Wireless Future: Ubiquitous Computing

Friedemann Mattern, ETH Zürich

Summary. Over the last 30 years, we have seen the power of microprocessors double about every 18 months. An equally rapid increase applies to some other technological parameters such as storage capacity and communications bandwidth. This continuing trend means that computers will become considerably smaller, cheaper, and more abundant – they are becoming ubiquitous, and are even finding their way into everyday objects. This is resulting in the creation of "smart" things that can access the Internet and its varied resources, and maybe even cooperate with each other. Mobile phones are a forerunner in this technological field – they are now true computers equipped with a whole range of functionality and may well develop into control centers for a multitude of other personal auxiliary services.

In the long term, ubiquitous computing will take on great economic significance. Industrial products will become "smart" due to their integrated information processing capacity, or take on an electronic identity that can be remotely queried, or be equipped with sensors for detecting their environment, enabling innovative products and totally new services to be developed. However, an "informatized" world full of objects that can detect aspects of their environment and communicate with each other also has serious societal implications. The social and political challenges of the ubiquitous computing era will be characterized by an increasing dependence on technology, control over the information to which everyday objects are linked, and the protection of privacy.

1. The trend towards invisible and ubiquitous computer technology

Given the continuing technical progress in computing and communication, it seems that we are heading towards an all-encompassing use of networks and computing power, a new era that Mark Weiser termed "ubiquitous computing" [10]. According to him, the computer as a dedicated device should disappear, while at the same time making its information processing capabilities available throughout our surroundings. Intrusive technology should make way for "calm technology": *"As technology becomes more imbedded and invisible, it calms our lives by removing the annoyances… The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*

While Weiser saw the term "ubiquitous computing" in a more academic and idealistic sense as an unobtrusive, human-centric technology vision that will not be realized for many years yet, industry has coined the term "pervasive computing" with a slightly different slant. Though this also relates to pervasive and omnipresent information processing, its primary goal is to use this information processing in the near future in the fields of electronic commerce and Web-based business processes. In this pragmatic variation – where wireless communication plays an important role alongside various mobile devices such as smartphones and PDAs – ubiquitous computing is already gaining a foothold in practice.

The vision of ubiquitous computing is grounded in the firm belief amongst the scientific community that Moore's Law, drawn up in the late 1960s by Gordon Moore [8] (which states that the number of transistors per chip, and consequently the power of microprocessors, doubles about every 18 months) will hold true for at least another 10 to 15 years. This means that in the next few years,

---

This article is based on a shortened and adapted translation of the paper „Ubiquitous Computing: Szenarien einer informatisierten Welt" [6], some parts have also been taken from the paper „From Distributed Systems to Ubiquitous Computing – The State of the Art, Trends, and Prospects of Future Networked Systems" [7].

microprocessors will become so small and inexpensive that they can be embedded in almost everything – not only electrical devices, cars, household appliances, toys, and tools, but also such mundane things as pencils (e.g., to digitize everything we draw) and clothes. In fact, technology is expected to make further dramatic improvements, which means that eventually billions of tiny and mobile processors will occupy the environment and be incorporated into many objects of the physical world. All these devices will be interwoven and connected together by wireless networks.

The effects of rapid progress in microelectronics and the convergence of communications and information technology can best be demonstrated using the example of mobile phones. A few years ago, mobile phones were still so big, expensive, and limited in their functionality that they didn't sell very well and were often used more as a status symbol than a practical tool. This has changed very rapidly. Many users have grown so accustomed to mobile phones and adapted their professional or even private lives to them that they can't imagine life without this technology.

Parallel to this development, within a short period of time the mobile phone has become a device that offers more than just the pure functionality of voice transmission. The SMS short messaging system has become a completely unexpected success. Cameras and colored displays, which permit the viewing of forwarded photos and video clips, are now being integrated into most mobile phones. The same applies to functionality that offers high-quality music reproduction. Another additional function is connection to the Internet. Mobile phones are now fully functional computers with the capability to execute Java programs, even those they receive wirelessly. All this opens up a whole new world of application possibilities.

