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Mobile Phones Will Become the Primary Personal Computing Devices

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A merger of the lowly USB memory stick and the mobile telephone provide a new platform for information solutions. Microscopic portable memory with capacity similar to today's PC disk drives will spark a transformation which will then be driven by new use models for mobile phones and a new class of "computer user", one that has no "personal computer" at all. Since more people carry phones than laptops the PC will fade into a role similar to today's view of the once mighty mainframe. Laptop-loving dinosaurs at the workshop will protest that phones will never replace their favorite machines, in much same way the mainframe developers scoffed at PCs throughout the 1980s.

Mobile computing but not "Personal Computing"

Imagine a mobile device with the shape of a modern cellular phone containing all of the functions we expect in such a phone plus wireless Internet radio connection and a digital storage of one terabyte. Since it looks like a phone, we call it a phone. Such a phone would have all the capabilities of a typical PC laptop except for two major shortcomings: the display and the keyboard are tiny. Indeed if such a device were connected to a keyboard and screen, the entire user experience of a PC could be reproduced in principle. On the other hand, such a phone would be much easier to carry than a laptop, it would be easier to store, and it would be much more convenient to use for audio/video services like music, telephony and simple video. There in lie the fundamental challenges – human control and visual output -- and the opportunities – extreme portability and simplified audio/video uses. If we can engineer solutions to the challenges we can unleash the potential.

Let us further imagine a world where work and entertainment spaces routinely contained full sized displays and keyboards. If we had the technology to bind the phone to these devices, then we would have the capability of a PC at work and home, but the portability of a phone in between or when traveling. This binding has been termed "opportunistic annexing" by Pierce and Mahaney [1].

Such a world, the combination of a mobile multi-network phone with vast digital storage and available displays and keyboards, would open up computing to different set of users, users that need visual output and keyboard input only intermittently. For example:

- Construction, maintenance, and service personnel who need to maintain records of activity and consult documentation occasionally.
- Health care workers charged with electronic medical record components.
- Sales and management workers requiring appointment and background information on clients, but seeking personal interactions rather than laptop-focused interactions.
- Casual computer users with personal photos, music, video, and digital correspondence to share while mobile.
- Mobile office workers charged with person-to-person communications.

These kinds of users are poorly served by laptop computers that require flat surfaces to support them, two hands to operate, create a barrier between the user and other people.

We also believe that many people who use PCs but not mobile laptops would find this combination of a mobile phone and fixed display convenient. Rather than find themselves at home without a document they need for an emergency call from work, or in a colleague's office without access to their files, such workers simply carry all of their office documents with them at all times as a side effect of carrying a mobile phone.

This description of new super phones and their users fits the classic criteria for disruptive technologies [2]. Phones with internal storage cannot compete with PCs for many things PCs do well. For examples, 3D computer games, complex spread sheets, graphical arts, and so on. But these phones can be effective for some existing PC users, opening a new channel of computing technology that will attract new users.

The use model for the computing aspect of these new mobile phones would build off the use model for auxiliary storage, specifically the now ubiquitous USB memory stick. A phone with large storage would connect to a display and show the user's media. We adopt this trivial model because we know we can get it to work and that users will understand it. Technically we expect that the connection technology will be wireless and include simple web browsing of data on the phone hosting a web server [3]. However, even the seemingly simple shift from the simple external drive model of USB memory to a wireless web server requires significant work on usability.

This use model makes file sharing even more trivial than today's USB memory sticks. Rather than connect the stick to one PC, copy a file onto it, move the stick to another PC and copy off the file, we cut out the first step and connect my phone directly to yours.

Having established the value of mobile phones with digital storage and their companion fixed displays, we next consider practical issues of the feasibility of such devices and challenges in getting them to work together.

Technology Allowing the Phone to Replace the PC

We next establish the practical reality of phones as the central mobile computing device, the trends in storage that point to extraordinary density in handheld form factors, and the technical feasibility and market acceptability of a phone with massive internal storage. To the expert in mobile systems these observations will not be new, but we lay them out here to lead you to see how to take action on this vision of the future of mobile devices.

