

The Upcoming and Proliferation of Ubiquitous Technologies in Products and Processes

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Ubiquitous computing is a research field that started in the late 1980s, and is now believed to be at the brink of a steep acceleration in terms of technology development and applications. Ubiquitous computing is often regarded as the third wave of computing, after a first wave of mainframe computing and a second wave of PC computing. It aims at supporting humans in their daily life activities in a personal, unattended and remote manner. Towards this end, it scatters computing capacity across the environment, and takes out the oblique PC man-machine interface. Instead it employs networked sensors and devices surrounding us. There is no dedication in the sense that many devices in an environment collectively serve multiple humans around. Both humans and devices are assumed to be nomadic, and possibly enter or leave the environment. In addition, to materialize a personal and context-dependent interaction, identification and context awareness are also key factors. Although the vision itself has become fairly well-conceived, several technological and non-technological problems are yet to be overcome. This paper provides a comprehensive overview and a critical survey of the current and future state of ubiquitous technologies.

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0 INTRODUCTION

Ubiquitous computing (or: UbiComp or UC) is a research field that started in the late 1980s [1] (Fig. 1), and rapidly expanded in the 1990s. The UC paradigm is centered on the idea of integrating computing power in devices and environments in such a way that they offer optimal support to human daily life activities [2]. Instead of going to a single specific device at a fixed location, and explicitly formulating the information or action sought, the environment and devices that sense us more or less autonomously serve us in a proactive, unattended and hardly noticed but effective manner [3].

Ubiquitous computing is the dawning era of computing, in which individuals are surrounded by many networked, spontaneously yet tightly cooperating scattered 'computers', worn or carried, mobile, embedded and remote. Many of them serve dedicated processes as part of physical objects [4]. Car manufacturers who traditionally have a relatively strong say over their suppliers, already successfully integrated safe braking, auto-activated lighting and screen wipers, navigation and active safety protection,

and a wealth of other electronic supplies, to assist in car diving without obtrusively demanding the driver's attention or intervention [5].

Ubiquitous computing is not just the same as mechatronics, intelligent systems, or the Internet-of-things. It is underpinned by different basic principles [6]. Weiser, M. is often seen as the founder of UC [1]. In fact, he named this field of interest while he was working at Xerox, and also defined its principal goals, the most of which still stand today [7]. Alternatively, *omnipresent computing*, *calm technology* [8], *pervasive computing* [9], and *ambient intelligence* [10] are nowadays also used and believed to be roughly the same as UC [11] and [12]. Several experimental devices, from active badges to smart class and conference facilities served as a vehicle to take the emerging technology further. Research in UC is inspired by two grand challenges, namely by humane computing [13] and integrative cooperation [14]. From the mid-1990s, humane computing advanced through a number of results in the domain of Human-Computer Interaction (HCI). Research in full-body gesture recognition was proposed in the AliveII research project [15]. Various methods and technologies

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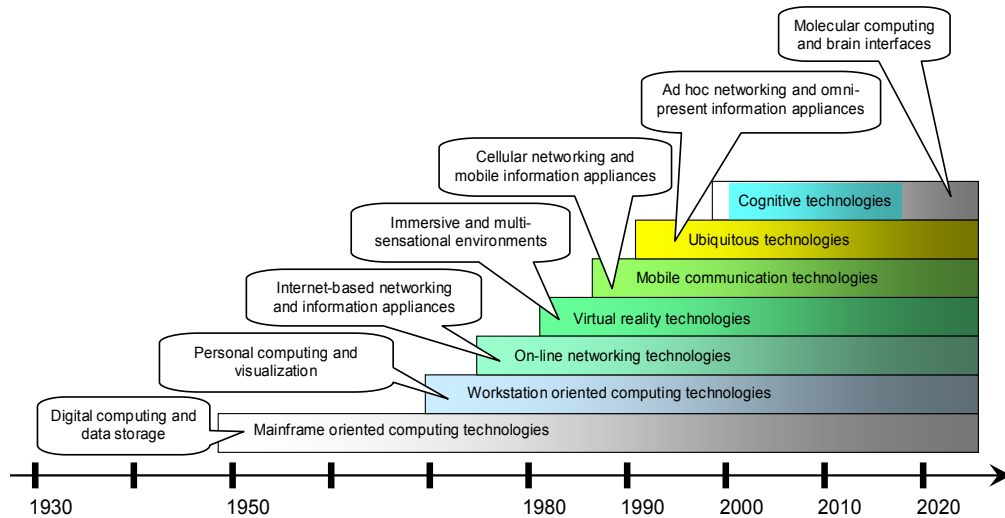


Fig. 1. Computing technologies advancements of the past decades

have been proposed to recognize moving objects [16], to track pointed-at objects on a desk [17], and to recognize objects drawn in the air by humans [18]. A recent and extensive overview of these developments is presented in [19].

These examples cast light on a specific characteristic of UC: it can be effective on a short distance: (i) inside and on the human body, (ii) between worn and/or carried personal devices, or (iii) between personal devices and environment. Humans are mobile and their personal devices are portable. Therefore UC is generally thought of as a class of *mobile* technologies. In addition to human-device interaction and mobile computing, a fully fledged UC implementation requires many more technological constituents, such as networked intelligent sensors, agents, data transmitters, and sensation generators.

The goal of this paper is to provide a structured and comprehensive overview of existing and emerging ubiquitous technologies and their application in smart customer products, information appliances and ambient processes. It also explores the potential role of ubiquitous computing in development scenarios for the future. Finally, it seeks to identify and formulate some major technological challenges of the next decade. In order to structure the survey of this widely ranging research field, we applied the *reasoning model* shown in Fig. 2. This reasoning model identifies five functional clusters of ubiquitous technologies, articulating their classes

of technologies. Actually, these classes reflect the relationships of functionally similar technologies to humans, artifacts and environments.

We must note that observing the industrial practice, this overview could be neither as structured, nor as comprehensive as we saw fit. In terms of structuring the overview of the clusters of ubiquitous technology, we had to face the multi-faceted implementation of these technologies, which hindered their sharp demarcation. Just to mention one example: integrated sensor nodes may be simultaneously sensors and transmitters, and elements of sensor networks. Then, do they belong to the cluster of sensing, transmission, or networking technologies? Additionally, the wide spectrum of technologies within each of these clusters and classes, forced us to neglect certain important domains, developments, and new applications. For instance, we could not consider and address broader societal problems being under debate at the moment. In addition, we had to restrict the focus of the study to enabling technologies, but to skip the related applications for the larger part. Finally, we had to stick to the surveillance of commonalities and trends, without digging into the finest details.

