use the component properly. Specifically, your app should respond to the LocationSensor.LocationChanged event handler. A LocationChanged.event occurs when the phone's location sensor first gets a reading, or when the phone is moved to produce a new reading. The scheme will use for this app is to respond to the LocationChanged event by placing the current address in a variable lastKnownLocation. Later, will change the response message to incorporate this address.

Here's how the blocks should look:

Figure 10. Tracking the phone's location

How the Blocks Work. The LocationSensor1.LocationChanged event is triggered the first time the sensor gets a location reading, and when the device is moved so that a new reading is performed.

Since you eventually want to send a street address as part of the response message, the LocationSensor's CurrentAddress function is called to get that information. Behind the scenes, this function makes a call to the Google Maps API in order to determine the closest street address for the latitude and longitude that the sensor read.

Note that with these blocks you've only finished half of the job. The app still needs to incorporate the location information, now stored in the variable lastKnownLocation, in the response SMS text sent back to the sender.

3.2.7 Sending the Location as Part of the Response

Using the variable lastKnownLocation, you can modify the Texting1.MessageReceived event handler to add location information to the response. Here is how the blocks should look:

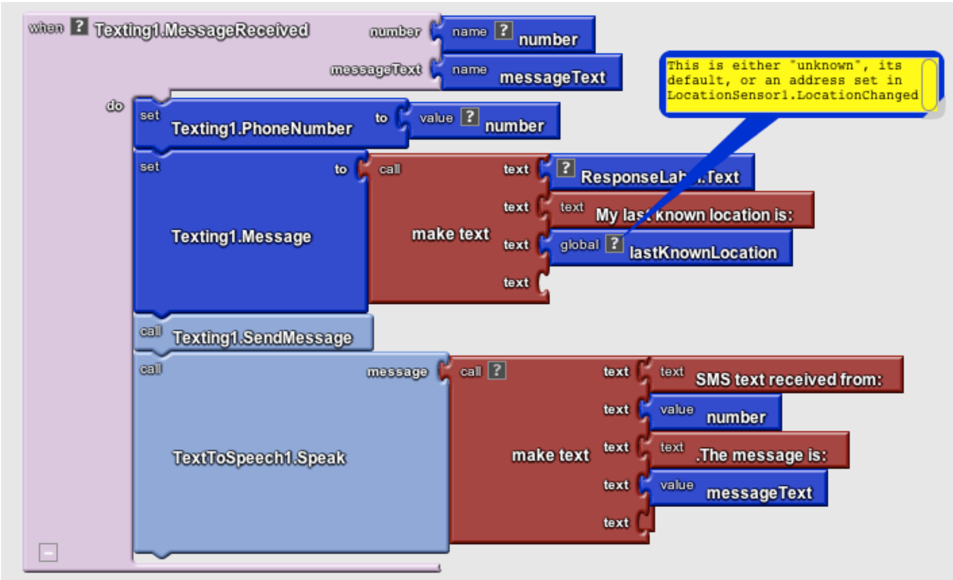

Figure 11. Adding location information to the response

How the Blocks Work. This behavior works in consort with the LocationSensor1.LocationChanged event and the variable lastKnownLocation. Instead of directly sending a message of the text in ResponseLabel.Text, the app first builds a message using make text. It combines the response text in ResponseLabel.Text with the text " My location is " and then the variable lastKnownLocation.The default value of the variable lastKnownLocation is "unknown", so if there hasn't yet been a reading by the location sensor, the second part of response message will contain the text "My last known location is: unknown".

If there has been a reading, the second part of the response will be something like "My last known location is: 876 Willard Street, San Francisco, CA. 95422".

3.2.8 The Complete App

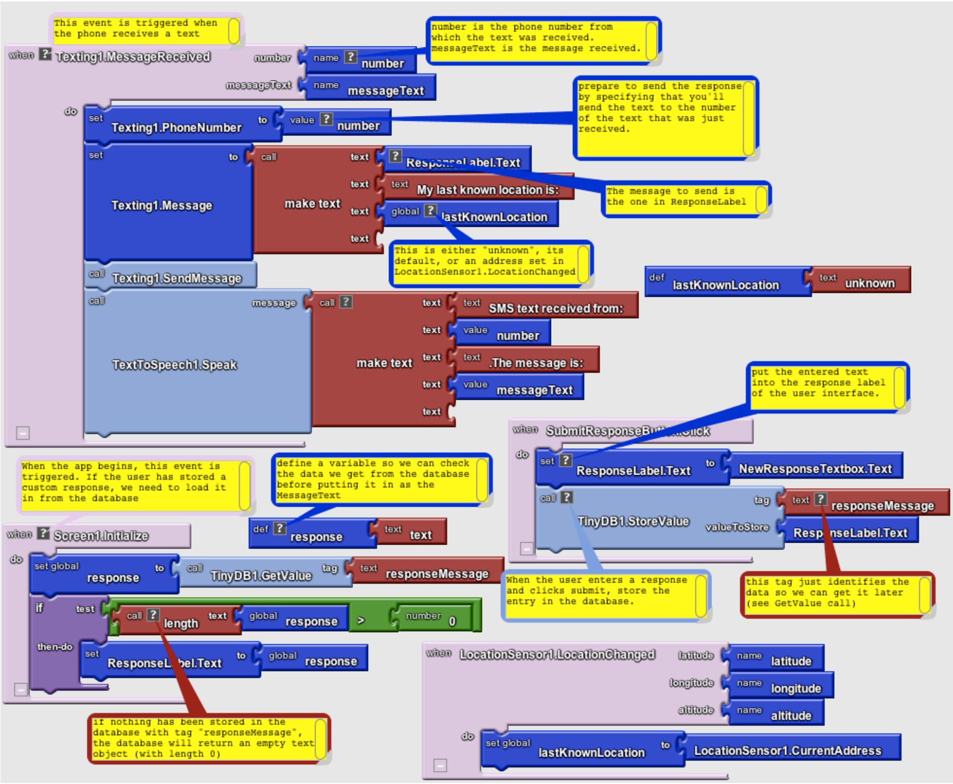

Figure 12. No Text While Driving, the complete app

4 App Inventor and Real World Impact

One student builds the mobile app, "No Text While Driving" and State Farm releases a similar app a few months later, the goal being to save lives. Another student is excited by a tool called FrontlineSMS that has helped people in developing countries communicate, so she builds the first Android version of it, and a non-profit in Helsinki customizes it to organize a thousand-person event. Another pair of students has an idea for an SOS app to help people when they're walking late at night, and the project turns into a startup and full-time job for one of the students.

These are just some of the stories from the courses I taught in 2009-2010. The stories exemplify an important aspect of App Inventor: in just a few weeks beginners can build apps that are not only fun, but have real-world utility. It allows creative people to transform their ideas into working, interactive apps that can be taken up by large companies, used by non-profit organizations, and turned into startups.

4.1 Broadcast Hub in Helsinki

In the Fall of 2010, Ken Banks, gave a talk in my App Inventor course and made a great impression with the work he does using mobile technology to help in developing countries. Ken had observed that in many places, there was no Internet access but people had cell phones and access to the mobile network. Furthermore, most could receive SMS text messages for free, but sending them on a large scare was expensive. What Ken wanted to do was facilitate the sort of broadcasted communication that the Internet makes possible, but use cell phone technology to do so.

For this reason, he developed FrontlineSMS [15], a PC-based tool which serves as a broadcast hub for SMS communication. With FrontlineSMS, a phone is connected to a computer which serves as the hub. People can register with the hub by sending a special text message to the hub's phone. Those registered then receive all the broadcasted messages from the hub.

The system has been incredibly successful. Amongst other things, FrontlineSMS has been used to and monitor election fraud in Afghanistan [16] and provide health information in Malawi [17]. As an example of the power of mobile technology in public service, I spoke about Ken's work early in my Spring 2010 App Inventor course and the students read a couple of articles about Ken and Frontline SMS. One student, Carly Kralj, was especially enthused about the project. For her final project, she chose to build the first

Android version of the FrontlineSMS software. Her idea was this: because some situations are so volatile, wouldn't it be nice if the hub itself, instead of being a stationary computer, could be a mobile Android device?

So as her final project, Carly used App Inventor to create a broadcast hub app that runs on Android. One great part of the project was that Carly was able to communicate with Ken Banks and his lead engineer Alex Anderson who were great in helping her understand how FrontlineSMS worked. She learned that, ideally, an Android version would make use of the Groups facility already built into the Android OS. Unfortunately, App Inventor doesn't yet provide full access to the contacts and groups, so Carly wasn't able to implement the app in that way. But in going through this process she was able to experience some real-world software development issues.

Carly went on to create a broadcast hub with its own list that doesn't use contact groups. I later created a version of the app as a tutorial for the App Inventor site. I called it BroadcastHub and it was a simple app that allowed 1) anyone to join the broadcast group by texting a special code to the phone, 2) any member to broadcast an SMS text to the group by texting it to the hub.

In August 2010, Ken Banks contacted me to tell me his group was creating a full-fledged Android version of FrontlineSMS. He very politely pointed out that Carly had named her app Android FrontlineSMS on the project page of her portfolio, and the course's app studio, USF Android Market. A Google alert had notified Ken of it, and he thought it would be less confusing if Carly changed the title.

We quickly made the changes and I made a note to do a better job monitoring projects and discussing the professional ethics in such situations. But it occurred to me—just as it had with the No Text While Driving app and the State Farm example—that this was something happening in the real-world, Carly, an International Design major in a core-curriculum course, had created something with utility, something with an impact on the world, something that Ken Banks cared about.

The story got better. Later that same week, I was contacted by a non-profit group in Helsinki Finland:

"My wife and i are respectively a cancer scientist and a bioinformatician who moved from San Francisco to Helsinki last year. We're working extracurricularly with a local arts organization to try to lift a central neighborhood to a more creative and inclusive plane, especially regarding the growing immigrant population. So there is at least some relatedness to the mission of FrontlineSMS.

So we're organizing events from now till 2012, when Helsinki is World Design Capital. The first such event is Saturday, and we're trying to get broadcastHub working in this way:

- a cell number on an Android (HTC wildfire) receives SMS's from people who want to be part of the event

- each SMS receives an auto-response reply

- each number that sent in an SMS receives several more messages over the next few days – simple text broadcasts

…

I was planning to learn App Inventor at leisure. But hours of searching for commercial SMS providers doing what broadcastHub does (for Helsinki users) turned up nothing."

It turns out that they were able to quickly customize the app for their specific event. I received this email a few weeks later:

Dave,

Our community raising event in Helsinki went off really well. About 1000 people came [see http://www.punajuuri.org/]

We needed SMS broadcast capabilty for up to a thousand people over a few days. We looked at FrontlineSMS, Clickatell, and others – nothing had the right fit. Then I got my invitation to App Inventor, looked at the broadcasterHub tutorial, and realized with a shock *this was the perfect solution. In a few hours I was able to modify the broadcastHub tutorial app to fit exactly our needs:*

Any SMS's sent to my phone number with the app running received an autoreply: "Text 'beatroot' to this number to sign up for our message list." Any numbers sending an SMS to me containing 'beatroot' or 'Beatroot' were added to the broadcast list. But because our event was in Helsinki, the broadcast messages needed to be in Finnish. So instead of writing them myself, I told the app to take any messages sent to me from Heta and Jon, the Finnish organizers of the event, and automatically re-send it to all the numbers on the broadcast list.

It really was incredibly fast and easy to modify the broadcastHub app to do only what we needed. The app worked perfectly and can be easily re-used, modified, and shared. Having the capabilities of an android phone plugged into a graphical programming environment is an amazing experience. You're not just learning logic, you're learning it in the context of the social world connected to your phone.

Thanks David and Google for bringing the next level, again.

We will be using your tools for more ambitious (but still local!) projects in the near future.

Cheers,

Myles Byrne, Heta Kuchka, Jon Sundell
: Punajuuri (Beatroot), Helsinki, Finland

Besides being happy and proud that Carly and I had helped someone so directly, the story struck me in the following way: App Inventor was not only an experiment in teaching programming, it was an experiment in open source software. Lots of software is open source, but in practice the software is only "open" if you have the key—expert programming knowledge (and the time and inclination to do the often arduous work of deploying a project). Myles and his group were able to use the BroadcastHub sample because, unlike most programming code and systems, App

Inventor source is decipherable, even to people who are not expert programmers.

4.2 SOS Safety App

Chris Witte and Elena Miguelena were in my first App Inventor class of Fall 2010. The first version of App Inventor began working about a week before school began and the bugs were not yet ironed out.

Despite these drawbacks, Chris and Elena came up with a great idea for an app: you're walking home at night, coming to that one quite and dark street that always gives you the creeps. Before you turn down it, you start the app and press a button. If you don't press the button again within the next minute, an SOS text message is sent to a pre-determined list of numbers.

They built a prototype of the app in class, and Chris showed it to his mom. Late in the semester, his mother mentioned Chris's app to a man sitting next to her at a basketball game. The man happened to be a former Vice-President at Apple, and really liked the idea. He gave Chris's mother his contact information and told her to have Chris call him.

Chris is now an employee at a startup which is developing the SOS app, and the company has applied for a patent on it. Now at USF we do a great job getting students jobs when they graduate, but rarely it is on the basis of an app the student has built. What makes this story even more incredible, of course, is that Chris is not a computer science student and only took the one course.

One interesting side note to the story is that Chris is dyslexic. He'd tried programming before and was overwhelmed trying to learn the Java programming language, which is text-based. Chris had much greater success with App Inventor's visual blocks language, and its color-coded blocks (Being a left-brain thinker, I didn't realize the colors were even significant until he told me).

5 Summary

App Inventor is a right-tool and the right-time technology. Scratch has popularized, refined, and proven the viability of a blocks programming language for end-users, mobile apps are the current craze with Android specifically growing astronomically, and tablets have captivated out collective imaginations. Blogs, wikis, and the technical expertise of today's youth have changed the culture so that people now expect to produce and not just consume information—and why should the app world be any different?

App Inventor's appearance at this time in history—at the confluence of these trends—could lead to the next evolutionary stage in people's ability to control and make use of technology. For scientists, App Inventor can help them expand horizons and integrate the lab, the outside world, and the virtual world.

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Mobile Application Development with Python

Pankaj Nathani
Nokia Research Center—Bangalore, India

Today, the pace of technology development and evolution of mobile devices is tremendous. Today's mobile devices better known as smartphones have advanced technologies like touch interface, sensors, GPS and networking abilities. With these ever-increasing capabilities, a cell phone is likely to become a powerful device in the near future.

Software Engineers and programmers have the liberty to develop mobile applications which utilize all the capabilities of a smartphone. This chapter would introduce you to Mobile Python, better known as Python on Symbian, which is a technology to develop mobile applications or prototypes rapidly. Besides Introduction to Mobile Python, the article focuses on how Mobile Python can be used to build scientific applications specially related to sensing.

If you are a mobile developer already, this article would introduce you to Mobile Python and how to start developing applications or prototypes on it with a focus on sensing. If you are totally new to mobile application development, this article would help you get started with it and teach you to develop mobile applications or prototypes with the minimum effort.

1 Python Programming Language

The Python programming language, created by Guido van Rossum in the early 1990's, is an interpreted, interactive, object-oriented, extensible programming language. The benefits of Python include a comprehensive core library and the ability to be extended using native code. Also, the convention to use clear syntax makes it easy to learn and highly productive. Python supports object oriented and functional programming styles and enable you to work more quickly and integrate your systems more effectively. You can learn to use Python and see almost immediate gains in productivity and lower maintenance costs.

Python on Symbian (also known as "Mobile Python" or "Python for S60" or "PyS60") is Nokia's port of the Python language for the Symbian platform. Python on Symbian was first released by Nokia at the end of 2004, and was contributed to the Symbian Foundation in early 2010. Python applications are compatible with all Symbian devices.

2 Mobile Python vs Other Technologies

As you begin reading this article, you may wonder why you should choose Python for developing applications for smartphones when there exists a plethora of other technologies. So let us have a look at the advantages of Python over other mobile application development technologies.

Pretty much summed up by the comic strip, Python is clearly a refreshing and easy to use technology while compared to other technologies viz. Symbian C++, Java, etc. Python can be used to develop a variety of applications: web applications, utilities, scientific computing, games, etc. Python's rich API availability makes it possible to create powerful applications that can leverage platform strengths.

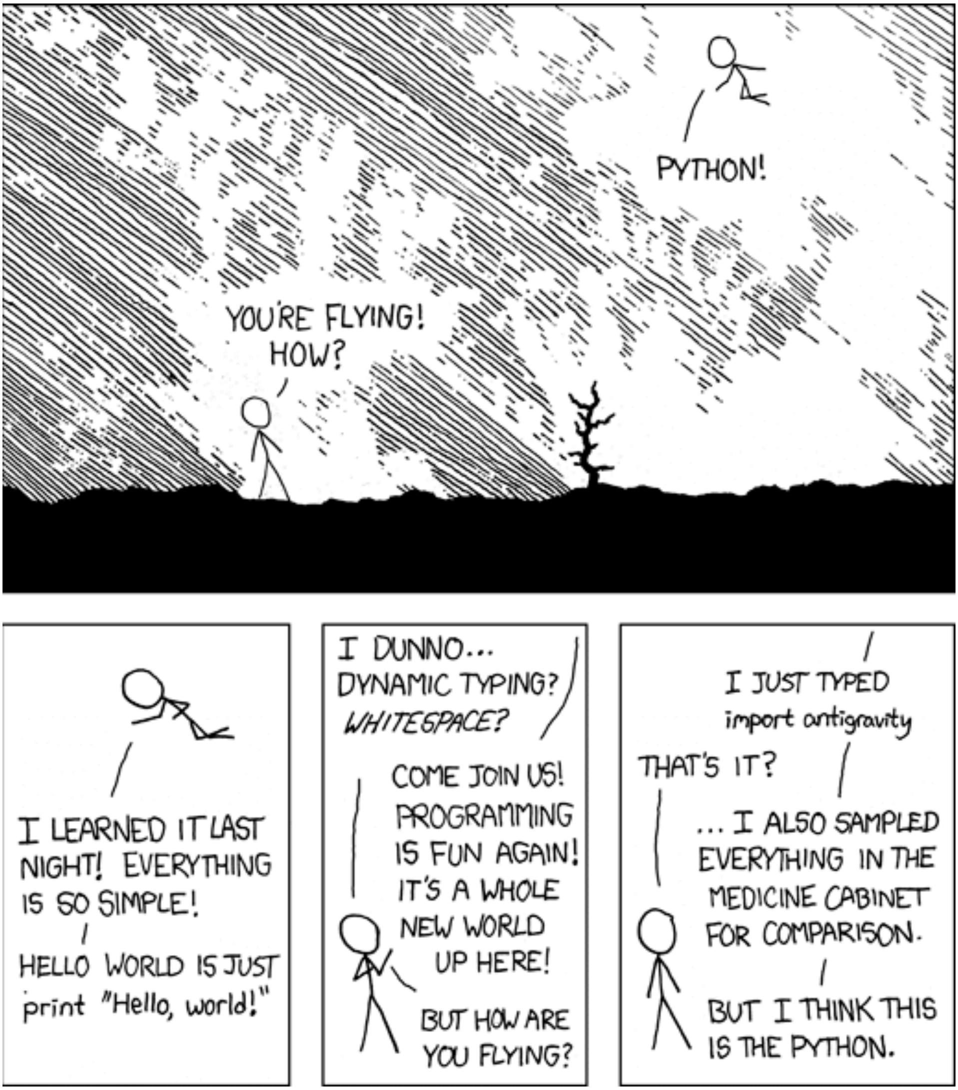

Figure 1: Comic strip indicating Python's "Ease of Use" [1]

For example, Python on Symbian gives seamless access to the file system, contacts database, messages, emails, camera, telephone, GPS, etc. just as the native technology Symbian C++ does. Besides this, Python on Symbian is easily extendable, i.e. you can write an extension in C++/C for extending functionality of Python which it does not offer originally. Thus, the ease of use, simplicity, plethora of API functionality and rapid prototyping ability makes

Python definitively one of the best technologies of smartphone application development.

To speak about the cons of the language, Python is a runtime and runtime normally has slower execution speed when compared to the native technologies. Python's performance is reasonable but still relatively slower than the native Symbian C++.

3 How to Get Started

Alright, now that you have an overview of Python and its benefits, let’s get started with it!

Note: **The Symbian emulator only supports Microsoft Windows operating system for now.**

For developing Python applications, you have the liberty to use a text editor of your choice as the code editor. Although Notepad or any simple text editor may suffice, we recommend using Notepad++/Textpad which provide Syntax highlighting for Python code. You can develop Python applications and test them on a Symbian phone or test it on a Symbian emulator.

In the next sections, we shall see how to install Python runtime on your device and your PC, to test your scripts.

3.1 Setting up Your Phone

You can download the files required for setting up your phone from the Symbian Foundation website at http://developer.symbian.org/wiki/index.php/Python_Downloads

Windows users: Download, unzip and install PythonForS60_2.0.0_Setup.zip

Mac/Linux users: Download and unzip PythonForS60_2.0.0.tar.gz

The SIS files you need are available in the \PythonForS60\PyS60Dependencies\ directory of your Python installation. Windows users can open the directory from the start menu.

Install the following files from the PyS60Dependencies folder to your phone. You may use Ovi suite (http://europe.nokia.com/support/download-software/nokia-ovi-suite) or PC suite (http://europe.nokia.com/support/download-software/pc-suites) for installing these files to your phone.

•Python_2.0.0.sis: the PyS60 runtime

•PythonScriptShell_2.0.0_3_2.sis: a Python Interactive Shell application

Once installed the above files you would find the Python shell icon in the Applications or Installations folder of the phone, as shown in the following figure.

