postnote

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PERVASIVE COMPUTING

Pervasive computing is a rapidly developing area of Information and Communications Technology (ICT). The term refers to the increasing integration of ICT into people's lives and environments, made possible by the growing availability of microprocessors with inbuilt communications facilities. Pervasive computing has many potential applications, from health and home care to environmental monitoring and intelligent transport systems. This briefing provides an overview of pervasive computing and discusses the growing debate over privacy, safety and environmental implications.

Background

Eight billion embedded microprocessors[1] are produced each year. This number is expected to rise dramatically over the next decade, making electronic devices ever more pervasive. These devices will range from a few millimetres in size (small sensors) to several metres (displays and surfaces). They may be interconnected via wired and wireless technologies into broader, more capable, networks. Pervasive computing systems (PCS) and services may lead to a greater degree of user knowledge of, or control over, the surrounding environment, whether at home, or in an office or car. They may also show a form of 'intelligence'. For instance, a 'smart' electrical appliance could detect its own impending failure and notify its owner as well as a maintenance company, to arrange a repair.

Pervasive computing has been in development for almost 15 years (see Box 1) but still remains some way from becoming a fully operational reality. Some core technologies have already emerged, although the development of battery technologies and user interfaces pose particular challenges. It may be another 5-10 years before complete PCS become widely available. This depends on market forces, industry, public perceptions and the effects of any policy/regulatory frameworks. There have been calls for more widespread debate on the implications of pervasive computing while it is still at an early stage of development.

Box 1. Pervasive computing history
Pervasive computing is the third wave of computing technologies to emerge since computers first appeared:
- First Wave - Mainframe computing era: one computer shared by many people, via workstations.
- Second Wave - Personal computing era: one computer used by one person, requiring a conscious interaction. Users largely bound to desktop.
- Third Wave – Pervasive (initially called ubiquitous) computing era: one person, many computers. Millions of computers embedded in the environment, allowing technology to recede into the background.

Pervasive computing technologies

Pervasive computing involves three converging areas of ICT: computing ('devices'), communications ('connectivity') and 'user interfaces'.

Devices

PCS devices are likely to assume many different forms and sizes, from handheld units (similar to mobile phones) to near-invisible devices set into 'everyday' objects (like furniture and clothing). These will all be able to communicate with each other and act 'intelligently'. Such devices can be separated into three categories:
- **sensors:** input devices that detect environmental changes, user behaviours, human commands etc;
- **processors:** electronic systems that interpret and analyse input-data;
- **actuators:** output devices that respond to processed information by altering the environment via electronic or mechanical means. For example, air temperature control is often done with actuators. However the term can also refer to devices which deliver information, rather than altering the environment physically.

There are many visions for the future development of PCS devices. Several research groups are endeavouring to produce networks of devices that could be small as a grain of sand. The idea is that each one would function independently, with its own power supply, and could also

communicate wirelessly with the others. These could be distributed throughout the environment to form dense, but almost invisible, pervasive computing networks, thus eliminating the need for overt devices.[2]

At the other extreme, augmented reality would involve overlaying the real world with digital information. This approach emphasises the use of mobile technologies, geographical positioning systems and internet-linked databases to distribute information via personal digital companions. Such devices could come in many forms: children might have them integrated into school bags, whereas adults might use devices more closely resembling personal digital assistants (PDAs).

Ultimately a spectrum of devices may become available. These will range from miniaturised (potentially embedded in surrounding objects) to a variety of mobile (including handheld and wearable) devices. While these could exist as standalone systems, it is likely that many will be interlinked to form more comprehensive systems.

Connectivity
Pervasive computing systems will rely on the interlinking of independent electronic devices into broader networks. This can be achieved via both wired (such as Broadband (ADSL) or Ethernet) and wireless networking technologies (such as WiFi or Bluetooth), with the devices themselves being capable of assessing the most effective form of connectivity in any given scenario. The effective development of pervasive computing systems depends on their degree of interoperability, as well as on the convergence of standards for wired and wireless technologies.

User interfaces
User interfaces represent the point of contact between ICT and human users. For example with a personal computer, the mouse and keyboard are used to *input* information, while the monitor usually provides the *output.* With PCS, new user interfaces are being developed that will be capable of sensing and supplying more information about users, and the broader environment, to the computer for processing. With future user interfaces the input might be visual information - for example recognising a person's face, or responding to gestures. It might also be based on sound, scent or touch recognition, or other sensory information like temperature. The output might also be in any of these formats. The technology could 'know' the user (for example through expressed preferences, attitudes, behaviours) and tailor the physical environment to meet specific needs and demands. However, designing systems which can adapt to unforeseen situations presents considerable engineering challenges.[3]

There is debate over the degree of control users will have over future pervasive computing user interfaces as the technology develops. Three very different forms of human-computer interaction are postulated: **active**, **passive** and **coercive** (see Box 2).

