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Abstract

Mobile devices such as smart mobile phones, personal digital assistants (PDAs) and other handheld computing devices have become very popular. The early findings about the use of mobile devices and mobile systems show that the mobile computing environment differs from the traditional desktop environment in significant ways. Several areas of computing, related to mobile devices, have surfaced over the last decade. These areas are said to be distinctively different from one another, yet they appear to overlap. Such areas are mobile computing, nomadic computing, ubiquitous computing, wearable computing and pervasive computing. This paper describes each of these areas of computing and identifies the design issues. The paper furthermore attempts to identify where systems developers should look for guidance for the development of mobile systems.

Keywords

Mobile computing, nomadic computing, pervasive computing, ubiquitous computing, mobility, design issues, use context

Introduction

Mobile devices such as smart mobile phones, personal digital assistants (PDAs) and other handheld computing devices have become very popular. The main buyers of these devices have been individuals who use them for personal productivity purposes. Organisations are now looking at harnessing these mobile devices as part of their enterprise information systems. This has led to an array of mobile solutions directed at personal productivity and accessing the enterprise information systems. But, these solutions are directed at managing the synchronisation and not the applications available on the mobile devices.

The early findings about the use of mobile devices and mobile systems show that the mobile computing environment differs from the traditional desktop environment in significant ways (Jing, Helal & Elmagarmid, 1999). A mobile user will use the mobile device in different settings where the environment cannot be controlled. Research in the use of mobile devices show that the design of the mobile device and the systems available on these devices will

impact the social interaction (for example: Dryer, Eisbach & Ark, 1999 and Scheepers & Steele, 2002). Further studies show that the implementation of mobile devices and systems impact the way in which users do their work (for example: Wiberg 2001). Additionally, empirical evidence suggests that the design of screens impact the useability of the systems (for example: Nilsson, 2001, Laux, McNally, Paciello, Vanderheiden, 1996 and Scneiderman, 1992). The use of traditional systems development methodologies does not necessarily cater for systems that will be usable in a mobile setting.

Several areas of computing, related to mobile devices, have surfaced over the last decade. These areas are said to be distinctively different from one another, yet they appear to overlap. Such areas are mobile computing, nomadic computing, ubiquitous computing, wearable computing and pervasive computing. In the unchartered area of the development of information systems for mobile use, to which of these areas should systems developers look when designing mobile systems. Our research, focusing on the development of systems for mobile/nomadic use, seeks to answer the following question: **what principles should guide the design of mobile systems?**

This paper is a conceptual study of literature that attempts to define the different areas identified above and discuss design issues. We first identify the principles and philosophy of ubiquitous, pervasive, mobile, nomadic and wearable computing to illustrate how they fit in the "big picture". We then discuss design issues in the above areas, identifying factors that require consideration from a conceptual as well as a technological perspective. Finally, a discussion summarising the understanding and findings of this paper is outlined.

Overview of Emerging Computing Paradigms

Ubiquitous Computing

Ubiquitous computing (Ubicomp) is a paradigm that boasts of omnipresent computers which allows enhanced computer use, but should be effectively invisible to the user (Weiser, 1993). Ubicomp desires to achieve the same pervasive nature of writing and scripture in our lives. It is not uncommon for one to intuitively reach out for a pen and paper and jot down a piece of information whether it is while conversing with someone, or passing a bill board with useful information. Ubicomp is a paradigm envisioned and proposed in the late 1980s. Its underlying technologies are now being anticipated to move from research laboratories to the real world (Hull, Reid & Kidd, 2002). The question remains if the technology is ready to be complemented in the real world today because of issues related to infrastructure as well as social acceptance.

Over the last decade and a half, we have seen the development of smaller and faster computers but have yet to see the implementation of invisible computers that are a part of Ubicomp. Ubicomp has helped kick off several other areas of wireless computing, which includes mobile computing, wearable computing and nomadic computing. However, Ubicomp is said to be different from mobile computing (Weiser, 1999). Mobile computing is neither a subset nor a superset of Ubicomp (Weiser, 1999).

Pervasive Computing

Analogous to Ubicomp is another computing concept – pervasive computing. Ubicomp literature in fact uses this term as a synonym (Weiser, 1996), suggesting that pervasive computing also supports invisibility of computers. While this may hold true in every instance of Ubicomp, it does not necessarily reflect an unconditional description of what constitutes pervasive computing. Telecommunication technologies are an example of pervasive technology. We often use a mobile phone not as a luxury telecommunication device, but as a necessity. It has become an object that pervades our lives. Desktop computers today makeup an integral part of our daily lifestyle, be it at home or at work. Many actions and interactions are almost unconsciously executed, reflecting pervasiveness. This type of interaction and computing will certainly not be considered Ubicomp, however exhibits traits of pervasiveness. Hence, pervasive computing does not only include applications supported by ubiquitous computing, but beyond as well.