The functionality of mobile phones is currently expanding in different directions. So-called smartphones, for example, take on the role of Personal Digital Assistants, with notepad and appointment scheduling functions. Another option is to add localization functionality. Already now, mobile phones can be localized to within a few hundred meters. By using satellite-supported GPS systems or new 3G synchronization means, localization can be as exact as about 15 meters outside buildings. Providing mobile phones with additional short-range radio interfaces (such as WLAN, Bluetooth, or ZigBee) is yet another option. It means that other personal devices belonging to the user can also profit from the communication and localization abilities of the mobile phone. The mobile phone then becomes a personal base station and control center for a variety of other devices and “smart objects” nearby.

Mobile phones and PDAs with Internet connections, small cameras, and localization capabilities that are able to communicate with their environment are only the first indicators of the dawning of a “post-PC era,” which is characterized by the virtually total networking of technical devices and computerized everyday objects. This era was once described by former IBM Chairman Lou Gerstner as follows: “*A billion people interacting with a million e-businesses through a trillion interconnected intelligent devices.”*

What can we expect in this regard from this rapidly growing technical progress? It is becoming ever clearer that we are standing on the brink of a new era of computer applications that will radically influence our lives. In recent years PCs, the Internet, and the Web have already changed much, especially in business life. Today we are seeing indicators everywhere of a major convergence of entire industries in the fields of media, consumer electronics, telecommunications, and information technology. But the approaching wave of the technological revolution will affect us more directly, in all aspects of our lives – it is becoming apparent that our future will soon be full of tiny processors communicating spontaneously with each other, which will be integrated into the vast majority of everyday objects due to their small size and low price.

One reason for this is to be found in the long-term trend of microelectronics. Moore’s Law has held true with astonishing accuracy and consistency. For the chip-producing industry, this has almost become a self-fulfilling prophecy, and they even produce their future-oriented “technology roadmaps” according to this law. A similarly high growth of efficiency can be observed for some other technology parameters such as energy requirements per computer instruction, storage density, and communications bandwidth. Conversely, prices for microelectronic functionality with the same amount of computing power are falling radically over time. Technology experts expect this trend to continue for many years to come, meaning that computer processors and storage components will become much more powerful, smaller, and cheaper.

Recent developments in the field of materials science and solid-state physics are also important in that respect. They could give information appliances and computers of the future a completely different shape, or even mean that computers will no longer be recognizable as such because they will completely blend into their surroundings. One example in this context is light-emitting polymers, which enable displays consisting of highly flexible, thin and bendable plastic foils to be created. They offer many processing advantages, including the possibility of making large-area or curved displays capable of delivering high-resolution video-rate images at low power consumption, visible in daylight and with wide viewing angles [11]. Flat and very cheap screens that can be fixed to walls, doors and desks are conceivable. The displays could be configured to present information such as weather, traffic or sports results extracted from the Internet. Once configured, users could place these displays wherever they felt it was convenient. As humans, we are accustomed to looking in particular places for particular pieces of information [13]. This way, dynamic information would become much easier to find and assimilate – a user might, for example, place today's weather forecast on the wardrobe door.

Laser projection from within spectacles directly onto the retina of the eye is another option currently being investigated as a replacement for traditional computer output media. Research is also taking place into "electronic ink" and "smart paper," which will enable pen and paper to become fully functional interactive and truly mobile input/output media. Although there is still a lot of technical development work involved and a broad commercial application may be some years off, prototypes of smart paper and electronic ink already exist. If paper can be transformed into a computer or, conversely, computers into paper, the practical significance of such a development cannot be overestimated: just imagine carrying your calendar and contact list on a foldable piece of electronic paper, or pulling out a large screen from a mobile phone or a tubular scroll containing the remaining electronics of a PC! Combined with small GPS receivers, maps that display their exact location ("you are here") will then be a real possibility.

The results of microsystems technology are also becoming more and more important. For example, they enable tiny integral sensors that can record a wide variety of different environmental parameters. One interesting development in this regard is radio sensors that can report their measured data within a few meters distance without an explicit energy source – such sensors obtain the necessary energy from the environment (for example, by being irradiated with microwaves) or directly from the measuring process itself (e.g., temperature change or pressure).

Electronic labels, so-called passive Radio Frequency Identification (RFID) tags, also operate without a built-in source of power – they collect the energy they require to operate from the magnetic or electro-magnetic field emitted by a reader device. Depending on their construction, these labels are less than a square millimeter in area and thinner than a piece of paper [3]. What is interesting about such remote-inquiry electronic markers is that they enable objects to be clearly identified and recognized, and therefore linked in real time to an associated data record held on the Internet or in a remote database. This ultimately means that specific data and information processing methods can be related to any kind of object.