"Mobile devices" typically mean battery operated digital devices, usually with computer-like functions. The central players have been laptop personal computers and personal digital assistants (PDA). The worldwide build-out of cellular telephone infrastructure makes mobile phones more and more valuable. Simultaneously, continual miniaturization of computing technology has allowed "smart" phones to incorporate many features of PDA and PDA developers have responded by adding cellphone radios. Market analysts predict that shipments of these "smart phones" will reach 100 million units by late 2007 and continue to increase at a rate faster than laptop PCs [4]. Thus miniature computer-like devices that users call phones will become pervasive over the next decade.

Smart phones currently differ from PCs in the choice of network and the economics of network deployment. Cellular phones use closed networks optimized for voice and the network operator recovers hardware cost through network access charges; PCs use open networks optimized for data and hardware is (typically) purchased directly by end users.

This network difference is slowly fading. A new generation of data-centric cellphone protocols and early deployment of wireless Internet protocol phone service make phones and computers much more similar. While the economic models have not begun to merge, two strong forces may complete the merger: inexpensive international phone calls over the Internet and the powerful effect of open networks in encouraging innovation in services. The first force will cause some cell phones to include Internet Protocol radios; the second force will then make these dual mode phones more valuable.

Our comparison of smart phones and PCs did not consider the central processing unit (CPU) differences. For most users, this difference will not be significant. In the PC world, the quest for more cycles per second has become limited by power dissipation: PCs will not be getting much faster soon. Moreover, much of the CPU in a PC goes into preparing and moving bits on to large displays not used on phones. The trend to multiple CPUs per user fits nicely with a model in which one CPU is mobile and dedicated to personal storage and communications while other CPUs work with displays and keyboards.

Storage Revolution.
More disk storage is probably not high on the wish list for most PC users. This reflects the exponential storage density improvements created by technological advances: storage technology has out-paced demand. Nevertheless the pace density improvement is not expected to slack off in the foreseeable future. Therefore the market has shifted from PC storage to storage for mobile devices. Digital music players, starting several years ago at a few megabytes, now (2005) reach 80GB. While it may be hard to internalize, the technology trends clearly show that portable devices with terabyte capacity will be available at consumer costs within a decade.

Smart Phones with Terabyte Storage.
The simple merger of an MP3 player and a phone would provide a single device with the capabilities of two separate devices available today. Eventually, as storage costs drop, the cost of a combination device will be only slight more than either device alone. Moreover, the combination would allow consumers to get two major functions while carrying only one device. Working against a combination is complexity: the user interface of the combined device cannot make listening to music and talking on the phone significantly more difficult than separate devices. In 2005, at least one merged MP3 phone device is one the market.

A MP3-phone combination is not quite a smart phone with terabyte storage. Most important, the simple merger would not allow the kinds of use models that we need to spark our vision of future mobile devices. We need access to the storage from outside the phone and we need user interface control over that access.

Future Televisions as computer displays

Given a smart phone with large internal storage, we also need to displays and keyboards for those occasions when intense, PC like work is called for. In most developed nations, work spaces already have computer monitors and entertainment spaces already have displays in the form of televisions. These devices are not ideally suited for use with a future super phone, but they do exist. Thus, to use displays to augment phones, we only need a small shift in the capabilities of the displays, not investment in displays for a new paradigm. As these devices are replaced, our phones could find ideal partners with better I/O capabilities. In the mean time, existing PCs can be adapted to serve as displays for our new phones.

In developing nations, a different logic may lead to the same result. Rather than investing in cellular phones, land-line phones, televisions, and PCs, a developing nation could skip directly to a world of super phones and modern televisions.

Some of these "televisions" could resemble today's laptops. Many lightweight laptops today are physically dominated by a screen and keyboard; the rest amounts the guts of a mobile phone. Innovative televisions can be cheap and simpler accessories to the phone and the combination would then complete the transformation from a PC oriented to a phone oriented world. [5]

Remaining Challenges

Our use models are modest extensions of what some users do today; our technology extrapolations are conservative. Therefore the topic that we put before this workshop is the challenge to deliver a truly useful multi-device system for users with mobile phone based computing devices. In this section we try to break down the challenge in to manageable problems.