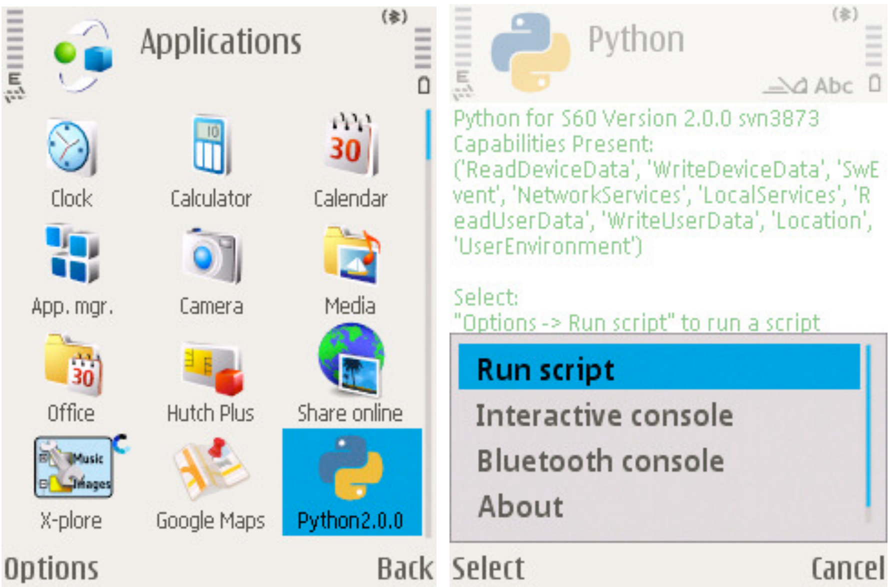

Figure 2: Python script shell installed on your phone

3.2 Setting up the Symbian Emulator

You can download the Symbian emulator from the Symbian Foundation website at http://developer.symbian.org/main/tools_and_kits/downloads/view.php?id=3.

Note: We have used the Symbian^1 emulator (which is the latest, at the point of writing) in this article. You may download any Symbian emulator of your choice. Older Symbian emulators are available from the Form Nokia website at http://www.forum.nokia.com/info/sw.nokia.com/id/ec866fab-4b76-49f6-b5a5-af0631419e9c/S60_All_in_One_SDKs.html.

Once downloaded, you may install the emulator on your system, since it consists of a normal executable setup file. Once you have successfully installed the emulator, you can verify your installation by going to Start->Run, type “epoc”-> Press ok. This should launch the Symbian emulator as shown in the figure, if the installation went alright.

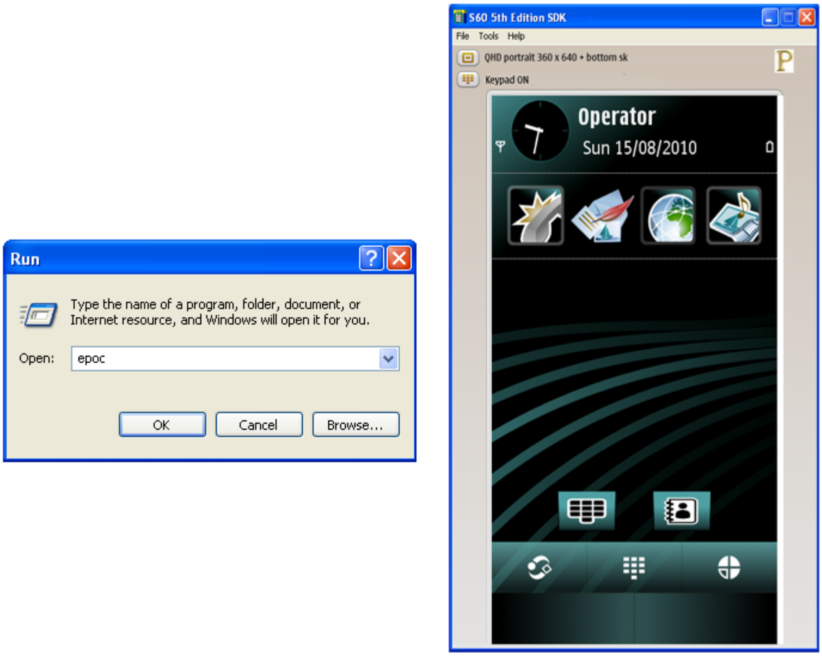

Figure 3: Launching Symbian Emulator

Now if your SDK is successfully installed, you may proceed to install the Python runtime on the emulator. You can download the Python runtime (Python_2.0.0_SDK_3rdEdFP2.zip) for the emulator from Symbian Foundation website at http://developer.symbian.org/wiki/index.php/Python_Downloads

You should unzip the Python runtime (Python_2.0.0_SDK_3rdEdFP2.zip) over the Symbian emulator i.e. unzip to C:\S60\devices\S60_5th_Edition_SDK_v1.0\epoc32 for Symbian^1 emulator. Accept all prompts to replace files during unzipping to allow this to happen.

Now the Python runtime is installed on your Symbian emulator and is ready to be used for development. You can check the installation by launching the emulator as we did earlier and checking the installation folder.

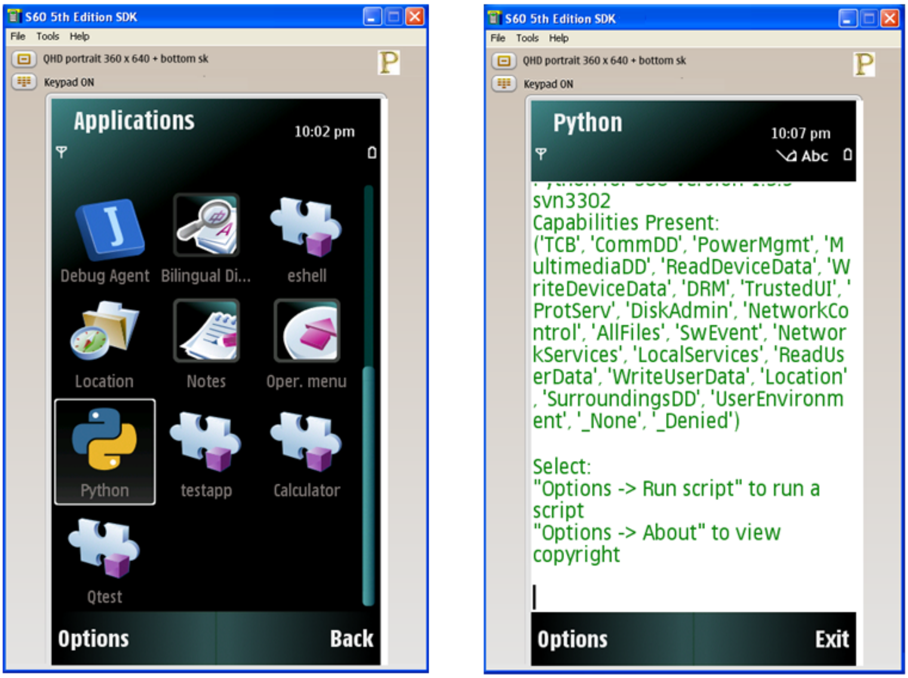

Figure 4: Python script shell on Symbian emulator

In the Python shell, you may select Open-> Run Script and select sample scripts to see how they work! You can start now writing your own python scripts to test on this emulator.

4 Basic Understanding

Now that you have installed Python runtime on your device/ emulator, let's start by writing our first Python script.

```
import appuifw
appuifw.note(u"Hello Python", 'info')
```

Copy and paste the above text in a text editor and save the file as hello.py (with .py extension). Python scripts have .py extension. To test in on the emulator you should place script in C:\S60\devices \S60_5th_Edition_SDK_v0.9\epoc32\winscw\c\data\python folder. To test the scripts on your Symbian phone, you should place the script in C:\data\python or E:\data\python folder. (Tip: You may PC suite to transfer files to your phone).

Once the script is in place, you can run the script by choosing Options|Run Script in the Python shell and selecting hello.py. When you run hello.py you can see a note saying "Hello Python".

There you go! You just created your first program!

The sections further would guide you briefly about basic user interface for applications and phone operations like telephony and messaging. To study these in detail, it is recommended to study the official Python on Symbian documentation. The online version of the documentation[2] is available at http://pys60.garage.maemo.org/doc/s60/s60.html

4.1 User Interface

Python supports a variety of Avkon (standard symbian) User Interface (UI) elements. The availability of these UI elements makes it possible for a Python application to have the same look and feel as the native Symbian C++ applications have. The UI skeleton of a traditional Python application is illustrated in the following graphic.

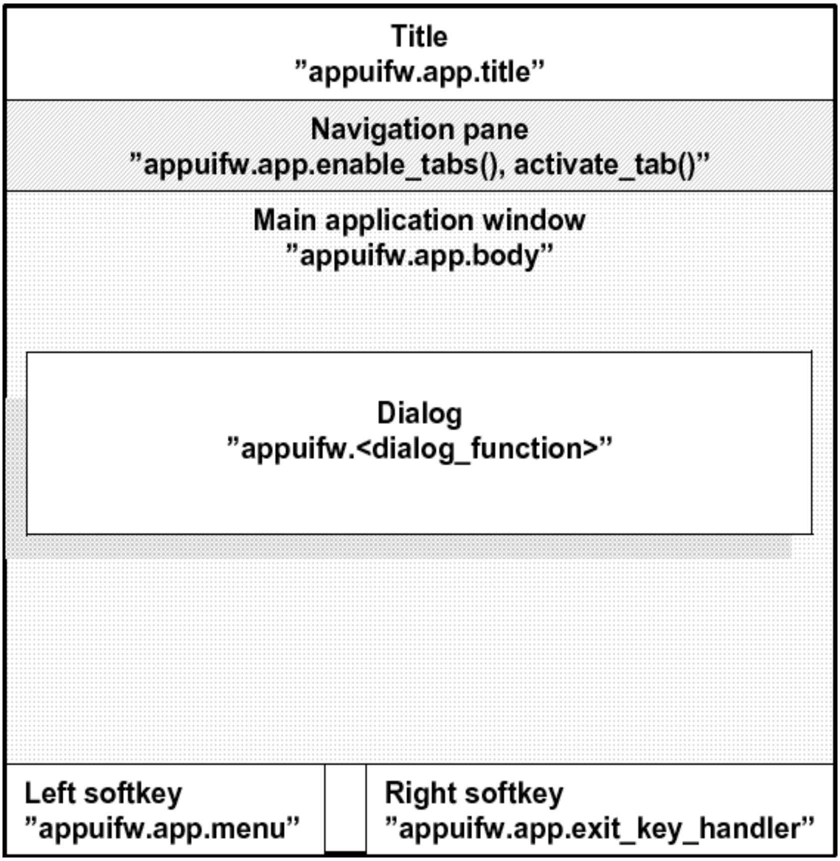

Figure 5: UI Skeleton of a Python application

The module which provides these UI elements is termed as appuifw (application user interface framework). We just saw an example of how to use the appuifw module to produce a “Hello Python” information note. Similarly, we can use the following notes to indicate other notes like confirmation and error notifications.

```
appuifw.note(u”Process complete”, ’conf’)
appuifw.note(u”Operation aborted!”, ’error’)
```

Python supports query dialogs which are easy to use. For example a query dialog to input text from the user can be implemented by the following,

```
name= appuifw.query(u”Enter your name”, ’text’)
```

Other queries including customized dialogs for accepting numbers, date, time, password, confirmation, etc. are also feasible. Please refer to the official documentation of the appuifw module [2] (http://pys60.garage.maemo.org/doc/s60/node18.html) for details.

Over and above, Python also supports Menus, Selection Lists, Listboxs, Forms and Text Editor. You may explore these UI components in the Basic User Interface of Python on Symbian Book[3] http://developer.symbian.org/wiki/index.php/Python_on_Symbian/04._Basic_User_Interface

4.2 Phone Operations

Since we are developing for mobile phones or smartphones, it is the best to learn to control phone operations like telephony and messaging, through Python.

4.2.1 Telephony

Python applications handle all the telephony functions using the telephone module. The telephone module allows the developers to perform basic functions like dialing or initiating a call, answering an incoming call and hanging up an ongoing call.

Dialing a call in Python is as simple as writing the following two lines of code,

```
import telephone
telephone.dial(u”9001234567”)
```

Note: The telephone number to be dialed should be in unicode format.

Hang up an incoming call

```
telephone.hang_up()
```

Answer an incoming call

```
telephone.answer()
```

Over and above the basic telephony functions stated above, the telephone module also allows developers to monitor the phone line status. For example, the following code waits for an incoming call and then uses the answer() function to answer the call.

```
import telephone
def phone_status_changed (phone_state):
   new_phone_state = phone_state[0]
   if new_phone_state == telephone.EStatusRinging:
         telephone.answer()
telephone.call_state(phone_status_changed)
```

The above code detects the ringing state of the telephone in the phone_status_changed function. Similarly, other states (for e.g. EStatusIdle, EStatusDialling, EStatusAnswering, EStatusConnected, EStatusDisconnecting, EStatusHold, etc) can be detected and required actions can be triggered accordingly. Refer to the Python on Symbian documentation[2] (http://pys60.garage.maemo.org/doc/s60/module-telephone.html) for more information on telephone module.

4.2.2 Messaging

Alike telephone, messaging forms a significant feature of the mobile phone. Python offers access to all messaging services viz. Short Messaging Service (SMS), Multimedia Messaging Service (MMS) and email services.

Python uses messaging module to access theses services.

To send an SMS,

```
import messaging
messaging.send_sms(”9001234567”, ”This is SMS text”)
```

To send an MMS

```
messaging.mms_send(”9001234567”, ”Image is attached”,
 ”C:\photo.jpg”)
```

where the third parameter is the path of file to be sent as attachment.

To send an email, the mms_send should have the first argument as the email address instead of the phone number in the above code.

As the telephone module allows waiting for an incoming call, the inbox module also allows to wait for incoming SMS to process it. The following code waits for an incoming SMS and prints the SMS on the screen.

```
import inbox
box = inbox.Inbox(inbox.EInbox)
def incoming_sms(message_id):
  print box.content(message_id)
box.bind(incoming_sms)
```

Similarly one could specify the instance for Sent items (ESent), Draft items (EDraft) and Outbox items (EOutbox) as well. Please refer to the Python on Symbian documentation [2] (http://pys60.garage.maemo.org/doc/s60/module-inbox.html) for more information.

5 Mobile Sensing Applications

Smartphones have become a ubiquitous tool for communications, computing, and increasingly, sensing. Many mobile phones and PDA devices commercially released over the past couple years have integrated sensors (e.g. accelerometer, camera, microphone, magnetometer, etc) and tracking devices like GPS/APGS (WLAN, Bluetooth, etc) which can be accessed programmatically and used to build innovative applications.

In this section, we would have an overview of the various multimedia, sensor and location tracking capabilities that can be used to develop applications with Python.

5.1 Multimedia and Camera

5.1.1 Multimedia

The multimedia services of a phone are available through the audio module in Python. The audio module allows developers to do the following operations which are discussed in detail.

1) Playing sound files

The audio module supports various sound file formats which are in turn supported by the device, for example MP3, MIDI, WAV, AMR, etc.

The following code would open and play the Test.mp3 file. The pre-requisite is that a Test.mp3 file should exist in the given path (i.e. :\\Data\\Sounds\\Test.mp3 for the following example)

```
import audio
sound =
 audio.Sound.open(”C:\\Data\\Sounds\\Test.mp3”)
sound.play()
```

In the same manner, other sound file formats can be played as well. The playback can be stopped by the following

```
sound.stop()
```

For using advanced playback operations, please refer to the documentation[2] for audio module (http://pys60.garage.maemo.org/doc/s60/module-audio.html)

2) Recording sound files

The audio module also allows to record sound files. The same sound object that was used in the playback can be reused to record a sound.

The following code would record a sound for 5 seconds and play it.

```
import telephone, audio
sound = audio.Sound.open("C:\\Data\\mycall_recording.mp3")
def phone_status_changed (phone_state):
    new_phone_state = phone_state[0]
    if new_phone_state == telephone.EStatusConnected:
        sound.record()
    if new_phone_state == telephone.EStatusIdle:
        sound.stop()
telephone.call_state(phone_status_changed)
```

3) Recording calls

The above example illustrating the recording of sound files can be also used to record a phonecall – incoming or outgoing. The call to sound.record() during an ongoing phonecall would record the phone call to the mentioned file.

The following example illustrates recording of an ongoing phone call. The recording is started in the EStatusConnected state when the phonecall is ongoing and stopped in the EStatusIdle state when the phonecall has ended.


```
import telephone, audio
sound = audio.Sound.open("C:\\Data\\mycall_recording.mp3")
def phone_status_changed (phone_state):
    new_phone_state = phone_state[0]
    if new_phone_state == telephone.EStatusConnected:
        sound.record()
    if new_phone_state == telephone.EStatusIdle:
        sound.stop()
telephone.call_state(phone_status_changed)
```


4) Text to speech conversion

The Symbian devices have a Text-to-Speech engine. The audio module provides the audio.say() function to read aloud any text that is passed to it.

For example the following code would speak aloud the text “Hi, This is your phone speaking”.

```
import audio
audio.say(“Hi, This is your phone speaking”)
```

5.1.2 Camera

The inclusion cameras into the mobile devices open up great opportunities for mobile sensing applications. Today there are many approaches, prototypes and even products that facilitate user interface on mobile devices focusing on camera-enabled mobile phones. Nokia Point and Find[6] (interactive augmented reality) and Nokia Image Exchange[7] (sharable image gallery) are two best examples showing how developers can use the integrated camera for innovative applications.

Python gives access to the camera (front and back) of the mobile devices using the camera module. The camera module offers functions like capturing and saving photos and videos. The photos and videos can be then processed with various image processing libraries to manipulate them. One of the examples of popular image processing libraries available for Python on Symbian is the Nokia CV library. This library provides standard image operations, as well as a set of linear algebra operations needed in many advanced imaging applications. Also, this serves as a building block for future advanced libraries. More information about the Nokia CV libraries can be obtained at Nokia Research Center website[4]

Capturing photos and videos

The following code can be used to capture photos,

```
import camera
# Taking photo in RGB mode, resolution =
 1024x768px, maximum zoom, flash disabled
 photo = camera.take_photo(’RGB’, (1024, 768),
 zoom = camera.max_zoom(), flash=”none”)
# Save the captured image
```

```
photo.save(”C:\\Photo1.jpg”, quality=100)
```

Note: The default camera to capture photos is the back camera. If one wishes to use the front camera, the postion of the camera must be set to 1. (pos=1)

The customizable parameters while capturing a photo are mode, zoom, flash, exposure, white_balance and position. For more information on the customization parameters refer to the camera module documentation[2] (http://pys60.garage.maemo.org/doc/s60/module-camera.html)

The following code snippet illustrates to capture videos,

The following code can be used to display the camera viewfinder to the user,

```
import camera, appuifw, e32
def view_finder(image):
        appuifw.app.body.blit(image)
def quit():
        camera.stop_finder()
        lock.signal()
appuifw.app.body = canvas = appuifw.Canvas()
appuifw.app.exit_key_handler = quit
# Start the viewfinder
camera.start_finder(view_finder)
lock = e32.Ao_lock()
lock.wait()
```

To capture video, the viewfinder has to be started. The function to start the video recording is camera.start_record –which accepts two parameters –savepath and callback function.

So the following line of code can be used to start the recording,

```
video =
  camera.start_record("C:\\Data\\myvideo.mp4",
    video_callback)
```

where video_callback is a userdefined callback function.

5.2 Mobile Sensors

Mobile phones are increasingly becoming a very attractive application platform since they are ubiquitous, highly mobile, provide significant computing power, and most of them contain sophisticated built-in sensors. There have been extraordinary and innovative mobile applications which use the information from the built-in sensors. For example, Nokia Activity Monitor[8] uses the integrated sensors to display charts and statistics, in real-time, about your movements while walking or running. It also counts the number of steps, and determines the distance covered and the energy expenditure. Similarly, Nokia Step Counter[9] uses the accelerometer sensor to count your steps and determines the distance you have covered to estimate your energy expenditure.

Python enables developers to access the Symbian sensor framework – which provides access to information from various sensors available on the device. Many of the smartphones available in the market contain accelerometers, light sensors, proximity sensors, magnetometers, and magnetic north sensors! For example, the Nokia N97 has all the above listed sensors.

To check which sensors are supported on a Symbian device and accessible by Python, we can use the sensor module.

```
import sensor
print sensor.list_channels()
```

This would print the following channels, indicating their type, id and name.

```
[{'type': 536929669L, 'id': 7L, 'name':
  'ProximityMonitor'},
{'type': 536919830L, 'id': 8L, 'name':
 'AmbientLightData'},
{'type': 270553214L, 'id': 9L, 'name':
```

```
 'AccelerometerXYZAxisData'},
{'type': 270553217L, 'id': 10L, 'name':
 'AccelerometerDoubleTappingData'},
{'type': 270553215L, 'id': 11L, 'name':
 'TSensrvTappingData'},
{'type': 536919776L, 'id': 12L, 'name':
 'MagnetometerXYZAxisData'},
{'type': 536919775L, 'id': 14L, 'name':
 'MagneticNorthData'},
{'type': 270553224L, 'id': 15L, 'name': 'OrientationData'},
{'type': 270553225L, 'id': 16L, 'name': 'RotationData'}]
```

Here we would see how to access data from the Accelerometer sensor. The Accelerometer sensor channel gives access to the current position axis of the devices – by giving values for X, Y and Z axis.

In the following code snippet, we create an instance sensor_monitor to observe change in the X, Y and Z axis values indicating the position of the device. The callback function xyz_changed is called whenever the values of X, Y or Z axis of the device changes.

```
import sensor
sensor_monitor = sensor.AccelerometerXYZAxisData
(data_filter=sensor.LowPassFilter())
def xyz_changed():
    global sensor_monitor
    print sensor_monitor.x + " " + sensor_monitor.y + " "
    + sensor_monitor.z

sensor_monitor.set_callback(xyz_changed)
sensor_monitor.start_listening()
```

The output of the above code snipped would be a sequence of X, Y and Z values as follows, indicating the position of the device.

```
-1,10,0
-1,15,2
-1,20,4
-2,25,5
-2,30,6
-6,40,8
-8,25,12
-14,10,21
```

By defining patterns for X, Y and Z values for popular gestures like swing, flip over, jerk, balance, flick, shakes, etc. we can use them in innovative applications and games to trigger functions.

Based on [10], the plotted gestures in Figure 6 can be identified and used in mobile applications and games.

