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ABSTRACT
Connecting small, mobile computers to other computers, especially when these connections are not preconfigured, is a critical element in the user experience of multi-device applications. We empirically studied the user performance and experience of such connections using WiFi phones with Session Initiation Protocol (SIP), Universal Serial Bus (USB), Bluetooth radio, and wired connections in a docking cradle. Results show that the gain of easier information access by connecting phones to larger displays and keyboards could outweigh the cost of making the connection for text entry with as few as a dozen characters.

INTRODUCTION

High capacity, microscopic digital storage devices allow mobile computing paradigms in which personal and work files move with users rather than with computers. In particular, mobile phones with large digital storage capacity are now technically feasible and economically practical. Many people already carry cellular phones: if the phone also contained the files typically held on a person computer (PC), then these people would have ready access to such files wherever they are and at all times. If, in addition, displays and keyboards could be easily attached to the phone, users could get much of the value of a PC without the effort to carry one at all times. The display/keyboard could be today's PCs interfaced to the phone or some future advanced televisions.

This use model would be especially attractive if we did not need to pre-deploy displays for phone, but could "opportunistically" use them to augment our phone [3]. Routine, practical augmentation faces many obstacles, including quick connection, media compatibility across machines, and safety of the data from loss and theft. To start tackling these problems we report here on the speed of connecting mobile devices to PCs. Quantitative measurements allow progress to be measured. Our primary conclusions should interest mobile computing technologists: the potential advantage of opportunistic augmentation is large and yet the existing connection technologies should to be much faster and easier for users.

We initially set out to quantify the costs and benefits one particular approach to augmentation [1] based on Session Initiation Protocol (SIP) [2]. This technique is wireless, but connection is established through a generalized "phone call": the user keys in a phone number or pushes their phone's number into a display using an RFID tag on the phone. The time cost includes connecting a phone to an available display (see Expt. 1 below); the benefit includes larger screens and easier to user keyboards (see Expt. 3). In looking for comparison data we were surprised to find very little published on the performance of device connection. Therefore we broadened our efforts to include measurements on connection time USB, Bluetooth, and docking techniques (see Expt. 2 below).

RELATED WORK

Scott et al.[4] measured the connection times for Bluetooth devices to demonstrate the advantage of bypassing in-network device discovery. They use a phone camera to read circular barcodes that contain the Bluetooth address of the device to be connected to, skipping the Bluetooth scanning step. The physical discovery methods we use for SIP addresses [1] are conceptually similar and our timing approach is comparable. In addition to expanding the technology arena by adding a SIP solution, we also compare to wired solutions of USB and docking.

Hinckley demonstrates that two devices can be "bumped together" to connect them with times below the level of human perception [6]. His technique requires that the devices communicate on a common wireless channel to exchange accelerometer data. Our work relies on existing wireless technologies and the two devices in our solution need not be on the same subnet and wireless channel. Nevertheless we note that all device connections techniques should aim for the connection times Hinckley has shown to be possible.

The cost of connection is only meaningful when considered against the gain of augmentation. For benefit measurement we compare text input via multitap keying on the phone to keyboard entry for similar data. James and Reischel [5] is one of the many extensive studies of text entry on phones; keyboard entry speeds are well known [7]. Our measurements of text entry times here are part of the complete augmentation experience: users are not just typing, but manipulating the phone, keyboard, and mouse to enter data. Text entry speed plays an important role, but so does user interface navigation speed and the device connection interface. We combine these elements in our study.

METHODS: CONNECTION TIME

Since our ultimate purpose is usable augmentation, we adopted a measurement for connection time that combined human interaction time with computer and network delays in setting up the connection. (As we discuss below, we also timed the computer and network delays separately). We constrained the technology to treat the devices as "strangers" in making connections. That is, we specifically did not treat the handheld devices as peripherals to a personal computer, but rather as mobile peers that could connect to any number of other computers.

We used three different devices in the study: 1) a SIP phone, ZyXEL model 2000 Prestige W, 2) a PDA, HP iPaq Model 6315, and 3) an Apricorn ez bus mini USB 20GB disk drive. We chose the USB disk drive over smaller USB devices so that all devices were similar in size and each required two hands to connect, one to hold the device and one to operate the connection controls. The SIP phone came equipped with a webserver that allows phone-book data entry over the network. We also timed users as they accessed the phone-book using the phone's keypad. The PC was a Thinkpad model T23 running Microsoft Windows XP.