If everyday objects can be uniquely identified from a distance and furnished with information, this opens up application possibilities that go far beyond the original task of automated warehousing or supermarkets without cashiers. For example, an intelligent refrigerator may make use of the labels attached to bottles, which could be useful for minibars in hotel rooms. Even more intriguing are scenarios where prescriptions and drugs talk to a home medicine cabinet, allowing the cabinet to say which of those items should not be taken together, in order to avoid harmful interactions. In a similar manner, packaged food could talk to the microwave, enabling the microwave to automatically follow the preparation instructions. With the emerging Near Field Communication (NFC) standard, mobile phones and other handheld electronic devices will be able to read RFID labels at short distances. The goal is to enable users to access content and services in an intuitive way by simply touching an object that has a smart label.

Significant technical advances have also been made in the field of wireless communications. GSM mobile phone technology has established itself extensively and next generation systems will allow higher bandwidth and better possibilities for data communications. Especially interesting are recent short-range communications technologies (such as ZigBee) that need less energy and make smaller and cheaper products possible. Researchers are also working intensively on improved possibilities for determining the position of mobile objects. As well as increased accuracy, the aim is also to make the receiver smaller and reduce its energy requirements.

Another exciting development is the field of "Body Area Networks," where the human body itself is used as a transmission medium for electrical signals of very low current. Simply by touching a device or an object, an individual identification code can be transmitted. (This could, for example, be supplied to the body by a wristwatch). This could be used for access controls, personalized device configuration, or the billing of services.

Many of these technological developments can be used together or even integrated. For example, fully-functioning computers including sensors and wireless networking functionality will be developed on a single chip that can be built into any device or everyday object for control purposes. High processor speed is not as important as producing chips that are small, cheap, and save energy.

If you summarize these technology trends and developments – tiny, cheap processors with integrated sensors and wireless communications ability, attaching information to everyday objects, the remote identification of objects, the precise localization of objects, flexible displays and semiconductors based on polymers, electronic paper – it becomes clear that the technological basis for a strange new world has been created: everyday objects that communicate and that are in some respects "smart," without actually being "intelligent."

2. Everyday objects become "smart" and network themselves

The "creeping revolution" induced by the sustained technological progress is leading to a situation where there will be a plentiful supply of computing power. Smart cards that become worthless after being used in the form of telephone cards, or electronic labels that act as a substitute for bar codes are the first indicators of a new wave of single-use or disposable computers.

This likely saturation of our world with information processing capacity heralds a paradigm shift in computer applications – tiny, cheap processors embedded into many everyday objects can detect their surroundings via similarly integrated sensors, and they can equip "their" object with both information processing and communications capabilities. This adds a completely new dimension to such objects – they could, for example, find out where they are, what other objects are in their vicinity, and what had happened to them in the past. They may adapt to the environment, behave in a context-sensitive manner, and provide useful services in addition to their original purpose. They will be equipped with spontaneous network capabilities and will thus be able to communicate and cooperate with other smart objects and to access all sorts of Internet resources. Connected together and exchanging appropriate information, they will form powerful systems.

Future smart devices will come in various shapes and sizes and will be designed for various task-specific purposes. Their user interface may be based on speech recognition, gesture recognition, or some other advanced natural input mode technology that is appropriate for their purpose, size, and shape. Ideally, all these devices will be so highly optimized to particular tasks that they will blend into the world and require little technical knowledge on the part of their users – they should be as simple to use as calculators, telephones or toasters [12].

Of course, many other types of smart devices are conceivable. Wearable computing devices will be used to keep people informed, connected, and entertained. The expectation here is that the computer functionality and the devices that incorporate it should not only be "portable," but also, to a certain degree, become part of our clothing and be worn more or less directly on our bodies. An appropriate comparison might be between a "portable" pocket watch, which has to be taken out and opened up if needed, and a "wearable" wristwatch, which can be read at any time. Since its sensors are located close to the body, a wearable computer is also suitable for reinforcing the user's sensory perception or for monitoring his or her health (and, if necessary, reporting values of vital functions via telemetry to a medical call center).