Alike the Accelerometer, other sensors can be accessed in the similar fashion. For example, the AmbientLight sensor can be instantiated by,

```
sensor_monitor = sensor.AmbientLightData()
```

Refer to the documentation [2] of the sensor module (http://pys60.garage.maemo.org/doc/s60/module-sensor.html) for more details.

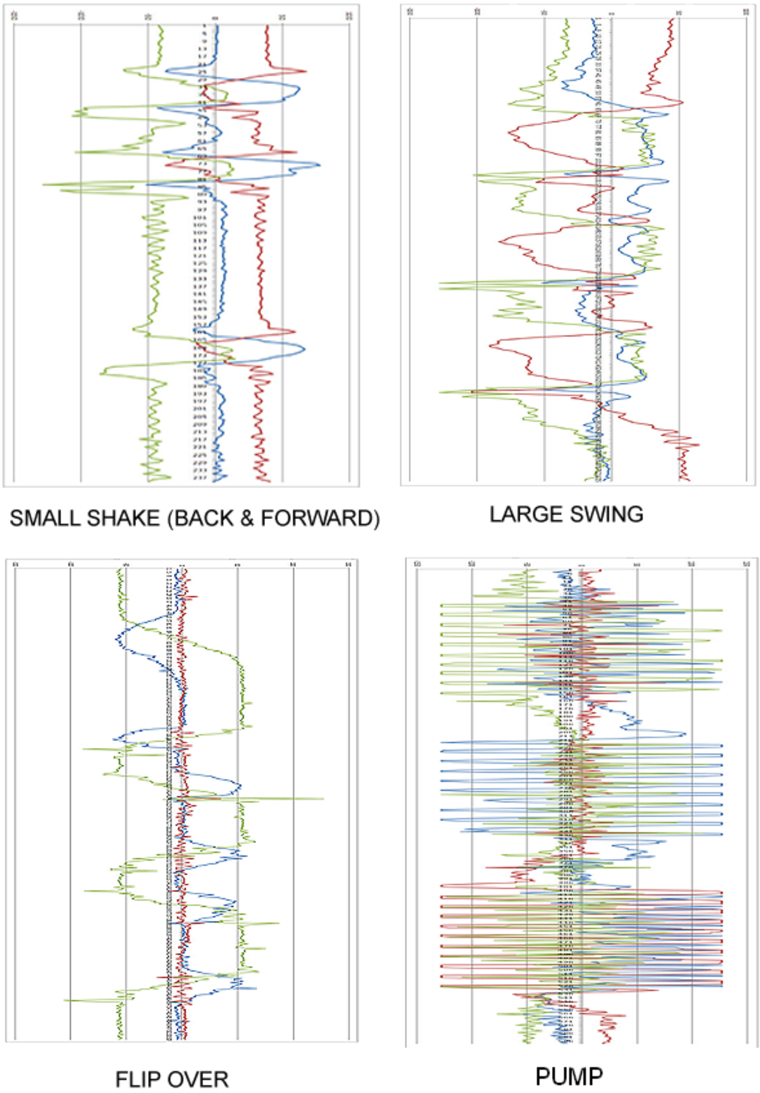

Figure 6: Graphical representation of the Accelerometer data

5.3 Location Tracking

Python enables developers to acquire location aware information which can be used to develop Location aware mobile applications. Basically, Python allows to fetch the location information from the Network information and from the GPS receiver (integrated or Bluetooth GPS receiver).

The location module can be used to obtain the location details from the GSM network information. This includes the values of MCC (Mobile Country Code), MNC (Mobile Network Code), LAC (Location Area Code) and CELL ID respectively.

```
import location
location = location.gsm_location()
print location
```

The following screenshot shows the output of the above snippet, where 404 is the MCC, 92 is the MNC, 1336 is the LAC and 6674 is the CELL ID. Each set of values identifies a unique location address which can be found out using Network operator databases (which are rarely available) or open source database API s like http://opencellid.org/api

Figure 7: Screenshot showing MCC, MNC, LAC and CELL ID

The positioning module can be used to obtain GPS data from the integrated or external GPS receiver. The following snippet illustrates printing a GPS data. Note that the phone (or the external GPS receiver) should be open to the sky to receive navigation signals from the satellites while using the following snippet.

```
import positioning
# setting requestors, this is mandatory
positioning.set_requestors([{"type":"service",
                    "format":"application",
                    "data":"yourappname"}]
print positioning.position()
```

The above code snippets has the following kind of output in ideal conditions,

```
{'satellites': None, 'position': {'latitude': 19.120155602532,
 'altitude': 16.0, 'vertical_accuracy': 7.5, 'longitude':
   72.895265188042, 'horizontal_accuracy':
    80.956672668457}, 'course': None}
```

If there were no satellite signal there would be no data available and the function would return NaN} (not a number) as shown below:

```
{'satellites': None, 'position': {'latitude': NaN, 'altitude':
 NaN, 'vertical_accuracy': NaN, 'longitude': NaN,
   'horizontal_accuracy': NaN}, 'course': None}
```

5 Concluding Summary

This chapter introduced you to Python on Symbian and how you can use it to develop scientific applications with powerful multimedia/sensor features. You can find more material on Python on Symbian by refering to the Python on Symbian book[3].

References

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[2] Nokia, S60 Module Reference. Url: http://pys60.garage.maemo.org/doc/s60/s60.html

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[10] Claire A Blackshaw, 2008. The use of motion in mobile device game, A study of accelerometers on the Nokia N95

Middleware for Grid Computing on Mobile Phones

Muthoni Masinde and Antoine Bagula
University of Cape Town, South Africa

Victor Ndegwa
University of Nairobi, Kenya

1 Need for Mobile Phone Applications in Africa

The low Internet penetration and lack of electricity in the rural areas of the developing countries of Africa make the use of computer-based solutions a big challenge. Yet there is dire need of such applications in these areas. Luckily, most of these countries have reported impressive adoption levels of mobile phones [3], a phenomenon that is now creating a paradigm shift; computing is slowly moving from the traditional PC to the phone. Coincidentally, advancements in the smartphone technology have produced such powerful gadgets that can ably compete with PCs of the 21st century. Today, for less than US$ 400, one can acquire a smartphone equipped with; 1000MHz clock speed, 512MiB (ROM +RAM), access to several types of data networks (CSD, HSCSD, GPRS, EDGE), and Wireless local-area network (WLAN) among other features [6]. With this kind of computing power, computer analysts/programmers can now develop both scientific and commercial applications to address numerous challenging facing poor people in the developing countries of Africa.

1.1 Using Mobile Phone as a Computing Device –The Challenges

A few challenges related to the use of mobile phones as computing devices need to be addressed before we see a wide deployment of mobile phone applications. Some of these are:

(I) Mobility – phones are highly mobile and their computation power may not be available where/when it is needed;

(II) Heavy reliance on battery power that gets drained fast especially under heavy computational tasks;

(III) Different hardware and software leading to high levels of heterogeneity among mobile phones;

(IV) Most of the phones found in the developing countries of Africa are low-end and may not provide the required computing power; and

(V) Mobile phones are highly personalized; the permission to use them for computational tasks may not always be granted.

1.2 Grid Computing on Mobile Phones

Grid computing on mobile phones is one way of addressing some of the above challenges. Computer grids have successfully been utilized to develop gigantic computer solutions especially for scientific use ([2] and [5]). This success can be replicated on a mobile phone environment as long a generic grid middleware precedes this. Grid computing middleware (hardware and/or software) is very critical for the operation of the nodes, its main roles being to support Single System Image (SSI) and to ensure enhanced system availability. Failure of a node for instance should not affect the operation of the system in anyway. To achieve this, the middleware enables the nodes to take advantage of services available in the grid transparently hence freeing the end user from having to know where an application will run. It also makes it possible to view all system resources and activities from any node as well as supports check pointing [7]. The latter occurs when process state and intermediate results are saved periodically to ease process migration when and if needed. MobiGrid [4] is an implementation of mobile phone grid middleware.

Like any conventional grid middleware, MobiGrid is a middleware prototype for mobile phones that provides an API on which distributed applications can be built. MobiGrid's uniqueness lies in the fact that the middleware is for mobile phones environment. MobiGrid was developed to bridge the technological gap that exists in the rural areas of the developing countries of Africa where the adoption of mobile phones technology is higher than that of other forms of ICTs. By using MobiGrid, computer-based applications that are currently a reserve for the developed countries and for resource-endowed cities of Africa can become a reality for all. Consequently, applications such as e-heath, e-education, e-farming, e-weather forecast and so on can then be implemented as mobile phone applications for use in the remote villages where they are needed the most.

1.3 MobiGrid Version 1 – The Limitations

Originally, MobiGrid was implemented using the Python programming language for S60 (pyS60) and tested on only two phone models: the Nokia E63 and Nokia N95. As described in the following sections, MobiGrid was designed based on a client/coordinator model where each phone can run either as a local/client server that manages the resources of the phone and responds to requests from the coordinator to provide a registered service to the mobile grid or optionally run a coordinator server that responds to requests from the client servers and monitors their health to ensures they are still running. In its earlier implementation, MobiGrid had several limitations; the two major ones being:

(I) MobiGrid could only recognize coordinators using the subnet mask 255.255.255.0. This was due to the lack of support for broadcast in PyS60, requiring use of a work-around. The implemented work-around was too slow for use with a wide range of IP addresses (e.g. addresses using mask 255.255.0.0) taking up to 5 minutes to find the coordinator. As a result, the middleware could only be used by up to a maximum of 254 nodes on the same network;

(II) For MobiGrid to function properly, it required that the two main modules (Local Server and Coordinator Server) be installed on each of the phones participating in the grid. However, due to limitations of S60 (at the time of developing the application), a phone could not run more than one instance of the application. This made it impossible to come up with a custom application to test MobiGrid.

In this chapter, the rich tools provided by the Android Framework[1] have been employed to address the above limitations. In particular, the account manager and the synchronization manager (through a sync adapter) have been used extensively. Using Android Virtual Device (AVD) tool, it is now possible to simulate a grid with hundreds of virtual phones, analyse and visualize performance of the grid using tools provided by the rich android.graphics class. Finally, it is now easier to control and manipulate the grid by remotely (using telnet) executing various commands such as for checking battery, network and memory status of the phones (virtual and real) participating in MobiGrid.

2 Analysis, Design and Implementation of MobiGrid

Both Exploratory and Operational Prototyping were used in developing MobiGrid. Exploratory prototyping was used to build and test individual features and once a feature had been fully tested, it was added to the operational prototype and further evolved.

2.1 MobiGrid Functional Requirements

MobiGrid should be able to:

(I) locate the coordinator and register with it;

(II) tell if the coordinator has failed;

(III) call for an election if no coordinator was available;

(IV) participate in an election and take over the role of coordinator if elected;

(V) register new services provided by applications running on the phone;

(VI) request for services that were registered with the MobiGrid;

(VII) provide a messaging system for communication; and

(VIII) provide an interface through which applications could use the grid.

2.2 MobiGrid Design

MobiGrid was designed to provide a middleware service that is always started and runs in the background to allow distributed applications to operate. This middleware service abstracts the developer of the distributed application from having to deal with the technicality of locating distributed services and managing remote nodes. The typical operation of MobiGrid is as follows:

2.1.1 Initialization

(I) The user starts the MobiGrid service on his/her phone by selecting it from the menu. The assumption here is that MobiGrid is already installed on his/her phone.

(II) MobiGrid searches for other phones running MobiGrid.

(III) If a phone running MobiGrid and acting as the coordinator is found, connect to this coordinator as a client.

(IV) If no coordinator is found, call for an election. The winner of the election becomes the new coordinator. If the caller of the election is not challenged, the caller is elected unopposed.

(V) Once a coordinator has been found, MobiGrid can connect to the coordinator and register any services it may have available. These services are provided by applications that use MobiGrid running on the phone.

(VI) If an application requires a service from MobiGrid, it passes a message to MobiGrid, which then provides the service or requests the service from the coordinator.

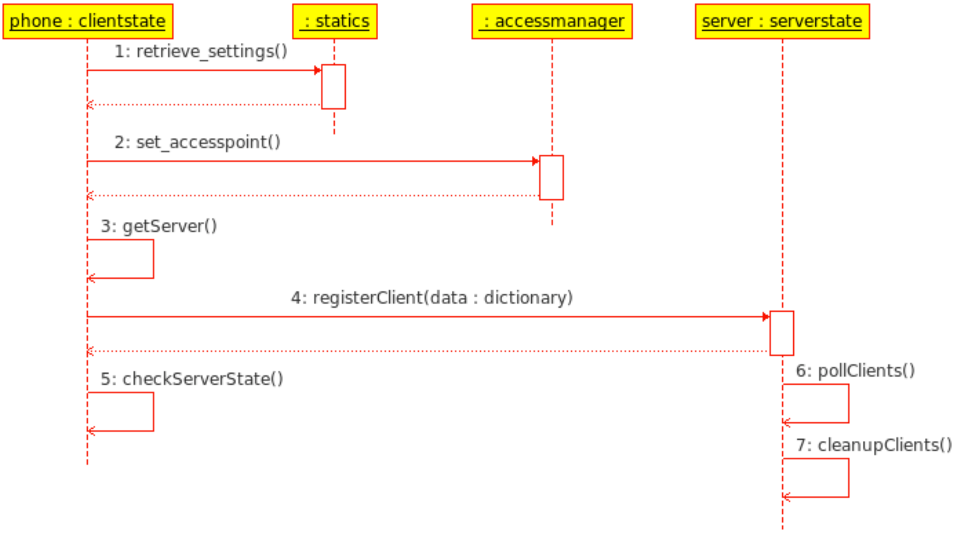


Figure 1: Initialization Sequence

Each phone runs a client/local server and may optionally run a coordinator server if it is the coordinator. The client server manages resources on the client phone and responds to requests from the coordinator (e.g. to provide a registered service). The coordinator server responds to requests from the client servers and monitors their health (i.e. ensures they are still running).

2.2.2 Finding the Coordinator

The coordinator is responsible for the following:

(I) determining which nodes are part of the grid;

(II) maintaining a dictionary of the services available on the grid and which nodes are offering them;

(III) checking which nodes are up and which have failed and

(IV) servicing request for services by finding the node offering the service requested and forwarding the request

The first node to join the grid automatically becomes the coordinator and other nodes register with it on joining. The steps involved in finding the coordinator are as follows:

(I) The client broadcasts to a given SERVER_PORT (default is port 2904) asking who the coordinator is

(II) The coordinator responds and registers the client. The client also registers the IP address of the coordinator

(III) If no response is received within a designated TIMEOUT period, the client calls for an election by broadcasting an !Election message to a designated CONTROL_PORT (default is port 7609). If a node with better election attributes receives a call for an election, it responds by calling its own election. If the caller of the election is not challenged, it automatically becomes the new coordinator

2.2.3 Registering/Requesting Services

When an application that uses the MobiGrid is started, it automatically registers services it offers with the coordinator by sending a !Service command. The coordinator then adds the service and a description of the service to a dictionary of services owned by that node. If/when the coordinator fail, all the services will have to be re-registered with the new coordinator.

A node can also request a service by sending a !Request command with the appropriate parameters (depending on the service). For example, PlotGragh(x,y,z) to request for a service to plot a graph given the graph coordinates (x,y,z).

The coordinator process receives and processes request from the local server running on the individual handset. It sends its response to the local server, which then forward the response to the application that made the request

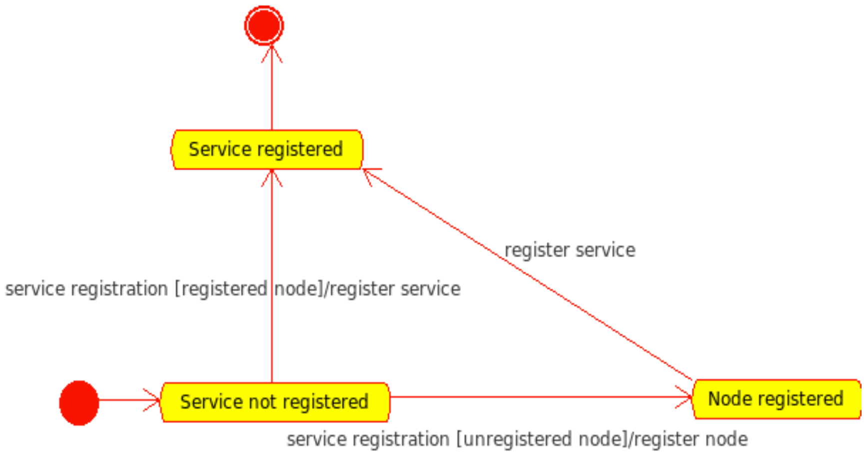


Figure 2: Add a Service - State Diagram

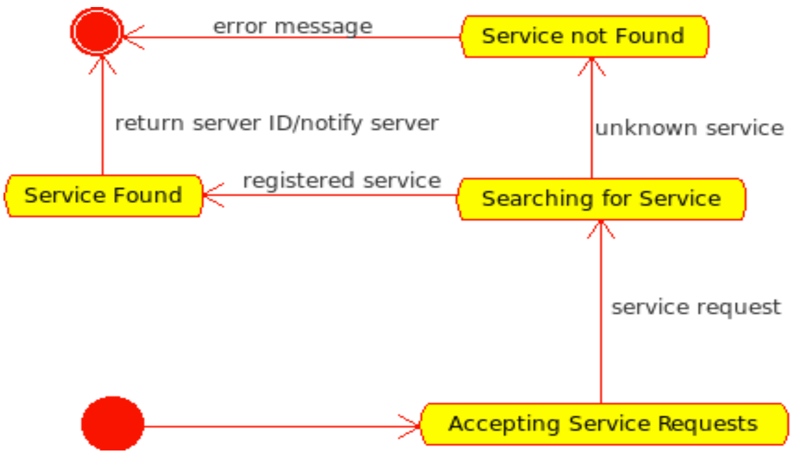


Figure 3: Request Service - State Diagram

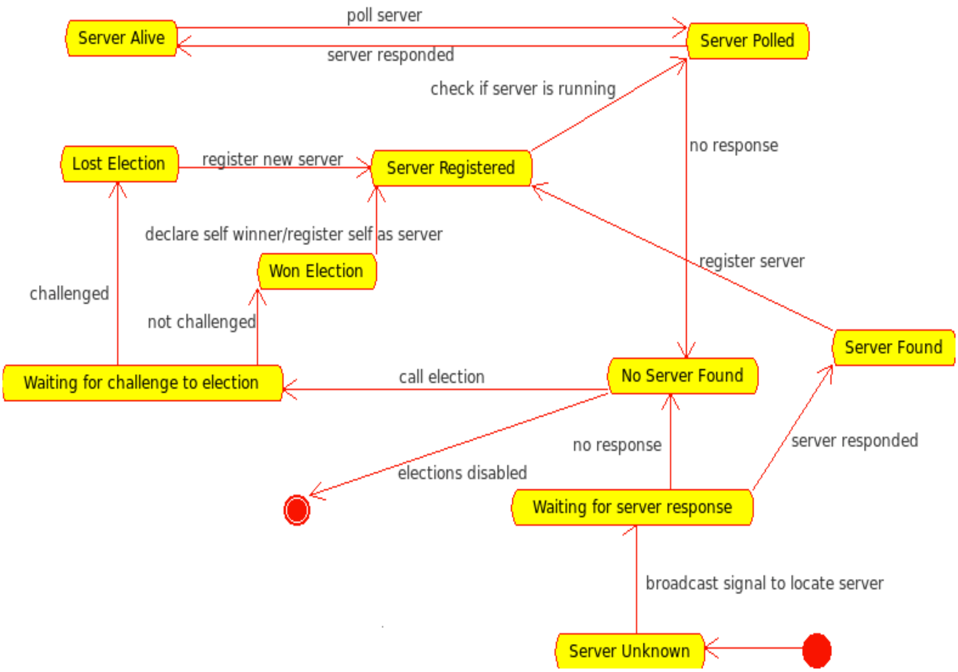


Figure 4: Elections - State Diagram

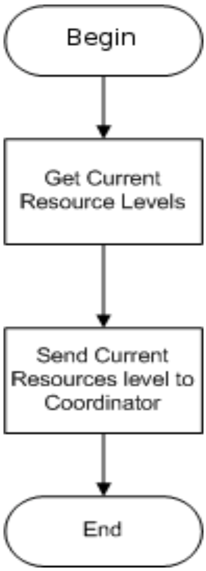


Figure 5: Responding to Polls

2.2.4 MobiGrid Coordination

The coordinator recognizes the following commands:

(I) **!Register**—register a new client by calling registerClient

(II) **!Poll**—client checking if server is still alive. It responds by calling notifyStillAlive

(III) **!PollResponse**—receive a response from a client node indicating that the client is still up and running. Update status of client by calling updateClientState

(IV) **!Request**—process a service request from the client by calling offerService

(V) **!Service**—register a new service from a client by calling addService

(VI) **!Quit**—shut down the coordinator by calling shutdown

2.2.5 Local Server Operation

Local server is a client of the coordinator but it is itself a server that is charge of any custom applications that may be installed on the handset

The local server recognizes the following commands:

(I) **!Election**—respond to an election by calling acknowledgeElections

(II) **!Winner**—declare self as winner of an election by calling signalRegisterServer

(III) **!Poll**—respond to a poll from the server to indicate that the client is still alive by calling respondToPoll

(IV) **!Alive—**a reply from the server indicating that the server is up and running. Processes using updateServerStatus

(V)**!Service**—register a service with the coordinator by calling registerService

(VI) **!Serve—**offer a service on request from the coordinator by calling doServe

(VII) **!Confirm**—a confirmation from the coordinator that the service offered by the client has been registered successfully. Processed by calling serviceConfirmed

(VIII) **!Request—**request a service from the coordinator by calling requestService

(IX) **!Found**—a notification from the server that a requested service was found. Processed by calling notifyClient