Further to this Introduction, the paper is organized as follows. Section 1 discusses a brief and instrumental overview of ubiquitous sensor technologies. Section 2 deals with the various transmission technologies. Section 3 investigates

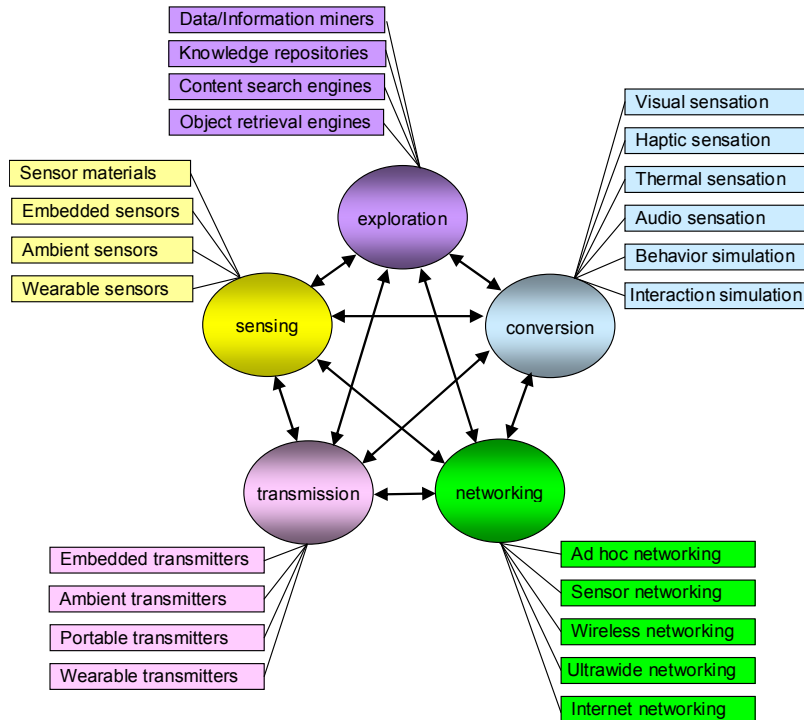


Fig. 2. Functional clusters of ubiquitous technologies

the various approaches of wired and wireless, and permanent and ad-hoc networking. Section 4 gives an overview of the various sensation generation and interaction simulation technologies. In Section 5, we discuss the major content exploration technologies and techniques with a view to understanding of contexts and building context-awareness. In Section 6, we classify and briefly discuss the application of UC technologies in next-generation products. The last section elaborates on the use of ubiquitous technologies in typical creative industrial processes, such as design and manufacturing. Finally, some concluding remarks are offered together with future research outlooks.

1 SENSING TECHNOLOGIES

Ubiquitous sensing technologies allow us to elicit and collect information about steady or changing states of artifacts, phenomena, and environments. As shown in Fig. 2, we can further classify them according to their placement so as: (i) sensor materials, (ii) embedded sensors, (iii) ambient sensors, and (iv) wearable sensors. Note that these classes are not orthogonal, i.e., not mutually exclusive: embedded sensors can also be

ambient, for instance. Sensors sample physical parameters from their environments, such as chemical agents, temperature, acoustic pressure, force, and light. These measured parameters can be associated with events such as a hazardous gas blow out, opening doors, human presence, tipping ladders, etc. Sensors not only sense but also actuate. Sensors come in a variety of forms; embedded, fixed, adhesive, as a gel, movable, wearable, etc. For UC appliances, sensors can also be mounted on an auxiliary device or cloth, such as a jacket [20] or a helmet.

Critical in the (non-)perception of UC is a rich, multi-modal humane HCI model as outlined in [21] to [24]. Important modalities of sensation in the context of UC are:

- view (visual modality), requiring image sensing and recognition technology;
- voice (auditory modality), requiring speech sensing and recognition technology and natural language processing;
- gesture, requiring gesture sensing and recognition technology;
- touch, force and grip, requiring touch sensing and haptic technology.

Lesser strictly human gesture-driven sensors are:

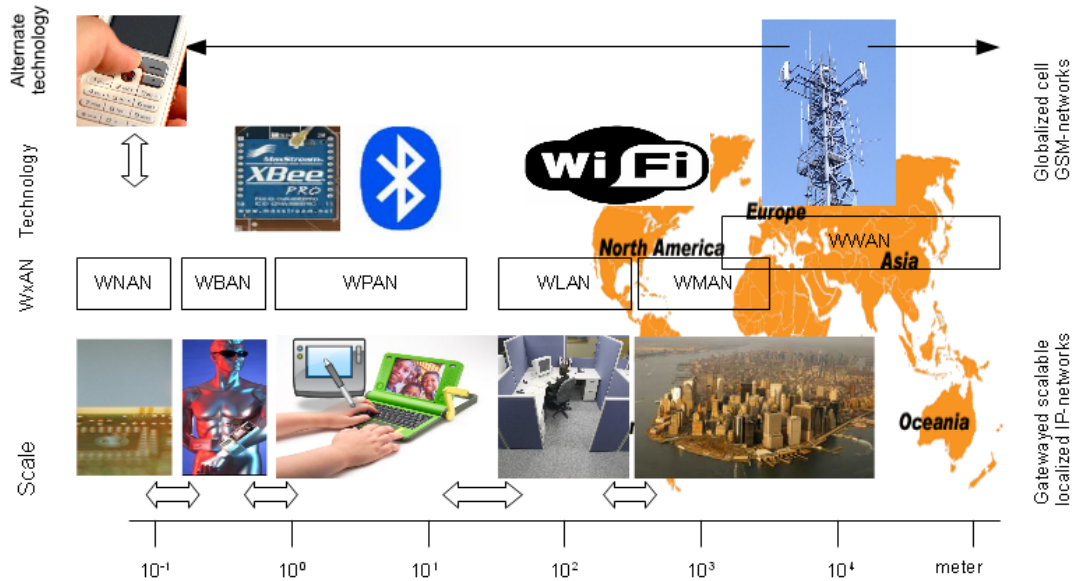


Fig. 3. Overview of wireless nano-to-wide area networks and network technologies

- presence and proximity, requiring (body) heat, movement or sound sensing and recognition technology;
- mood, requiring gesture, vocal and facial sensing and recognition, image analysis and expression analysis technology;
- activity and motion (accelerometers); much like presence, possibly combined with mood.

