Towards a Smart World and Ubiquitous Intelligence: A Walkthrough from Smart Things to Smart Hyperspaces and UbicKids

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***Abstract*— A cyber world (CW) is a digitized world created on cyberspaces inside computers interconnected by networks including the Internet. Following ubiquitous computers, sensors, e-tags, networks, information, services, etc., is a road towards a smart world (SW) created on both cyberspaces and real spaces. It is mainly characterized by ubiquitous intelligence or computational intelligence pervasion in the physical world filled with smart things. In recent years, many novel and imaginative researches have been conducted to try and experiment a variety of smart things including characteristic smart objects and specific smart spaces or environments as well as smart systems. The next research phase to emerge, we believe, is to coordinate these diverse smart objects and integrate these isolated smart spaces together into a higher level of spaces known as smart hyperspace or hyper-environments, and eventually create the smart world. In this paper, we discuss the potential trends and related challenges toward the smart world and ubiquitous intelligence from smart things to smart spaces and then to smart hyperspaces. Likewise, we show our efforts in developing a smart hyperspace of ubiquitous care for kids, called UbicKids.**

***Index Terms*— Smart world, ubiquitous intelligence, space, hyperspace, context, trust, kids care, UbicKids**

I. Introduction

Two of the greatest inventions in the last century were computers and the Internet/Web. Their combination has given birth to the so called global digital information/resource world or cyberworld (CW) created on cyberspaces [57], [58]. The power of the cyberworld lies on the interconnection and cooperation of billions of machines ranging from stationary supercomputers, clusters, workstations, servers and PCs to moveable laptops, PDAs, handhelds, and so on. The new world has brought revolutionary changes to human living, working, learning and so on based on Internet Distributed Computing (IDC), web computing (webcomp), mobile computing (mobicomp) and other IT technologies. The changes are made basically via mapping or converting things in the real world into some kinds of their virtual counterparts, i.e., e-things, in the cyberworld so that many conventional activities can be moved to the e-world and handled with e-ways. An e-action such as a complex financial trading can be executed fast by simply clicking the mouse as an e-command.

From the end of the last century, another revolution has emerged, which is based on Weiser's vision [45] that a great number and variety of computers with different sizes and functions will be everywhere, so ubiquitous around us and pervasive in our environment. The associated technologies and applications were called ubiquitous computing (ubicomp or UC) by him and later called pervasive computing (percomp) [53] by IBM. The coming of the ubicomp wave/era is mainly due to two fundamental technology trends, i.e., the continuing miniaturization of electronic chips and electro-mechanical devices, and their interconnections especially using wireless communications and the next generation Internet based on IPv6. Cyberworld brings us to the computerized virtual digital world. Ubicomp, in contrast, brings us to the computerized physical real world.

The ubicomp or percomp vision with services in any place, any time and any means has greatly stimulated researches and developments on embedded or wearable computers, universal identification electronic tags, sensors/actuators, motes, location positioning devices, MEMS/NEMS and novel materials as well as associative ubiquitous network infrastructures and open service frameworks. Lots of studies have been devoted to the ubicomp related technologies in system OS, middleware, interface, model, design, deployment and management. The broad vision of ubicomp (partially with mobicomp) has recently stimulated many novel but more specific computing mechanisms and paradigms, such as context-aware computing, sentient computing, invisible computing, disappearing computing, everyday computing, wearable computing, proactive computing, autonomic computing, organic computing, sustainable pervasive computing, ambient intelligence, embedded agents, palpable computing, amorphous computing, spray computing, etc.

One of the fundamental questions is that, what the future world will be once the above ubiquitous computers, networks and services are gradually available and related technologies have progressed largely in the next certain years. We envision that the future world will possibly be a highly computerized physical world known as the smart world (SW), which is created on both cyberspaces and real spaces. It is mainly characterized by ubiquitous intelligence or computational intelligence pervasion in the physical world filled with smart real things ranging from man-made artifacts to natural objects, from everyday appliances to sophisticated embedded systems, from small rooms to large buildings, from enclosed sites to open areas, and from stationary places to moveable vehicles. The smart world is aimed at offering novel ubiquitous services in the right place, right time and right means with some kinds/levels of smart or intelligent behaviors. The power of the smart world lies at the seamless integration and mutual actions of the real world and the virtual e-world.

Actually, researches related to the smart things have been going on for about one and a half decade since Weiser's pioneering work around 1990. Its past and future researches can be roughly divided into three phases. The first phase, i.e., from when it started to the end of the last century was characterized by making some test samples of smart objects and building few prototypes of smart spaces with relatively limited context-aware functions. The second phase which started from this century is the spread of researches on a variety of smart everyday objects [21] and environments/spaces [11]. We are still at the second phase. Surely, the current experimental smart objects and spaces need to be greatly improved for practical applications, and more and more smart spaces will appear in the next few years. However, these spaces are currently isolated and look like small islands in an ocean. Users may move between different spaces and some decisions can be precisely made only when considering the contexts at both the user's present site and the previous/next sites where he was/will be. Therefore, the third phase which is yet to come, we believe, will be to first interconnect some associated smart spaces together to form a smart hyperspace, and then integrate all the smart spaces/hyperspaces together with the cyberworld, to finally create the smart world.