(X) **!Quit**—shut down the local server by calling shutdown

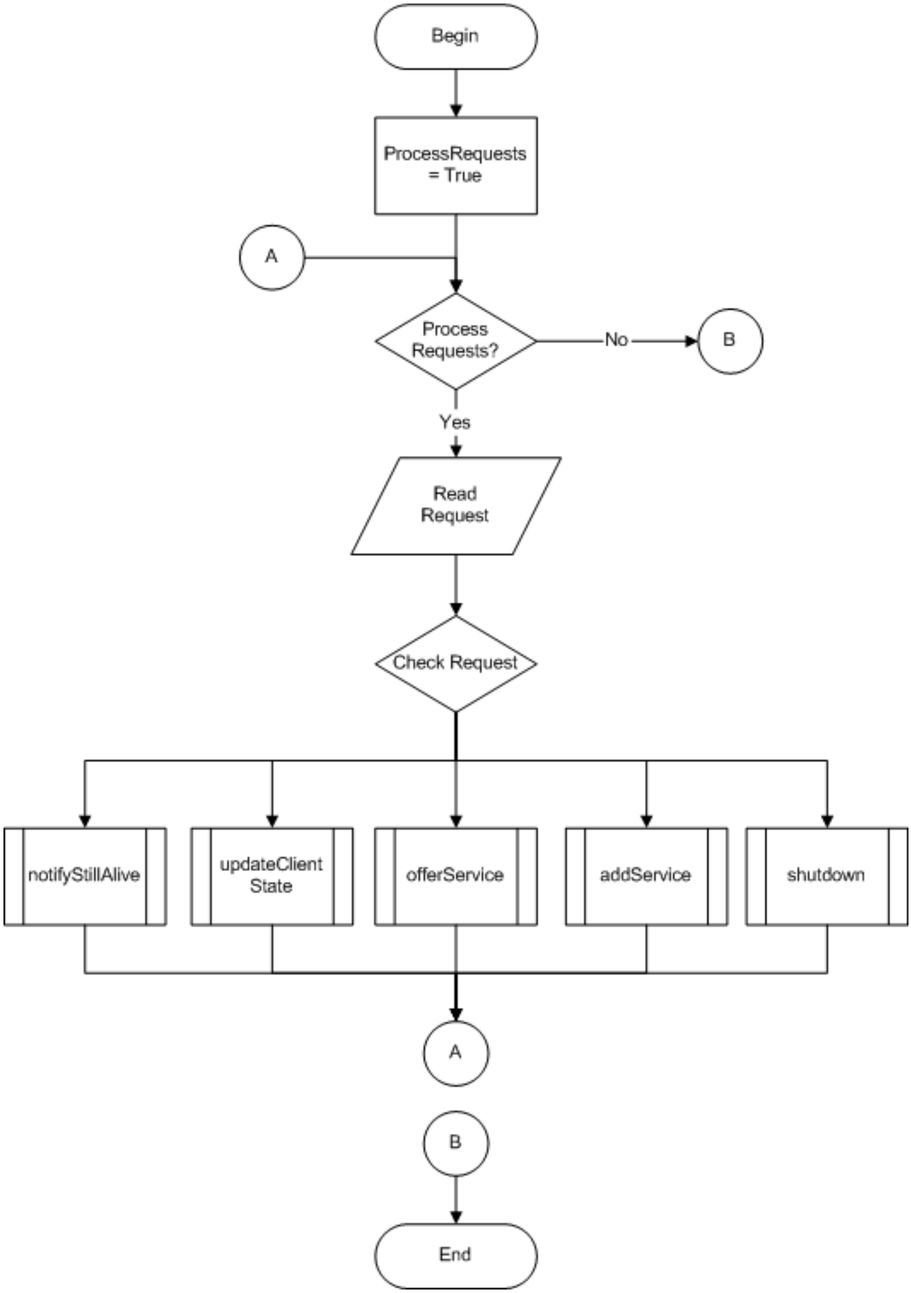


Figure 6: MobiGrid Coordination

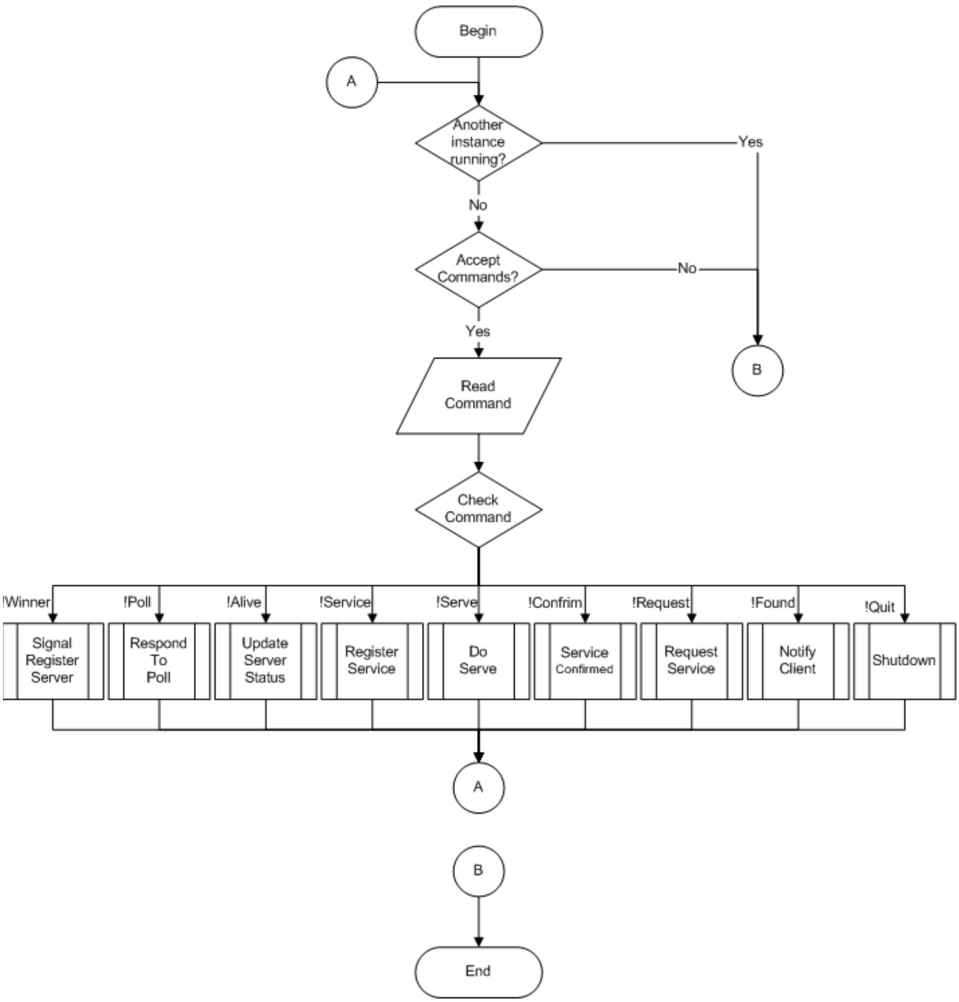


Figure 7: Local Server Operations

2.2.6 Keeping Track of Nodes

Like in any other grid, the coordinator has to keep track of which nodes are still up and which have failed. The nodes also need to continually check if the server is up and running. This is achieved by the nodes and the coordinator polling each other at regular intervals and checking and keeping count of the number of times a node/coordinator has failed to respond.

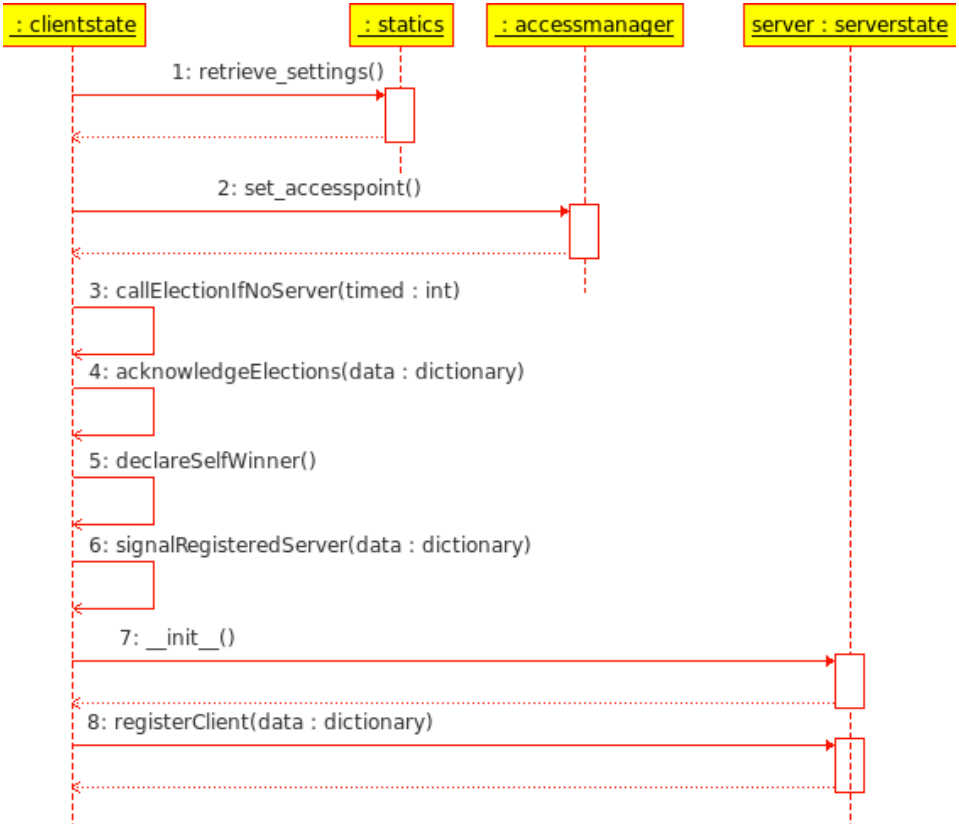


Figure 8: Keeping Track of Nodes

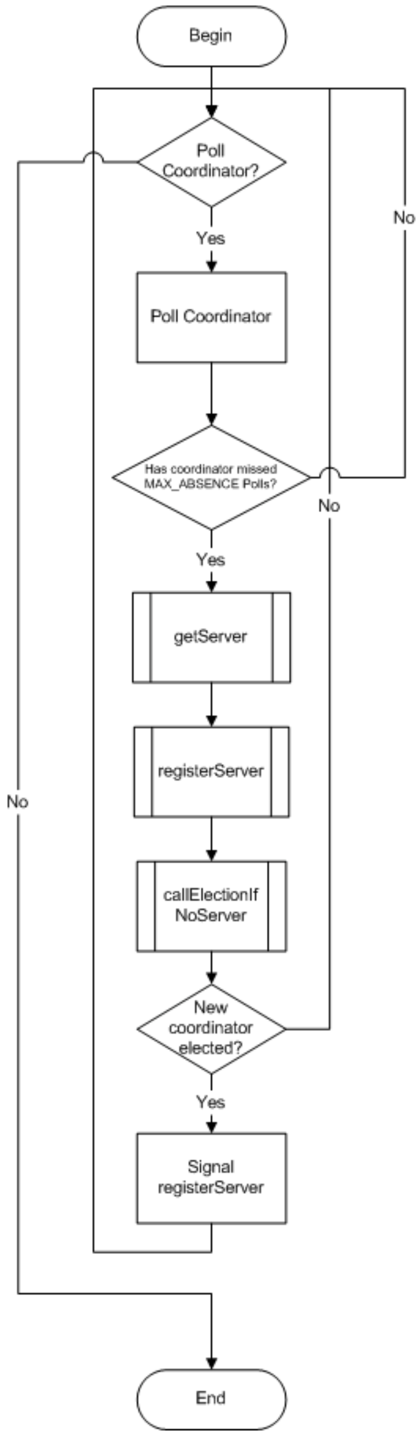


Figure 9: Checking state of the coordinator

2.3 MobiGrid Version 2 Implementation

MobiGrid Version 2 is being implemented using Android SDK 2.2 with the latest (0.97 at the time of implementing MobiGrid) version of Android Virtual Device (AVD) plug-in for Eclipse 3.6. The development (main) machine being used is MacBook Pro running Mac OS X 10.5.8 (9L31a). At the time of writing this, MobiGrid had not been tested on actual phones but was extensively tested on several AVDs.

To depict the design presented under MobiGrid Design as well as maintaining the structure of MobiGrid Version 1, two main modules have been implemented:

(I) **Coordinator Module** to run on the phone acting as the coordinator for the grid

(II) **Local Server Module** to run on all the other handsets and act as the server to manage the handsets' resources (hardware and software) needed/participating in the grid

The design also requires that all the handsets be installed with both modules in order to:

(I) empower all the phones with the ability of playing coordinator role when/if elected

(II) provide a means for servicing request to run applications running on the handset (and are part of the grid)

(III) provide statistics of resource (battery and memory in this case) utilization on the handset

Note: The Coordinator Module remains 'dormant' in all the handsets except in the one playing the coordinator role.

3 MobiGrid Version 2

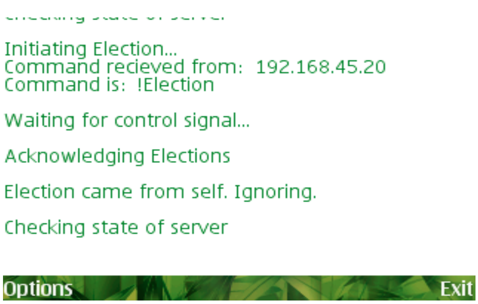
Though the implementation of MobiGrid is still on going, the following are the new features that Android has added to MobiGrid Version 1:

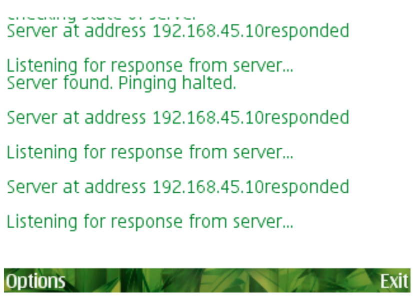
3.1 Broadcast Communication

Android directly supports broadcast communication through android.content.BroadcastReceive class. This is a base class for code that will receive intents sent by sendBroadcast(). This drastically reduced the communication overhead that was experienced during the communication from the Coordinator instance to the Local Server instances.

3.2 Multiple and Graphical Testing

By initializing multiple AVDs, it is now possible to effectively test the various aspects of MobiGrid. This is contrary to the MobiGrid Version 1 (see the sample below) that was command based (see screenshot below) and only run on two physical Nokia phone models. Acquiring tens of phones for the tests was an uphill task.





3.3 Testing MobiGrid Version 2 – Screen Shots

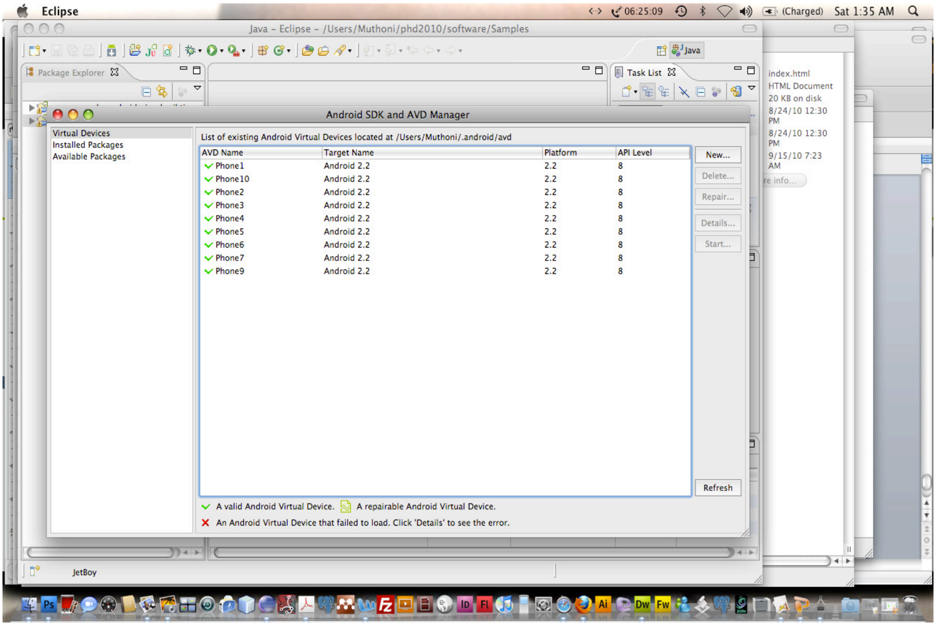


Figure 10: Creating Multiple AVDs

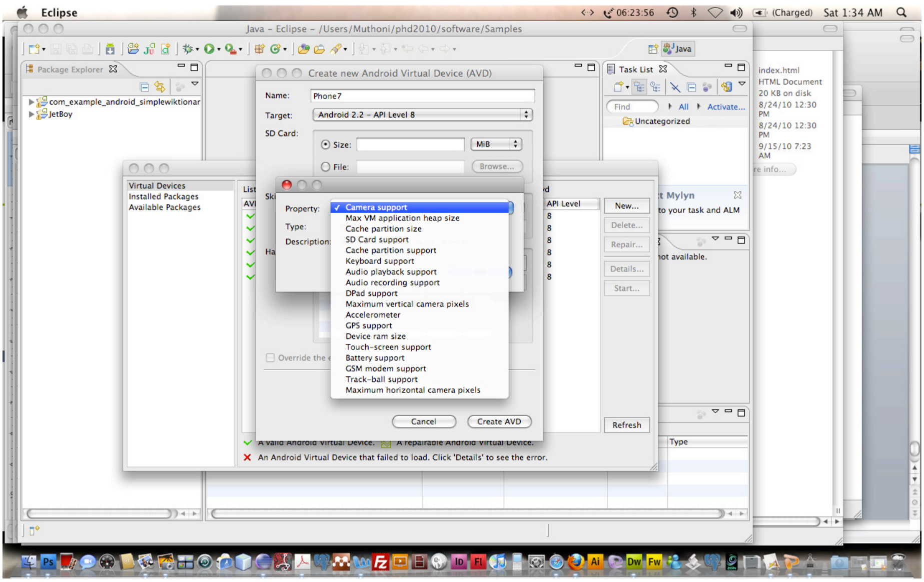


Figure 11: AVDs with Different Features

Figure 12: Running Multiple AVDs

3.4 Other Features

In the current implementation, the following features of Android are being utilized to further improve MobiGrid.

3.4.1 Location Services

This is to enable both the Coordinator and Local Server get the actual location of services/servers. android.location class is being used to achieve this

3.4.2 Improved Security

In MobiGrid Version 1, no efforts were made to impalement security. This is now being incorparated into MobiGrid Version 3 by use of the android.net.wifi subclasses such as WifiConfiguration.AuthAlgorithm and WifiConfiguration.Protocol

3.4.3 Centralized Management

Unlike in MobiGrid Version 1, management of all the nodes in the grid is now possible from a central point through telnet. Through this, nodes can be shutdown and battery/memory/network status checked

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Data Encapsulation and Mobile Access to the Protein Data Bank

Gregory B. Quinn, Garrick Berger and
Philip E. Bourne
San Diego Supercomputer Center, USA

An increasingly important demographic is the researcher who accesses scientific data not from a desktop PC but from mobile devices such as Smart Phones and tablet/slate computer devices. Typical usage scenarios may range from Smart Phone data access during a meeting or lecture, to accessing data from the laboratory bench with a tablet-like device. As mobile devices become more a part of our lives, we naturally integrate them into the way we perform tasks. At the same time, the capabilities of mobile devices are increasingly dramatically, rivaling those of desktop PC's, with powerful, energy-efficient multicore CPUs, hardware-accelerated 3D graphics, gigabytes of local storage space and high resolution displays. This makes them potentially very attractive devices for accessing life sciences data on-the-go, and whilst the larger form factor mobile devices such as the Apple iPad are obviously advantageous in that they are nearer to desktop screen resolutions and size than Smart Phone devices, smaller form factor devices such as the Smart Phone or connected music device such as iPods are more likely to be in the users pocket at any time.

1 Challenges of Data Access on the Smart Phone

Although the modern Smart Phone, as typified by the Nokia N82 and N95, both of which have hardware-accelerated OpenGL rendering capability, has network access capability through both 3G and WiFi connectivity, applications targeted for these kinds of devices usually need to be written in such a way that they can function in poor data access environments such as on a subway train, plane or remote location. Whilst part of the problem is that data transfer speeds can be low and/or sporadic, a major problem with mobile remote data access is the time lag between requesting data and that data being returned to the device, i.e. latency. Latency on WiFi at between 1-10 milliseconds is typically 1-2 orders of magnitude less than those experienced with 3G data connections [1], and can be in excess of 150 milliseconds for EDGE connections. For the end user of a connected mobile application which needs to make a number of data connections, this can seriously affect the usefulness of the application, as well as impacting the overall user-experience. For example, the typical web page not only contains textual information but usually a number of non-textual elements such as images, Macromedia Flash content, style sheet styling and JavaScript files, etc. each one of which requires a separate call to the server to retrieve the component. For this reason, using a web browser on a 3G connection can be a frustrating experience at best.

One way to mitigate the effects of network latency is to reduce the number of server calls for data; there are a number of ways to do this; web pages can be created with far less complexity, and image elements where needed could be included using inline image data URLs. For data access, larger payloads instead of more requests for smaller data payloads may result in faster overall data access.

2 Creating a Single Data Payload

The exchangeable image file format or EXIF from the JEITA specification [http://www.jeita.or.jp/cgi-bin/standard_e/list.cgi?

cateid=1&subcateid=4] is designed for digital cameras images in which metadata tags are added to JPEG and TIFF images to enable the images to be self-describing. Some examples of these tags include camera manufacturer, camera model, image resolution, a thumbnail image and many others. For JPEG images, the size limit for EXIF data fields is 64k. A number of libraries such as Apache Sanselan [http://incubator.apache.org/sanselan/site/index.html] are available for different platforms that enable image EXIF fields to be both read and written to.

We wanted to test the feasibility of including data in an EXIF data field as a mechanism of data encapsulation that could potentially reduce data connection requirements and thereby help mitigate network latency effects. For this experiment, we used images and data from the RCSB Protein Data Bank (PDB) [2], an archive of experimentally-determined protein structure information. The Structure Explorer page on the RCSB website typically makes multiple connections to the server to obtain summary data for an entry. In the mobile context, this potentially makes for inefficient data access. Reducing the data request to a single object has the potential to dramatically improve data access time. At this time, there is no mechanism to retrieve parsed PDB data in a single object.