Sensors must fit underlying physics and deliver a fitting output signal. Sensors can function individually, clustered or networked.

1.1 Sensor Materials

Sensor materials are a natural manifestation of physical sensors. These materials change their state and properties, if sensing physical change [25]. Multi-functional materials and bio-engineering materials lend themselves to this class of sensors [26] and [27], giving rise to the emergence of a new class of products, manifesting in smart exo-skeletons and endo-prosthesis, as well as in sports, outdoor and well-being activity devices, and veterinarian, food and beverage applications [28] to [30].

1.2 Embedded Sensors

Robust, self-contained and self-organizing miniaturized sensor nodes are easily embedded in

products and environment [31]. This includes even full functional video cameras. Gluing techniques and Shape Deposition Manufacturing (SDM) technology allow for swift embedding [32]. Synthetic multi-functional materials are structured materials that are designed and engineered to possess multiple principal behaviors and properties that can be tuned to specific applications. Nanostructured such materials allow for the embedding of nano-electromechanical building blocks (NEMS) and will cause further integration of sensors-processing-actuator systems into multi-functional materials [33]. Apart from synthesized materials, biomaterials that can perform the same functions [26] and [27] are being developed. Bio-chemical and mechanical problems represent significant challenges here, and operational lifetime. Perhaps the most compelling technological challenge to overcome is energy consumption [34]. Most embedded sensors are still AAA- or AA-battery powered and battery change is tiresome or even impossible. Technological challenge for the coming decade is recharge from heat, pressure, motion, solar power, or otherwise. A sub-200 μW power consumption per NEMS (node) is believed to be necessary for that. Radio integration and energy consumption remains another challenge, addressed later on.

The concept of Subscriber Identity Modules (SIM) was introduced in 1996, to authenticate and bind users to devices, and devices to networks by means of a device mounted smart card (SIM card). The use of SIM cards technology is one way to authenticate humans by means of a device-mounted smart card. SIM technology is a preconfigured hardware solution with limited capabilities. Since preconfigured in the device, no real time assessment as to the authentication of its user is possible. Multi-modal identity tracking is a key technology in UC that may replace SIM authentication for that (and other) purposes.

1.3 Ambient Sensors

Ambient sensors are sensors capable of jointly sensing multiple physical phenomena in various surroundings. Note that in industry, the term is also used for sensor systems that, for instance, combine different classes of light. Apart from smart rooms and buildings [35] to [37], ambient sensing techniques have been applied to urban environments [38] to [40]. Application of ambient sensor technology to human motion tracking purposes is discussed in [41]. A method for human identification and tracking in a smart room using pan-tilt-zoom cameras and phase-array auditory localization was presented in [42]. Group-level and individual level identification is combined for scene analysis. Several issues related to localization, remoteness and non-intrusiveness have been discussed in [43].

One of the primary technological concerns is the sensor timing and synchronization of heterogeneous signals and data. In mid- and long distance combined auditory and vision localization, auditory signal timing can bring down the overall sensing bandwidth and thus introduce positioning and tracking errors [43]. At present, global time synchronization is common, but at the cost of considerable overhead [44]. An approach has been proposed based on the total sensor node residence time of arriving samples, and align times in the end, in order to reduce overhead [45]. Signal travel or arrival time differences are not the only cause of a-synchronicity; processing, encoding, transmission and presentation can also be sources of timing mismatch. In fact, the whole service pipeline

needs to be transparently in sync to the perceiving process. Further technological issues are:

- filtering off noise, for instance traffic noise in an urban setting, and
- juggling the bandwidth, particularly with ambient sensing.

Multi-functional materials will play an important role in future ambient sensor technology [27]. Together with the above issues, the technological potential of ambient disposable, environment-powered, self-organizing, and ambient sensors has also been discussed in [10]. Familiar examples are *smart dust* and the Carnegie Mellon *claytronics* project [46].

1.4 Wearable Sensors

Wearable sensors invade many remote spots and scenarios [40]. Essentially, wearable wireless sensor networks can be carried anywhere, but operation conditions may make effective operation hard [41]. The concept of on-body wearable sensors is gaining more and more attention in research [47] and [48]. They can be networked in a Wireless Body Area Network (WBAN) (Fig. 3) [34] and [49]. At present, mood and emotion recognition is an active topic of research. Recognizing emotions and expressions may help to track aggression, violence, suspect behavior but also illness, boredom, weakness, unconsciousness, death, in tele-surveillance approaches [50]. Technological challenges are the positioning of the sensors in a controlled affix position, without hindering body movements. Further technological challenges are posed by body fluids such as sweat, and shocks.

2 TRANSMISSION TECHNOLOGIES

In telecommunications, transmission is the process of sending, propagating and receiving an analogue or digital information signal over a wired or wireless transmission medium. Transmission technologies support communication by means of transmitting signals in a peer-to-peer (1:1), peer-to-cluster (1:N), or cluster-to-cluster (N:M) manner. In the literature the terms point-to-point or point-to-multipoint transmission are also used. There are multiple viewpoints and classification principles that can be applied to them. One view is represented in Fig. 2, and this identifies (i) embedded, (ii)

ambient, (iii) portable, and (iv) wearable classes of these technologies. In addition to this exploitation oriented view, another view arranges UC technologies according to their functionalities on device level and network level, respectively.

2.1 Device Level

As predicted by Moore's law, miniaturization of VLSI microprocessors and memories is progressing rapidly; sub 20 nm CMOS technology at near radio-frequencies is current state. In the 1990s, the development and mass-production of, a few-dollar cost, dime-size 8-bit hardware platforms for Wireless Sensor Networks (WSN) for generic industrial applications readily took off [51]. These hardware platforms are known as *sensor nodes* [52] or: *notes* [31]. ZigBee and Bluetooth were developed as low cost radio frequency (RF) communication technologies applicable to standard notes, replacing infrared. The development of ZigBee started back in 1998, with an initial support by Philips, and a first release appeared in 2004. ZigBee is now under the patronage of the ZigBee Alliance. Bluetooth has been developed by Jaap Haartsen at Ericsson in 1994, and is now under the auspices of the Bluetooth SIG. A third industry technology, Wi-Fi has been developed for a short distance wireless networking. Wi-Fi was developed in 1991 by Vic Hayes at Agere Systems, in the Netherlands, and is now under concern of the IEEE Group 11 and the Wi-Fi Alliance. The transfer rate of ZigBee is 40 to 100 KBit/s, Bluetooth 2.0 has a transfer rate up to 2.1 MBit/s, Wi-Fi up to 54 MBit/s. ZigBee is for low level and simple control data, Bluetooth is for serializable data, Wi-Fi for full office data. All three have been unified in the IEEE 802-family of standards (Table 1).