In what follows, we will further discuss the smart things and ubiquitous intelligence related to the smart world in the next section. Some clarifications on basic features of smart spaces and smart hyperspaces as well as the key challenging issues are discussed in Section 3. Section 4 explains our fundamental motivations and main objectives to start the project UbicKids - a smart hyperspace environment of ubiquitous care for kids. Its typical functions and representative scenarios are also presented in this section. The UbicKids system related basic technical issues and general architectures are discussed in detail in Section 5. Not only technical issues, but also other factors involving social, psychological, ethical and other aspects are very important in ubicomp. These non-technical factors and possible issues associated with the kids care system are described in Section 6. Finally, in Section 7, we summarize our views about ubicomp characteristic and ubiquitous intelligence, and give our brief concluding remarks on the study of smart hyperspace and UbicKids towards the smart world.

II. Smart Things and Ubiquitous Intelligence

Weiser and Brown summarized the modern computer history in three phases/eras/waves/trends: the mainframe, the PC and the UC, which corresponds to the three relationships between computers and us: one-to-many, one-to-one and many-to-one [62]. They described the typical usages and roles of computers in each of the three eras or trends, and further proposed that the so called calm technology would be a fundamental challenge in the UC era. Moreover, we thought it is also very important and necessary to find out the most fundamental driving force and the most representative element in each era or trend. In the mainframe trend, the main driving force is the higher speed/performance computation and the corresponding core element is the data, around which many theories and technologies have been invented. In the PC trend, the faster available/rich information is the main driving force and digital media or multimedia play as the central element in many information technologies. It seems, in the UC trend, that more ubiquitous computation/information/service would be the main driving force, and the corresponding essential element would be the various smart/intelligent ubiquitous things or u-things.

Many of these things are real ones with attached/embedded/blended computers and/or some kinds of other devices such as sensors, actuators, e-tags and so on. Due to the attachment/embedment/blending as well as ubiquitous networks, ordinary things surrounding us are capable of (1) computing and communicating, (2) connecting or being connected to each other, and (3) behaving smartly with certain intelligence. Our world would evolve towards what we called the smart world filled with such smart u-things.

One of the profound implications of such ubiquitous smart things is that various kinds and levels of intelligence will be a ubiquitous existence residing in everyday objects, environments and even ourselves, and possibly being extended from man-made to natural things. Computational intelligence, from AI to soft/natural computing and software agents, has been studied for about half a century and gotten wide applications mainly as mechanisms, methods, algorithms, functions, and tools in solving complex computational problems or making various sophisticated systems. Due to the ubiquitous intelligence existence, we have to treat the computational intelligence not only as methods or tools, but also as some kind of independent entities integrated with the usual physical objects and pervaded in the ambient environments and the whole world.

The ultimate goal of the ubiquitous intelligence is to make the intelligent things behave trustworthily in both other-aware and self-aware manners to some degrees and circumstances. Certainly, the intelligent ubiquitous things which fulfill the strict meaning of human-like intelligence would not come in the near future. Although the chess supercomputer Deep Blue successfully defeated the world chess champion Garry Kasparuov several years ago, many ambitious attempts to make intelligent machines including the fifth generation computer in the 1980s are still far less than what they were originally expected. It also cannot be expected that many computerized intelligent things can pass the Turing test in the near future. A reasonable expectation is to let the computerized things to have certain level or limit but truly useful intelligence in a broad sense. This is why we prefer to use the softer and more flexible term of 'smartness' instead of 'intelligence'.

A smart thing can be with different levels of intelligence from low to high. An object with an attached passive RFID, may have no intelligence at all, but at least it has some capability of computing and communicating. However, the word 'smart' is a little bit subtle and vague, thus its exact meaning is relatively hard to comprehend by the general audience and it has yet to be widely adopted by all of ubicomp or percomp researchers. It is therefore, very normal to see that lots of ubicomp researches and applications have been named, besides smart and intelligent, with other terms, such as *aware, context-aware, active, interactive, reactive, proactive, assistive, adaptive, automated, sentient, perceptual, cognitive, thinking*, etc. Among these, 'smart' is probably the most often used in literatures in recent years. It looks, at the current stage, that the term smart is a more general one possibly covering the meanings of the above different terms in the context of ubicomp. And it should be emphasized that a smart thing should necessarily behave with some extent of intelligence. It is also commonly seen that the two terms, smart and intelligent, are interchangeably used in some cases with almost equivalent meanings in ubiquitous/pervasive computing contexts.

Generally speaking, a smart/intelligent thing can be anything from a virtual to a real one. However, our emphasis is the latter, i.e., the smart real thing or more specifically the u-thing, for us to address the ubicomp special focus that is different from web intelligence [63], semantic web [6], intelligent cyber e-things and others. The smart things can be roughly classified into three categories, i.e., smart object, smart space and smart system, according to their appearances and functions.

The first category is about smart/intelligent ubiquitous objects or u-objects. They may be very sophisticated equipments such as smart TVs, cameras, cell phones and so on, but many of them are usual things like keys, watches, pens, bags, clothes, books, tables, windows, doors, etc., that is, almost all objects in the world. Although the smart/intelligent object, as a common term, is relatively acceptable for this category, other terms are also used in literatures, such as smart devices, cards, labels, e-tags, sensors, artifacts, appliances, instruments, goods, furniture, textiles, materials [8], etc., for more specifically covering different sets of smart objects. The robots can also be seen as some kind of smart objects, but some of them are aimed at human-like or animal-like behaviors with relatively high intelligence and more complex as compared with these everyday smart objects.

