Cell Phones as Mobile Computing Devices

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Increases in the computational power of mobile processors, improvements in mobile operating systems, and the popularity of mobile broadband make cell phones the best candidate for sophisticated mobile computing devices. Learn about potential applications and their corresponding challenges.

Our cell phones are getting more and more versatile. Originally designed for voice communications, cell phones can now do much more than just make phone calls. Today's cell phone can include a Web browser, camera or camcorder, music or video player, modem, GPS navigator, gaming device, or radio or TV receiver.

Furthermore, there's been a massive increase in the computational power of mobile processors and considerable improvements in modern mobile operating systems. Coupled with the popularity of mobile broadband, these changes make cell phones the best candidate for serving as mobile computing devices that can perform sophisticated or even scientific applications.

Here, I identify the features that give modern cell phones their potential, present some promising new applications, and discuss the corresponding challenges.

Cell Phones' Potential

Modern cell phones comprise many resources and properties that benefit mobile computing (see Table 1).

Fast Mobile Broadband

Mobile networks have gone through several upgrades, from analog to digital signals and from circuit to packet-switched networks. The data transfer rate has increased substantially, from 9.6 kilobits per second for the Global System for Mobile Communications (GSM) to around 171 kbps for General Packet Radio Service (GPRS).

Recently, we've had speeds of 384 kbps with Enhanced Data rates for GSM Evolution (known as EDGE) and two megabits per second with the Universal Mobile Telecommunications System (UMTS). Furthermore, we've now reached 7.2 Mbps with High-Speed Downlink Packet Access (HSDPA). Also, in February 2007, Japan's

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NTT DoCoMo achieved a maximum packet transmission rate of approximately five gigabits per second. They were using 100-MHz frequency bandwidth to downlink to a mobile station moving at 10 km per hour in a field experiment of fourth-generation radio access (see www.nttdocomo.com/pr/2007/001319.html).

Along with continued upgrades to mobile network infrastructures, the number of mobile broadband users has also increased substantially in recent years, thanks to improved ease of use, lower prices, and the convenience of being able to access the Internet almost anywhere. Internet connectivity has become the default function of smart phones, facilitating mobile computing applications needed to communicate with peers or between clients and servers.

Table 1. Resources of cell phones and their corresponding benefits for mobile computing.

Resource	Benefit for mobile computing
Fast mobile broadband	Lets applications communicate among peers or with servers with short latency
Powerful processors	Facilitates computationally intensive mobile applications
Large storage	Facilitates applications that require massive (raw or meta) data
Rich libraries for application development	Lets developers write applications and control the phone with maximum freedom and flexibility
Advanced user interfaces	Facilitates applications with designs for more intuitive and easy-to-use user interfaces
High pervasiveness	Facilitates location-aware or distributed computing applications

Powerful Processors

Today, smart phones' processors are so powerful that even low-end laptops or netbooks can use them. For example, Qualcomm's 1-GHz Snapdragon processor can drive screens of up to 12 inches at resolutions of up to 1,440 × 900 pixels. Several recent smart phones use this processor, including HTC's HD2, Google's Nexus One, and Sony Ericsson's Xperia X10.

The mobile processor is entering the era of dual or multicore configurations, and Qualcomm plans to release a dual-core Snapdragon processor sporting a pair of Scorpion cores at 1.5 GHz by the end of 2010. This kind of processor could facilitate even more sophisticated mobile computing applications.

Large Storage

Several years ago, smart phones commonly came with 32 to 512 Mbytes of internal storage. Today, they usually provide data-storage capacities of four to 32 Gbytes.

Considering the continued advances in storage technologies (such as small form-factor disks and flash memory), future smart phones will likely provide even larger storage capacities.[1] Although most users store just multimedia content, they could start storing massive (raw or meta) data to conduct computing tasks on the go.

Rich Libraries for Application Development

Modern mobile platforms (such as the iPhone and Android) typically include a wide range of useful libraries and APIs for developers. In addition to libraries for accessing internal sensors—such as accelerometers, GPS, or magnetometers (a digital compass)—there are libraries for making voice calls and connecting to the Internet, for playing multimedia, and for drawing maps.

These libraries and APIs let developers write new applications and control the phone with maximum freedom and flexibility. For example, an application can combine information from the Web with data stored on a cell phone (such as the user's contacts or the phone's geographic location) to provide a more relevant user experience.

Advanced User Interfaces

In recent years, there have been many advances in user interface designs for cell phones.

The most noticeable advancement is multitouch technology.[2] A multitouch screen can track more than one touch simultaneously, providing more intuitive interaction. For example, to zoom in on a photo using a multitouch interface, a user can first touch the photo with two fingers and then spread the fingers apart. The interface reacts as if the two fingers were stretching a printout on a rubber sheet.

Many high-end cell phones use multitouch technology, and software developers are also using it to design various innovative applications.

High Pervasiveness

The number of mobile phone subscribers worldwide reached four billion by the end of 2009, and

it's expected to grow annually by one billion. Some people even have multiple cell phones—for example, some prefer to have one for personal use and another for business use.