Antenna-based Near Field Communication (NFC) technology, used in cellular devices, smart cards, and for Radio Frequency Identification (RFID) labels emerged from ISO/IEC 14443 [53]. RFID technology was developed by IBM in the 1980s and early 1990s [54]. Originally designed for supermarket products, RFID developed into a general purpose product identification code in the time period from 1999 to 2003. This advancement was fostered by EPCglobal founded by the Uniform Code Council. Nowadays EPC provides

generic ID-tag technology [55]. For longer distances, exceeding the typical range of a Wireless Personal Area Network (WPAN), connection can be made to a (Wireless) Local Area Network (WLAN) or Wireless Metropolitan Area Network (WMAN) gateway by using Wi-Fi or global communication technologies such as Global System for Mobile Communication (GSM) networks and Universal Mobile Telecommunications System (UMTS) (Fig. 3 and Table 1).

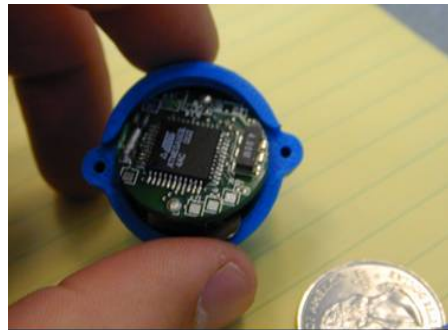


Fig. 4. Berkeley ATMEGA103-/TR1000 100 m range, 50 KBit/s, radio-based MICA node

The basic technology of GSM was developed in the period 1982 to 1987, focusing mainly on Europe. Founding work on the GSM standardization is generally attributed to Torleiv Masing of SINTEF (Norway), who at that time was also working for NATO in the Netherlands. Roaming, a technology allowing a single device or user to be discovered and serviced by different networks in a transparent manner was introduced in 1993. Currently, GSM EDGE (3G) is the standard technology. UMTS was introduced in 1999. Similar to GSM, it applies USIM cards. Since 2006, many UMTS networks switched to High Speed Downlink Packet Access (HSDPA).

Although the hardware platform for sensor nodes is highly integrated, at a functional level there is a difference between the functions of sensing, processing, transmission and actuation, like sensation generation. In Fig. 2 the classes of technologies are displayed as separated, but in reality the distinct functions are interlaced, even holistically integrated. A good example of the integration of various components in one device is the Berkeley MICA node shown in Fig. 4. Its basic architecture is shown in Fig. 5. On the I/O connector, analog/digital sensor signals come in,

which are processed locally by a Micro Controller. The output digital stream of packets is transmitted by the radio. The node is timed by a timer. Master nodes may orchestrate slave nodes in a WSN. Operating system updates are *flushed* from a separate incremental programming server.

A sensor node can organize itself as well as its position in the network topology. It is capable of powering itself up, uniquely identifying itself, establishing a connection with the master node (if present) and preparing messages for transmitting up the network. The micro controller does the local signal processing, validation and encoding and prepares a stream of data packages (assuming a digital radio) for transmission. The timer coordinates the functions in the sensor node, most prominently the radio transmission. Once cleared by the timer, the radio sends off its packets.

2.2 Network Level

Wireless sensor networks are not only typical manifestations of combined information eliciting and transmission technologies, but also typical from the point of view of issues related to the operation of transmitters on network level. Depending on the task, the topology of the WSN, and its synchronization, data transmitted by the nodes may be aggregated and processed further, in a master node, or dedicated host. Common topologies are star and tree networks but more flexible topologies are also possible, at the cost of extra overhead and negotiation time. In that respect, WSNs can be subdivided into broadcast-based and preconfigured connection-oriented networks. To operate WSN nodes, work on tiny operating systems and micro-kernels began in the late 1990s. A working group at Berkeley developed TinyOS, in collaboration with Intel and Crossbow, the first release of which was presented in 2002. TinyOS is now in widespread use.

Timing and synchronization is a complex issue. Centralized control, slotted time and fixed topology solutions can be synchronized fairly well, but in industrial practice, ad hoc networking with dynamic topology and changing control tasks cannot. Ambient signal transmission also adds additional complexity [56]. Most technological approaches try to tackle this with a multi-layer or coarse-and-fine-grain timing,

negotiating allocation of larger time blocks for any of the three states: sending, receiving, idling (sleeping). Within a so-allocated coarse grain time slot, internal timing (at the MAC- or media access control level) can control data transmission. Keeping connections alive all the time is overly energy consuming and typically, sensors enter a sleeping mode when commanded so by a master node or otherwise [31].

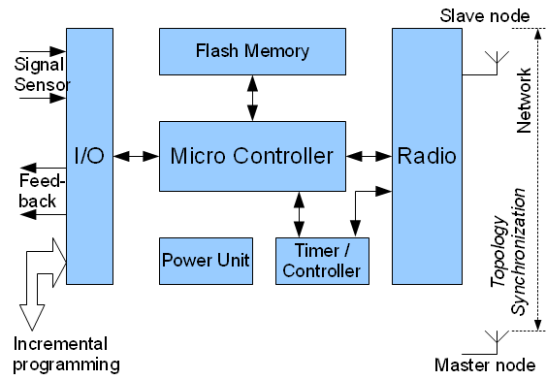


Fig. 5. Basic sensor node architecture

Table 1. Wireless (top), communication (middle) and future (bottom) technologies

TECHNOLOGY	IEEE 802 MEMBER	APPLICATION/PURPOSE	DISTANCE
ZigBee	802.15.4	Industry, command and control	WPAN
Bluetooth	802.15.1	Serial protocol, serializable data	WPAN
Wi-Fi	802.11x	Full office data	WLAN