The second category is about smart/intelligent spaces or u-spaces, which are electronic-enhanced real spatial environments, or u-environments, including not only a number of various smart u-objects but also other relatively powerful computers/gateways to manage and serve these smart objects. The more detailed discussion on the smart spaces is left to the next section as they are closely related to the smart hyperspace, one of the research focus of this article.

The third category is about general smart systems or u-systems that are usually hard or sometimes impossible to describe by spatial attributes. They can be common service infrastructures including communication network systems, traffic management systems, some environment/activity monitoring systems, information delivery systems, etc. Or they are open software/hardware platforms, adaptive middleware and a kind of general service frameworks to support or serve smart u-objects and smart u-spaces as well as their u-services or u-applications. Although autonomic computing is targeted in making the self-manageable systems to cope with the problem of increasing complexities [34], such autonomic systems can be actually regarded as some kinds of smart systems.

The ubicomp/percomp can be regarded, in a sense, as the computing of all these smart/intelligent u-things, which are the basic elements and components of the smart world. However in practice, it is hard to say a u-thing is absolutely smart or not. Probably, any smart u-thing possesses two co-existing facets: smart and stupid. A same u-thing may be smart in certain situations but stupid or annoying in other situations. Even if it is assumed smart in a particular situation at specific time, but it may not be so in another time. Not only the situation and time, the smartness of a u-thing may be felt in various ways or probably with opposite feelings by different users. That is, an absolutely smart thing may not exist, just like no person in our world is completely perfect. Furthermore, it is also hard to say that smart is absolutely better than stupid in all cases. Despite all of these, the u-things will surely be able to become smarter and smarter along with the progress in theories and technologies.

Although more often we use the relatively softer term of smart for trying to reduce unrealistic expectations to the ubiquitous intelligence because of current theoretical/technical limitations and to avoid unnecessary debates about complicated or abstruse philosophical, cultural, social, ethical, and other implications, we have to be coolheaded and clear in realizing the extreme difficulties and challenges in making real things truly smart. All of these difficulties mainly come from the real world diversity and complexity, which need to be well abstracted, precisely modeled, and semantically represented for any following computing. The grand challenges will be multidisciplinary in order to move from universal services of any place/time/means to trustworthy services in the right place/time/means. There are always gaps between the visions and realms [41] at every current and future stages in the next decades or more [37], [40] for making smart things towards the smart world. What is worthwhile to point out regarding the underlying research and development of a smart thing is that "we should be cautious about setting the timing for its achievement" [59] with due consideration to both vision and feasibility at the corresponding stage.

III. Smart Spaces and Smart Hyperspaces

The words, 'space' and 'environment', are often used interchangeably, which are relatively abstract concepts of general sites or places. According to our research focuses and application scopes, the two abstract words can be replaced by more concrete things such as room, office, laboratory, home, shop, road, car, park, land, etc. The research on smart space can be traced back to Boulder's Adaptive House [27] since 1993 and Buxton's Reactive Environment [9] in 1995. In the late 1990s, several famous research projects were Georgia Tech's Aware Home, Inria's Smart Office, Stanford's iRoom, Cisco's Internet Home, Essex's Intelligent Inhabited Environments, H-P's Cool Town, etc. Around the year 2000 and later, many projects have been launched in universities and big companies to develop a variety of smart spaces or environments including ATR's Creative Space, CMU's Aura, Xerox's Smart Media Spaces, IBM's DreamSpace, KTH's comHOME, Microsoft's EasyLiving, MIT's Oxygen, Philips' Home of the Future, UW CSE's Portolano, Intel's Proactive Health, UF's Assistive Smart House, Keio's SSLab, etc.

Due to the diversity of real spaces and environments as well as different research backgrounds and targets, there are various definitions of smart space. The FCE group at Georgia Tech has emphasized that the (smart) environment must be aware of the users it is interacting with and be capable of unencumbered and intelligent interaction [13]. Gaia team has defined that active spaces, are extension to physical spaces which are capable of sensing user actions and equipped with a large variety of devices that will assist users with different tasks [43]. A broad vision on the future smart space was called ambient intelligence (AmI) by ISTAG [51], European Community, in 2001. The AmI refers to electronic environments that are sensitive, adaptive and responsive to the presence of people. A compact definition by CSIRO is that a smart space is able to sense, think, act, communicate and interact with people [55]. Das recently defined smart space as, it is able to acquire and apply knowledge about you and your surroundings, and also adapt to improve your experience [10]. One of the latest definitions by Shrobe is that smart environments combine perceptual and reasoning capabilities with other elements of ubiquitous computing in an attempt to create a human-centered system that is embedded in physical spaces [26].

No matter what word is used and what definition is given, we can figure out the core and essential features which are common in smart spaces. First, it is a physical environment equipped with electronic devices and embedded systems, which may be in different shapes, sizes, forms, functions, etc. These devices and embedded systems are interconnected by wired and/or wireless networks forming a digital virtual space, which must be closely integrated with the physical environment. That is, the smart space is a merger of physical and digital spaces. Such physical space oriented smart environments are clearly differentiated from pure web-based e-environments and virtual reality (VR) environments. The distinction between the smart spaces and augmented reality (AR) or mixed reality (MR) environments looks not so clear, and is probably dependent on the concrete AR/MR system [54]. Second, it must have some kinds or levels of abilities of perception, cognition, analysis, reasoning and anticipation about a user's existence and surroundings, on which it can accordingly take proper actions. These abilities can be regarded as a kind of intelligence, which is the origin of the term smart. The most basic characteristic of smartness is the context semantics and awareness for a real space/environment. The context is any information that can be used to characterize the situation of an entity [2]. Third, it aims at truly adapting to humans rather than the reverse, providing better services to users in their everyday environments without limiting to their desktops/laptops, and providing adequate support for their various daily activities in the real world via the merger of spaces and smartness.