The perception of pervasive computing being associated with *wireless* computing and technologies is misleading. SearchNetworking.com definitions even explicitly state that "*pervasive computing devices are not personal computers as we tend to think of them, but very tiny – even invisible – devices,…*". As we speak of pervasiveness and "invisibility" to be comparable to a carpenter's well-balanced hammer that "disappears" into his hands while working (Weiser, Gold & Brown, 1999), the role of desktop computing in today's world is undisputedly pervasive.

Wearable Computing

Wearable computing facilitates a human-computer interaction comprising a small body-worn computer that is always on, ready and accessible. A wearable computer is included in a user's personal space and is controlled by the user; it has full functionality of a computer system that is as reconfigurable as the desktop computer whilst being inextricably intertwined with the wearer (Mann, 1998).

Wearable computing is formally defined by Mann (1998) in terms of three basic modes of operations and six fundamental attributes. The operational modes are

- constancy – always ready to interact, does not require a start up period as it has a constant user interface

- augmentation – as opposed to traditional computing concepts, computing is *not* the primary task of wearable computers and will occur whilst the user is simultaneously doing something else

- mediation - wearable computers encapsulate users to experience solitude and privacy by filtering information and blocking undesired material and experiences, perhaps altering perceptions of reality in a mild manner

The six attributes (also known as signal paths) of wearable computing are unmonopolozing of the user's attention, unrestrictive to the user, observable by the user, controllable by the user, attentive to the environment and ability to communicate to other mediums (Mann, 1998)

Mobile Computing

People have always had the need to be "on the move" but were restricted with the lack of facilities that allowed them to manage their work – be it personal or professional. The time spent travelling to work and back would leave a person disconnected from their respective 'networks'. Data and information were required whilst performing tasks in a different setting, but could not be retrieved because there was no access to the desktop at work. Today however, the growing infrastructure of wireless and mobile computing has made it possible for people to have instant access to vital information while maintaining their mobility. Mobile phones in particular have taken the market by storm, owned by people of different walks of life – from high school students to corporate executives. This has allowed people to remain connected with their personal and professional network whilst maintaining their mobility. In fact, the pervasiveness of mobile phones has carried it to the extent of being used as a media to pay for parking (Cauchi, 2002) as well as function as a digital camera and a radio (Nokia.com, 2003). Intensive use of mobile technologies has dramatically mobilized human interaction (Kakihara & Sørenson, 2002). Nulden and Lundin (2002) outline three assumptions about mobility amongst people in general: the fact that they are increasingly mobile, that several new types of wireless access will be available in the next few years, and that the area of mobile information technology will provide new possibilities for mobile people.

A mobile computer, simply defined is a "*computing device which can communicate through a wireless channel*" (Chlamtac & Redi, 1998). This field covers a wide range of applications from personal digital assistants (PDAs) to tablets, web pads and wearable computers. Ubiquitous and mobile computing have been used interchangeably, when in actual fact ubiquitous computing is not the same as mobile computing neither is it a subset or a superset (Weiser, 1996; Dawson, Fisher & Scheepers, 2002). The significant difference between Ubicomp and mobile computing is that the former broadly deals with computing that is invisible to the users, that does not 'live' on any personal device but exists in our surroundings. The use of and interaction with such computing will be unconscious – data and information is exchanged without being realized. Devices such as PDAs and cell phones do not fall into this (ubiquitous computing) bracket of computing as the initiation of its use is a conscious attempt to communicate or use the device. PDAs and cell phones are defined better as being a part of mobile computing. Hence, mobile computing can be defined as *computing that occurs whilst a user is able to move or is moving around, using a device (often handheld) directed by the user that is location independent and can communicate through a wireless channel*.

Nomadic Computing

Nomadic computing on the other hand is the use of portable devices like laptops, notebooks and handheld devices in conjunction with mobile communications technologies to enable users to access the Internet and data from anywhere in the world (Kleinrock, 1996). In nomadic computing, the need for a device to be portable in order to support a user's nomadicity is vital; however it does not have to function only in a wireless network; it can also function in a wired network. When a user travels from one location to another and attempts to connect their laptop via a wireline analog modem at their destination location, a nomadic move has occurred though no wireless communication takes place (Kleinrock, 1996).