Our user study had three Experiments: Expt.1). Connection times without application choice, applied to two SIP phone techniques, the manual IP technique, and navigating to a data entry menu using the phone's keypad; Expt.2). Connection times with application choice, applied to two SIP phone techniques, docking, USB, and two Bluetooth techniques; and Expt.3) Data entry measurement, for data input to the SIP phone's phone book, using both the phone keypad and the connected PC's keyboard.

Twelve people participated in Expt 1 and 3; twelve different people participated in Expt 2. All participants where briefly trained in the connection and data-entry techniques; the order of the techniques was randomized across users.

In Expt 1 and 2, a trial started when participants picked up the mobile device from one table, turned to a nearby table, and connected the device to a PC on the second table. The connection procedure for each technique differed as described below. A trial ended when the users had navigated on the PC to a specific document stored on the mobile device over the connection they had just established. Separately we also timed the system delays for each technique, three times for each technique.

Expt 1 and 2 differed in one part of the connection procedure. Expt 1 offered the user no choice of application (or media rendering program); Expt 2 prompted the user to select from a list of 2-4 applications. For example, the choices might be 1) web browser/server and 2) VNC client/server. Only the phone techniques could be tested both with and without application selection.

As much as possible, we tried to keep the overall task similar to preparing to enter several new phone book entries. Device drivers were preloaded for the USB and docking cases, but no information about which specific devices would connect, such as Bluetooth pairing was stored on the PC. The connection task details for the seven techniques of connecting a mobile device to a personal computer (PC) are as follows:

SIP phone, user dialed: The participant picks up the SIP phone, observes a phone number displayed on the PC screen, and keys the phone number into the phone. The phone connects to the PC. For Expt.l , a web browser opens on the PC, with the URL pointing to the home pages of webserver in the phone; for Expt. 2, a pop-up dialog box appears and the user must select web browser from the menu, after which the browser opens as for the first trial. Users next select the “phonebook” link and the test ends. For implementation details, see “dial-a-display” in [1].

SIP phone, RFID: The participant picks up the SIP phone, now with an attached RFID tag provided by the experimenter, and places it over an RFID reader attached to the PC. The augmenting computer calls the mobile phone and the participant answers. The remaining interaction is as described for “SIP phone, user dialed”. For implementation details, see “click-a-display” in [1].

Manual IP address entry: The participant browses the phone menus to display the phone's IP address. Then they open a web browser on the PC and key in the IP address in the web browser's address field. When the phone's web server responds, they navigate using the “phonebook” link.

PDA Docking: The participant picks up the PDA and places it in the docking cradle of the PC. The PC puts up a dialog box with 5 entries, the participant selects “open folder to view files”, and navigates to a file named “phonebook”.

USB disk drive: The participant picks up the USB drive and connects it to the USB port on the PC. The interaction proceeds as for PDA docking.

Bluetooth from PC to PDA: The participant picks up the PDA but uses the PC's Bluetooth control panel to search for available Bluetooth devices. Once the device has been found, the participant accesses the file transfer protocol from the list of available services displayed by the PC’s Bluetooth control panel. The Bluetooth device connection protocol enforced a security step not included in the other techniques; we measured this time separately and subtracted it from the analysis.

Bluetooth from PDA to PC: As Bluetooth from PC to PDA, but controlled from the PDA.

Methods: Data Entry

While many contextual and personal issues determine technology benefit, we adopted a testable metric for opportunistic augmentation: for a user keying text into a digital phone book, they benefit from augmentation when the larger keyboard allows them to enter text faster. Typically, augmentation takes more setup time than keying text directly into a phone: users only benefit if the setup or connection time is small enough relative to the gain from having a larger keyboard for typing. Measuring connection time is therefore critical to understanding the cost and benefit of opportunistic augmentation of mobile devices.

For the data entry experiment, each of twelve participants entered three phonebook entries through a web browser and through the phone's keypad using multi-tap. The entries included contact name and phone number, they were 24, 25, and 34 characters in length. Entry errors had to be corrected during the trials.

RESULTS

Expt 1. For the tests without application selection, connection time varied significantly with connection technique: $F_{3,33} = 22.6$, $p < 0.0001$. *Post hoc* tests (Fisher's PLSD) show that every pair wise comparison was significant ($p < 0.05$) or nearly significant ($p=0.077$), except the two SIP phone methods (dial vs. RFID) ($p = 0.45$). The results for each technique are summarized in Table 1 and Figure 1.