For the purposes of our initial experiment, we chose a 500x500 pixel image and structure information for the molecular structure of yeast 1 enolase, PDB entry id 7ENL [3], Figure 1. Using the PERL EXIFTool application [http://www.sno.phy.queensu.ca/~phil/exiftool/], we crafted an image file that contained protein sequence information as well as reduced precision C-alpha Cartesian coordinates for both chains and other information such as the entry authors, primary citation abstract and structure refinement data. In short, to those not familiar with protein structure, an image and important metadata associated with that image. This data was entered into the “Description” EXIF tag in JavaScript object notation or JSON format. Our reason for using JSON-based data is that this kind of formatted data can easily be extracted and used both by web pages, for example by using Nihilogic Labs Javascript libraries [http://www.nihilogic.dk/labs/exif/], and in native applications. Table 1 displays the JSON-formatted data included in the image file in initial testing.

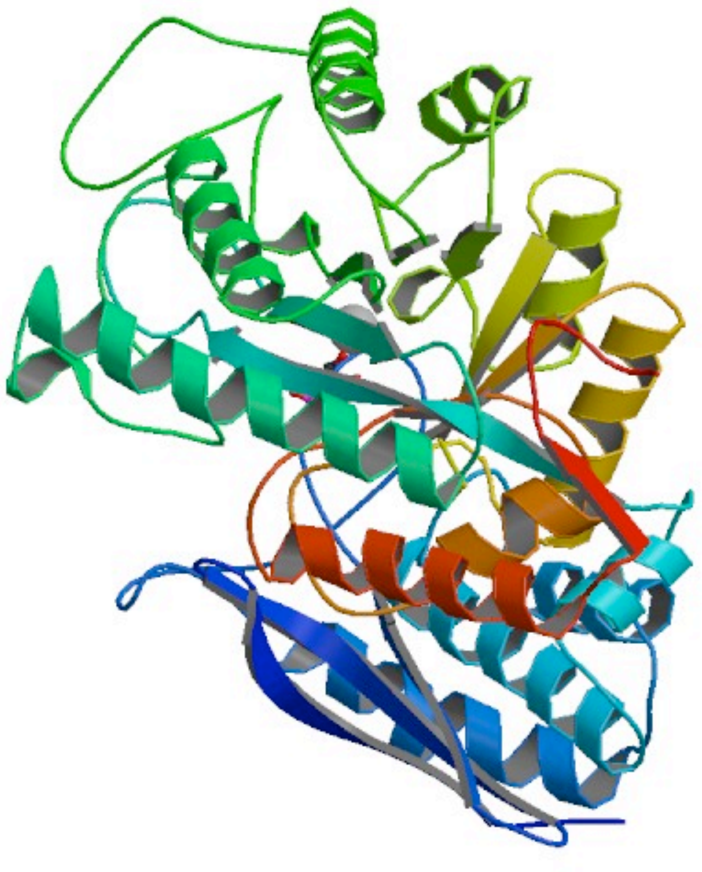

Figure 1: Image of PDB entry 7ENL used in the tests

3 Developing the Application

For the application, we wanted to be able to display the structure image, structure data and 3D C-alpha molecular view. Of the three potential language/sdk technologies to use for this Symbian-based application, Java/MIDP, Symbian C++ and Qt/C++ [http://developer.symbian.org], Qt/C++ was chosen. Qt provides excellent features for developing an 'architecturally clean' implementation relatively quickly (especially for C++). The choice also dovetails nicely with Nokia's indicated future operating system direction. The outcome of this effort would therefore be well positioned to be ported to future (Nokia or other) platforms with minimal modification.

4 Application Architecture

The application is structured as an MVC type architecture [4], with extension to accommodate the 3D aspects. The structure is reflected in the source tree organization.

Major divisions are listed here.

Controllers (ctlrs)

Consists of the singleton App class—which is accessible by everything and serves the major architectural components on request—as well as the LoaderController and SceneController classes.

Views (views)

Consists of the MainWindow class (along with the menu constructs), and various views and dialogs.

Model (model)

The model contains the pixmap image and a MolStruct instance, which contains the panel output text data, and the raw 3D coordinates for the 3D scene.

GL View (glview)

Consists of the 3D OpenGL-ES based viewer and support components. Note this viewer is a native Symbian dialog in the current implementation, due to the QOpenGL module support missing from Qt, at the time of implementation.

GL Scene (glscene)

The scene modules contain the OpenGL-ES code that describes and renders the CPath. The GL View calls this class to draw the scene, after setting up the viewing environment.

Utilities (utils)

A couple of utility classes that don't fit anywhere else, including a utility to scan the EXIF section of an input JPEG file, and another (header only) to provide explicit Symbian support.

EXTERNAL LIBRARIES REQUIRED

Beyond the libraries and dlls required for Symbian/Qt support, two external libraries are statically linked into the executable:

QXSAP (JSON Parser)

The CPath information in the EXIF section of the JPEG file is formatted in JSON syntax. A parser is required to extract the structure elements. QXSAP is a very resource conserving and speedy implementation.

EGLUtils (EGL Support Classes)

This is a set of classes that were provided by Nokia for extended EGL support under OpenGL-ES. The library provides GLFixed and GLfloat implementations of Vector, Camera, and ModelView classes.

Of these, it turns out the only classes that were useful were the GLFixed and GLfloat TVector classes. Much has been commented out of the source. It would likely be advantageous to lift those classes out of the EGLUtils lib and simply include them in the application project.

5 Data Access using the Proof-of-Concept Application

Figures 2a and b show the initial screens displayed by the application. The “Load New” menu option (Figure 2b) opens a textbox into which a PDB ID can be input. For testing purposes, there is only one entry available (7ENL). In a practical application of this delivery paradigm images containing the EXIF data would be generated on-the-fly and would be available for all PDB entries (currently over 67,000). Figure 3 shows screen captures of the image display panel. Selecting the “Show 3D” menu option (Figure 3b) causes the coordinate data to be rendered by the application (Figure 4a) in an OpenGL ES window as a C-alpha display, slowly rotating about the vertical Y axis. By selecting a display control (Figure 4b) the user can precisely control the orientation of the molecular rendering using the navigation keys on the Symbian device. Figure 5 shows two other data display panels available for this entry.

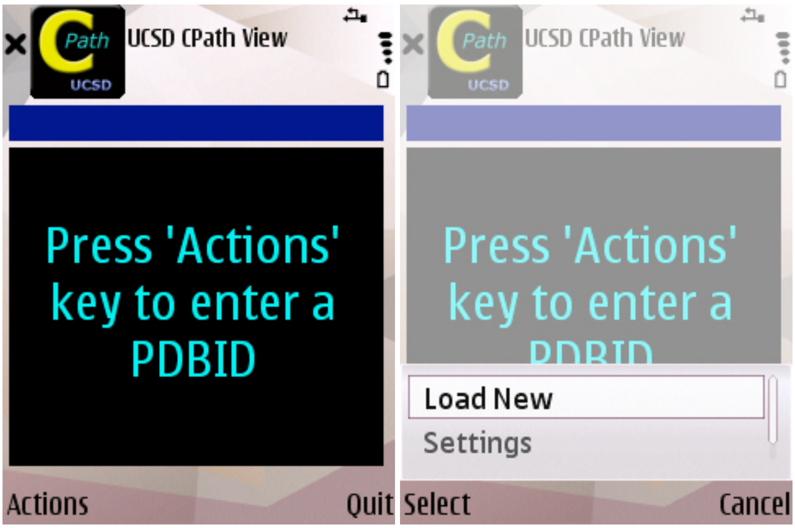

Figure 2: Opening screen(a) and menu options (b)

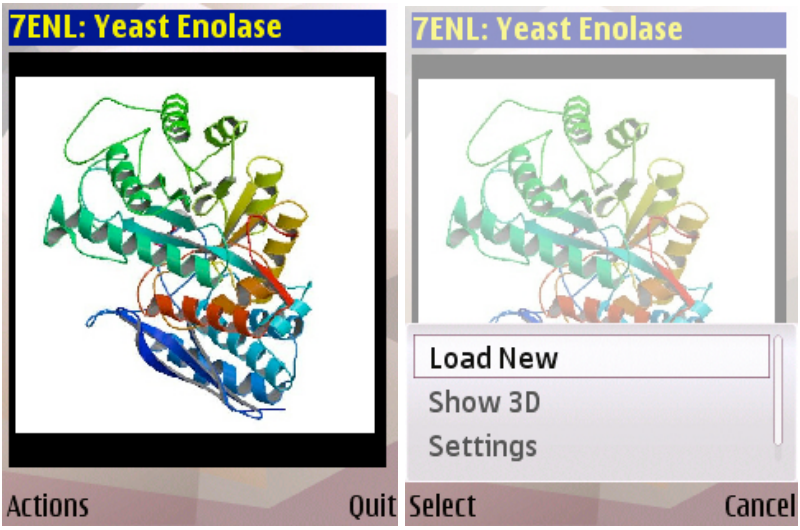

Figure 3: After data is loaded the image displays (a) and new menu options appear (b)

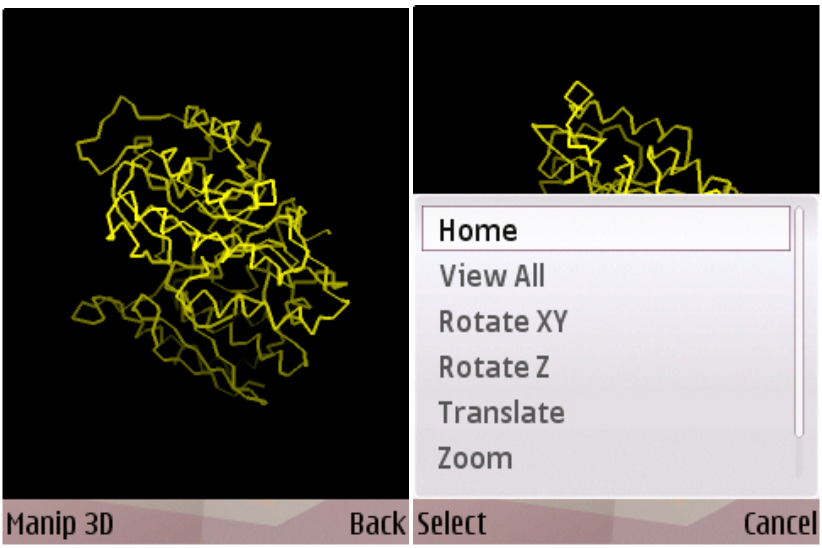

Figure 4: C-Alpha coordinate display with depth cueing (a) and user control (b)

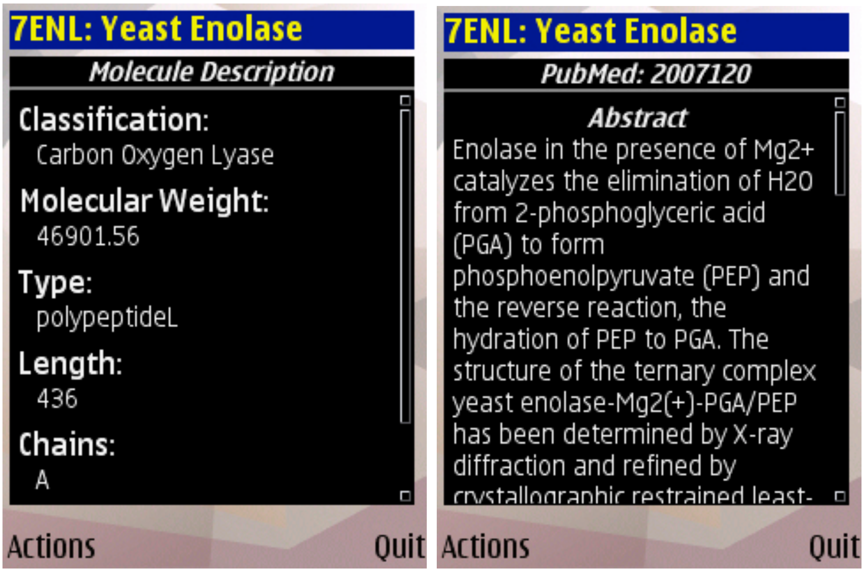

Figure 5 (a and b): Some of the available PDB Entry data information panels, including primary citation abstract (b)

TABLE 1: Abbreviated listing of PDB entry data in JSON format

{
'sequence':[
'AVSKVYARSVYDSRGNPTVEVELTTEKGVFRSIV
PSGASTGVHEALEMRDGDKSKWMGKGVLHAVK
NVNDVIAPAFVKANIDVSDQKAVDDFLISLDGTA
NKSKLGANAILGVSLAASRAAAAEKNVPLYKHLA
DLSKSKTSPYVLPVPFLNVLNGGSHAGGALALQ
EFMIAPTGAKTFAEALRIGSEVYHNLKSLTKKR
GASAGNVGDEGGVAPNIQTAEEALDLIVDAIKAA
GHDGKVKIGLDCASSEFFKDGKYDLDFKNPNS
DKSKWLTGPQLADLYHSLMKRYPIVSIEDPFAED
DWEAWSHFFKTAGIQIVADDLTVTNPKRIATAI
EKKAADALLLKVNQIGTLSESIKAAQDSFAAGWG
VMVSHRSGETEDTFIADLVVGLRTGQIKTGAPA

RSERLAKLNQLLRIEEELGDNAVFAGENFHHGD
KL'
],
'structure':[
114,17,19,
111,18,18,
109,15,16,
…
114,46,35,
117,48,37,
116,47,40
],
'Molecule':'Enolase',
'Classification':'Carbon Oxygen Lyase',
'MW':46901.56,
'Polymer':1,
'type':'polypeptideL',
'length':'436',
'chains':['A'],
'EC':'4.2.1.11',
'SourceSciName':'Saccharomyces cerevisiae',
'sourceCommonName':'Baker`s yeast',
'LigandChemicalComponent':[
['2PG','2-PHOSPHOGLYCERIC ACID','C3 H7 O7 P'],
['MG','MAGNESIUM ION','Mg'],
],
'SCOP':'2 domains',
'CATH':'2 domains',
'PFAM':'2 domains',
'GO':'13 terms',
'DepositionAuthors':[
['Lebioda, L.'],
['Stec, B.'],

],

'DepositionDate':'1990-11-13',

'ReleaseDate':'1992-04-15',

'LastModifiedDate':'2009-02-24',

'ExpMethod':'X-RAY DIFFRACTION',

'ExpData':'N/A',

'ExpResolution':2.20,

'ExpRValue':'0.169 (obs.)',

'ExpRFree':'N/A',

'ExpSpaceGroup':'P 42 21 2',

'ExpUnitCell':[122.00,122.00,67.00,90.00,90.00,90.00],

'StructureLinks':[

[

'The Glycolytic Enzymes', 'http://www.rcsb.org/pdb/static.do?p=education_discussion/molecule_of_the_month/pdb50_1.html',

],

],

'PriCiTitle':' Mechanism of enolase: the crystal structure of enolase-Mg2+-2-phosphoglycerate/phosphoenolpyruvate complex at 2.2-A resolution.',

'PriCiAuthors':[

'Lebioda, L.',

'Stec, B.',

],

'PriCiAbstract':'Enolase in the presence of Mg2+ catalyzes the elimination of H2O from 2-phosphoglyceric acid (PGA) to form phosphoenolpyruvate (PEP) and the reverse reaction, the hydration of PEP to PGA. The structure of the ternary complex yeast enolase-Mg2(+)-PGA/PEP has been determined by X-ray diffraction and refined by crystallographic restrained least-squares to an R = 16.9% for those data with I/sigma (I) greater than or equal to 2 to 2.2-A resolution with a good geometry of the model. The structure indicates the substrate molecule in the active site has its hydroxyl group coordinated to the Mg2+ ion. The carboxylic group interacts with the side chains of His373 and Lys396. The phosphate group is H-bonded to the guanidinium group of Arg374. A water molecule H-bonded to the carboxylic groups of Glu168 and Glu211 is located at a 2.6-A distance from carbon-2 of the substrate in the direction of its proton. We propose that this cluster functions as the base abstracting the proton in the catalytic process. The proton is probably transferred, first to the water molecule, then to Glu168, and further to the substrate hydroxyl to form a water molecule. Some analogy is apparent between the initial stages of the enolase reverse reaction, the hydration of PEP, and the proteolytic mechanism of the metallohydrolases carboxypeptidase A and thermolysin. The substrate/product binding is accompanied by large movements of loops Ser36-His43 and Ser158-Gly162. The role of these conformational changes is not clear at this time.',

'PriCiKeywords':[

'Amino Acid Sequence',

'Binding Sites',

'Glyceric Acids',

'Magnesium',

'Models',

'Molecular',

'Molecular Sequence Data',

'Phosphoenolpyruvate',

'Phosphopyruvate Hydratase',

'Protein Conformation',

'Saccharomyces cerevisiae',

'X-Ray Diffraction',

],

'OrgAffil':'Department of Chemistry, University of South Carolina, Columbia 29208.',

'JournalName':'Biochemistry',

'JournalYear':'1991',

'JournalVol':'30',

'JournalPages':'2817-2822',

'DOI':'10.2210/pdb7enl/pdb',

'PDBID':'7ENL',

'pubmedid':'2007120',

}

Extensive benchmarking of data download and rendering speeds has not yet been made, but initial tests indicate that connection, image and data display occurs within approximately one second of the request for a 500x500 pixel-sized image. This compares favorably with data rendering speeds for the structure explorer page on the main PDB website for the same entry ID (7ENL), making this a competitive application from a scientific perspective.

6 Future Work

The success of this proof-of-concept data delivery model and application has prompted us to move forward in using image-based data encapsulation as a practical data delivery mechanism for PDBMobile, the RCSBs new mobile application for PDB data access.

7 Conclusions

We have presented our initial work to develop a data encapsulation model that could potentially benefit other areas of mobile data access. We will continue to pursue mechanisms that enhance data download speed not only for website data access but also mobile applications.

Acknowledgements

This work was supported by a research grant to GBQ from the Nokia Research Center. This source code for the software will shortly be made freely available; please contact GBQ for further information.

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Supercomputing on a Cell Phone: MIT Stories

Larry Hardesty
News Office
Massachusetts Institute of Technology, USA

Many engineering disciplines rely on supercomputers to simulate complicated physical phenomena—how cracks form in building materials, for instance, or fluids flow through irregular channels. Now, researchers in MIT's Department of Mechanical Engineering have developed software that can perform such simulations on an ordinary smart phone. Although the current version of the software is for demonstration purposes, the work could lead to applications that let engineers perform complicated calculations in the field, and even to better control systems for vehicles or robotic systems.

The new software works in cases where the general form of a problem is known in advance, but not the particulars. For instance, says Phuong Huynh, a postdoc who worked on the project, a computer simulation of fluid flow around an obstacle in a pipe could depend on a single parameter: the radius of the obstacle. But for a given value of the parameter, calculating the fluid flow could take an hour on a supercomputer with 500 processing units. The researchers' new software can provide a very good approximation

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of the same calculation in a matter of seconds.

“This is a very relevant situation”, says David Knezevic, another postdoc in the department who helped lead the project. *“Often in engineering contexts, you know a priori that your problem is parameterized, but you don’t know until you get into the field what parameters you’re interested in”*.

Each new problem the researchers’ software is called upon to solve requires its own mathematical model. The models, however, take up very little space in memory: A cell phone could hold thousands of them. The software, which is available for download [1], comes preloaded with models for nine problems, including heat propagation in objects of several different shapes, fluid flow around a spherical obstacle, and the effects of forces applied to a cracked pillar. As the researchers develop models for new classes of problems, they post them on a server, from which they can be downloaded.

1 Advance Work

But while the models are small, creating them is a complicated process that does in fact require a supercomputer. *“We’re not trying to replace a supercomputer”,* Knezevic says. *“This is a model of computation that works in conjunction with supercomputing. And the supercomputer is indispensable”*.

Knezevic, his fellow postdoc Phuong Huynh, Ford Professor of Engineering Anthony T. Patera, and John Peterson of the Texas Advanced Computer Center [2] describe their approach in [3]. Once they have identified a parameterized problem, they use a supercomputer to solve it for somewhere between 10 and 50 different sets of values. Those values, however, are carefully chosen to map out a large space of possible solutions to the problem. The model downloaded to a smart phone finds an approximate solution for a new set of parameters by reference to the precomputed solutions.

The key to the system, Knezevic says, is the ability to quantify the degree of error in an approximation of a supercomputing calculation, a subject that Patera has been researching for almost a decade. As the researchers build a problem model, they select parameters that will successively minimize error, according to analytic techniques Patera helped developed. The calculation of error bounds is also a feature of the phone application itself. For each approximate solution of a parameterized problem, the app also displays the margin of error. The user can opt to trade speed of computation for a higher margin of error, but the app can generally get the error under 1 percent in less than a second.

Figure: New software that runs on a smart phone can approximate in seconds computations that would take a supercomputer hours. The software works for problems whose form is know but whose particulars aren't; slider bars allow users to set the values for which they want the problems solved. (Image courtesy of David Knezevic and Dinh Bao Phuong Huynh).

2 Turning the Tables

While the researchers' software can calculate the behavior of a physical system on the basis of its parameters, it could prove even more useful by doing the opposite: calculating the parameters of a physical system on the basis of its behavior. Instead of, say, calculating fluid flow around an obstacle based on the obstacle's size, the software could calculate the size of the obstacle based on measurements of the fluid flow at the end of a pipe. Ordinarily, that would require several different computations on a supercomputer, trying out several different sets of parameters. But if testing, say, 30 options on a supercomputer would take 30 hours, it might take 30 seconds on a phone. Indeed, the researchers have already developed a second application that calculates such "inverse problems".

In the same way that a simulation of a physical system describes its behavior on the basis of parametric measurements, control systems, of the type that govern, say, automotive brake systems or autonomous robots, determine devices' behavior on the basis of sensor measurements. Control-systems researchers spend a great deal of energy trying to come up with practical approximations of complex physics in order to make their systems responsive enough to work in real time. But Knezevic, Huynh and Patera's approach [3] could make those approximations both more accurate and easier to calculate.