Box 2. Human-Computer Interactions (HCIs)
Active: Users could have overt control over pervasive computing technologies and devices in the environment. This could be achieved through language-based interfaces, allowing users to issue direct spoken or written commands. 'Digital companions' (possibly in the form of smartphones and PDAs) could act as personal, wireless control units for the intelligent environment (activating a home central heating system prior to returning from holiday, for example).
Passive: Pervasive computing could disappear into the background. People would no longer know they were interacting with computers. The technology would sense and respond to human activity, behaviour and demands intuitively and intelligently (for example, lighting altering in reaction to users' location, mood and activity).
Coercive: Pervasive computing could control, overtly or covertly, lives and environments (for example if a device did not have an off-switch or a manual over-ride). Decisions made by developers (such as programming a system in accordance with health and safety regulations), development errors, unintended device interactions and malicious interference could all lead to loss of user control, and could possibly have negative implications for users.

Applications for pervasive computing
Pervasive computing could have a range of applications, many of which may not yet have been identified. Applications in healthcare, home care, transport and environmental monitoring are among the most frequently cited, as discussed below. Research is taking place in industry and academia, often collaboratively, and some government activities are underway (Box 3).

Box 3. Government initiatives
The Next Wave Technologies and Markets Programme was a government initiative launched in 2001. It was established as a virtual interdisciplinary research collaboration dedicated to developing pervasive computing technologies and establishing potential markets. Seven projects have been funded through this initiative, including PCS applications in health care, domiciliary care, 'integrated home environments', cities/buildings and environmental sensing They are expected to report towards the end of 2006.

The UK Foresight Programme began a project on Intelligent Infrastructure Systems in September 2004. This project, now entering its final phases, examines how science and pervasive technologies might be applied within modern transport systems.

Healthcare
Pervasive computing offers opportunities for future healthcare provision in the UK, both for treating and managing disease, and for patient administration. For instance, remote sensors and monitoring technology might allow the continuous capture and analysis of patients' physiological data. Medical staff could be immediately alerted to any detected irregularities. Data collection on this scale could also provide for more accurate pattern/trend analysis of long-term conditions such as heart disease, diabetes and epilepsy. Wearable sensors may offer greater patient mobility and freedom within hospitals and save both time and money by reducing the need for repeated and intrusive testing.

Hospital administration could also be transformed. Patients might be tagged with wristbands containing digital photographs and medical notes. These wristbands would allow patients to be traced more effectively through hospital administration systems, reducing the risk of misidentification and treatment errors.

Domiciliary care
Over the next 20 years there will be a rise in the proportion of people over 65 years old in most developed countries. In the UK the over-65s will increase from 20% to 40% of the total population by 2025. These people may increasingly require care from a diminishing working population. PCS may help address the consequences of this imbalance. Improved methods for monitoring health and wellbeing could allow people to live longer in their own homes. Sensors embedded in items of clothing, for example, might allow constant monitoring of heart rates, body-mass index, blood pressure and other physiological variables. Further sensors embedded throughout the home could detect movement and fluctuations within the ambient environment (such as temperature change) to alert care-workers to any irregularities. Visual displays or voice messages could also have the potential to remind people to take medications, while video telephones could provide personal contact with friends, family and carers.

Environmental monitoring
Pervasive computing provides improved methods to monitor the environment. It will allow for continuous real-time data collection and analysis via remote, wireless devices. However, this poses significant challenges for PCS developers. Devices may be required to withstand harsh environmental conditions (such as heat, cold and humidity). There is also a risk that devices, once deployed, may prove too costly or impractical to recover; thus they will have to be cheap and, where possible, environmentally sensitive (see 'Issues'). Power is also a challenge as systems will need to operate over long periods of time, requiring high levels of energy efficiency and robust energy supplies.

Intelligent transport systems
Traffic congestion and accidents cost the UK £25 billion a year in lost productivity and wasted energy. Pervasive computing technologies are being employed in the development of intelligent transport systems to try to alleviate these costs. Such systems seek to bring together information and telecommunications technologies in a collaborative scheme to improve the safety, efficiency and productivity of transport networks. Electronic devices could be directly integrated into the transport infrastructure, and into vehicles themselves, with the aim of better monitoring and managing the movement of vehicles within road, rail, air and sea transport systems. Computers are already incorporated into modern cars via integrated mobile phone systems, parking sensors and complex engine management systems. Intelligent transport systems take this process further by introducing 'intelligent' elements into vehicles. Vehicles could become capable of receiving and exchanging information 'on the move' via wireless technologies and be able to communicate with devices integrated into transport infrastructure, alerting drivers to traffic congestion, accident hotspots, and road closures. Alternative routes could be relayed to in-car computers, speeding up journey times and reducing road congestion. This would bring added coordination to the road transport system, enabling people and products to travel more securely and efficiently. Greater communication and coordination between different transport sectors (road, rail, air, etc.) may help fulfil integrated transport policies.

Issues
There are engineering problems to be solved before many of the envisaged applications of PCS can become a reality. Moreover, the operation of PCS raises questions over privacy, security, safety and environmental impact. Many of these issues occur already with ICT such as the Internet or mobile phones. However the potential ubiquity and integration of PCS into the environment pose additional challenges.