The first challenge is to connect our new fancy phone to available displays. As the workshop participants sit to listen to this talk we can try a simple test: try to transfer a file from any machine in the room to any other one. There are a variety of ways to accomplish this task, but none are fast and easy. We recently tested this claim in our lab, having users connect a handheld device to a PC via SIP-phone call, USB, Bluetooth, and docking cradle [6]. Our results showed our SIP based technique to be marginally better, but no method was adequate for routine use. To leverage mobile data devices we need simple, fast connections. The work of Hinckley et al. shows that devices on the same subnet of a LAN can be connected in sub-seconds: that should our goal for general network connections [7].

The second challenge is a standard for using a connection once it is established. A flexible and open standard that novice users and service providers can understand would allow connection of any new super phone to any display. We need a standard that allows future devices to give excellent user experience and yet allows current PCs to be used as displays. Ordinary users of web browsers can contact machines around the global with a few mouse clicks: we should be able to help them use files in their phone on a nearby computer.

The third challenge is a safety. We need a system that supports users who carry many gigabytes of personally organized media on devices that can be lost and stolen. The goal cannot compromise usability. Our personal experience with PC backup technologies suggest that adapting them to

future super phones will not address this challenge. Very large mobile storage suggests that incremental techniques will be needed.

The fourth challenge is security. Phone users want some assurance that connection to a future television will not cause their personal or business data to be accessible by other people without consent. This is a form of digital rights management (DRM) where the digital content is personal or business data rather than commercially developed entertainment media or software. Consequently the techniques under development for DRM will apply to phone data as well. This area is primarily a concern in transition, when today's insecure PCs are used with phones.

The fifth challenge is PC-like functionality while mobile without nearby large displays. In one sense this is a fundamental limit: phones won't have PC-like functionality. But numerous alternatives to today's phone interface may emerge. New I/O techniques [8] may help; lightweight display/keyboard combinations may emerge to allow mobile augmentation; and flexible or projection screens may become practical.

Other Models for Data Mobility or Mobile Data

Our position differs from other approaches to mobile data, primarily in pointing to a first step based on the model of massive local storage, accessible from fixed displays as well as from a phone. Compared to Want et. al, we put a phone face on our personal server [3]; compared to Pierce and Mahaney we take an easier UI model for our opportunistic annexing [1]. We also advocate thinking about new display devices for phones as “televisions” of the future. This future is almost here.

Why use local data storage when networks are fast and pervasive? Partly our answer is empirical: as a community we tried network file systems and most of us now use local storage on our PC: remote storage does not work as well for rapid access to changing data. Local storage gives local control: we can adjust the tradeoff between security and ease of use (mostly towards easier). Partly our answer is it does not matter: backed up local storage or locally hoarded network storage [9] could have similar user experiences.

Why stop at mobile data if mobile workspaces are possible? Mobile workspaces [4] address a different user model: workers who transition between fixed locations then work intensely in a PC like fashion. These users benefit from continuity in work. We address a different set of users or use models, where the activity is more unpredictable or location dependent in a way that cannot be predicted. Perhaps more important, our approach is just simpler and we want to be practical.

Isn't the PC already better at Mobile Data than a phone every will be? For a narrow audience of highly trained, motivated, and patient users, PCs are better at mobile data than phones will ever be. We believe a new class of users would adopt these super phones and displays. These users want a simple and seamless experience resembling the use of phones and televisions, not the experience of PCs. They will trade expressive power for ease of use.

Earlier we described phones as powerful devices that are fundamentally "not PCs" because they lack large screens and keyboards. When necessary and available, adding I/O devices to the phone would create a composite machine with the capabilities of a PC. However the type users who would adopt our new phones will not patiently endure the problems of PCs. Moreover, even the

best composite machine would not have the full range of the phenomenal capabilities of a general purpose PC. Phones should not be PCs, but they can be very useful mobile computing devices that offer some of the functions of today's PCs. We must set out to create a unique and useful experience combining phone and computer functions.

Call to Action

We propose that important progress in mobile computing should start with straightforward local convergence of smart phones and computer infrastructure via simplistic mobile data use model. Instead of fancy infrastructure, we raise the challenge to make the connection of two co-located machines very fast, very simple, and useful everywhere. Then we claim that solving a set of resulting challenges will enable the new generation of storage equipped mobile phones to lay claim to grow into the primary computing device used by billions of people. The technical leaders at this workshop are in a great position to lead this transformation.

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