TECHNOLOGY	STANDARD	APPLICATION/PURPOSE	DISTANCE
NFC	ISO/IEC 14443	Active/ Passive RFID	Near field, antenna
GSM	ETSI TISPAN	Voice	Any distance, cells
UMTS W-CDMA	IMT (3G)	Data	

FUTURE TECHNOLOGY	STANDARD	FUTURE APPLICATION	DISTANCE
UWB	None (UWB.org)	FUTURE High rate	WPAN
WiMAX	IEEE 802.16	FUTURE General purpose	WP/LAN WMAN

Technological research on low energy consumption WSNs will receive strong emphasis in the near future. Many innovations are expected such as:

- CMOS-improvements, multi-cores and Network-on-(a-)Chip (NoC) deep integration [57] and [58];

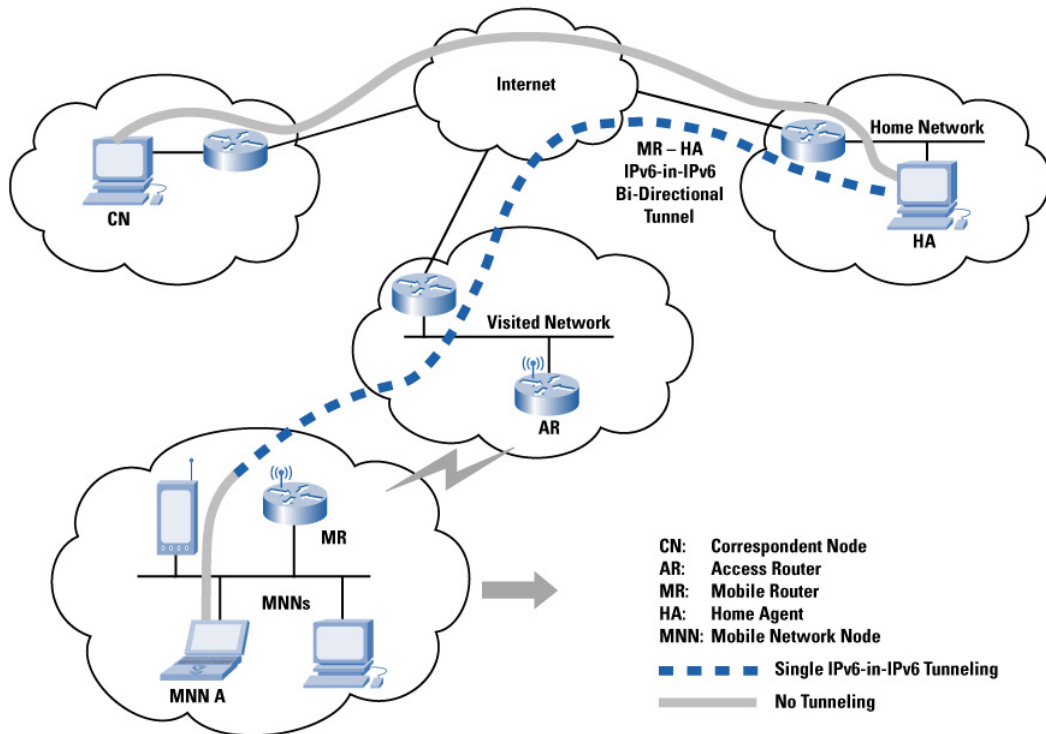


Fig. 6. MANET (vehicles: VANET) topology (source: www.Cisco.com)

- Digital radio and frequency sharing [59];
- Enhanced (zero-conf) stack services [60] and [52];
- New technology batteries and environment rechargeable batteries;
- Power management systems [61];
- Data loss (which may be in access of 50%) prevention [34];
- New multi-hop strategies and enhanced active-sleep timing strategies;
- Enhanced noise control, reducing overhead and processing cost;
- Low cost sleep states [62] and (Tiny)OS enhancements.

Ad hoc networking appeared not only as an alternative to traditional fixed-topology networks, but also as a competitor. Significant progress has been achieved in the domain of Mobile Ad-hoc NETWORKS, which is often referred to by the acronym MANET [41] and [63] (in vehicles also: VANET). Mobile computing involves moving WPANs. This technology has been developed to be capable of embedding PANs. In a car or a train, it can provide, for instance, for vehicle-to-environment (or: vehicle-to-infrastructure), vehicle-to-vehicle and vehicle-

to-driver/passenger HCI in parallel. With a fast moving object, like a car, complicated steps are the development of multi-homing, employing multiple Internet access channels in combination with vertical and horizontal *handover* protocols and fast media switching. The recently developed 6loIPv6 technology also provides mobile routing by combining a fixed node in a home network with a temporary care-of node in the local network [64] and [65]. MANETs are not exclusive to traffic but for general mobile computing purposes. A typical MANET topology is shown in Fig. 6. A VPN-like tunneling is used over the locally wirelessly visited network to connect to a fixed home network. This network topology incorporates mobile routers.

Distributed and ambient transmission dialogues have also come to the focus of research. An approach to distributed ambient dialogues, device capabilities-dependent device switching, and state- and failure safe dialogues has been proposed in [66]. They propose a client and device abstraction in the form of an Application Programming Interface (API) and/or middleware to prevent stalled dialogues in combination with a standard device library. An Interaction

Specification Language (ISL) has been proposed to abstract interaction specification [67]. This proposal combines a versioning model and a separation of user interface and presentation, in the first place between users themselves and devices. To process a context-aware service interaction request, interaction specifications are parsed and fitting user interfaces are generated by a selected interaction engine. HTML, Java AWT and Swing and Tcl/Tk have been considered in this set of engines, but the list can be arbitrarily expanded. The major technological challenge for the next decade is the development of scalable and reconfigurable HCI snippets and a programming platform to construct flexible multi-modal multi-device UC HCI-interfaces [24].

3 NETWORK TECHNOLOGY

UC wireless networking technology relies basically on various WPAN technologies (e.g. on ZigBee and Bluetooth), with an extension upward to LAN technology (Wi-Fi), and downward to NFC (RFID, EPC) for sub-meter distances (Table 1, top). In parallel, GSM and UMTS communication is used for short and long distance multi-channel communication (Table 1, middle). WiMAX and UWB (Table 1, bottom) are future technologies. In Table 1, NFC is assumed sub-meter, WPAN covers a distance of 1 to 10 m, up to 100 m for a class 1 Bluetooth radio, while Wi-Fi extends to 300 m. For the future, WiMAX covers up to or even above 10000 m. Fig. 3 shows the working distances.