Moreover, it is very important and necessary to have some taxonomy to classify the great number of diverse smart spaces created till now and the ones to be created in the next few years. Such classifications should take into consideration different aspects, such as space functional purposes, space spatial attributes, and space services and technologies, as given in the following.

Classification based on space functional purpose:

- Room, home, office, laboratory, classroom, etc.
- Building, library, school, campus, factory, etc.
- Shop, restaurant, hotel, clinic, hospital, etc.
- Street, yard, park, athletic ground, city, etc.
- Vehicle, road, railway, station, airport, etc.
- Land, mountain, pool, lake, river, etc.
- .....

Classification based on space spatial attribute:

- Small versus large
- Enclose versus open
- Still versus mobile
- Shape and dimension
- Partition and layout
- Position and relationship of inside objects
- ....

Classification based on space service/technology:

- Private versus public
- Specific versus general service
- Targeted users (kid, elder, student, patient, etc.)
- Number and activity of users

- Smart object, device and computer used
- Networks and media used
- Context type, number and usage
- ....

For example, typically a home is a still, close and private space usually with partitions and several family members. An office and a laboratory are similar as a home but with different purposes and functions. A car is a mobile, private and small space. A shopping mall is a still, public and large space often with many users. Such diversity and heterogeneity of real spaces or environments are one of the main difficulties in deploying a research-based system to practical environments. To build a smart space system, it is very important to clarify the space characteristics according to the above categories. Of course the above taxonomy proposed by us is quite preliminary, and a more general framework on smart space taxonomy and corresponding smart space specification criteria should be developed for clear guidance and systematic evaluation of various smart space systems as well as services in the future. These are also essential to make future smart space standards.

To make a smart space, some basic principles should be generally followed. The first one is the context awareness principle that a smart space must take proper actions according to certain *situational* contexts inside the space. Although Weiser pointed out the importance of the location and surrounding information for a computer in the early 1990s [45], the term context aware computing seems to be firstly coined by Shchilit, Adams and Want in 1994 [7]. It covers wide computing research areas, but it is also essential and indispensable in a smart space. The second one, i.e., boundary principle suggested by Kindberg and Fox in 2002, is that a smart environment should be with a clear boundary criterion often, but not necessarily related to a boundary in the physical world [56]. That is, *spatial* features of a smart space must be clearly drawn. The third one is the continuous interaction principle, proposed by GT's FCE group's people, that moves computing from a localized tool to a constant presence while addressing these *temporal* features of informal daily activities without a clear beginning or end, attention switching due to interruptions, concurrent multi activities, relationship changes along with time, etc. [23]. In summary, the above three can be regarded as *situational-spatial-temporal principles* in making a smart space system to serve users' activities inside the space.

However, a person's daily activities often cover multiple spaces or environments. For example, the spaces involved in a professor's working day may include an office, a laboratory, a library, a few classrooms and other rooms. Suppose each of the rooms has been made smart, but it is still hard to expect all the rooms as a whole to be capable of providing optimal services to the professor if all of the smart rooms are isolated with each other, i.e., without information exchanges and having no context on the professor's transfer between the rooms. Except for working, the professor's other activities also exist in the home, shops, car, subway, etc. Generally speaking, an individual's daily activities are often related to many spaces, which form some kind of associations.

For these multiple related spaces, therefore, there should be the fourth one, i.e., *interrelation principle* that addresses situational-spatial-temporal relationships of associated events and actions between the multi spaces. This principle is based on common activity facts: (1) A present situation may be related to events in the past/future probably at other spaces; (2) A current event may result in a sequence of follow-up events in different places/time; (3) A user may frequently move between different spaces in daily activities; and (4) A user may be sometimes interested to what happen in other places at a particular time. That is, for these related spaces, we should not only make each space smart but also let the spaces associated with each other to become smarter as a whole. Such a set of associated smart spaces, once interconnected, can be regarded as a higher leveled super space, i.e., a smart hyperspace or hyper-environment, as mentioned previously. A smart hyperspace treats a set of related spaces as a whole while emphasizing the possible situational, spatial, and temporal relationships between the spaces for further understanding of users and thus providing better services to them. Spaces in a hyperspace may or may not be physically connected or close to each other.

Actually, about 10 years ago, we realized the importance of integrating the multiple real and virtual environments, called the hyperworld, in which "we can, not only get passive multimedia information but also sense and control the real worlds directly and actively" [38]. The foreseen hyperworld vision was a natural extension based on our previous research on active devices and media, tele-presence, multimedia networks, augmented reality and mathematical visualization modeling. We also proposed a one-to-many hyperworld interaction reference model [33] by extending the Dexter hypertext model [24]. What we called the hyperworld at that time can be regarded as something like the hyperspace in this article. Abowd, et al, in 1998, also called for research on correlated smart spaces, i.e., "ubiquitous smart spaces: demonstrations of smart spaces that encompass entire working communities, and cover all aspects of each participant's life" [22]. The recent project GLOSS (Global Smart Space [15]) was targeted at providing global location-aware services as opposed to a small-scale, restricted, smart space.