Just like the carriage clock of 300 years ago that subsequently became a pocket watch and then a wristwatch, personal electronic devices are expected to become items that can be worn as clothing, jewelry, and accessories [15]. This might even go so far as having spectacles that look perfectly normal, but which display information over your normal view or even blend into it – which might some day even enable the virtual red carpet, which the personal navigation system rolls out in front of your eyes to help you find your way in an unknown environment.

Localization technologies also have great application potential. In the future, it may be virtually impossible to lose valuable things, or it may be possible to relocate lost objects, because the objects will know where they are, and can communicate this if necessary. Localization modules which, for example, use the GPS system are still too large, expensive, and imprecise, and consume too much energy for many applications. But continuing progress is being made on all four parameters. As localization technology progresses, simpler things will also profit from this possibility. Parents might appreciate it, for example, if their children's shoes and coats revealed their whereabouts.

Location-awareness, however, is only one aspect of context-awareness as the encompassing concept, which describes the ability of a device or program to sense, react to, or adapt to the environment in which it is running. Context-awareness enables new applications based on the special nature of the physical context. However, it may also be exploited in determining the form of interaction supported and modifying interface behavior. For example in a car system, unimportant feedback may be limited during periods of rapid maneuvering [9].

As a consequence of ordinary objects being able to communicate with each other, the Internet will also undergo an enormous change. The growth of the Internet is not only characterized by rapid, currently almost exponential growth with regard to the number of computers connected, but also by its qualitative growth. In the 1980s, it was primarily used for *person-to-person* communication – e-mail was the dominant application at that time – but the 1990s brought a completely new form of usage with the Web: now *people* were communicating via browsers on one side, with *machines*, namely Web servers, on the other side. The consequence of this was the multiplication of data traffic and, at the same time, this led to the rapid commercialization and popularity of the Internet. But now another qualitative leap forward has become apparent: the Internet of the future will be used principally for *machine-to-machine* communication – or rather, *object-to-object* communication. Since nowadays almost all computers in the world are connected to the Internet, an expansion of the Internet into everyday objects is the next step. Neil Gershenfeld from MIT's Media Lab expressed this as follows: "*In retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net*" [4].

But what exactly does it mean if objects become smart and can communicate with each other? Envisioning concrete applications is not easy. However, the potential seems to be very high if objects can cooperate with each other, can access information stored in databases or on the Internet, and can use any suitable Internet-based service available. So an automatic lawn sprinkler will profit not only from being networked with humidity sensors in the ground, but also from obtaining the current weather forecast free from the Internet. Smart toys are another appealing prospect. Compared to an ordinary toy, a networked toy would have access to a huge world of information and could be more responsive to its owner and environment. For example, a toy that teaches spelling could access a large dictionary. It could also invoke a speech recognition process running on a remote computer to convert a child's story into text. A toy (such as a smart teddy bear) might also act as a telecommunication device or even a telepresence device and serve as an avatar for the friends and family of the toy owner [14].

Many more applications are imaginable. The limits are less of a technological nature than an economic one (business models, standards, amortization of infrastructure, costs of information access etc.). Initially, it will be the higher priced appliances, tools and other objects that benefit from ubiquitous networking and "artifact intelligence". Sensor-supported information processing and communications capabilities will provide objects with substantial added value. But soon a lot of other, more trivial, objects will use the Internet with its many resources to carry out their tasks, even though their users may not be aware of this. Applications for ubiquitous computing will certainly be found in areas where the Internet already plays an important role, such as mobile commerce, telematics, and entertainment, but without doubt many other traditional areas (e.g., healthcare and education) and newly emerging areas will benefit from ubiquitous computing technologies.

The long-term consequences of a world in which things "talk" to each other are not yet clear, but the prospects are fascinating. Savvy business consultants have already coined an expression for business transactions that are carried out between objects without human intervention: "silent commerce."

3. Ubiquitous computing gains great economic significance

Together with the possible resulting applications, the new basic functions resulting from the progress of information and communications technology in general, and the development of ubiquitous computing in particular, are set to gain great economic significance in the medium to long term. This can be illustrated using the example of remote identification.