Technique	*Mean*	*Std Dev*	*Std Error*	*Median*
Phone Menu Browsing	14	8	2	11
Manual IP	54	24	7	51
SIP Phone user-dial	28	8	2	26
SIP Phone, RFID	24	4	1	24

Table 1 Results for connection times, tests without application selection. Averages over 12 subjects, in seconds.

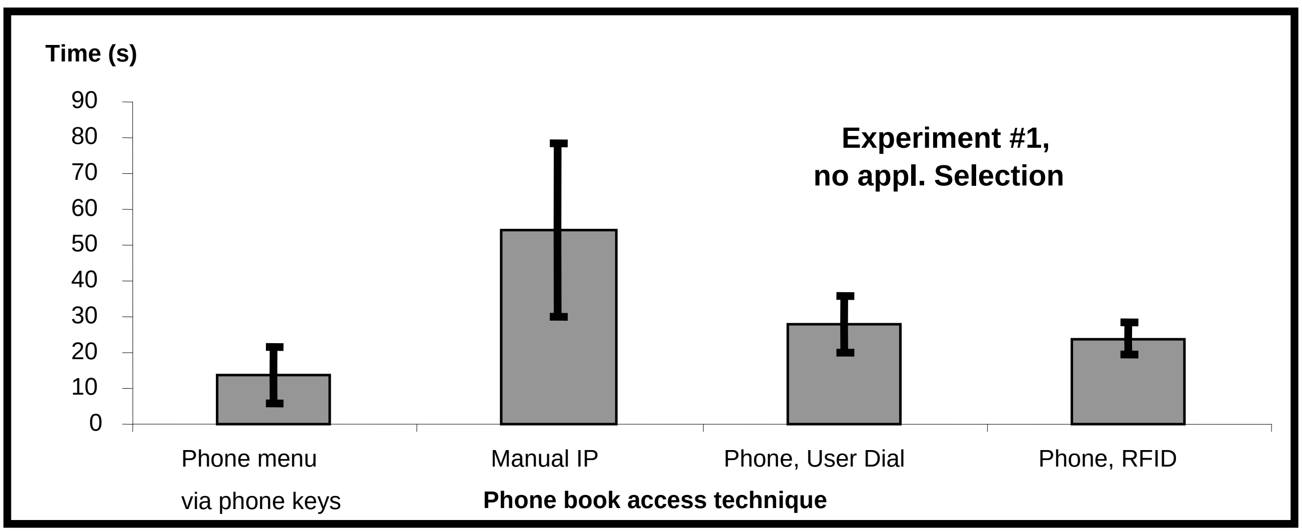

Figure 1: Mean time to access phonebook for different connection methods; std. dev. as "I" bars.

Expt 2. Connection technique again had a significant influence on completion time $F_{7,77} = 9.34$, $p < 0.0001$. Among the pair wise comparisons, a notable result was the lack of a statistical difference between the two Bluetooth techniques: it did not matter if the connection was initiated on the PC or handheld device. The results for these tests are summarized in Table 2 and illustrated in Figure 2.

One perhaps surprising result is the similarity of the wired (docking and USB) and wireless (SIP phone) connection times given that the user has to key in the phone number. As Table 2 shows, the system delays, the total time it takes the hardware, network, and software to recognize the device attachment and launch a user interface, (first column) are a significant fraction of the total time: these techniques have fast human interaction times but slower system time.

Expt 3. With the phone's multitap keypad, our users averaged 3.5 sec/character; on the computer keyboard 1.0 sec/character. Data entry time varied significantly between the two methods: $F_{1,11} = 430$, $p < 0.0001$. The text entry tasks showed that text entry was three times faster (in char/sec) on a standard keyboard in web form than on the phone keypad, which is consistent with other studies of text entry [5].

Participants complained about the user interface of the phone, which felt slow (did not register key presses if users were too fast) and misleading (the back button did not take them to the previous step of the entry but to the beginning).