A gateway is a connection between two different networks. At the current state of technologies, Bluetooth and ZigBee gateway easily to IP networks, for instance, through a laptop or a dongle, using the so-called *zero-configuration* whereby only lower level IP services are used, for which no IP-address is required (often at the cost of decreased security and control). Gateways commonly take care of or are supported by routers that can establish connection at all OSI-layers, as needed.

4 CONVERSION TECHNOLOGIES

Conversion technologies are enablers that allow generating computed feedback on sensations and converting this into human conceivable forms. In the context of UC,

conversion technologies allow virtual sensation at remote places and environments.

4.1 Visual Sensation Generators

A dominant presentation mode for the near future is video presentation (visual modality). With the advent of high resolution large displays in various configurations, new technologies are needed for HCI-optimized appliances. A survey of the needs is presented and the emergence of these new technologies has been investigated in [68]. Taxonomy of multi-person-display ecosystems has been proposed in [69]. In a distributed environment, the two major issues are the possible large-scale heterogeneity of the display devices (ranging from airborne volumetric visualization to alphanumeric displays), and displaying different visual contents on display surfaces of various characteristics (physical size, resolution, interactivity, and refresh rates [70]).

4.2 Haptic Sensation Generators

Haptic feedback is an intuitive, culture-free and basically non distracting modality. At the present state of technology, haptic sensation in mobile devices is generated by coetaneous technology:

- Vibration generating technology;
- Piezoelectric skin (e.g. finger tip) stretching technology;
- Voice coil transduction technology;
- Electric sensation generation technology by means of a piezoelectric ceramic film.

The technological potential of low-frequency force by kinesthetic feedback generators is high, but no suitable technology exists at present. From a mechanical point of view, only limited force can be generated in smaller devices. Spinning gyroscopic generators using a change in angular momentum are suited for a small device application, but gyroscopic effects are not translational. In order to achieve a perception of force in all directions, multiple gyroscopic generators spinning in different planes may be combined. A small oscillating mass haptic generator was proposed in [68], using miniaturized slider-crank, crank-piston or cam-spring mechanisms, perceived as an all-

directional force. Forces can be controlled using frequency control.

4.3 Multi-Modal Sensation Generators

The major challenge in multi-modal sensation generation is the fusion of heterogeneous data and information, at model level but also at processing and exchange level [71]. Mobile spatial interaction is a HCI branch that focuses on showing more than the visible and more than the obvious [72]. It seeks to augment current environment perceptions by augmenting information and sensation. Augmenting sensations can be in the form of augmented reality scene generation, high end graphics but also by complementary auditory sensations.

Hypo-vigilance analysis is the analysis of a human attention and mood level, by observing expressions such as yawning, eye movement, etc. indicating fatigue and inattention. Multi-modal analysis, among others facial image analysis, was applied to discover hypo-vigilance among drivers in a simulator [73]. These researchers combined ECGs and GSRs, and combined this with the hypo-vigilance indication. Attention regain is obtained by an alarm and haptic sensation in the form of steering wheel vibration.

5 EXPLORATION TECHNOLOGIES

In general, ubiquitous exploration technologies allow remote and controlled elicitation, aggregation, filtering, codification and formalization of data, information, and knowledge from various knowledge sources, such as digital repositories, electronic documents, Internet warehouses, and information handling processes. Exploration typically happens according to specific objectives in mind and in varied contexts. Fig. 3 identifies the forms of explorations that are considered in this paper.

5.1 Data and Information Mining

Knowledge management, in this context, is the process of creating value from an organization's intangible assets [74]. It is composed of the combined problems of knowledge coordination, knowledge transfer, and knowledge reuse [75]. Knowledge coordination is the problem of semantic compatibility of

seemingly non-conforming data. Knowledge transfer is the process of exploration and transmission of (codified) data from its discovery location to the process of context-awareness generation in the UC-environments. Knowledge reuse generally includes a set of facts (data) that can be inserted into processing rules, so as to infer further facts, asserting them with a certain degree of certainty.

5.2 Knowledge Repositories and Ontology

In the present day, Knowledge Management Systems (KMSs) are commonly combined with or embedded in *groupware* and online collaboration frameworks. Knowledge repositories can furthermore be databases of structured data, but also WIKI's, manuals, etc. containing unstructured data. It has to be noted that the larger amount of data on the web is unstructured. Examples of large database can be found in engineering, health care and pharmaceutical research, crime fighting and defense etc. Structured online repositories can be subdivided into:

- Semi-structured registers, like Universal Description Discovery and Integration (UDDI) repositories for web services and other maintained registries such as OASIS (Organization for the Advancement of Structured Information Standards);
- Electronic Knowledge Repositories (EKRs) for codified explicit and tacit knowledge.

Codified knowledge is knowledge that has been analyzed and validated, and stored in online EKRs for subsequent structured retrieval by a KMS [76] and [77]. Information that can be codified and stored in EKR includes customer, supplier and product information [78].

In this paper, knowledge use and reuse is primarily considered as an enabler of UC decision making. Data retrieved from the Internet are used as facts in context-aware decision making. Formulating the search context permits dedicated searches, if not additional structuring algorithms are needed somewhere in the server-to-UC environment chain. Two principal techniques are usually applied in data mining [79]: (i) supervised classification, and (ii) unsupervised clustering. A variety of algorithms has been developed for these classification and clustering operations, including trees and rules for classification and

regression, association rules, belief networks, classical statistical models, nonlinear models such as neural networks, and local "memory-based" models.

The kernel approach writes N vectorial or non-vectorial data as an N by N matrix of data and features. In kernel-based learning, three classes of methods have been developed for learning vector-based supervised classification [80]:

- Support Vector Machines (SVM);
- Kernel Fisher Discriminants (KFD);
- Kernel Principal Component Analysis (KPCA).

These classes of algorithmic have also been applied to unsupervised (no learning vector) clustering. Current trends are moving towards hybrid, highly stable and robust algorithms [79]. Fast k -Means algorithms on kernel matrices allows for fast and robust unsupervised learning over large data sets. Another challenge for the next decade is controlling the quality of context-aware UC decision making. The Expected Value of Information (EVI) associates the risk of not knowing in decision making with the cost of acquiring additional data, thus quantifying a trade-off between data acquisition cost and acceptable uncertainty in the decision [81].