A whole range of constantly improving techniques exists for identifying objects over a distance of a few meters. In addition to options that are not yet suitable for general use, such as purely optical recognition (the automated identification of faces and vehicles is already yielding promising results, however), there are the smart labels or RFID tags mentioned above. A smart label is a small (few square millimeters in area), low-power microchip combined with an antenna. In some systems, the antenna is replaced by conductive ink. The substrate of the labels is usually paper or plastic, yielding a paper-thin and flexible label, which can be self-adhesive and be printed on. The smart labels can be stuck onto objects or integrated into them during the manufacturing process. Each label has a unique serial number and can contain other programmable information, on some types of tags it is also possible to store a limited amount of information. The labels cost between €0.1 and €1 each, and therefore have the potential for replacing traditional barcodes for the identification of goods in certain areas. Their big advantages are that individual products rather than whole product groups can be differentiated, and that (unlike the laser scanners currently used in supermarkets) they do not have to be placed in the line of sight of the reading devices – in particular, they work through plastic, wood, and other materials. The RFID reader transmits a radio signal to the labels and recognizes their unique radio echoes, which works for distances of up to a few meters.

Smart labels have been prototypically used to optimize warehousing and production processes. For example, parts boxes on vehicle assembly lines can automatically control their own stock and transmit a signal to the warehouse and supplier as soon as they need replenishing. Using this method, suppliers receive precise information regarding the requirements and can deliver the necessary parts just in time.

Until now, most pilot applications for smart labels have been found in the automobile, logistics and transport industries. More recent application examples come from the retail sector. An example is a pilot application of a supermarket chain, where electronically labeled recyclable containers for perishable products are resulting in a reduction in the supply chain lead time and therefore increasing the time products spend on the supermarket shelf. This involves detectors automatically identifying every box and recognizing the expiry date of the contents in the warehouse and at the retail store.

Simple ubiquitous computing applications are limited to basic functions such as identification, localization, and tracing, where – by technologies such as RFID – only the identifier is stored locally on the object. More complex applications are increasingly using sensors for the decentralized collection of data from the environment and working with what are known as notification services: in other words, smart objects report automatically if a specified condition occurs or if a preprogrammed rule (for example, regarding permitted temperature or duration of stay) is violated.

The ultimate goal are "self-aware", smart products. A smart product can on the one hand automatically download the latest information such as a destination or updated user instructions; and on the other hand it can independently supply its informational counterpart, which resides somewhere on the Internet, with sensor data such as its location. In a certain sense, you could think of the object itself (including its electronic label, sensors or embedded electronics) as the "body", with its informational counterpart being the "soul" of the object, storing object-specific data and even acting and communicating autonomously as an active information unit.

Generally speaking, the new technologies of ubiquitous computing are automating the process of linking the real world with everyday objects, products, and means of production with the virtual world of the Internet or e-commerce and supply chain management systems; in many ways, they are replacing man as the mediator between the real and the virtual world. As a consequence, this is facilitating new business processes that bring additional benefits to manufacturers, suppliers, and clients. These technologies are helping to reduce lead times, warehouse inventories, risks, and error rates. They can contribute to new solutions in the fields of maintenance and repair, security and liability, quality assurance, waste disposal and recycling, and ultimately create a variety of new services such as the consistent individualization or personalization of goods throughout the entire life cycle. Peter Harrop, IDTechEx expert, expressed his expectations as follows: "*The next evolution involves fully automated communications on a vast scale... Many new consumer benefits will be offered such as the food that tells the microwave how to cook it... Many markets for position services will be created such as low-cost gadgets that trace lost children, assets and animals and tags on one million vehicles permitting them to be located and their tax, license, etc. verified remotely.*"

In the longer term, the process of remotely identifying objects along with wireless information access, mobile communications technology, and "wearable computing" pave the way for possibilities that go far beyond the optimization of business processes mentioned above and, to some extent, amount to an informatization of the world. To give an example, imagine everyday objects such as furniture, packaged food, medication, and clothing being equipped with a label that contains a specific Internet address as digital information (a "URL") which, to put it simply, points to the homepage of the object [5]. If you then read this Internet address with a device similar to a mobile phone just by pointing it at the object (e.g., by using technologies such as NFC for RFID labels, or by using the phone's camera and embedded image processing software for optical labels), the mobile phone can, independently and with no further assistance from the object in question, access and display the corresponding homepage or some other related information via the mobile telephony network.