Max Gunzberger, Frances Eppes Eminent Professor of Scientific Computing at Florida State University says that the MIT researchers' work has a "cuteness aspect" that has already won it some attention. But "once you get over the cuteness factor", he says, *"if you talk about serious science or serious engineering, there's a potential there"*. Gunzberger points out that while the researchers' demo concentrates on fluid mechanics, *"there's lots of other problems that their approach can be applied to. They built the structure that they themselves or others can start using to solve problems in different application areas"*.

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“Dissemination

Mobile Social Network in a Cultural Context

Liu Jun
University of Copenhagen, Denmark

The swift proliferation of the mobile phone as a communication tool within past decades has changed the information environment and facilitated interactivities in ways that earlier mass media have never been able to do [1]. The general nature of user-friendliness, affordability, accessibility, mobility, and intimacy that is imbedded in mobile communication has provided unprecedented opportunities for the developments of interpersonal relationships and social networks [2]. On the other hand, technology penetration and application cannot be separated from concrete political, economic, and socio-cultural factors. Different contexts have therefore shaped the characteristics of mobile phone-mediated interactions and mobile social network on different levels [3]. Nevertheless, few scholastic studies have been carried out to investigate which cultural factors contribute to the characteristics of mobile interaction and mobile social network, or how they do so [4].

Benefitting from the political and bureaucratic incentives in telecommunication network building, enormous market demands, low-cost handsets and downward price on the usage of mobile phone [5], mobile phones, including cellular phone (aka shouji (handset phone) in Chinese) and Little Smart (aka Xiao Lingtong in Chinese [6]), have become popular in people's everyday lives in China. It is worth noting that since 2001, China has the largest number of mobile phone subscribers in the world, touching 747 million by the end of 2009 [7]. Indeed they now number more than the entire 722 million mobile users in all the European countries [8]. More than half of the 1.3 billion Chinese people own a mobile phone. The figures also mean that one in every six mobile phone users in the world is Chinese. More astoundingly, the national mobile phone SMS volume soared to 771.3 billion in 2009, a 770-fold increase within ten years [9]. With a vast rural market still keen for basic communications, migrant workers desperate for extending family cohesion, and city slickers craving the up-to-date whizz-bang handsets, no wonder China is still enjoying a growth period in the mobile phone market. Researches on mobile communication for social interactions in China typically focus on the questions of telecommunication policies [10], rumours and gossips under highly-controlled situations [11], and the political implication of satiric SMS against authorities and bureaucracies [12]. Yet, of the many individuals experiencing the convenience of telecommunication development, of the many individuals suffering from information censorship, and of the many individuals engaging in SMS criticism, only a few talked about “guanxi”, a cultural term relevant to understanding interpersonal relations and the social network system in Chinese society. By examining the spread of Severe Acute Respiratory Syndrome- (SARS) and war-related rumours via mobile phone and Internet in China, Ma argues that the combination of technology convenience, media censorship and guanxi in Chinese culture makes Chinese society a place that “tends to very easily become a warm bed for rumours” [13]. However, herein lies the dilemma: if guanxi penetrates Chinese people’s daily life, why does guanxi only appear in case of rumours? If guanxi does not, how can the understanding of mobile phone interactions and mobile social networks be extended under the particular guanxi structures of Chinese society?

Given the specific features of this cultural context, my goal is to sketch a framework for understanding the formation of guanxi-embedded mobile social network in China. I will first introduce guanxi, the heavy reliance on interpersonal relationships in Chinese culture. Second, I will explain the characteristics of guanxicohesive mobile social networks by looking at different cases where Chinese people use mobile communication to cultivate, maintain and strengthen guanxi, and further, breed new ways of social cohesion with mobile communication. The paper at the end highlights and addresses the dynamics of guanxi-based mobile social network that has emerged in China in the wake of wireless telephony communication. This study also provides another way of understanding the relationship between social network and mobile communication in China, and the influence of socio-cultural factors on technology application, in contrast to several existing studies, which drew their conclusions ignoring influences from the distinctively Chinese guanxi culture.

1 Understanding the Dynamic of Guanxi

1.1 Guanxi in Chinese Society

Guanxi, literally meaning “relation” or “personal connections”, stands for the endemic interpersonal relationship and social ties among various parties that make up the network and support another in various Chinese milieus [14]. As Yang defines it, guanxi *“means literally ‘a relationship’ between objects, forces, or persons. When it is used to refer to relationships between people, not only* *can it be applied to husband-wife, kinship and friendship relationships, it can also have the sense of 'social connections,' dyadic relationships that are based implicitly (rather than explicitly) on mutual interest and benefit"* [15].

Distinguished from the independent existence of the individual in Western thought, the nature of a person is "a relational being, socially situated and defined within an interactive context" [16] in Chinese Confucian view. In other words, as Bian and Ang elaborate, *"[the] self is identified, recognized, and evaluated in terms of one's relations to the groups and communities to whom one belongs"* [17]. The individual in Chinese society is always considered an entity within a network of guanxi, the social ecology of relational interdependence.

In addition to personal identity, guanxi conjures up both personal ties and social network (shehui guanxi, guanxi wang), the extended form of guanxi, with implicit claims on mutual emotional, interest or benefit involvements. The most common bases for building guanxi include blood relation and spatial connections (e.g. friends, neighbours and classmates) [18]. So and Walker [19] reinforce that people's sense of self-worth depends on how well they deal with those related to them within their guanxi network. In this way, according to Fei Xiaotong, *"the [Chinese] society is composed …of overlapping networks of people linked together through differentially categorized social relationships"* [20]. Regardless of an ever-changing set of social practices from pre-revolutionary, pre-reform to the reform eras, Chinese everywhere seem to rely heavily on guanxi to adapt themselves to the changing environment and strive for resources to satisfy their needs [21].

As a powerful lubricant to survival and success in Chinese society, guanxi has extended into political, economic and social dimensions [22]. For instance, guanxi has been widely recognized by both Chinese and non-Chinese businessmen and investors as a key element to successful business [23]. Observed by Ruan in his 1986 survey in Tianjin, ordinary workers in enterprises must cultivate guanxi with officials who will "use their discretionary power in distributing goods, services and other benefits" [24]. Yan reveals as well that in rural communities guanxi exists "in its multiple functions in everyday life" [25]. He also notes that *"one's guanxi network covers all ramifications of life in the community, ranging from agriculture production and political alliances to recreational activities"* [26]. That's why Chinese society should always be described as "guanxi shehui" (guanxi-based society). Due to *"the strong relationship orientation of Chinese culture"* [27], those who are introverted and incapable of cultivating and maintaining guanxi are as a result *"relegated to socially disadvantaged positions"* [28].

1.2 Characteristics and Application of Guanxi

Always adapting itself to new institutional arrangement and functioning in a unique Chinese way, guanxi has three key characteristics [29].

First, guanxi takes root in familiarity or intimacy, which means the totality of personal connections rather than only being based on money. Connecting two peoples in a bond, guanxi also means that both sides must *"know a great deal about each other and share with each other frequently"* [30]. In other words, guanxi includes not only a utilitarian view of relationship but also ganqing (affection, attachment), the rapport of an emotional interpersonal relationship.

Second, guanxi carries reciprocal obligation. Guanxi usually develops between persons who are strongly tied to each other, and is a mutual obligation for both sides to respond to requests for assistance. As a reciprocal process, guanxi not only stimulates endless circulations of favours and gifts [31], but also embeds itself within Chinese society to a far greater extent as *"a dynamic process embedded in social interactions in everyday life"* [32]. If people fail to fulfil their obligations, they will be isolated, depraved, lose face (mianzi), even suffer the ultimate price of losing their guanxi networks and the social resources embedded in them [33].

Reciprocity also means both sides will share each other's social circles after they set up guanxi. Therefore, guanxi also acts as an intermediary to tap into other's social connections and resources. To do this, guanxi extends to guanxi networks, the intricacy of guanxi development and hidden rules of social interactions and network structures permeating in Chinese society [34].

Third, and the most important characteristic of guanxi as I see it, is personal reliability. Guanxi involves not just material interest, but also various degrees of reliability of personal relations and social supports, including trustworthiness, solidarity, loyalty and friendship, according to the degree of guanxi between people [35]. For one thing, personal reliability accounts for the credibility of information exchange and effectively prohibits the occurrence of opportunism with, for example, false diplomas or certifications for education, training and work experiences [36]. Also, the significance of guanxi had been reinforced in a Chinese environment that is characterized by inadequate social infrastructure, weak legal institutions which failed to provide *"a trusted third party adjudication and enforcement of private agreements"* [37], and *"unpredictable risks of arbitrary bureaucratic intervention"* [38]. Furthermore, according to Yan's anthropological work, the decline of social trust leads *"one to trust only those individuals in one's personal network and to behave in accordance with a particularistic morality"* [39]. When rules are still not as important as personal relations, people in China always focus on the exceptionality of present circumstances and make their decisions and judgments *"based on acquaintance or lack of acquaintance with others"* [40] instead of resorting to law or other formal rules [41].

To initiate, maintain and strengthen guanxi requires a huge amount of frequent interactions. On the one hand, social interactions, such as gift-giving, sometime easily conflated with bribery, corruption and illegal payment, are required as an effective method to initiate guanxi and create a sense of long-term obligation for the recipients because *"frequent contacts with each other foster understanding and emotional bonds"*. On the other hand, *"for the further development and maintenance of guanxi, conformity to renqing (favour, human feelings) rules, in particular, reciprocity and continued social interaction as well as the utilization of the guanxi relationship are essential"* [42].

Despite the above efforts, most studies have failed to include guanxi in their analyses of the impacts of technological elements, for instance, the Internet and mobile phone. Acknowledging the proliferation of mobile telecommunication infrastructure as a new grounding for interpersonal connections and "quasi-mass communication" [43], what is needed is an analytical focus on guanxi in the context of mobile technological innovation.

2 Case Studies and Data Collection

This study explores the relation between guanxi and mobile social network through three types of cases, including New Year SMS greeting (New Year SMS), mobile communication and job allocations for migrant workers, and rumours via mobile network in China. I first elucidate the reasons for selection of cases, and second, explain the data collection.

2.1 New Year SMS

My first case study focuses on the exchange of greeting text messages during Spring Festival in China. Spring Festival, also known as Lunar New Year, is the most important and prevalent traditional Chinese holiday. Although many traditional parts of the celebration have disappeared or have been banned [44], the meaning of paying New Year calls remains unchanged. Greetings exchanged around holidays, in particular Spring Festival, keep people connected and strengthen their guanxi. The exchange of New Year greetings therefore is a useful means of measuring the composition of one's guanxi network [45].

As the ubiquity of mobile devices increases, Chinese Spring Festival sees mobile messages flower. In addition to oral greetings to friends and relatives via a phone, the popularity of New Year SMS has overtaken visits to relatives and friends and sales of New Year Greeting Cards, developing into the best way to greet friends and family and spread the good cheer. A total of 23 billion short messages and 1.33 billion Multimedia Messaging Service (MMS) were sent during the 2010 New Year Festival, with 13 billion on the first two-days alone, i.e. New Year's Eve and New Year's Day [46]. It means an average of 30.8 wireless messages had been sent per person based on the 747 million mobile users. In the 2009 Chinese New Year holiday, SMS traffic was about 19 billion messages, while in 2008, 2007, 2006 and 2005, the figures were 17 billion, 15.2 billion, 12.6 billion and 11 billion messages respectively [47]. Although people criticized stylized messages as being devoid of human emotions compared with traditional door-to-door greeting, so many people tried to SMS on New Year's Eve that networks became jam-packed and many of the messages arrived hours late. Why do people's passions for New Year SMS exchange run high and suffer not wane as the year passes? What is the relation between guanxi network and New Year text messages?

2.2 Mobile Communication and Job Allocations for Migrant Workers

The allocation of jobs is another case that is often used to illustrate social networks [48]. In China, job-hunting accounts for a considerable proportion in everyday life of "migrant workers". Migrant workers are a floating population from less-developed central and western areas which move to more prosperous coastal areas and big cities in order to hunt for jobs [49]. By the end of 2008, the number of migrant workers has been estimated at 225 million or nearly 17.0% of the population [50]. The low-cost of Information and Communication Technology (ICT) devices, including prepaid phone cards and Little Smart mobile phones, and cheap tariffs encourage mobile phone penetration among migrant workers. Data shows that 72.9 percent of migrant workers own a mobile phone, which is much higher than the average mobile phone penetration rate in China in the same year—45.5 percent [51]. My ethnographic survey in 2008 about migrant workers and their use of mobile phone shows that, of the respondents in both urban and rural areas, over 90 percent had a mobile phone, which also reflects the popularization of the mobile phones among migrant workers [52]. The mass use of mobile services also gives mobile phone a significant role in the migrant workers' daily life, including maintenance of emotional connections between geographically dispersed family members, formation of “translocal networks”, organization of group scuffles, negotiation of romantic relationships, and transmission of job information [53].

Pursuing better job opportunities to earn more money and improve quality of life is central in many migrant workers’ everyday lives. Provision of job information also plays a key role enabling local government to decrease unemployment rate and ensure social stability in urban areas. However, as several studies show, job information still mainly comes from the network of kinship, fellow-villagers and friends. Recently the mobile phone has been an important part of this communication [54]. Indeed, local governments have built up various supporting systems, including SMS job alerts by local telecom service providers (SPs) as one of the most important elements, to spread job information and help migrant workers find work [55]. Compared with job information within groups of migrant workers, SMS job alerts have advantages in both quality and quantity. One may ask, however, how migrant workers feel about mobile phone-spread job messages from their guanxi network and those from local SPs? What are the characteristics of the mobile social network among migrant workers?

2.3 Rumours via Mobile Network

The third case examines mobile phone rumours and guanxi networks during the 2003 SARS epidemic [56] and the 2010 Shanxi earthquake panics [57]. The word “rumours” here refers to messages denounced by governments and expertise agencies, for instance, medical institutions in 2003 and earthquake bureaus in 2010 [58]. Since 2003, rumours via mobile network have initiated mass panic, stirred up disturbances and even triggered mass incidents, including riots, protests, demonstrations, and mass petitions [59]. Why do people believe mobile rumours instead of clarifications from governments? In particular, how do people consider mobile rumours and their social network? The case study shows a relation between mobile rumours and guanxi network.

2.4 Data

The data for this study are interviews carried out between 2003 and 2010. The first study on “New Year SMS” is based on over 30 face-to-face, telephone and web semi-structured interviews with mobile subscribers in Beijing, Shanghai, Guangzhou, Nanjing, Wuhan and Fuzhou during Spring Festivals in 2005, 2007, 2008 and 2009. The framework of the interview included:

Demographic data, including age, gender, education, career, socio-economic status and mobile phone usage time.

Behavioural data on New Year SMS practices such as how many SMS they send during the seven-day Spring Festival vacation, when, to whom, and why? Are there any personal experiences or stories about New Year SMS? Our interviewees always found it difficult to provide the accurate number of text messages they sent and received during the Spring Festival period. Instead, I asked the interviewees to estimate the number of New Year SMS according to the receipts from telecom service providers and then to compare the list of SMS senders and receivers with their guanxi network. Neither the lists of senders nor those of receivers represent the whole guanxi network of one person. For example, a teacher recalled that he never sent any SMS greeting back to his students because *“the students are not within [his] guanxi network”* [60]. Nonetheless greetings via mobile network *“cover a majority of [people’s] guanxi network”* [61].

Attitudinal data: viewpoints towards New Year SMS.

To explore migrant workers’ mobile phone use and their job searches, I hired two assistants to organize two focus groups of migrant workers in Fuzhou in May and August 2008. Each group consisted of eight people. We went to four labour markets for migrant workers and five selected companies which had over 50% migrant workers amongst their total workforce from rural and urban areas [62]. The selection procedure used a random sampling protocol from list of names first, and then followed voluntary principles. We obtained detailed information about the use of mobile phone in exchanging job information from personal observations and interviews. We carried out interviews in interviewees' workplaces and asked them to talk freely on the basis of their experiences of job searching and, in particular, the use of mobile phone, encouraging a full, meaningful answer using the subject's own knowledge and/or feelings.

Third, I conducted the study of "mobile phone rumours" using in-depth interviews with 17 mobile phone users, six in Guangzhou during the 2003 SARS epidemic and eleven in Shanxi Province among January, February and September, 2010 [63]. Two additional things worth mentioning are earthquake rumours. First, after the magnitude 6.8 earthquake in Sichuan in 2008, rumours appeared about new earthquakes. These rumours ran rampant and created large scale social panics, for instance, in Beijing, Tianjin, Inner Mongolia, Shaanxi province, Henan province and elsewhere in China [64]. Second, earthquake rumours appeared twice in Shanxi in 2010 [65]. On January 24, an actual quake in Yuancheng county of Shanxi province happened after national and local earthquake bureaus dispelled the first earthquake rumours. As a result, when the identical rumours returned a month later, in February, for a second round, the earthquake rumours sparked a more far-reaching public panic in Shanxi. To separate the influences from mobile network with earthquake scare, I focus on people's attitudes toward the messages from mobile communication channel rather than the content of the information. I also ask respondents whether or not they have forwarded rumour messages, if so, how many, to whom, when and by what reasons.

3 Findings and Discussion: Guanxi and Mobile Communication in China

3.1 New Year SMS and Guanxi Network

During my interviews, New Year SMS were seen as the best, low-cost way to convey people's New Year wishes and greetings. Each respondents had sent greeting SMS in the past three years in the seven-day Festival vacation, particularly on New Year's Eve. Of the respondents, 92.3% (24 of 26) stated that they mostly favoured SMS greeting via mobile network when asked about their greeting activities.

The data shows that the New Year SMS's reinforce guanxi. All of my respondents noted that New Year SMS had an active role in keeping and strengthening their personal guanxi and guanxi network. As one respondent notes, *"there is nothing more important than sending greeting SMS at the proper time in the New Year's Eve, not too early, not too late"* [66]. With regard to greeting SMS, it is a convenient and implicit way to say *"I remember you on this specific day. I would like to send you my best wishes. You are a very important person in my personal guanxi network"* [67]. Therefore, on the one hand, for the people you always contact, New Year SMS means greetings at the specific time to show that you have appreciated their help and friendship in the past year. On the other hand, for those friends with whom correspondence was irregular, greeting messages implicitly tell them that they are not forgotten. Over 92 percent of respondents in that year's survey agreed with this thought [68].

Furthermore, the connotation of a New Year SMS is more complicated than it appears. First of all, selecting receivers is neither a random process nor a simple inclusion of all the names in a person's mobile phone directory. The process means *"to choose the person with whom you have a guanxi and a level of intimacy"* [69]. As one explains, *"the higher-ups and the person who helped you in the past years should be the first and foremost one to receive the greetings"* [70]. Second, it is also an act showing regard for these people. *"The earlier you send the messages [in the New Year's Eve] to someone who has meant a lot to you, the bigger impression you will leave on them. Because people will get tired later with hundreds of greeting SMS coming from other friends"* [71]. In particular, as one added, *"you can mention implicitly in the SMS the help you get from the person, this can remind your receivers that you are still keeping good memories of* *what they have done for you. Then they will appreciate your thought"* [72]. That becomes a useful way to nurture and further strengthen guanxi between sender and receiver.

It's also a sense of achievement when you send hundreds of greeting SMS, *"because it shows that you have abundant guanxi and social resourses"* [73]. Mr. Luo, a staff member in a local telecom company, sent over 350 SMS greetings on New Year Eve in each of the past four years. *"It is cheaper for telecom staff to send SMS. More importantly, sending New Year SMS offers you a chance to consider how much guanxi you still have, and how much guanxi you would like to maintain"* [74]. To do so, New Year SMS exchange provides the best way to map one's guanxi network.

On the other hand, guanxi suffers when the receiver does not return the greeting. *"That may lead me to think about what happened between us. Is there anything wrong between us? But in the long run, I may choose not to send greetings to this person in the next holiday. The absent mutual greetings at least showed that our guanxi is not as strong as I thought, or the person does not respect me so much"* [75] According to one respondent, *"I will regard the people who do not send back their SMS greetings as a penny-pinching person. They did not want to send an SMS of 0.1 Renminbi, so are unlikely to help me in future"* [76].

People feel "guilty" when they forget to send a New Year SMS, or are unsure whether or not they have already done it. One respondent says: *"I once unintentionally forgot to send an SMS greeting in New Year's Eve to one of my friends. Then I got an SMS [greeting] from her. I immediately felt guilty, guessing that she maybe regarded me as taking no account of her. I therefore chose one SMS with special greetings and sent to her with my apology"* [77]. *"Being the first to send the greeting SMS"*, as a result, has an implication: *"to me, you are a much more important friend and I am really concerned with you as I am sending my greetings before you do so to me"* [78]. Another respondent recalls that one of her friends asked her after the vacation that *"did you receive my [greeting] message? I did not receive yours"*. She felt embarrassed because she cannot remember exactly whether or not she has sent. She chose to lie to her friend and said *"yes, yes, yes. I also sent my regard to you. Did not you receive that? Maybe it is because of the SMS jam [that you did not get my feedback]*". This respondent explained to me that *"it is not a deliberate lie. Because I do not want to disappoint my friend, no matter I forgot to send her SMS greetings or my message had been jammed".* In addition to the easy, fast, trendy and also cost effective advantages of SMS, the obligations in guanxi therefore implicitly play a central role in the exponential volume of Chinese New Year SMS, as people feel the necessity to send greetings to everyone who might send to them in their guanxi networks.

Wireless telecommunication technology brings the blessings of the new approach, as well as a means of modernization in maintaining and strengthening guanxi. Mobile communication does not merely entail a convenient way of interacting greetings but also facilitates the formation of guanxi-embedded social connection. The staggering volume of SMS greetings indicates the size of receiver's guanxi network, or "social capital" [79], because everyone within the network is obligated to reply the greetings. Consequently, maintaining and strengthening guanxi lies at the heart of exchanging New Year SMS. Through mobile communication, during holidays in particular, people greet each other, maintain and nurture their guanxi network, and build up *"a real virtuality integrated with other forms of interaction in an increasingly hybridized everyday life"* [80].