5.3 Content Search Engines

Knowing the inquiry context has lead to specific search engines and dedicated search channels. Context-aware searching may include the currently available UC device output capabilities. To illustrate, consider a domestic UC environment issuing a request resulting in a streaming multi-medial data, which may be processed as follows:

- A present cellular phone is given a text;
- Audio content goes to an audio device;
- Video is streamed to a video wall.

A metamodel for context awareness that can be applied in context-aware searches has been proposed in [82]. A UC environment (device) may generate such search requests; the environment or a *proxy server* (loosely: a server that handles the internet search request on behalf) forwards the inquiry to a network service or dedicated search engine.

Content search engines should also support data and information preprocessing,

transmission and distribution. In this context, the concept of Knowledge Transfer Networks (KTN) deserves attention. A KTN is composed of heterogeneous human nodes, such as (groups of) individuals, organizations, and non-human nodes such as repositories, web pages, databases, *web crawlers* and *web bots* [83] and [84]. Web crawlers and web bots (or: *bots* or: *spiders*) are intelligent programs (*agents*) that autonomously search the web for data associated with a topic [85]. Data and information transmission requires various technologies to:

- Discover and access to facts (data) in data stores and repositories;
- Verify and assess data quality and rank online repositories according to quality, plus:
- Ontologies, taxonomies and methods to map unaligned data definitions onto a common agreed definition;
- Tools to locate and fetch the data and deliver them timely and in the right format.

Verification and assessment, mapping and other functions may be performed *server-sided*, by the crawler, or downstream in the UC-environment [86]. Simple data and information can be delivered directly by simple crawlers [87] and [88]; (semi-)structured data are easily transcribed in the form of XML for immediate transmission. More complex data can be preprocessed by the crawlers themselves, or delivered at some remote classifiers or clustering application to further structure and codify them. *Servlets* are small sever-side web programs that can present queried data in a structured manner. Web services are server-side SOAP/XML-based services that can do the same. Preprocessing can also be conducted by a more advanced crawler (*metabot*), using ontologies to classify unstructured and semi-structured data. Crawlers may even learn new ontologies, using unsupervised clustering techniques and verify and assess proposed classifications using supervised classification [89]. Preprocessing in the UC environment itself and the overall coordination of the transmission may be dedicated to a proxy or another device in the UC environment capable of doing so.

The experiences with inquiries in context and convenience of *Napster*- and *Kazaa*-like tools have led to specific search engines and transmission technology, such as peer-to-peer and *multicast* synchronous and asynchronous *overlay*

networks and distributed content systems. Using peer-to-peer (P2P) transmission or content sharing are ways to robustly boost efficiency, potentially entirely *machine-to-machine*, using web services. This may also invoke an infrastructure for paid services; many B2B XML-services networks have emerged in industry. It remains as a technological challenge for the coming decade to bring about maturation of distributed hash technology (DHT) to implement more robust industry content distribution schemes.

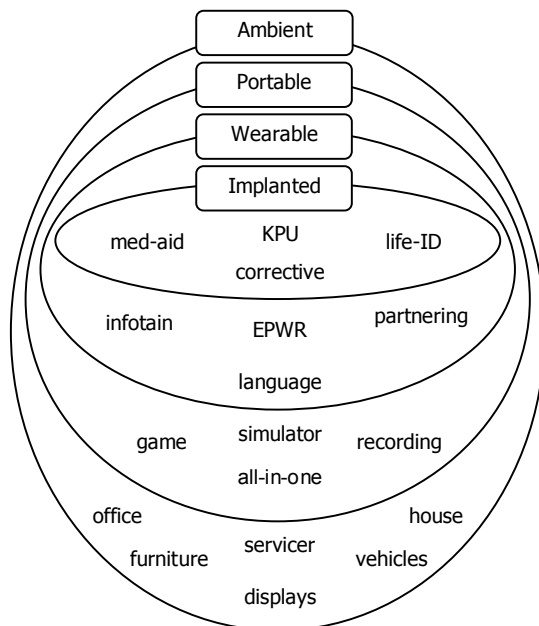


Fig. 7. Four genres of artifacts/products with ubiquitous computing

5.4 Object Retrieval Engines

The goal of object search methods is to provide intuitive shortcuts to 3D objects or classes of objects, and retrieve models with requested characteristics, which are useful for designing. The basis of retrieval can be resemblance of global forms, existence of local shape features. Three major steps of retrieval are input specification, computational search and selection, and output presentation and assessment. Input specification can be based on descriptive parameters, graphical sketches, technical drawing, digital geometric models, and surrogate physical models [90].

The technological challenge for the next decade is to step up from textual description to generic form-feature and semantic descriptions that can be handled by object retrieval engines and shape matching technologies. A further technological challenge is to fit object descriptions (object templates), to observed objects in scenes and images. One of the applications is supply chain management and manufacturing. Design-by template (extended knowledge-based engineering) is another future application. Technology may be developed in the coming decade to implement and operate EKR of product designs.

6 UBIQUITOUS COMPUTING IN PRODUCTS

It seems that only our fantasy poses limitations to UC applications, whereas additional considerations, such as consumer acceptance and social effects, determine its eventual success. The progress in some specific fields, like smart offices, living environments, urban regions, public spaces, medical care taking, etc. are evidence of the legacy and enormous potentials of UC enhanced artifacts and processes [6], [37] and [91]. The infinite number of existing, emerging and potential applications is prohibiting, even the discussion of the most representative applications would require a multiple volume book, instead of this paper (Fig. 7). Therefore, the below survey and analysis cannot be anything else but sketchy and incomplete. An additional technical issue is that the related literature reflects many different views, concepts, interpretations and definition of ubiquitous artifacts/products and the exploitation of ubiquitous technologies in products.