Although it has been realized that the large scale smart space or hyperspace is very important and necessary, there is yet no systematic research about this. It is certainly very hard to study and develop a smart hyperspace because the research on various individual smart spaces and their practical applications are still in their infancy stage. However, we believe that now is the high time to study the features, issues, models and technologies related to the hyperspace. It looks like there are many challenging issues in creating hyperspaces, such as:

- Hyperspace abstraction and modelling
- Hyperspace semantics and representation
- Connections of heterogeneous smart spaces
- Context interrelations and sharing across spaces
- Smoothness of uneven spaces or space jitters [44]
- Coordination of associated smart spaces
- Security, privacy and trust in multi-spaces
- Scalability and manageability of a hyperspace
- Interface and interaction of a hyperspace
- Hyperspace network infrastructure

- Hyperspace platform and middleware
- Hyperspace social/economic/ethical implications
- etc.

It is interesting to make some conceptual and methodological comparisons between hyperspaces and hypertexts as well as the recent new web technologies. The success of hypertext is due to the combined results of the hyper text markup language (HTML), the http protocol, and the server/client model. The success of web services is based on XML, the SOAP protocol and a general mechanism of service description, registration, discovery and communication. The web service approaches are adopted by UPnP, JXTA, OSGi (Open Service Gateway Initiative), OGSA (Open Grid Service Architecture), etc. Can we follow the above ways to make a successful hyperspace? If yes, what will be the hyperspace markup or description language, the connection protocol, coordination mechanism, and so on? If no, what new things/concepts/ideas are needed and how to start them? The semantics has been recognized as the core issue of the next generation web. What are the real space/hyperspace semantics and the relationships with the semantic web? How difficult to define and make computable real world semantics? Is it possible to extend the RDF language and scheme to describe real spaces/hyperspaces? We don't have any answer yet to these questions. It is one of the main motivations for us to launch the UbicKids project to deeply probe the above challenging issues and questions, and contribute to the forthcoming third phase of smart thing research, i.e., the smart hyperspace towards the smart world.

IV. UBICKIDS: OBJECTIVES AND SCENARIOS

It is greatly challenging and also extremely hard to develop truly applicable smart space/hyperspace systems. The difficulties are basically from two aspects: the technical complexity in developing such novel systems and the real world complexity due to the great diversity and heterogeneity as well as various non-technical factors in their practical uses. Almost all of smart space systems have to face a variety of profound social, psychological, ethical and other problems [4]. Among them, a critical issue is the users' concern of privacy [42], which is closely related to but beyond the security of conventional information systems. Actually, it is often one of the big barriers for practical applications of many smart space systems.

Considering both system complexity and privacy concern, our initial fundamental strategy to start the research on smart hyperspace was to choose a proper application area that can cover multiple usual but related spaces to form a representative smart hyperspace, and whose privacy requirements may not be so critical in the beginning but can be gradually improved during its development process and practical use. The kids care is one such area in ubiquitous applications. This is because, (1) taking care of kids exists not only inside the home but also in other spaces including the yard, road, park, car, etc., which should be virtually linked together to form a smart hyperspace for helping parents' take care of their kids; (2) the privacy is not a very serious problem due to the special relationships between parents and their young kids. In the first stage, it may be enough to keep the family's data secure by blocking the access of non-family members, and make the system dependable by resisting attacks from the outside.

An interesting survey [28] recently made in Japan reported that 72.5% parents worried about their kids, 82.3% parents felt tired in caring their kids, and 91.9% parents had no enough time to satisfactorily take care of their kids. The above survey data may vary in different countries/regions, but caring kids is obviously not so easy and consumes a lot of time/energy to many parents. Although lots of efforts are exerted by parents to ensure child's safety, however unexpected matters may sometimes happen and small accidents often occur. In other words, parents cannot always watch their kids and give them prompt supervisions/helps in 24/7, but they do expect their kids to be well taken care of with their preferred means in every place at all times. Caring kids, as one kind of ordinary human activities, looks too trivial to be ignored, and they should actually and whenever possible, be greatly supported via ubicomp technologies.

Furthermore, although kids are enjoying the fruits of developments brought by IT, i.e., mainly digital games, animations and contents as well as chip-embedded toys for children to play or learn, they have not been specifically treated and well researched as one independent group of important users in most computing fields. Computers and their corresponding environments were originally designed for experts and then moved to ordinary people, mainly adults. We are pleased to know that an international workshop on Interaction Design and Children (IDC), which was first held in the Netherlands in 2002, is now an international annual conference [29] in cooperation with ACM SIGCHI. The IDC themes are nice but are limited and currently without emphasis on the impacts of ubicomp (by IDC2004). Kids should be studied more widely and should also greatly benefit from computer and information technologies, especially ubicomp.

Based on all of the above fundamental considerations, we started the Project UbicKids, a smart hyperspace environment of ubiquitous care for kids, from early 2004 [32]. Its main objectives are three folds: (1) To develop a set of smart u-applications for helping parents to take care of their kids with more convenient, prompt, precise, reliable, secure and trustworthy services; (2) To build a representative smart hyperspace environment for probing and researching the novel issues, models and technologies related to general hyperspaces and ubiquitous intelligence towards the smart world; (3) To study both positive and negative impacts of ubiquitous kids care applications to families, especially the children's growth and development of their intellect, character, habit, psychology, etc., and find feasible solutions for making UbicKids systems and applications truly trustworthy and acceptable in terms of these non-technical factors.