4.2 Job Allocations, Guanxi and Mobile Network

As a convenient way to spread and receive information, mobile communication also provides migrant workers with most of their job information, and further increases their social and geographical mobility. As one respondent says, *"after I arrived in this city, all the information about my three jobs came from my friends and townees via my mobile phone. Twice I got information via SMS and once through calling. I also shared [job] information [via mobile network] with my friends and relatives"* [81]. Another respondent adds that *"we always exchange job information via our mobile phones. It is* *hard for yourself alone to find a job in a strange city. You have to depend on your relatives, friends and, in a word, [your] guanxi network. Getting up-to-date information also enhances our competitiveness. The mobile phone is a convenient tool to achieve that goal"* [82].

Migrant workers prefer job information which comes from their guanxi network to that which comes from service providers and local governments. All interviewees knew about the SMS job alerts network supported by the local telecom services. While 10 received job information from telecom services, only two used that information.

Why did they ignore or even "immediately delete" [83] job information from the government? A typical answer during our observations and interviews is *"I do not have the ability to judge real or fake job information [from telecom servicers]. And I trust those messages from my friends, relatives and townees"* [84]. One of our interviewees adds that *"we do not mean that the information [from government] is fake. But messages from [our] guanxi network are more reliable [to us]"* [85]. Personal connections from guanxi-embedded mobile communication mean that the information obtained is given high credibility.

This practice of job allocations in China distinguishes from Granovetter's "strength-of-weak-ties" argument [86]. In his classic studies of job-seekers' networks, Granovetter emphasizes the importance of "weak ties" (of group with low intimacy or infrequent interaction) as an access to *"information and resources beyond those available in their [people's] own social circles"* [87]. However, as Bian's fieldwork of job assignments in China shows, guanxi, not matter direct or indirect ties of exchange relations, facilitates "strong ties of trust and obligation" [88] with personal influence. Consequently, in job searching activities, Chinese people, first and foremost, locate a "personal helper" or "individual control agency" within their guanxi network, or seek to build up indirect ties through their existing guanxi network. If you do not have guanxi, your job application could most probably fail even though you have the correct information. In contrast, a different scenario with guanxi was identified empirically by Bian where the "strong ties" of job-seekers' guanxi network was even used to influence job-control authorities. In this way, information, the key element in "strength-of-weak-ties", becomes "only a by-product of influence received" in guanxi network.

Both trust and reciprocal obligation embedded in the strong ties of guanxi network play pivotal roles in information diffusion among migrant workers' job searching. On the one hand, as Zhai finds out, *"reliable information always comes from individuals [who build up guanxi]. On the contrary, social institutions usually spread unreliable information"* [89]. As a migrant worker receives more identical message from one's guanxi-embedded mobile network, the information gains higher credibility. As the information increases in credibility, the message disseminates wider and faster. As one respondent stresses, *"if you always keep [job] information to yourself and never share it with others, how you can expect other people to help you? How can you build up your guanxi?"* [90] Another respondent adds that *"when we share job information, we are following a well-known Chinese saying: 'sharing the fortune and bearing the hardship together' ('share and share alike' in English). We will strengthen our guanxi network and get more reliable information from each other"* [91]. Consequently, information duplication, the enemy of information diversity in "strength-of-weak-ties" argument, provides reliable information in migrant workers' job-seeking activities. That is why migrant workers pay less attention to governmental SMS job alerts, even when the information is true.

Three features distinguish migrant workers' job-search activities with guanxi-embedded mobile communication. First, migrant workers actively share job information via their mobile networks. In addition, mobile phone-mediated guanxi network among migrant workers concretizes the migrant network in studies of Chinese migrant workers, playing a key role in migration living, "chain migration" [92] and their job searching. Second, the guanxi-embedded mobile connection illustrates the heavy reliance of migrant workers on mobile phones in their job searching. Third, mobile phone networks embody migrant workers' guanxi and social network. On the one hand, SMS information duplication increases the credibility of messages. On the other hand, mutual obligations promote identical messages flow within guanxi network, and in turn, enhance mutual dependence.

3.2 Guanxi Network and Mobile Phone Rumours

The last case to be considered here is the phenomenon of mobile phone rumours. During the 2003 SARS epidemic, mobile phone rumours proliferated throughout China after SARS hysteria popped up in Beijing, Guangzhou, Shanghai, Hong Kong and elsewhere. One version of the rumours asserted that fumigating rooms with boiling vinegar could kill SARS germs and prevent the spread of pneumonia. Another claimed that Ban Lan Gen (isatis), a kind of Chinese herb, can enhance the body immune system, and particularly, ward off SARS. Mobile rumours triggered widespread panic buying of vinegar and Ban Lan Gen as effective SARS-deterrents. Many supermarkets soon ran out of vinegar, while local herbalists also reported brisk trade on items of herbal medicine.

Another theme in SMS rumours was earthquakes. In the early spring of 2010, panic arose in several cities in Shanxi province as a text message claimed that an earthquake was about to strike Shanxi. Earth experts tried to dispel the rumours through local media, vowing that they did not predict a "destructive earthquake" in the near future. Instead of blowing over, earthquake rumours emerged as a constant in conversations, mobile chats and in instant messaging. One of the mobile rumours said that *"there will be an earthquake before 6 am tomorrow around the areas of Yuci and Taiyuan [of Shanxi Province]. Please be sure to pay attention to [earthquake]. Please forward this to your friends. Bear in mind!"* [93] Propelled by mobile texts and the Internet, public fear of an imminent earthquake in Shanxi intensified and the panic became palpable. Around 3 am in the night of February 21st, thousands of citizen in different cities in Shanxi were walking down the streets and squares, some people with canes in their hands, anxiously waiting for "the predicted earthquake" [94]. As one respondent describes on the next day, *"all of Shanxi was sleepless last night"* [95]. Even though local governments and public security bureaus refuted the rumours, few responded and went back home. How and why did these mobile rumours spark worry and disturbances in society?

One respondent recalled that *"my colleagues texted the messages to me, saying that vinegar and Ban Lan Gen function as prophylactic measures of SARS. Lots of my relatives, including my parents, received several mobile texts and callings in similar content. Actually I am not fully convinced by this information. But I still followed what the message said, meanwhile forwarded it [to my close friends and relatives]"* [96]. In SARS case, all respondents forwarded the information, either via callings or through text messages, to their relatives, colleagues and friends. *"Although there are some doubts over the curative effects [of vinegar and herbs], I am quite sure that my friends and relatives will neither lie to me nor hurt me. So I believe [the message]. I also forward mass text messages to my friends and relatives, because I hope to remind them [of this possible way to prevent SARS]. And it is convenient to send bulk SMS via mobile communication"* [97].

We find similar reactions to mobile rumours of earthquake. Even though some people remained in doubt about the authenticity of the rumours, few hesitated to transmit such messages. One respondent admitted that *"the more mobile text messages I get about earthquake, the more scared I become" because all these messages comes from "people I trust, including my relatives and close friends"* [98]. Many people hastened out of their houses in a great rush while still calling their relatives and friends *"to rush to open spaces"* as *"these people mean a lot to me"* [99].

If the SARS epidemic is the first time mobile phone rumours sparked public panic, mobile rumours related to natural disasters, including earthquake and acid rain [100], have frequently been spread. In particular, the "high credibility" of mobile phone messages obtained through guanxi network does not mean that people take for granted that the information from their guanxi network is true. To be sure, as in the case of the mobile rumours on earthquake, it is almost impossible for any person to make the judgment between fact and falsehood. A combination of trustworthiness and reciprocal obligation from guanxi puts aside the fact and highlights the perceived reliability of the near friend, or as one respondent argues *“it’s better to believe it than not, especially when messages are coming from the people you trust”* [101]. In a word, both reliability and obligation characteristics of guanxi network and the instantaneity (calling and text messaging), synchronism (calling) and wide circulation (text messaging) characteristics of mobile communications contribute to continuous spreading of rumours of alleged credibility in Chinese society.

4 Conclusion: Guanxi-embedded Mobile Social Network in China

Both theoretically and empirically, this paper examines the dynamics of guanxi in Chinese society teeming with mobile connectedness. The ubiquity of mobile phone coverage in China has not only influenced interpersonal communication in the way Chinese people interact with each other, but also brought forth a revolutionary transformation of styles of guanxi and guanxi networks.

First, by investigating patterns of calling and SMS activities, we observe that mobile communication plays an increasing role in keeping in touch with people from the same locality, or with similar age, socioeconomic status, stage in the life-cycle, and life-style. Due to the technical capabilities of wireless telephony, urban and rural residents participate in guanxi-embedded mobile phone interactions of various kinds during their everyday life, from festival wishes to daily greetings, and from job search assistance to emergency contacts. In other words, Chinese people have not only adopted the mobile phone but they have also harnessed its assets by integrating mobile devices into their guanxi practice. Mobile social networks have therefore come and established themselves as an implicit substitute of guanxi networks in everyday lives of Chinese people.

Second, embracing the characteristics of guanxi in Chinese culture, in particular mutual reliability and reciprocal obligation, mobile messages enjoy high credibility. Further, the combination of high-credibility information and high-efficiency technology encourages the proliferation of the identical message within mobile social network in a short time. In a circle, the credibility of message expands its dissemination in mobile social network, and the high-efficiency dissemination in turn increases the credibility of the message and pushes more and more people to forward it. This process is both positive as well as negative. On the one hand, it keeps citizens informed in spite of media censorship in China. On the other hand, it makes mobile users easily credulous towards the messages they receive via mobile social network as they are unable to make judgments based on reasons or facts. That is why mobile rumours can easily trigger social disturbances in contemporary Chinese society.

In a word, mobile social network in China features not only the technical characteristics of mobile telephony, but also guanxi, a distinguishing characteristic of Chinese culture. As guanxi-embedded mobile social network integrates into Chinese people's routines, the omnipresent mobile communication articulates guanxi-based interpersonal relationships and social networks, reformulates a new cultural model of meaning in which the ultimate meaning is defined by both the content and, most importantly, the senders and their guanxi with receivers. In China's new, fast-paced environment, mobile phone-mediated guanxi network therefore has become more entrenched than ever, heavily influencing Chinese political landscapes, social behaviour and commercial practice.

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Use of Mobile Devices in Self-Managed Learning

Violeta Chirino, Julieta Noguez, Luis Neri, Víctor Robledo-Rella, Gerardo Aguilar
Tecnológico de Monterrey, D.F. México

The technologies available today for educational purposes have, in some areas, evolved faster than the educational practices which still do not take proper advantage of them. Almost fifteen years ago, studies were developed focusing on some misconceptions about the role that computers had in e-learning. The question: *"Is it [teaching learning strategies] old wine in new bottles?"* [1] focus on this problem. In studies carried out to find out the potential of information and communication technologies (ICT) applied to education, researchers agreed on the principle that one learns with the computer instead of the idea of learning from the computer [2]. This change of focus implied the need to define instructional design practices which consider, among the most important tendencies, the necessity of integrating computer simulations devoted to perform scientific learning by discovery [3], to develop conversational frameworks [4], to integrate strategies focusing on Computer Mediated Communication [5] or to initiate the focusing on situated learning to frame ICT in education [6].

Even in our current times, when mobile devices (a paradigm of convergence technology) appear to be powerful tools for education [7], we still find ourselves asking similar questions: Are Mobile devices just different media for the same educational contents? Are we using XX Century educational tactics with XXI Century technologies?

The use of mobile devices as educational tools foster the deployment of more personalized learning practices. When used as media for delivery content resources embedded in mobile devices, they help to provide context to in-class activities as well as to reinforce key concepts understanding. When integrating ad-hoc applications mobile devices are useful tools for, self-assessment as well as teacher on-demand assessment. By taking advantage of multimedia communication applications, mobile devices also enhance peer to peer collaboration and evaluation [7,8].

Applied to higher education, mobile learning is a pathway to develop simultaneously professional as well as technological skills as far as mobile devices (e.g. smartphones) are both used and manipulated to enhance learning experiences. We have found through action-learning approach applied to a 2008-2010 Mobile Learning Project Deployment in Tecnológico de Monterrey, that mobile devices can be as powerful to serve as a media delivery as well as educational tools. Here we introduce some findings and reflections supporting our approach to mobile learning as “learning through mobile”.

1 Mobile Learning Framework

Digital convergence is a characteristic of the evolution of information and communication technologies (ICT). This digital convergence has permeated educational technologies in such a way that it is necessary to reframe the didactics involved in educational practices. This implies to take as much advantage as possible of available technology innovations, while at the same time, the students learning of contents and development of technology mastering skills is enhanced. Generally speaking, technology applied to education in face-to-face environments, can serve as delivery media, as well as a source of active learning tools, [7]. The consideration of mobile devices as educational tools implies the design of active learning activities to be carried out by students, satisfying both specific knowledge acquisition as well as transversal technology skills development. We are now facing what can be named as “face-to-face and distance learning strategies convergence”, together with the fifth generation of learning in which converge distance learning evolves with face-to-face student centered learning [9].

The literature offers diverse Mobile Learning definitions. So we can state that the construct—and so is the model behind it, is still searching for a common ground [10-12]. Some key elements provided by mobile learning researchers are: mobility [13]; possibilities to enhance of enhancing learning [14]; technology, user interaction [15,16], and potentiality due to technological capabilities [8], among the most accepted one.

The definition of mobile learning constitutes the undependable framework for the definition of teaching-learning strategies. So, in order to provide a pursuable orientation to all participants in a mobile learning model it is important to assume the most descriptive as comprehensive definition as possible.

Sharples et al. [11] emphasized the importance of identifying the specificities that make mobile learning special, compared with other types of learning. They offered a very comprehensive framework for defining a theory of mobile learning based on Activity theory in which mobile devices could be considered as instruments to perform “tool-mediated learning activities”.

Thus we integrate a definition based on the consideration that, mobile learning constitutes an approach to knowledge acquisition that enhances a student´s self-directed learning, taking advantage of appropriate educational resources, a well-defined instructional design and the potentialities of the 4 R´s of mobile devices recall, retrieve, relate and research, fostered by intended designed applications. So is that through mobile devices, a more personalized learning is performed focusing on giving context to in class activities, reinforce domain key concepts comprehension, self assessment, teacher "on demand" assessment, peer to peer collaboration and evaluation and practice of future professional mobile based activities (active learning approach), applications designed with these intentions in mind [7].

Within this approach, mobile devices are educational tools that are naturally a media channel, that can be handled to realize active learning, and that can also be used as a communication and research tools.

On the other hand, students, digital era natives have grown playing video games, exposed to a large quantity of visual and acoustic stimulus and inhabit a world strongly influenced by Information Technology (IT). Mobile devices have been previously explored by students in a social and entertainment context than most of their professors. As a result, achieving knowledge, understanding and motivation during the teaching-learning experience has become more challenging. Taking into account that the ultimate goal has been creating enhanced learning environments attractive enough to engage learners.

Due to the attributes of mobile devices: the possibilities to make available knowledge contents expand, the diversity in learning activities increase, and so is the need to enhance instructional design to focus on a more personal learning approach instead of "one design fits all" becomes the challenge in today's learning pedagogy.

In August 2008 the Tecnológico de Monterrey, a Mexican multi-campus university system, started the process of integrating mobile devices as educational tools in its undergraduate programs. Nowadays it has extended to serve more than 3000 students, with 81 different senior high and undergraduate courses with a participation of 294 teachers.

A decision was made to initiate the project—having strong support from administrative authorities, in the subtlest manner possible in order to diminish the amount of resistance among teachers as well as from the students. This implied taking advantage of the technological and human resources currently available at the Tecnológico de Monterrey in order to facilitate the generation of the educational resources which would complement the traditional face-to-face model of delivering a course with the addition of a mobile element. That implied to generate an ex-profeso designed resources taking into consideration the possibilities and constraints of mobile devices to be used in this case Blackberry Pearl smarthphones.

On the communication advantages of mobile devices side, lecturers were encouraged to give students assessment and advice through mobile devices in order to promote a deeper engagement with students support. The mobile learning application model defined at the beginning is shown in Figure 1.

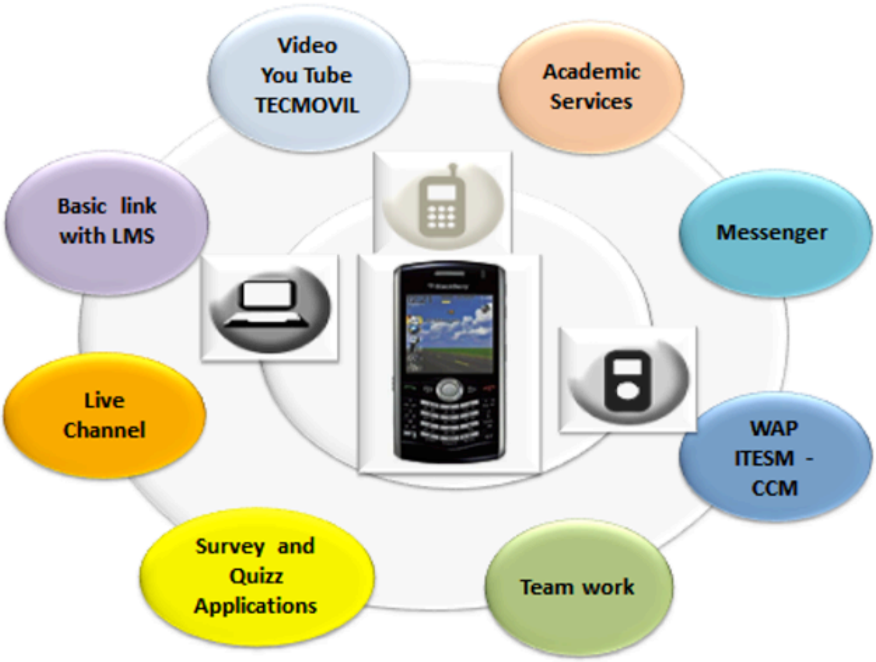

Figure 1: Tecnológico de Monterrey's
Mobile Learning Teaching- Learning Model at 2008

2 Mobile Learning Model Evolution

2.1 The First Stage

At the launching of the Mobile Learning project, three main types of resources were selected to be delivered through these devices. The most important of these resources were educational audio and video capsules focused on reinforcing core concepts as well as on giving context to in-class activities. In addition, some conferences and important lectures were offered through a Tecnológico de Monterrey Virtual University dedicated web channel and finally, a basic application was made available so to make formative assessments of learning. All the resources were delivered through a WAP (Wireless Application Protocol) designed for this purpose. Due to the fact that the time required to launch the project was short -one month and a half- the strategy followed by our Campus focused on:

• Finding open minded professors willing to face the extra work in order to develop mobile resources to be included into their current courses.

• Integrating a production-cell oriented to produce audio and video capsules taking advantage of human resources and equipment already operating on campus. The highly experienced on multimedia production team, included a producer, a graphic designer and an instructional designer.

• Defining basic quality standards in terms of content structure as well as on the best way to display and present this content.

The application of mobile learning into the Tecnológico de Monterrey undergraduate courses became known as “learning through mobile”. This approach meant to focus on the quality of content being delivered so that students were able to have a better use of spare and travel time in one of the most crowded cities on the planet (Mexico City). Taking into consideration that the time required for most students to travel from home to the university is about one hour, we thought that this period of time could be a good opportunity and be used to learn.

To launch the Mobile Learning Model several workshops were offered so to address the professors' lack of experience in operating mobile learning into their courses. These workshops focused mainly on the potential use of certain devices, on the production process of video capsules and on some issues regarding instructional design adapted to mobile resources.

2.2 Initial Mobile Learning Results

Even still, having analyzed the feedback gathered from teachers and students about the perception and use of mobile learning after the first semester of operation, we found that only around 42% of students found it useful to see the capsules through the mobile devices at the first sight, and almost all preferred watching the lectures face to face. Only around 35% of the students declared it useful to have assessments given through quick test. This result was closely related to the professors' extent of use of the application. Nevertheless, three "pull" uses of mobile learning appeared to be important to students as well as for teachers, 64% of students underlined the utility of the mobile device to realize "research activities", using Internet facilities, and 81% declared that they took advantage of pin to pin and Blackberry messenger to develop collaborative work. Also some activities related to peer in class assessment were reported.

Those results lead to perform seminars with Mobile Learning participant professors. It was decided to disseminate knowledge among Mobile learning community about best practices and also to integrate Tecnológico's Digital Library Access to mobile (EBSCO). It was also discussed and decided about the necessity of integrate active learning activities, presenting them as text integrated in WAP portal in their respective course. So this new type of educational resource presents an activity guide for students, who have to follow the instructions integrated in it in order to analyze and comment a video which link was included; or to make a survey using mobile applications, and so on. Table 1 shows the standardized type of activities integrated to courses with Mobile learning.

Table 1. Mobile learning activity educational resources

Type of activity	**Mobile applications used**
Video/ audio realized by students	**Video camera, Blackberry messenger, WAP, Internet, Digital Library**
Peer to peer assessment	Video camera, voice recorder, messenger, e-mail
Distance assessment on social projects	Video camera, voice recorder, messenger, e-mail
Research projects	WAP, Internet, Digital Library, Video camera, voice recorder, messenger, e-mail

One year later, the same questions were posed to the students, and also to some of the more enthusiastic professors were interviewed about the use of mobile learning devices as a complementary tool to their learning process. These same lecturers were also asked regarding their perceptions about the enhancement in the delivery of their classes, respectively. What were the results? From the teachers' perspective, it was found that a pull strategy was the most effective. What does this mean? Well, instead of merely spoon-feeding the contents to the students, some teachers asked them to develop resources which would explain the applications of the concepts learned through the integration of storytelling, sketches, short videos, or audios. Thus it was found that in practice an enhanced mobile learning model had been developed by participant professors and students.

The results were attractive. We saw educational resources which varied from a Rap with civil law definitions; tales about law application, history tours, and so on. These resources served to assess students' learning derived from a homework duty as well as learning materials in further courses to analyze misconceptions in concepts.

On the other hand, in the surveys, the students' responses showed that they use mobile devices to enhance learning thanks to or even in spite of the fact that their teachers were not deeply committed to the model. So more than 70% of the students use the mobile devices to realize distance group work through group chats; nearly 70% declared that they used the mobile devices as a research tool to find information on the web. Also the majority said that they found applications they didn't use before such as the use of agenda and group tasks. The students also manifest a more deeply engagement with their technological skills development. Table 2 shows the main results on surveys realized with 152 students with a reliability level of 90%.