Nomadic computing closely emulates the desktop environment as opposed to mobile computing.. Processing, memory and screen sizes are very similar to the personal computer (PC), allowing the user to experience much of the benefits of desktop whilst being mobile.

Summary

Based on the characteristics of the individual areas of wireless computing, the Venn diagram in Figure 1 describes how we view the role of the paradigms discussed in the 'big picture'.
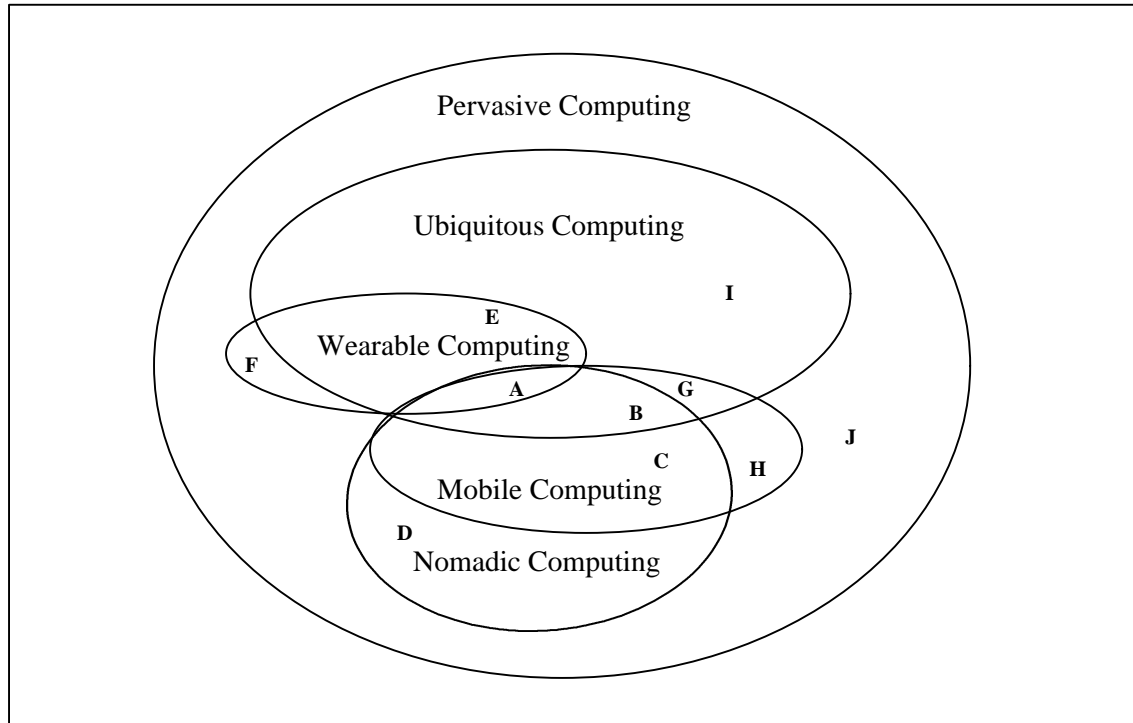

Figure 1: Venn Diagram of Emerging Computing Paradigms

We describe an application/scenario or device within each intersection as an example in Table 1 to get an overview of what we perceive of the emerging computing paradigms.

Intersection	Description	Example
A	Capable of communicating with embedded devices/computers in a ubiquitous environment to update context specific information as well as send specific information requested by the embedded computers. The device further allows a mobile worker to access information on the fly while travelling with regards to weather updates or urgent e-mails and messages from his head office, justifying mobile computing access whilst being a nomad.	Wearable computer device such as a wristwatch (Mann, 2000)