At the first glance, the UbicKids system and related technologies somehow look trivial and simple but actually they involve a series of hard issues, such as knowing where the kids are, what they are doing, why they act in some manners, when do they need help, and how to optimally help them, etc. Many similar theoretical and technical issues in other ubicomp systems will also certainly exist in UbicKids. The ultimate goals of UbicKids applications will be targeted at precisely-promptly knowing the kids-parents and surrounding contexts, and actively anticipate their needs to provide ubiquitous natural interactive, even proactive and further autonomic caring helps or services to them with the right means in the right place at the right time. It is however, not aimed to completely replace the important and indispensable roles of parents in raising their children.

Recently, there have been many ubiquitous applications developed or under development, such as the health monitoring systems for patients, home media appliance management for adults, learning support tools for students, location-aware mobile services for customers, etc. However, as to our knowledge, there are only very few ubiquitous research for kids. MIT Media Lab's KidsRoom is for making an interactive and immersive story environment [16] and UCLA's Smart Kindergarten project is targeted at a sensor-instrumented classroom for early childhood education [14]. From our current survey, UbicKids seems to be the first project specially focused on kids care. With respect to general technology features and functional characteristics, UbicKids is comparable with PIHS (Personalized Instrumented Health System), a joint research effort by the UR, GT, MIT, and UF groups [49]. But PIHS is targeted at caring the elderly, while we focus on caring the children.

UbicKids is mainly focused on two types of users, i.e., parents and kids. There are usually two parents (father and mother) and one or more normal children. A family with a disabled member may have a stronger need to use such kids care system, but this case needs extra medical or health cares. UbicKids can be used for a single parent family, but this will not be treated as a typical case in our research. At the moment, a family with grandparents, a nurse or a house helper in the household is not taken into account. It is common that at least one parent has a job at some working site, perhaps with certain distance from home. Certainly, the ways of caring kids are greatly diverse and heterogeneous for different families with various backgrounds in characteristics, preferences, cultures, histories, countries, etc.

The kids' age currently assumed in UbicKids ranges from 2 to 12 years old. Although some UbicKids functions can be used for taking care of babies less than 2 years old, they will not be particularly focused here since special cares are needed for them. Children over 12 are usually able to manage their daily lives without permanent and very frequent parents' attention. They start to have their own way of thinking and privacy, and may not feel happy if they are always being watched by parents. Kids in UbicKids are roughly divided into four groups according to their ages: 2-3, 4-5, 6-8 and 9-12. The kids' characteristics and the ways of caring them changes very much for kids in different ages. Some may disagree on this group division and would probably prefer some finer or other division. Any opinion on this should be respected, where the point is its value in designing and building useful kids care environments.

To support many various activities in kids care, UbicKids must include a set of well designed and structured functions for knowing and adapting to the rich dynamic contexts of parents, kids, physical environments, social rules, the digital world, etc. The UbicKids functions are basically divided into three categories:

- Kids Awareness – space eye/ear
- Kids Assistance – space mouth/hand
- Kids Advice – space brain/head

Thus it is characterized by 3As, which can be seen as space perception organs (eye/ear), space motion organs (mouth/hand) and space thinking organs (brain/head). Some typical functions for each of the 3As are given in Figure 1.

The kids awareness functions are for parents to know the kids contexts, such as location, activity, and state. The above contexts are physical information related to kids. Mental and emotional contexts are much harder to capture, and should be studied at certain stage since they are very interesting and useful. The term of context covers broad meanings referring to some states and situations of a human, animal, plant, natural object, artifact, virtual thing and so on, as well as their spatial, temporal, social and other relations in both the real physical world and the virtual cyberworld. To be simply understood, the context can be regarded as 5Ws, i.e., who, where, when, what and why [23]. The kids assistance functions are for helping kids in doing something, such as finding a toy, looking for a parent, adjusting light brightness for a kid who is reading, guiding a kid on the road, etc. The kids advice functions are to give prompt advices/reminders to kids and/or parents when necessary, such as an umbrella reminder, an advice to keep quiet, recommending a care approach, etc. These functions often need more contexts, perhaps including all '5Ws' plus 'how'.

To partially get more concrete images on what UbicKids can help parents in taking care of their children, the rest of this section shows three scenarios, i.e., after-school monitor, toy finder and umbrella reminder, which corresponds to the three functional categories of kids awareness, kids assistance and kids advice, respectively.

A. *After-school monitor*

For a working couple, the most likely concern is if their child comes home on schedule and what the child is doing after school. Let us assume that a working couple named Denis and Mary has a boy called Bob. Denis is a doctor, Mary is a teacher, and Bob is a grade school pupil. As a doctor, Denis does not like to be disturbed except during emergency. As a teacher, Mary mainly has teaching duties in the classroom, meetings in some place, or other activities in her office. Bob has regular school classes from 8:30am until 3:00pm from Monday to Friday, a piano lesson on Monday evening, badminton club on Wednesday afternoon, and a swimming lesson in a sport center on Thursday late afternoon. The after-school monitor is assumed to know the regular schedule and its tasks assigned by parents. The followings are scenarios on what the after-school monitor does in a week.