Times in seconds	**sys. delay**	**Total connection time**			
	Mean	*Mean*	*Std Dev*	*Std Error*	*Median*
Phone, dial	11	34	5	1	34
Phone, RFID	10	25	3	1	26
Docking	26	30	5	1	29
USB Disk	5	25	7	2	25
Bluetooth from PC	25	46	38	11	37
BlueTooth from iPAQ	9	52	15	4	49

Table 2 Connection times for different technologies when users must also select an application. Column labeled "sys. delay" includes only computer and network operations.

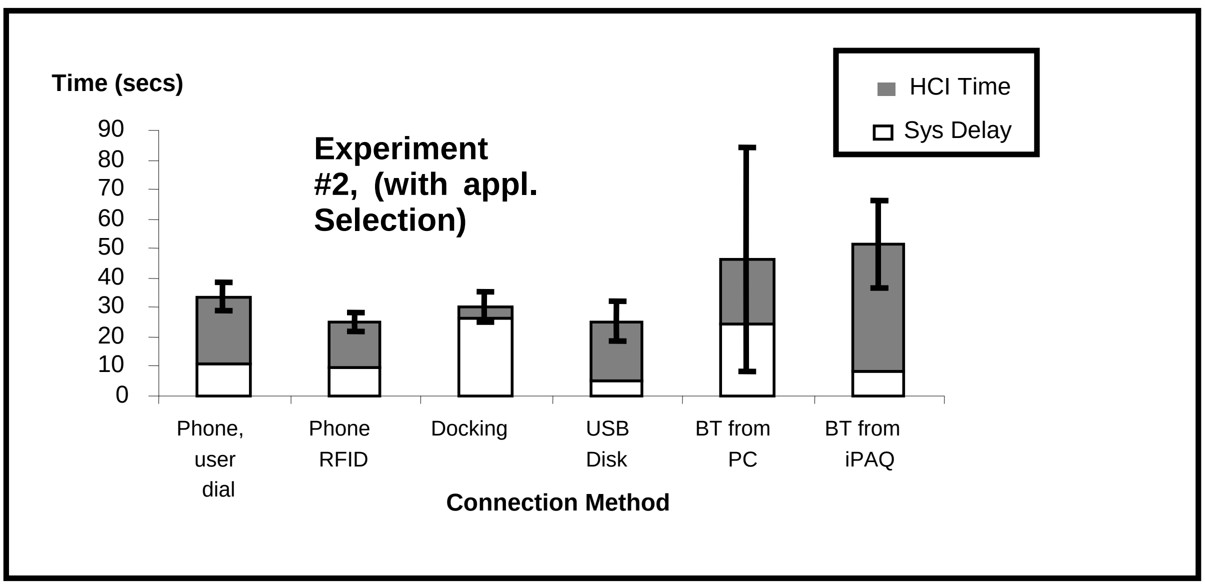

Figure 2 Expt. #2 Mean times in seconds including time for application selection, for different connection techniques. System delays from Table 2.3

OPPORTUNISTIC AUGMENTATION MODEL

When will opportunistic augmentation be advantageous? Based on data collected in our experiment and from the text entry literature [5], a proposed more general performance trade-off model follows. Using T_c for the technique's intrinsic connection time, H_c for the human interaction time required by the technique, C for characters required by the task and E for the time required to enter a character:

$$Total\ time = T_c + H_c + C*E;$$

From our data for a mobile device without augmentation, T_c is zero, H_c is 11 seconds and the char entry time is 3.5 sec/char; For an augmented device, using application selection, $(T_c + H_c)$ is about 30 seconds, but the text entry needs 1 sec/char. According to the model, to enter 8 characters, a user with only a mobile device using multi-tap takes 39 seconds; a user with an augmented device takes 38 seconds. For more characters, augmentation benefits users.

Note that task completion time is a composite performance measure reflecting not only time per se, but also the level of difficulty, frustration, or the user experience in general. Our result may be somewhat optimistic: the commercial IP phone used in this study was not designed for easy text entry, we tested only one specific (but relatively short) input task, and the PC was ready for augmentation. On the other hand, our measured text entry on the keyboard is slower than other studies, probably because the text was entered into several boxes in a form, not just typed. Whatever the balance we see our results as encouraging.

CONCLUSIONS

We measured the time to connect a mobile device to a PC using a number of common methods and two new ones that we believe is especially useful for phones with IP support and large internal storage. Our results show that users can benefit from the extra step in opportunistic augmentation if more than very brief text entry is needed. The SIP-based technique was competitive with the more common methods.

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