Furthermore, most cell phone owners never leave home without their phone. Cell phones provide the most convenient way for people to handle their daily tasks, such as managing personal information, staying connected with friends, and even conducting business.

Cell phones are clearly pervasive and can perform distributed computing tasks and run location-based applications.[3]

Prototypes and Projects for Sophisticated Functions

Many different kinds of mobile computing applications can exploit cell phones, but they all fall into one of two categories: applications that can be conducted with a standalone phone, and those that require adding nonstandard hardware to a phone.

At National Instruments, engineers successfully used an iPhone as a car's remote control.

The first two applications presented here fall under the first category; the rest require additional hardware.

Car Remote Control

I still remember how stunned I was a decade ago to see James Bond use a cell phone to control his car in a movie. Since then, several projects have attempted to put the idea into practice, including one at National Instruments, where engineers successfully used an iPhone as a car's remote control.[4] They installed two systems in a modified car:

- an automobile control system (ACS) that comprises motor control, electronic control, and power distribution; and
- a remote system that receives instructions from a remote controller (the iPhone) and sends commands to the ACS.

These systems let the iPhone application wirelessly command the car to actuate its pedals and steering.

The iPhone application has two sliders, one for controlling the gas and one for the brakes. By rotating the phone (which provides the accelerometer technology), people can use the application to steer the car.

More specifically, the range of motion of each of these three controls (gas, brake, and steering) is defined as values in the range of 0 to 255. The application converts these values to ASCII characters and sends them to the remote system (inside the car) using User Datagram Protocol packets via a Wi-Fi network. For example, if the iPhone application sends a string of "€!t," then the system knows that the user wants to assign values of 128, 33, and 116 to the steering, gas, and brakes, respectively.

2D Bar-Code Reader

Unlike the traditional bar code, which has black-and-white lines of varying thicknesses, a 2D bar code is a 2D matrix of tiny squares, dots, or other geometric patterns. You can encode a 2D bar code with different kinds of information, such as a Web address, descriptive text, or numbers.

You can also use camera-enabled cell phones as portable bar-code readers. When a phone captures a 2D bar code, the software on the phone can decode it and act accordingly. For example, a traveler at a railway station could use his or her phone to capture a poster's bar code, allowing the phone to bring up a Web page with the train schedule.

Another example might be a customer in a grocery store. Using a phone to capture the bar code on a can of food, the customer could obtain the food's nutritional components. These examples present a new way to deliver information through mobile phones.

Mobile Environmental Sensors

Some countries use environmental sensors to detect air pollution and measure temperatures. For example, the city of Cambridge is building an urban-scale sensor network (see www.citysense.net). The network currently consists of 100 wireless sensors deployed throughout the city on light poles and on both private and

public buildings. This sensor network is, of course, static.

However, researchers could turn a cell phone into a wireless mobile sensor and create a dynamic sensor network. By incorporating various environment sensors into GPS-equipped cell phones,[5] they could gather data about pollutants, including the levels and locations of carbon monoxide, nitrogen oxide, and nitrogen dioxide. The cell phones could then transmit the collected data, over the Internet, to a remote computer for interpretation and analysis.

The main advantage of this dynamic sensor network, using cell phones, is that researchers could obtain samples (of pollutants) from different places in the city, providing a more meaningful picture of the city's environmental conditions. They could also quickly pinpoint pollution trouble spots.

Medical Microscope

Researchers have converted the standard cell-phone camera into a clinical-quality microscope with five to 50 times the magnification abilities.[6]

Clinical-quality microscopes are necessary for even the most basic medical evaluations, and many developing countries lack medical equipment such as a dark room and mercury lamp, especially in rural areas. Yet these areas need this type of equipment to detect common diseases such as tuberculosis (TB) and malaria. The new cell-phone telemicroscope, called a *cellscope*, will help doctors diagnose and treat people in such areas by letting the doctors remotely interpret microscopy data.

To build the cellscope, researchers attached compact microscope lenses to a holder hooked onto a camera-enabled cell phone to capture high-resolution microscopic images. They also developed image-analysis software that runs on the phone and can, for example, count the number of cells in a given sample.

Using the cellscope to examine samples of infected blood and sputum, researchers captured bright field images of Plasmodium falciparum, the parasite that causes malaria in humans, and sickle-shaped red blood cells. For TB detection, a spit sample is infused with a dye called auramine. The light source on the end of the device opposite the cellscope emits a blue LED, which the auramine dye in the spit sample absorbs, turning the sample fluorescent green and illuminating any mycobacterium TB bacteria.

Health Monitor

Chronically sick people, the elderly, or those living with a condition that needs regular monitoring are restricted to hospitals and clinics. Many of them feel insecure when they stay away from their healthcare providers. Moreover, welfare costs are on the rise because of the high costs of hospital visits and treatments.

Consequently, a system that lets doctors follow-up with patients remotely while the patients are free to continue their daily activities can be useful and help cut costs. It also enables these patients to monitor their own physical condition and obtain advice and information when necessary.

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Researchers are developing cell phones with sensors as personal health monitors to help manage certain health conditions, such as diabetes, asthma, and high blood pressure. The sensors can be external devices (such as a blood pressure monitor) or can be attached to the user's body (for example, electrodes for electrocardiogram recording). The phone can then run special software to gather and analyze the data received from the sensors in real time.