On Monday, Bob comes home on schedule. The monitor detects Bob entering the house and sends a message, like "I am home" to Mary either on her computer screen or with Bob's recorded voice since the table watcher knows she is in front of her desk. Because of the piano lesson on Monday

Kids Awareness	Kids Assistance	Kids Advice
KidsWhere	ThingsFinder	KidsReminder
· KidsInOutHome	· ToyFinder	· Key/Umbrella/ClothReminder
· KidsInsideLocation	· LostGoodFinder	· GoodHabitReminder
· KidsOutsideLocation	· ParentFinder	· BackHomeReminder
· KidsWhereWas	ThingsNavigator	· ReadPostureReminder
KidsWhat	· RoadNavigator	KidsAdvisor
· KidsDoingWhat	· GameConerNavigator	· Read/PlayTimingAdvisor
· KidsWhenDidWhat	ThingsAutoAdjustor	· BeQuietAdvisor
· KidsForgetWhat	· ReadingLightAdjustor	· SaftyAdvisor
· KidsWillDoWhat	· TemperatureAdjustor	· Praise&Criticism
KidsState	· AirconWindowOpenClose	ParentKidsCommunicator
· KidsKickCover	ThingsTeleOperator	· JustInTimeMessage
· KidsHealthMonitor	· TVProgramRecorder	· KidsAwarePhoneCall
· KidsADHDMonitor	· ToyTeleController	· ParentAwarePhoneCall
KidsSurrounding	ThingsProvider	ParentsAdvisor
· KidsSurroundingWhat	· InformationProvider	· GrowingRecorder
· KidsSurroundingWhere	· SchooldHomeScheduler	· KidsAssesment
· KidsSurroundingRelation	· OutsideGuard	· KidsCareRecommender
etc	etc	etc

Fig. 1. Typical kids care functions.

evening, Bob is requested to do his homework before doing free activities in the afternoon. The monitor keeps watching Bob and reports his behavior to Mary.

On Tuesday, Bob comes home on schedule. After finishing homework and piano practice, he goes out to play with his friends. The monitor makes sure Bob left the house and reports this unscheduled event to Mary's mobile phone signaled with some vibration modes since Mary is in a meeting. At the same time, it keeps track of Bob's location and situation, and in particular, records those potential dangerous situations for future reference by Bob's parents.

On Wednesday, Bob exceptionally comes home during lunchtime and gets the badminton bag. It is rather stupid if the monitor sends Mary the message like "I am home". In this situation, it can infer the real situation by observation. Depending on the importance of the exceptional event, it can decide whether to notify his parents or not. If not, the statistical data is kept and reported to his parents weekly.

On Thursday, Bob has a swimming lesson. After coming home, he usually has something to eat as snacks, get himself ready, and go by bus. However, Bob somehow does not look right today. The monitor knows Bob may have a fever from the body temperature sensor embedded on his shirt, and gets in touch with both Mary and Denis with emergency signal to report this unexpected situation.

On Friday, Bob does not come home on schedule. In such situation, the monitor can get Bob's location and situations outdoor. If Bob is on his way home, it can predict his arrival time and send the message like "He is on his way home" to his parents. If Bob takes part in an unscheduled activity after school, it can collect information from school and Bob, and inform his parents with the updated schedule.

On the weekend, both Denis and Mary are at home, the monitor can be set aside or partially relinquished from its "active duty" except in making the weekly review and statistics of recorded data, information and situations, and reporting them to Bob's parents.

B. *Toy finder*

As a parent, you must have the same experience that your children sometimes ask your help to find their lost things, like a book, a watch, a key, a toy, a game card, etc. Finding things could be tedious and quite stressful work for parents. Below gives two situations to show how the toy finder can find toys for children with different ages.

Tony is a 3-year old boy. All his toys are registered and their images are stored in a small portable terminal. With a very simple operation of moving the vertical or horizontal scroll bar, he can get the image he wants by looking at the terminal screen and point it with his finger. The toy finder will find it by searching where the toy is normally found inside the house and give him the voice guide. Tony sees the direction signs shown at the terminal while listening to the voice guide. Being only a 3-year old boy, sometimes Tony may misunderstand the guide and go the wrong way. However, it does not matter since the finder gives the guide based on the relative location of Tony and the toy and it can continually guide him towards where the toy is. Once he gets to the toy's location, the terminal screen shows the toy's image to remind him to get it. If he can not reach the toy by himself, it may be a good idea to ask a home robot for help. When the toy is in Tony's hand, the finder automatically switches off the portable terminal.

Alice is a 10-year old girl in a primary school. She has many activities and they are not limited inside the house. She may take her toys and play somewhere inside or outside the house. When she wants to find a toy, she can input some key words that are descriptive to the toy and the finder then searches Alice's toy database, and displays some relevant toy images on the screen for her to select by pointing at it. If the toy is inside the house, the finder takes a similar search strategy to find the toy. However, the voice and direction guide used in Tony's case may be too much for Alice because she may no longer like to be treated like a little baby anymore. The finder can simply tell her the toy's location by voice or by displaying it on the terminal screen. If the toy has a record of being taken outdoor, the finder has to retrace the sequential order of Alice's prior physical locations and may need to ask her to recall her last interaction with the toy. Once having any clue, the finder can ask the other finders residing in other places like restaurant, children center, bus, etc., for help to search for the missing toy and expect a confirmation message back.

C. Umbrella reminder

In the morning, it is always a topic if primary grade school children should take their umbrella with them or not. In general, children tend not to take umbrellas if it is not raining in the morning and the parent has to check the day's weather forecast from TV or other sources and make a decision. As we all know, in the morning during working days, everyone is busy getting ready for work and it is not surprising that parents sometimes forget to remind their children to take their umbrella with them. As an umbrella reminder, it should do a better job than parents. At least, it does not forget to remind the children.