Engineering issues
The UK Computer Research Centre (UKCRC) highlights specific issues including the current lack of low cost technology to locate devices and the lack of suitable power sources. Also the complexity of PCS systems means that their communications, software and hardware are likely to suffer from faults. These might be accidental, or the result of deliberate attempts to damage the system.[3] The National Consumer Council (NCC) suggests there may be questions over liability – for example if systems are interconnected it will be harder to establish who is responsible if something goes wrong. The NCC also points out that faulty systems may be harder to repair because of the degree of interconnection.

Privacy, security and safety
Pervasive computing systems may have implications for privacy, security and safety, as a result of their ability to:
- gather sensitive data, for example on users' everyday interactions, movements, preferences and attitudes, without user intervention or consent;
- retrieve and use information from large databases/archives of stored data;
- alter the environment via actuating devices.

Privacy
With personal information being collected, transmitted and stored in greater volume, the opportunities for data interception, theft and 'ubiquitous surveillance' (official and unofficial) will be heightened. PCS could be embedded in places considered private, such as the home. Data on many aspects of personal life could be recorded and stored, with the risk of breaches of privacy.

The advent of pervasive computing may mean that data can be collected without a person's knowledge or consent. Some argue that this could violate existing data protection law[4]. This law also requires that personal data should be collected for a specified purpose only. However the opportunities for 'data mining' activities could be vastly increased with PCS. Data mining involves

processing large quantities of data to spot patterns and trends. In terms of consumer data, this can lead to more effective targeted marketing. However, because data mining activities can detect unknown relationships in data, some argue that there is the potential to violate existing legislation. There is debate over how privacy can be protected while still realising the benefits of pervasive computing, and whether new legislation will be required.

Safety and security
Pervasive computing also gives rise to debate over safety. Integrated transport systems could involve road vehicles having actuating devices that intervene in the driving process, possibly responding to hazards more quickly than humans. For example the new Mercedes S-Class features an active braking system that can detect rapidly slowing vehicles in front, activating the brakes without driver intervention. While this may help avoid accidents, there are also potential risks, for example if the security of the vehicle's controlling software is breached. Similar concerns exist over prospective PCS applications in domiciliary care. Breaches of security could expose vulnerable individuals to malicious acts within their own homes – for example the withholding or over-prescribing of medications.

Technological measures
It is argued that privacy, safety and security can be better protected if appropriate procedures and protocols are integrated into PCS at the design level rather than implemented retrospectively. Three measures are frequently cited as vital in establishing robust security measures: [5]
- the volume of transmitted data should be kept to a minimum;
- data that require transmission should be encrypted and sent anonymously (without reference to the owner);
- security should be treated as an ongoing and integral element of PCS.

These principles are accepted by many centres of PCS research and development. However, consumer groups such as the NCC say that developers need to give more consideration to privacy issues. The NNC argues that in the case of RFID,[6] privacy issues were considered only late in development and have still not been fully addressed.

Environment
While the consumption of natural resources might be reduced through the miniaturisation of PCS devices, any gains are likely to be offset by technological proliferation. This may be compounded by problems of treating microelectronic waste embedded in other objects and has implications for recycling because of the possibility of such waste contaminating recycling channels. While some of these issues are likely to be covered by the transposition into UK law of the EC Directive on Waste Electrical and Electronic Equipment, further action (including further regulation) may be required.

Health
Non-ionising radiation is a by-product of the wireless signals that are likely to be used to connect pervasive computing devices into broader networks. As these devices may be carried close to the body (more so than current ICT) and remain constantly activated, there may be increased risk from exposure of body tissues to the potentially damaging effects of such radiation.

Digital divide
There is a risk of technological and social isolation for those who do not use the technology (whether it be through choice, lack of income or skills). For instance, banking, education and retail services are likely to be delivered through PCS embedded within smart homes; this could lead to some consumers being deprived of access and freedom of choice. Pervasive computing could improve the lives of those with illnesses and disabilities, and the elderly. However, it is widely agreed that in order for these groups to benefit from PCS, their needs and capabilities should be considered from an early stage in the design of the system.

Overview
- There is a wide range of potential benefits for government, service providers and consumers as computing technologies become more pervasive.
- There is debate over how to address concerns over privacy, security, safety and sustainability while still realising the benefits of pervasive computing.
- Such concerns may need to be addressed by means of voluntary guidelines, legislative measures, physical design, or a combination of these.
- Many say there is a need for greater public debate on the implications of pervasive computing.

Endnotes
1 An embedded microprocessor is one that forms part of a computer system built into another device, for example a printer.
2 See for example the Specknet Computing Consortium of Scottish Universities (www.specknet.org) ; Centre for Embedded and Networked Sensing at UCLA (www.research.cens.ucla.edu)
3 Written submission to POST from UK Computer Research Centre (www.ukcrc.org.uk)
4 EU Directive 94/46, implemented in UK law as the UK Data Protection Act 1998.
5 Information Society Technologies (IST), *Safeguards in a World of Ambient Intelligence (SWAMI),* July 2005
6 POSTnote 225, Radio Frequency Identification, July 2004.