The user has the impression that the object itself has "transmitted" the information belonging to it, although in fact it has been provided to the mobile phone via the URL from the Internet [1]. The information could for example be instructions for a tool, or cooking instructions for a ready-to-serve meal, or the information leaflet for medication. The details of what is displayed may depend on the "context" – for example, whether the user is a good customer and paid a lot of money for the product, whether he is over 18 years of age, what language he speaks, his current location, or to which world explanatory service from which encyclopedia company he has subscribed. In the future, we might therefore see more and more hybrid products – products that consist of a classical physical part on the one hand, and some associated and valuable information part on the other hand. Clearly, the digital added value of a manufacturer's own products can be very different from that of physically similar products marketed by the competition, and can tie clients more closely to his own added value services and compatible products.

The appliance that we describe as a "mobile phone" may in the future take the form of a special pair of spectacles, or a piece of electronic paper for displaying information, in conjunction with a "pointer". Furthermore, it will not only be human users who are interested in the additional information on objects, but also other smart objects. A trash can, for example, may be very curious about the recycling characteristics of its contents, and a medicine cabinet may be concerned about its medication's possible side effects and best-before date. Theoretically, at least from a technical point of view, there is nothing to stop objects (or their informational counterparts on the Internet) exchanging information amongst themselves i.e. almost speaking with each other, as long as a common basis for communication in the form of a standardized formal language exists.

Even if a detailed assessment cannot yet be made of these, it is clear that completely new applications will come into existence based on this multitude of smart objects. It seems to be clear that ubiquitous computing in general will, in the long run, have dramatic economic effects: many new services are possible that could transform the huge amount of information gathered by the smart devices into value for the human user. The maintenance and ongoing development of the global infrastructure necessary for cooperating and communicating smart everyday objects – including the measures required to meet the increased need for security and privacy in such an environment – might eventually even occupy a whole industry, similar to today's energy and telecommunications enterprises.

4. Social and political challenges

While a technical analysis may be able to predict what the future *could* bring, the question of what the future is *allowed* to bring can only be answered by means of a social process.

If information is attached to "electronically enhanced" objects, in other words physical objects effectively become media, who can or should determine their content? If, for example, ready-to-serve meals contained an electronic label, would a consumer protection institute be permitted to map this number using its own electronic directory onto information other than that which the producer intended (for example, to warn of allergies to the ingredients)? Or should this at least be permitted if the "viewer" specifically requests it?

To put this in more general terms: if objects are equipped with information or a means of identification that enables a personal digital assistant to explain the world, can real-world objects then be interpreted by the manufacturer of the digital assistant or the associated service provider in any way he likes? World views have often been the cause of disputes. Given a situation where cyberspace is approaching reality, partially overlaying or even merging into it, there are some things we must be prepared for – ultimately, some political questions of a fairly explosive nature must be asked.

Many other questions are generated by the informatization of the world, only a few of which are touched on here: if many objects can only function properly if they have access to the Internet or a similar infrastructure, this results in a far-reaching dependency on those systems and their underlying technology. If these fail, for whatever reason – design errors, material defects, sabotage, overloading, natural disasters etc. – then it could have catastrophic consequences on a global scale. If the correct functioning of the information technology infrastructure is vitally important to society and individuals, not only do we have to have appropriate security mechanisms, but the systems have to be designed from the outset with this in mind.

Last but not least, we should pay particular attention to the protection of privacy. This is of course a primary concern when devices or smart everyday objects can be localized and traced, and when various objects we use daily report their state and sensor information to other objects. Whereas until now only a relatively limited view of a person could be obtained by rummaging around in data, in a future ubiquitous computing world a much more comprehensive picture can be painted of this person and his day-to-day behavior. It seems clear that, without effective data protection measures, the technology of ubiquitous computing could be used to create a surveillance infrastructure that would render ineffective many existing laws and privacy protection mechanisms. Therefore basic legal considerations and new technical approaches, as well as much social and organizational effort, will be required in order to prevent this brave new world of smart, interconnected objects becoming an Orwellian nightmare.

5. Perspectives

The technology trend is pointing quite clearly towards a continued informatization of the world. It is clear, however, that we are moving only gradually towards the ultimate vision of ubiquitous computing where inanimate everyday objects communicate and cooperate. Much remains to be done and already from a technical viewpoint there are many challenges to consider – the energy supply for smart objects, communications standards, and much more besides. Furthermore, a considerable infrastructure would have to be implemented before the vision could become a reality.