Based on the analysis, the phone then gives the user immediate feedback. With Internet connectivity, the cell phone can also send the data gathered to a health server that can record it for further analysis by qualified medical specialists.

This kind of personal health monitoring can help reduce the number of hospital visits by patients, relieve pressure on the National Health Service, and most importantly, increase the likelihood of timely intervention when needed. (See the related article in this issue, "MORF: A Mobile Health-Monitoring Platform.")

Challenges

Using cell phones for mobile computing obviously offers many benefits, but it also presents several challenges.

Performance

At the core of mobile computing is the mobile processor. Though mobile processors have improved significantly, their computational power is still less than that of a regular computer. Yet many people want their cell phones to work like a regular computer, creating a demand for higher-performance cell phones.

Increasing a processor's clock rate requires tackling the issue of overheating. Because cell phones are small, they can't use a fan and there's little space for heat dissipation. Overheating could cause the phone to fail or, in the worst case, explode (if the battery experiences a thermal runaway reaction).

The idea is to have a supercharged clone of a phone that lives in the cloud.

Instead of directly using a faster processor, researchers have attempted to use "cloud" services to enhance performance and extend cell-phone capabilities (see http://berkeley.intel-research.net/bgchun/clonecloud). The cloud is essentially a collection of servers running cooperatively on the Internet. The idea is to have a supercharged clone of a phone that lives in the cloud. When the phone needs to perform any processor-intensive task, it can offload the work to its clone in the cloud (using its high-speed Internet connection).

More specifically, the cloud clones the phone by creating a whole-system image of the phone. When the application on the real phone identifies a computation task for remote execution, it transfers its state to the clone and enters a sleep state. The clone will execute the task in the cloud and transfer its state back to the phone upon completion. When the phone receives the state, it awakes from its sleeping state and continues its task execution.

These operations are transparent to users, making them feel that their applications can finish tasks much faster. For example, one experiment created a test application that performed facial recognition of photos (see http://berkeley.intel-research.net/bgchun/clonecloud). Results show that it required about 100 seconds for a standard Android phone to finish the job, but it took only one second when run by a clone of the phone in the cloud, where the cloud was actually a general desktop computer in the experiment.

Power Consumption

Cell-phone power consumption is another mobile computing challenge. In general, the more computations a cell phone performs, the more power it consumes. Unfortunately, there isn't much space for a bigger battery in a small phone, because the phone already contains the processor and storage chips as well as many radio frequency antennas and slots for external uses.

Intelligent power-control systems and energy-efficient chipset designs are common methods for reducing power consumption, but the advent of wireless power harvesting (using ambient radiation) might offer another solution. This won't reduce the phone's power consumption rate, but it will recharge the phone battery continuously so that the phone is less likely to run out its battery.

The ambient electromagnetic radiation (emitted from Wi-Fi transmitters, network towers, and so on) can be converted into electrical energy. The Nokia Research Centre in Cambridge already has a prototype device that can harvest five milliwatts (http://research.nokia.com/research/labs/nrc_cambridge_uk_laboratory). However, the minimum requirement to charge a cell phone when turned off is 50 milliwatts, so it might be a few years before we can commonly adopt this technology.

Cost Considerations

If a novel mobile computing application requires a new technology or function, it might require a special chip inside the phone or another radio frequency antenna to communicate. This increases costs and imposes

constraints that could limit the application's popularity.

Consider the mobile environmental sensors discussed earlier. If phones with chip-based sensors were widely available, researchers could easily obtain a more complete and meaningful picture of a city's environmental conditions. However, the chip's cost would be a concern when manufacturing this kind of phone, limiting the application's popularity. This could be why, although the University of California, Berkeley demonstrated a prototype of the cell-phone-based pollution sensor in 2005,[5] there's still no corresponding commercial product on the market.

Security and Privacy Issues

Using mobile phones as mobile computing devices can also cause security threats. First, modern mobile platforms typically run various third-party applications. Malicious applications could exploit an uncovered platform vulnerability, causing the phone to malfunction or lose user data.

Second, if a mobile phone is part of a network of distributed phones, an attack could occur over the network. There have been incidents of hacking and viruses in high-end phones.[7]

Finally, without proper security measures, attackers can abuse the operation of mobile computing applications. For example, in the application where the phone captures a 2D bar code and reacts accordingly (displaying a Web page, for example), an attacker or prankster could replace the legitimate bar code with another, presenting an unsuspecting user with false information from a rogue server.

Mobile computing applications must also address privacy issues—particularly applications that store or transmit users' personal information. The common personal information stored in a phone includes the user's (the phone's) location, birthday, and credit card number. However, additional applications could produce other sensitive information, such as tuberculosis images taken by the medical microscope application or blood pressure information measured by the health monitoring application.

Although most of the mobile computing applications I've discussed here are prototypes or are still in the conceptualization phase, these are applications that were mere fantasies a few years ago. Someday, gadgets shown in science fiction could become real with our cell phones. How about a lightsaber phone? IT

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