B	In this intersection, the devices rely on a wireless network to access information as they travel or are away from their 'base station'. These devices will also have the ability to communicate with embedded devices/computers in a ubiquitous environment. For example, downloading the synopsis of a show and the session times upon entering a theatre.	Mobile devices such as cell phones and PDAs carried by nomadic workers that rely on a wireless network for communication
C	Use of mobile devices in this intersection does not incorporate any form of communication within an environment that has other embedded devices/computers, i.e. ubiquitous environment. For example, retrieving messages or information from a central Information System while travelling	Mobile devices such as cell phones and PDAs carried by nomadic workers that rely on a wireless network for communication
D	Such an example is when a worker carries his notebook from his office to a hotel. The person may choose to connect his notebook to the telephone line connected in his hotel room. This indicates that the worker has experienced a nomadic move, however, he is not accessing the wireless channels for communication	Mobile devices that access information through a wireline
E	Such a device might form part of the clothing of the person and will identify the location of a person.	Wearable devices that communicate within a Ubicomp environment but serve no purpose as a mobile device.
F	Allows a user to perform computing activities without interacting with the Ubicomp environment. In our diagram, we have included wearable computing as a subset of pervasive computing despite the fact that currently, wearable computers are not really pervasive. This is because of the vision foreseen for wearable computers in the future that aims to be pervasive.	Wearable computer, such as a wearable jacket (Randel & Muller, 2000)
G	Use of mobile devices within a Ubicomp environment, but without any nomadic moves involved. The devices are used in their 'base environment'.	Mobile technology in assisting road guards (Esbjörnsson, 2000)
H	Use of mobile devices outside a Ubicomp environment, but without any nomadic moves involved. The devices are used in their 'base environment'.	Mobile phones, PDAs and handheld devices
I	All extensions of anticipated Ubicomp environment, mostly related to embedded systems that communicate through wireless channels.	MIT's Project Oxygen (Project Oxygen, 2000), CMU's Project Aura (Project Aura, 2002)

J	Computers that are visible, accessible consciously and communicate through a wired infrastructure, but play a role so vital in one's daily life that it is *pervasive*.	An example is the role of desktop computers today in homes and offices.

Table 1: Summary of Emerging Computing Paradigms

We have outlined the characteristics of the growing and emerging computing paradigms starting from the more recent establishments like Ubicomp and going back to the start of mobile computing. The cross-sections that occur indicate that though each paradigm is distinctly different in characteristics from the other as we have seen in the overview section, there is a fundamental relationship between these paradigms. It could also be speculated as stepping stones in the quest of realising Ubicomp in the future. Recognising this relationship leads us to believe that there is more to understanding and designing mobile systems than merely working around technical issues that provide computing solutions.

In the next section we look at how the design issues have evolved from mobile computing to Ubicomp. Design issues of pervasive computing include approaches used in traditional desktop computing systems development life cycle (SDLC) as well as overlap with design issues of ubiquitous and mobile computing. Ubicomp share similar design issues as wearable computing whereas nomadic computing have design issues that overlap with mobile computing and the desktop computing. Therefore, we discuss design issues in the mobile computing paradigm as compared to the ubiquitous computing paradigm to identify areas and principles that should be drawn upon when designing mobile systems.

Design Issues

Design issues that are considered and studied when building mobile systems tend to focus more on the technical aspects and limitations as opposed to the use of the system. This includes the limited processing capacity of the scaled down integrated circuit and power supply, variety and flexibility of input devices, hard disk/storage capacity and bandwidth available (Chlamtac & Redi, 1998). Producing smaller integrated circuit is essential in catering for the various numbers of portable devices that gets smaller. While scaling down of silicon technology appears technically feasible, higher levels of integration at higher speed end up increasing the power consumption of logic chips (Stork, 1995). Several technical limitations that pose as design issues for portable devices and mobile systems are resolved with compensation from higher power consumption. One example is the improved display capacity of mobile devices that cater for a larger variety of colour at the expense of high battery usage. Portable devices regularly used by mobile and nomadic workers require long periods of power supply whilst accompanying a mobile user. Hence, a major focus of building systems for portable devices is to develop applications with reduced power consumption.

The average consumer however expects the same convenience and computing power in mobile devices as the desktop computer (Chlamtac & Redi, 1998). Considering the technical limitations faced in wireless computing, emulating the desktop is a tall order. Often, the approach in the SDLC taken for mobile computing is very similar to designing applications for desktop computing. Developers work around the limitations of technology and resources that support mobile systems in their attempt to emulate the PC. The technical solution

eventually address the requirements specified by users to complete tasks involved. However, satisfaction in using the applications is likely to fall short of acceptable. This is not solely because of the technical limitations of wireless computing, but a highlight of these limitations when used in an uncontrolled and unexpected scenario such as found in the mobile use location. The nature of nomadic and mobile workers creates a need for users to function and carry out their designated tasks in different places and in a variety of settings.

The technical limitations discussed above exist in mobile computing as well as ubiquitous computing. However, a distinct approach in designing for Ubicomp and wearable devices is the emphasis placed on context-awareness (Abowd et. al, 1997, Dey & Abowd, 2000, Dey et. al., 2001, Hull et. al, 2002). The challenge of achieving the ideal environment and make the device invisible in Ubicomp is a driving factor in this emphasis of context-awareness in Ubicomp. Context that involves the shared cues of gestures, facial expressions, relationship to other people and objects in the vicinity as well as shared histories is defined to be *"any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object"* (Dey & Abowd, 2000).