Table 2. Frequency of learning activities realised by students using mobile devices *

Activities	Students **
Accessing Internet to do homework "any place"	71%
Taking photographs to integrate them in academic projects	68%
Research activities using Internet in mobile devices	63%
Watching you-tube videos or web pages	62%
Collaborative work with classmates	46%
Agenda approach for academic activities follow up.	45%
Educational resources (audio) listening	42%
Audio recording	41%
Video recording	40%
Watching educational resources (video), produced by my teachers	38%
Use of "tasks" application for my activities follow up	36%

* Dec 2009

** Percentage of students who declare to realize those activities "very often"

2.3 The Second Stage

At the end of the 2009 Fall semester upgraded versions of the so-called "Quick-Test" and "QuickTime" applications were introduced. These new applications turned out to be more useful and attractive to professors as well as to students due to their capability of showing the results of tests and surveys instantly—the former versions required professors to integrate data from Excel worksheets by themselves. The use of these upgraded versions increased the integration of diagnostic and formative assessment in class. Some professors carried out action-research using the survey application installed in the mobile devices.

Also a more creative use of quick test mobile application was made. Quick-Test was used by some professors as an assessment, at the beginning of the class, in order to verify reading comprehension. At the same time this served as an ice breaker when making jokes about what the evidence revealed concerning their comprehension. These quick tests also promoted contests to see if this can be solved in order to get better results if students were able to find out the origin of misconceptions. This was also used for in-class debates.

Finally, a possibility has been found to integrate the 4R potential of mobile devices applications (recall, retrieve, relate and research) to active learning in the field with a notorious enrichment of project results. Applications such as direct surveys using the Telebyte software and pictures taken with mobile devices in Marketing courses to integrate Product development projects; comparative architecture practices taking advantage of camera existing in mobile or remote medical practices using videos, messenger and voice where among the most successful technological practices applied.

Regarding the resources' quality in terms of access time and resource display and content design, it was found that students' main objections were the excessive length (some resources being longer than 10 minutes) to access and connectivity problems caused by limited IT infrastructure, and to the fact that some mobile resources were quite unattractive. Indeed, an important observation was that students didn't find it attractive to only watch "plain text" with voiceovers repeating the text's content.

Other important findings were those related to the locations where students used mobile learning. Contrary to expectation, students were more likely to use mobiles devices at home or at school rather than when traveling from home to school or vice versa. . Also, the use of mobile devices as tools made classrooms important places in which to use the devices. The explanation for this behaviour was revealed in some of the interviews made to students. The criminality in the city makes it dangerous to openly use smartphones or PDAs while on public transportation and the fact that most resources were videos, cumbersome to watch in "high mobility". Figure 2 shows student mobile device location use preferences.

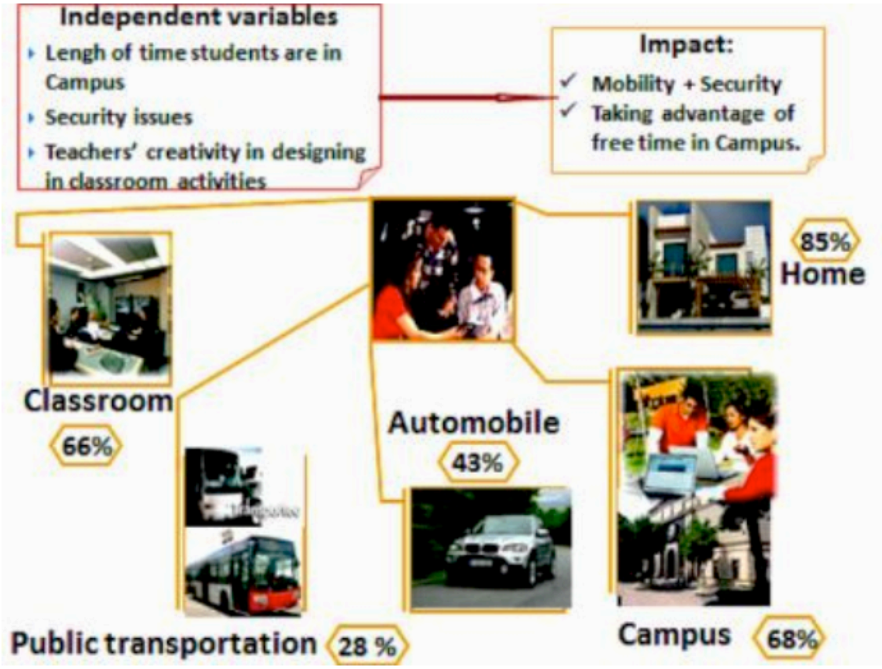

Figure 2: Mobile learning use location preferences.

3 Case Study on Learning Gains on Mathematics

In order to assess the impact of the use of mobile resources on students' learning, we have carried out a case study in Mathematics, subject that is traditionally found difficult for most undergraduate students. The study was carried out during the 2009 August–December and the 2010 January–May terms. The purpose was to determine whether students using these resources had larger learning gains than students who do not use them. The undergraduate Mathematics II course of Tecnológico de Monterrey, Campus Ciudad de México was selected for this study. The detailed study is discussed by Aguilar el al. [17].

Math II: This course covers the topics of Integration in one variable, Differential Equations, Optimization in Several Variables. Sequences, Series, and Matrix Algebra. It is intended for second semester engineering students.

Due to the fact that the integration module is the most difficult of the course, 3 ML resources were made for the integration by substitution topic (Topic 1) and 1 resource for the Trapezoidal Rule topic (Topic 2). For Topic 1 the resources included: a) an introductory resource with a general explanation of integration by substitution, b) a resource where students were asked to create an integral that can be solved by substitution, using the chain rule for composed functions, and c) a resource where students were prompted to made a video for mobile devices in which they explain the technique of integration by substitution, choosing an appropriate example. For Topic 2, the students also create a video in which they explain how to approximate the value of a given integral using the trapezoidal rule. It is important to mention that the third topic was intended for student self-study.

3.1 Methodology

The methodology was as follows:

Pre-test. A pre-test was applied for both topics the first day of classes, in order to quantify the base-line understanding level for both topics. The pre-test for Topic 1 had 5 items and the corresponding one for Topic 2 had 4 items.

Participants. Data from 93 and 85 students were obtained for Topics 1 and 2 respectively. The samples were randomly divided in two groups: one group used the ML resources (hereafter "Focus Group) and the other group did not use them (hereafter "Control Group"). It was the same professor for both groups and for both terms

Experiment design. For Topic 1 the Focus group had 44 students and the Control group 49. For Topic 2 the Focus group had 41 students and the Control group 44. For Topic 1 the introductory resource was used during class, while the second resource was viewed by students outside the class. At the end of the topic students were asked to produce a video, which was presented to the full class. For Topic 2 students were asked to make a video and presented it in class. On the other hand Control group students were asked to study the same topics using traditional written materials.

Post-test. At the end of each topic and when focus students ended their ML activities, a post-test was applied to both the focus and control groups. For each topic the post-test included 5 items very similar to those of the corresponding pre-test, reagents in both topics.

Data Analysis. Average and standard deviations for the pre-test and post-test grades were calculated, in a 1—100 scale. We also calculated individual an average relative gains for focus and control students for both topics. The individual relative gain was obtained by the relation (Neri, et al. 2010):

$$g_i = \frac{Post_i - Pre_i}{100 - Pre_i}$$

This relative gain represents the quotient between the absolute learning gain that each student gets and the maximum gain he/she could obtain. On the other hand, the integrated relative gain for each group/sample was calculated based on the methodology described by Hake (1998):

$$G = \frac{\langle Post \rangle - \langle Pre \rangle}{100 - \langle Pre \rangle}$$

Here the brackets “< >” represent the average of a group/sample of students, so G is a measure of the learning gain of this selected group/sample of students. The obtained results for Topics 1 and 2 are shown in Tables 1 and 2, respectively. From these tables it is evident that focus groups obtained larger average individual relative gains and integrated gains than control groups for both topics. In order to assess if this difference is statistically sound, a Z-test was carried out for the average individual relative gains. It was found that with 95% confidence, the mean difference (focus – control) is in the range [0.045, 0.208] for Topic 1, and in the range [0.074, 0.225] for Topic 2. These results support the conclusion that the obtained average relative gains for Focus students are larger than for Control group students. Table 3: Number of students, average and standard deviation of pre-test, post-test and individual relative gain, and integrated gain of the Focus and Control groups, for Math II - Topic 1.

Table 3. Number of students, average and standard deviation of pre-test, post-test and individual relative gain, and integrated gain of the Focus and control groups, for Math II - Topic 2

Group	N	$\langle Pre \rangle$	$\langle Post \rangle$	$\langle g_i \rangle$	G
Focus	44	1.1 ± 4.0	78 ± 17	0.78 ± 0.17	0.78
Control	49	0.82 ± 3.4	65 ± 30	0.65 ± 0.30	0.66

Group	N	$\langle Pre \rangle$	$\langle Post \rangle$	$\langle g_i \rangle$	G
Focus	41	0 ± 0	69 ± 25	0.69 ± 0.25	0.69
Control	22	0 ± 0	54 ± 16	0.54 ± 0.16	0.54

The evidence found so far supports the conclusion that is better to use the resources than do not use them in the respective topics. Of course, it is necessary to increase the student sample to increase the reliability of the study results.

4 Conclusions and Recommendations

With that evidence one can say that mobile devices are more effective as learning tools if they are used to learn with them rather than through them. Also it can be said that we should consider "new wine" for the bottles which is to say that we should design more innovative strategies that are oriented toward active learning by taking advantage of the students' proclivity to engage with technology if we really want to get the most of innovation in educational technology. Tecnológico de Monterrey promotes to integrate efforts related to the incorporation of the best mobile learning practices, innovations as well as technological developments related to it.

The case study carried on Math showed that the use of ML resources helped to increase student learning on this subject. These results encourage us to continue working in this field.

This is a case of intensive use of a mobile device integrated to a good instructional design. Therefore, we can say that the professors' involvement in the model and well established guidelines are critical factors in terms of implementation.

Now research lines are oriented to improve resources structure, to evaluate activities deployed by mobile devices as text, the use of mobile devices as tools, as well as the critical analysis of some resources already made available. Evolution of the model is still in progress, but the main lessons learned were that mobile devices are more effective as learning tools rather than just as media to deliver content and that skilled and motivated professors willing to do action research make the difference in deciding the best strategies to follow.

As future work we are planning to make more research in order to realize learning gains and development of technological skills enhanced by mobile learning applications in different knowledge domains.

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m-Learning in Sri Lanka: A Case Study

Guiomar Parada
Economics and Technology Journalist

Sri Lanka has a total population of 20,061,000 people of which 85% are inhabitants of rural areas. GDP per capita approaches US $ 3,750 per year. The northern parts of the country are exiting a 30-year war period, a war for which the whole country paid a high toll. Nonetheless, the country features a very high literacy rate —92,4% (94,8% male and 90% est. female). Sri Lanka introduced compulsory education regulations in 1998 for children up to 15 years. Children of primary school age who are out of school total just 1%, according to UNESCO statistics, and over 83% of its student population reaches the secondary level of education.

However, even if the policy of free education for all Sri Lankan citizens extends to tertiary education, only 17 to 19% of the students who qualify actually get the chance to enter university, regardless of talent. This is due a) to the limited number of seats available which hovers around 17.000 and b) to the inescapable

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The findings, interpretations, and conclusions expressed in this Case Study are entirely those of the author, who also gathered the information, and should not be attributed in any manner to the University of Colombo, Sri Lanka; to Mobitel Sri Lanka; to Wataniya Maldives or others.

need for the students to relocate to Colombo. The limited possibilities in accessing higher education are more likely to affect the underprivileged, the poor, the females, the minorities, and the disabled.

Location of Sri Lanka (courtesy of Wikipedia)

Thanks to the high literacy, the highest in Asia —and lately to an average computer literacy that has been estimated to be rising at an annual rate of 15%— open and distance learning programs, that are especially relevant in the higher education sphere, have found in this country a conducive environment [1]. However, it is important to remark that, before the project featured in this study, almost all programs were aimed at providing higher education to working adults rather than younger generation students.

1 The Tertiary Education Institution

The University of Colombo (UoC) is 150 years old and one of the oldest in the region. Well aware of the difficulties of increasing the number of students because of the aforementioned reasons, pursuing the clear goal of becoming “partners of socio-economic, cultural and environmental development” and deeply believing that access to the Internet and to Intranet were first and foremost important in fulfilling its mission and achieving its objectives [2], in 2006 UoC started looking for means to bring tertiary educational programs to the broader masses, possibly by addressing traditional learning shortcomings through advanced technology.

2 Technological Infrastructure

In December 2007, Sri Lanka Telecom Mobitel had launched a 3.5G High Speed Packet Access (HSPA) technology based service capable of 14.4Mbps on downlink and up to 1.98Mbps on uplink and expected to offer speeds of 20Mbps on downlink and 12Mbps on uplink. The first and only operator in all of South Asia and among the top ten networks in the world to implement a Super 3.5G/2G network, it had done so primarily because of its 10 years lag in competition in GSM adoption that offered no other business perspective than embracing the latest generation of mobile technology. Investments committed to date in the 3.5G/2.5G networks and for service offering amount to over US$300mn. The company plans to increase its combined number of base stations to 3000 by the end of 2010. This project is an extension of the company's Corporate Social Responsibility initiative.

3 The m-Learning Project as an Opportunity for Quality Tertiary Education

Given the 3G coverage of about 95% of the population, UoC approached this mobile operator for the development of a joint platform, which would make Higher Education accessible to everyone, anywhere. In 2008, the platform was ready. The University of Colombo provided the teaching material and content, Microsoft the platform, and Mobitel the needed mobile connectivity. The m-Learning pilot project enrolled 30 students who have just graduated and who testify of an extraordinary experience.

a) **Features**

> I) Students enroll for a yearly fee of Rs. 150,000 (around US $1,000) inclusive of tuition fee and bundle. The latter consists of a mini laptop with original Microsoft Windows & Office licenses, a 3G dongle with Internet usage for one year and a concession rate on a prepaid connection for voice

calls (2 SIM cards), as well as access to all UoC resources. Course intake is periodic.

II) With whichever device that uses mobile technology, students link to the physical classroom at the University in Colombo and are able to attend the lessons participating in real time, thanks to multiple user interactive video conferencing features, slides, virtual smart boards, material upload facilities, content management facilities as well as SMS, email, and offline messaging. Thus, access to any materials presented by the lecturer or any other learning materials available is guaranteed. Feedback to the classroom, to the lecturer, and to the student community is instantaneous and is a one hundred percent interactive element to the learning experience.

III) The first course offered via m-Learning was the Executive Diploma in Marketing of the Faculty of Graduate Studies. Now there are three faculties offering courses via M-Learning: aside from the Faculty of Graduate Studies, the Faculty of Science and the Faculty of Arts. The Diploma in Travel and Tourism Economics and Hotel Management of the Department of Economics of the Faculty of Arts was added a few months ago to the m-Learning offer.

IV) The possibility given to students to interact with the classroom where the lesson is being held gives m-Learning students much more visibility than traditional distant learning.

V) The m-Learning Higher Education process of UoC is financially self-sustainable.

b) **Three are the substantial differences with other experiences**

I) UoC's m-Learning learning process can be performed be means of any mobile and hand-held device—Mobile Phones, Personal Digital Assistants (PDAs), Laptops and Tablet Personal Computers.

II) UoC has chosen to adopt with m-Learning a top-down approach, i.e. to initiate the offer with the most prestigious courses, the top Master courses, with the objective of positioning M-Learning among the learning processes of excellence and add value to this innovative educational alternative.

III) UoC m-Learning allows for a direct and immediate interaction with the physical classroom. Sharing is almost instantaneous among everyone using the same content, which leads to the reception of feedback and makes it collaborative.

IV) The platform allows for tailored learning content.

c) **Future Developments –internal and external**

I) The offer is being extended to other Diploma and will include in the future Undergraduates courses.

II) The partners, UoC and Mobitel, have signed an agreement with Leeds Metropolitan University in the UK, by which the Sri Lankan operator and the University of Colombo will be able to offer Leeds Metropolitan's Master courses and PhDs to students back Sri Lanka enrolling in the UoC m-Learning program.

In fact, students in Sri Lanka with good English skills will be able to participate in the very same lectures being held in Leeds, and as with the other UoC m-Learning courses, they will have the advantage of:

I. being able to interact back with the British lecturers and with the classroom in Leeds.

II. being linked to any electronic boards and any other digital resources in the classroom in Leeds for total access.

III. disposing of a recording of all lessons, so avoiding the need for taking notes. Students will just need to play back the digital recording, being able to do so as many times as needed.

III) The M-Learning process is being expanded to Maldivian students. Sri Lanka has a large population of Maldivian students that need to relocate themselves in Colombo from the Maldives if they want to access higher studies. Through the Maldivian operator Wataniya Telecom Maldives and its 3G+ network, now the same UoC M-Learning program will be available in the Maldives with a hybrid, or blended, learning solution, i.e. a mix of face-to-face and online delivery systems, since once a month the Maldivian students will travel to Colombo to interact in sessions at UoC. The first m-Learning course available under this initiative is the Executive Diploma in Marketing. Students enrolling for this course will receive a wModem and a Wataniya mobile broadband connection prepaid for the yearly duration of the course.

IV) This project has paved the way for another pilot project in the area of the Agricultural Sciences, in which scientist in Colombo will teach and interact with farmers about agricultural issues, with the possibility for the farmers to show the actual crops to the lecturers at UoC and to expose problems in order to get expert advise, as well as to interact with other localities that may have the same or similar problems. The platform will thus allow to share knowledge and solutions even with the most remote villages of the country.

4 Lessons Learned

1. **Quality/access** – Recommendations from authoritative sources in the field of distance learning have tended until now to advocate the use of ICTs as a means to improve management efficiency and enhance educational quality (and primarily give a boost to the study of English and IT), rather than to expand access. M-Learning

challenges this view by showing that a Mobile Learning Platform can do in fact both and indeed more:

— it can make of educational quality an intrinsic feature;

— it can avoid for “Distant” Higher Education to be of lesser quality than that received by the students that attend physically tertiary education institutions;

— it can expand access without undermining quality.

2. **Infrastructure, partnership and collaboration** – The success of this experience has been widely determined by the existence of a very advanced and commercially viable and sustainable broadband infrastructure already in place, whereas the availability of the mobile operator’s management to undertake such projects and to define a common vision with an educational institution does not appear to be a main obstacle in the region. Indeed, the industry companies’ Corporate Social Responsibility area (CRS), should be seen as an opportunity not to be missed. CRS should be considered a ground on which to commonly build projects aimed at braking through traditional boundaries and address traditional learning shortcomings through the use of the cutting edge technologies offered by the state of the art of the industry.

> From a financing-partnership point of view, it appears important to note the similarities of the m-Learning partnership with that of the Asia-Pacific Development Information Programme (APDIP) with Cisco Systems through the Networking Academy Programme, an institutionalized education project which provides students in Asia-Pacific countries with an up-to-date, two-year IT curricula and international certification. The program runs in countries where access to specialized training does not exist or in states within larger countries that are marginalized or underdeveloped. To date, 17 academies have been set up within tertiary learning institutions in Bangladesh, Bhutan, Cambodia, Fiji, India (x2), Nepal, Mongolia, Papua New Guinea, and Sri Lanka.

3. **Expandability and globality** – There are no limits to expanding internally and externally a Mobile Learning Platform such as mLearning once the platform is developed and the project is rolled out (except for obvious language limits):

— at regional level, as in the case of the Maldives mentioned above;

— at global level, as in the case of the recently signed partnership between Mobitel Sri Lanka and the Chartered Institute of Management Accountants (CIMA), that serves with more traditional means already students in 168 countries. The m-Learning platform will now allow CIMA to reach further across the globe, initially offering courses to students in the Maldives, in Pakistan, in Bangladesh, and in the Middle Eastern countries.

4. **Potentialities** – Especially in developing countries, a Mobile Learning Platform such as m-Learning appears to be an ideal solution to:

— tackle the problem of limited capacity and resources within universities;

— address the problem of low survival rates at the tertiary level, where social conditions or remote inhabitance are the cause;

— help in the long run enable local universities to connect globally, which in turn would result in better opportunities for students;

— act as a stepping stone that paves the path towards the knowledge economy in Developing Countries;

— "e-export knowledge" at regional or global level, while allowing at the same time for tailor-made educational environments and programs that are respectful of national cultures and educational needs;

and last but not least:

— contribute to efforts directed at promoting equality of opportunity for all individuals across the chronic urban-rural, rich-poor, male-female, and advanced-developing countries divides.

References

[1] Sri Lanka was among the first Asian countries to follow the British idea of an Open University, or distance learning, which was set up in this country less than ten years later the British one, in 1978. The Open University of Sri Lanka (OUSL) has been a pioneer provider of distance learning programs at the tertiary level of education targeting working adults.

[2] As the Vice Chancellor of the University of Colombo, Professor Kshanika Hirimburegama, puts it, *"With the rapid phase of technological advancement one cannot escape the ubiquitous globalization now embracing all aspects of our daily lives. The University of Colombo is no different to other universities worldwide. We need to have universal focus on thinking innovatively while being dramatically acting to suit the local environment scenario. Modern technological advances in communication have created a virtual space for information sharing, collaboration, debate and intellectual discourse"*.

m-Science: Sensing, Computing and Dissemination

Mobile technologies offer tremendous benefits to academic research and education, and to society as a whole throughout the world. This is an opportunity that deserves attention and promotion, especially in less developed areas where mobile phones are the first telecommunications technology in history to have more users than in the developed world.

Simply put, we define in this open access book **Mobile Science** (or "**m-Science**" in short) as the term that comprises sensing, computing and dissemination of scientific knowledge by the use of mobile devices. This include data gathering, the analysis and process of data and the access to on-line services and applications directed to nurture scientists and scholars.

The potentialities of m-Science need to be spread out on a larger scale so that its benefits can become widely accessible to a potentially large mobile audience. This book aims to engage the scientific community, engineers and scholars worldwide in the design, development and deployment of the newest mobile applications.

www.m-science.net

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