There are trends that facilitate, and others that impede proliferation of the paradigm of ubiquitous products. Conventionalism, worry about impacts, and lack of awareness and understanding can be mentioned as major factors in slowing down proliferation. On the other hand, many social and technological trends in the field of electronics, information technology, social well-being and ecological conditions are enabling and urging, respectively, the progress in this direction. As concrete examples of these latter trends, we may refer to: (i) the periodical duplication of the computing power and capacities of microelectronics, (ii) the continuing reduction of the size (miniaturization) of

microelectronics components and products, (iii) the growing concerns about the access to and availability of critical material and energy sources, and the rate of material and energy consumption, (iv) the changing role of artificial products in the society and the growing emphasis on service products, and (v) the influence of information and knowledge as production and business objective in the knowledge and innovation economy.

A good illustration is the EU i2010 Intelligent Car Initiative, based on the idea that with the assistance of ubiquitous technology, traffic can be safer, more efficient and comfortable with cars in which some delicate driving tasks are overtaken or supervised. Technology for networked vehicles was developed in the InternetCAR project [63] to [65]. Its objective was to incorporate nested WPANs in cars in order to allow auto-configuring usage of mobile personal devices such as PDAs within an Internet-connected car with minimal or no driver distraction. The proposed solution is multi-level mobile computing, embedding an interior WPAN child in a moving car WPAN mother. UMICS mobile information access gathers additional traffic data and information from net-based locations during travel, with the aim of increasing safety and consuming less fuel [92].

In the coming decades, a significant part of customer durables will manifest as smartly behaving products [93], autonomously intelligent products [94], or emotionally intelligent products [95]. *Catoms* have been designed in the Carnegie Mellon *claytronics* project to have products constructing, shaping, empowering themselves from elementary intelligent particles (catoms), and adapting themselves to environmental demands in an evolutionary manner [46]. Nanostructured multi-functional materials permit product structural and state sanity monitoring on a continuous basis. Product structure mechanical and environmental load recording may also become a standard product feature [27]. In order to be equipped with adequate such competences, the designers' curriculum should be enriched with UC theory and design methodology [96].

7 UBIQUITOUS COMPUTING IN CREATIVE PROCESSES

Similar to the case of artifacts, there is an extremely large number of real-life processes, no matter if they are natural organic processes or artificially created processes, which can benefit from ubiquitous computing. In our view, UC will blur the boundary between products and processes even further. Miniaturized devices will be melting up in processes, like smart dust in agriculture and catoms in intelligent devices. Sensors, detectors, tags and counters embedded in customer products not only help the realization of information processing processes, but their functionality and behavior is determined through these processes. As smart information appliances, products can collect information not only about their location, but also about the time and frequency of use, operational circumstances, status of maintenance, incidental failures, damages of the product, the way of interacting with the product, and the users, unless it conflicts with privacy, personal interest, and confidentiality. These pieces of information can be recorded on a daily basis and forwarded to the designers through wireless communication, with the goal to provide additional intelligence or feedback for their work [97].

We believe that UC can have its largest impact in creative processes, such as design, innovation, development and management [98], which in turn raise the need for ubiquitous (on-demand, trans-professional, and lifelong) learning [99]. Creative processes are of high importance for the reason that intense (overdriving) innovation is seen as one of the top trends in the 21st century [100]. Researchers dealt with issues related to the application of UC throughout the entire product (part) life cycle too [101]. Product realization processes may be extended with the following, UC enabled functionalities:

- Support of operative design research either in the form of providing means for nomadic observational, explorative and experimental research actions [102], or in the form of indirect data gathering through products, which is becoming a modern form of empirical research;
- Elicitation and aggregation of information about stakeholders, who are either involved in designing of new products (e.g. fellow

designers, manufacturing experts, service providers), or influenced by the designed products (e.g. customers, operators and asset managers). In addition, in the early stages of design, prototypes may also deliver early feedback on their performances;

- From the earliest stages of production onwards, the supply chain and the adaptive manufacturing processes may organize and supervise themselves using UC [103], intelligent agents [86], and self-aware components [55]. This holds for materials, stock parts, sub-assemblies, and bundled and assembled products, and can be extended in the direction of business organization [4], and across the product life cycle [101];
- As a layer-oriented manufacturing process, Shape Deposition Manufacturing (SDM) can be considered for the deposition of substrates to create films, layers, channels, etc., for instance, for printing of fiber optic sensors on products [104] and [105]. Digital manufacturing also support the fabrication of natural (bio-) sensor networks in and on products, while fulfilling the requirements for sustainable products and manufacturing [26] and [106]. SDM is expected to become multi-scale, and to become able to also print large-scale objects. During the stage of usage, feedback can be provided for designers, suppliers and manufacturers on a *per item* basis, like maintenance, end-of-life and reuse/recycling.

Efficient process organization and control assume an understanding of the context of the process, in addition to people and artifacts. In the perspective of ubiquitous design support, context is considered a construct of any important information that has direct or indirect influence on a situation of entities, and can be used to characterize and to reason about a particular situation. The source of context information is data recorded by a configuration of sensors, which can combine measurement with the computer's ability to display, record, and communicate visualizations of the measured data [107]. This facilitates interpretation of real-life situations and processes. Currently, the main challenge of ubiquitous computing is the limited scope to teach computers about processes.

8 CONCLUSION

In this paper we have surveyed the extraordinary wide research field of UC technology. In many parts of the discussion, we restricted ourselves to WSN and data and information retrieval technology in WSNs, as a field of current strong interest. We have discussed sensors, transmitters and sensation generators that can be applied in products and environments. More or less autonomous technological developments include the design of motes, generic miniature networked intelligent sensor units that organize themselves, HCI for UC and MSI for augmented environments. Not discussed deeply in the paper, but no less important technological developments such as bio-engineering and multi-functional materials, NLP, agent technology and AI, and kernel technologies are all favoring to the above developments. Energy consumption is a constant technological concern (in particular, in case of WSN) and synchronization issues also need attention, specifically in dynamically changing ad hoc networks (MANETs).

Based on the five clusters of ubiquitous technologies, a new generation of products can be expected soon, already able to (i) explore and reason with information and knowledge, (ii) sense their status and surroundings and build awareness of contexts, (iii) transmit signals on short to long ranges, (iv) remotely generate and provide sensations, and (v) network via heterogeneous platform in a volatile manner. Further research will be focusing on the route towards true cognitive environments, as expressed in Fig. 1, such that the *cognitive overburden* is taken off the hands of humans [108]. When migrating from well-bounded task and services models to evolutionary and unattended unsupervised autonomously developing open service models, human intervention models and roll back protocols will have to be developed and installed to guarantee unconditional and persistent human control under all circumstances.

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