In the next years, quite some innovations are therefore necessary to come close to the vision of an “Internet of things”. What comes first and how successful the various contributions will be depends, of course, on a variety of circumstances and is not easy to predict. Technical factors as well as economic factors, but also acceptability play an important role. From a technical viewpoint we can already estimate what at least appears to be feasible in the next few years by extrapolating current trends. What would appear to make sense from an economic viewpoint – for example, regarding the construction of an infrastructure or possible business models – is a far more difficult question to answer. It is equally difficult to predict how particular ubiquitous computing technologies and applications based on it will be accepted. Whether innovations develop into something useful and acceptable for citizens can often only be decided with hindsight.

If technical progress means more and more everyday objects are becoming “smart” and therefore behaving unconventionally towards humans, then this will ultimately lead to a different world from that to which we are accustomed. The changes won't happen overnight; instead, this process will be more of a creeping revolution. Taken to its logical conclusion, a world which is literally permeated by information technology will sooner or later bring with it major social and economic consequences [2], adding a political dimension to ubiquitous computing and its technologies.

The driving forces behind the foreseeable technological achievements are microelectronics together with computing and information technology, supported by basic research in the fields of physics and materials science. Dynamic development in these areas is continuing unabated, and its effects are increasingly influencing everyday life. It is therefore clear that the 21st century will be characterized less by major technological structures such as moon colonies, underwater cities, and atomic cars (as suggested by earlier popular futurologists), than by the application of tiny, practically invisible technology that is therefore easy to replicate and distribute. It is certainly already now worth thinking about the economic prospects and the social consequences ubiquitous computing could have, and what role different sectors of the information and communication industry, but also society in general, should play in designing and building the emerging “Internet of things”!

References

1. Barrett, E.; Maglio, P. (1998): Informative Things: How to Attach Information to the Real World. Proceedings UIST ’98, pp. 81-88
2. Bohn, J.; Coroama, V.; Langheinrich, M.; Mattern, F.; Rohs, M. (2004) Living in a World of Smart Everyday Objects – Social, Economic, and Ethical Implications. Journal of Human and Ecological Risk Assessment, 10(5), Oct. 2004, www.vs.inf.ethz.ch/publ/papers
3. Finkenzeller, K. (1999): RFID-Handbook. John Wiley & Sons
4. Gershenfeld, N. (1999): When Things Start to Think. Henry Holt & Company
5. Kindberg, T. et. al. (2000): People, Places, Things: Web Presence for the Real World. Proceedings of IEEE Workshop on Mobile Computing Systems and Applications (WMCSA2000), Monterey, Dec. 2000
6. Mattern, F. (2004) Ubiquitous Computing: Scenarios for an informatized world. (Original German title: “Ubiquitous Computing: Szenarien einer informatisierten Welt”) In: Axel Zerdick, Arnold Picot, Klaus Schrape, Jean-Claude Burgelman, Roger Silverstone, Valerie Feldmann, Dominik K. Heger, Carolin Wolff (Eds.): E-Merging Media – Kommunikation und Medienwirtschaft der Zukunft, Springer-Verlag, pp. 155-174, 2004
7. Mattern, F.; Sturm, P. (2003) From Distributed Systems to Ubiquitous Computing – The State of the Art, Trends, and Prospects of Future Networked Systems. In: Klaus Irmscher, Klaus-Peter Fähnrich (Eds.): Proc. KIVS 2003, pp. 3-25, Springer-Verlag, February 2003
8. Moore, G.. (1965): Cramming more components onto integrated circuits. Electronics, Vol. 38, pp. 114-117
9. Roden, T.; Chervest, K.; Davies, N.; Dix, A. (1998): Exploiting Context in HCI Design for Mobile Systems. First Workshop on HCI for Mobile Devices, 1998
10. Weiser, M. (1991): The Computer for the 21st Century. Scientific American, Vol. 265 No. 9, pp. 66-75
11. www.cdtltd.co.uk/
12. www-3.ibm.com/pvc/
13. www.media.mit.edu/pia/Research/AnchoredDisplays/
14. www.media.mit.edu/~r/academics/PhD/Generals/Hawley.html
15. www.extra.research.philips.com/password/passw3_4.pdf