Context-awareness will be important as users move away from their desktops and into environments where contexts are changing constantly and rapidly (Morse & Dey, 2000). Mobile systems provide solutions that focus around the task required to be completed but not with much consideration of the circumstances in which the user is working. Design approaches taken do not emphasise studying the context, culture and environment that the users are in when using the devices. Based on our model illustrating the relationship of the different computing paradigms, the role of mobile and nomadic computing manifests as being involved in realising Ubicomp.

Mobile devices used by workers in organisations come in various shapes and sizes. Catering for a large variety of mobile devices that have different capabilities furthermore increases the complexity in designing applications for mobile systems. The use of multidevices within an environment creates five problems related to: use, design, synchronisation, harmonisation and standardisation (Kasbo, Gallis & Herstad, 2001).

Discussion

A number of issues come to play when systems are developed for mobility. On the one hand the resource poor environment that mobile devices provide require careful design and development of systems. The development of systems that provide access to enterprise information systems is further complicated due to the use environment and the resource poor device. The same interface for a typical desktop environment will not be applicable for use on a mobile device. It could further be said that providing the same system will not provide the applicable information in a typical mobile use environment.

On the other hand it appears as if the use of mobile systems has a huge impact on the work done by users both on the physical activities that the users perform (Nilsson, 2001), but also on the social interaction that takes place (Dryer et. al., 1999)

As we view the areas of nomadic, mobile, ubiquitous, wearable and pervasive computing in the "big picture", the overlapping relationships in these areas provide a basis for extracting design principles that could guide better design and development of future mobile systems. There is an acknowledged need to break away from the traditional desktop computing paradigm in areas like mobile, ubiquitous and wearable computing by taking the mobile

nature of users and their changing context into account (Abowd, Dey, Orr & Brotherton, 1997). Kleinrock (1996) outlines that the *desirable characteristics of nomadicity include independence of location, motion, computing platform, communication device and communication bandwidth, with a widespread presence of access to remote files, systems and services*. Each of these characteristics, though specifically identified in the area of nomadic computing, is relevant to mobile, ubiquitous and wearable computing as well.

The ideal for Ubicomp is that information technology should be an integral and seamless part of people's lives (Weiser 1991) and would be effectively invisible to the user (Weiser 1993). At this stage the ideal is still a challenge and the focus of ongoing research efforts (Abowd et al, 2002; Davies & Gellersen,2002; Satyanarayanan,2002). Abowd and Mynatt (2000) identify three themes for the development of ubiquitous systems: natural interfaces, context aware systems and finally automated capture and access to information. Natural interfaces support natural forms of communication instead of the desktop paradigm of keyboard/mouse/display.

The emphasis on context-awareness seems to be popularly associated with ubiquitous and wearable computing (Abowd et. al., 1997), but is less noticeable in examples of mobile computing. Mobile systems need to be reviewed and designed with the same tangents foreseen in designing Ubicomp applications. A working model for context-aware mobile computing suggests that there is more to context than location (Schmidt, Beigl & Gellersen, 1999). In this model, two ways of acquiring context is identified – explicit context acquisition, where a user specifies the context, or implicit context acquisition, achieved by monitoring user and computer-based activity. The latter approach is essential to grasp the actual circumstance faced by a user when dealing with a mobile device or system.

Conclusion

A plethora of emerging areas of computing has come to the fore in the last decade. In mapping these areas of computing we have been able to identify that even though pervasive computing and ubiquitous computing is used as synonyms they refer to different aspects of information technology.

Furthermore, we have identified the design issues for each of these computing areas. The paper attempts to postulate that design issues related to Ubicomp should be included when mobile systems are developed. The reasons we have provided for the inclusions of the design issues relate to the impact the use of mobile systems have on various aspects of the mobile users work environment. A mobile device becomes an integral part of the workers work environment and should blend into the use context. The challenge facing systems developers when developing mobile systems is to identify in what way they should go about identifying the use context and how this will impact on the requirements of the system. Most users will not be able to explain what they require from a mobile system in a use context. Observation and ethnographic methods have been used in the development of a number of 'proof of concept' projects. We therefore suggest that the use of observation and ethnographic methods should be investigated to form part of the systems development life cycle for mobile systems.

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