First of all, the reminder can take the latest weather forecast information from the Internet/Web, and concludes whether an umbrella is needed according to the child's school schedule. Then the reminder has to further make an appropriate decision such as whether to give a reminder or not, where, when and how to give the reminder, etc., based on its observation of the child's behavior. It is important for the reminder to do the right thing, at the right time, in the right manner. Below, let us go through several situations with the child, Bob.

It is a fine day, in principle, there is no need to remind him. Bob, however, unexpectedly takes an umbrella since he would like to return the umbrella to his classmate. As for the reminder, it does not know whether Bob does it for a certain reason or unconsciously. In this case, it may be worthwhile to give Bob a weather report rather than a reminder.

It is cloudy in the morning but will be fine later on. Bob may take an umbrella or may not according to his own judgment. If Bob has no intention of taking an umbrella, it is better for the reminder not to do anything. Otherwise, it can make a suggestion not to take an umbrella and explain the reason.

It is not raining now but will rain later on. In this situation, the reminder has to first figure out such weather information. It will remind Bob to take an umbrella if the reminder finds he has no intention of bringing one, or sometimes praises him if he does.

It is raining right now and it's a common sense that Bob should take an umbrella. The reminder does not need to make a reminder. Or it may just remind him to bring back the umbrella if it knows that it will not rain after school, and further check if he forgets to bring the umbrella back home.

V. UbicKids: Technical Issues and Architectures

We have shown various kids care functions in Figure 1, and they are usually in diverse situations and with diverse features as described in the above scenarios. Therefore, the first fundamental issue in developing concrete UbicKids applications is to have some kinds of general architectures able to grasp common but essential elements in the different kids care functions and scenarios. The general architectures should be high-level system abstractions so that they can guide further the design and implementation of various applications in diverse situations and with diverse features. It is also expected that the architectures could be possibly extended to study and make other kinds of smart hyperspace systems. The two general architectures of the whole system and networks are discussed below.

A. General system architecture

Figure 2 shows our general UbicKids system architecture, which is explained from the bottom to the top in the following.

As we described earlier, the smart world is built on both real and cyber spaces, and a hyperspace is formed by a set of associated spaces. Although Figure 2 shows only two real spaces, the one around a kid and the other around a parent, it should be noted that a variety of sites related to the family members may be involved in terms of ubiquitous kids care. Certainly, a home is the most important site that we must pay more attention. However, we need also to consider other sites, such as yard, nearby park, community center, town library, school and so on where kids go often, and office, shop, meeting room or some working place where parents usually stay. The school routine and transportation vehicles should also be included. Having multiple spaces is one of special characteristics of the general UbicKids architecture as compared with other smart space/environment researches.

The multiple related real spaces needs to be further connected by UbicKids internal networks and/or the outer networks such as public wired/wireless telecommunication networks, the Internet, and other communication service infrastructures. Some functions in the UbicKids system may need to be interacted with cyberspaces to get some information from the web, resources from grids or other e-services from the cyber world. It is probably another special characteristic for the UbicKids system to generally include connections with the outside in order to get necessary services. Of course such connections may become system security holes, which must be carefully assessed and somehow overcome.

In a ubiquitous smart system, there are often many instruments distributed to spaces, and a variety of real smart objects

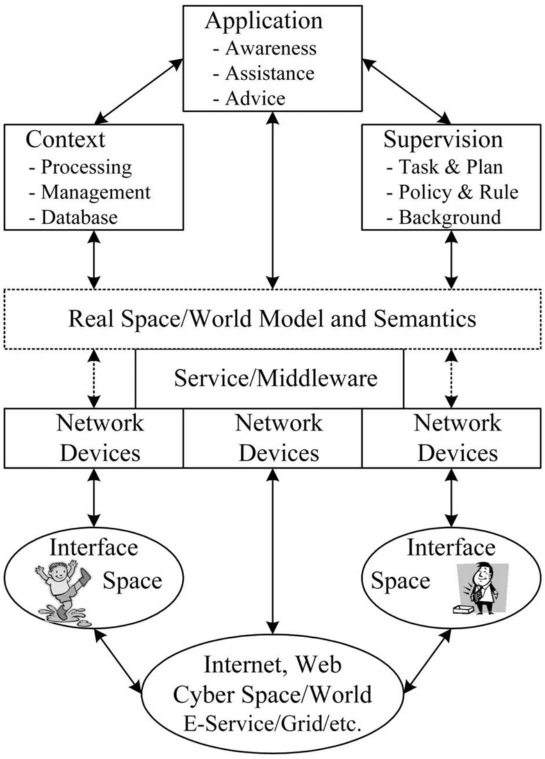

Fig. 2. General UbicKids system architecture.

with attached/embedded/blended computers. We generally call them devices, which may be immobile or mobile, or carried/worn by users. Their sizes range from very small ones like smart sensors [5] and RFIDs [61], to middle ones like PDAs, cell phones and RFID readers, and to large ones like laptops and PCs. An important issue is how to make natural interfaces for users in order to conveniently and spontaneously interact with the many various devices, some of which are even invisible. A smart device usually includes both hardware and software as well as some basic communication function. Devices will be organized into groups according to their types and purposes, and each group of devices is necessarily connected by some wired or wireless network. Several or more networks often co-exist in the physical spaces of a ubiquitous system with multiple functions like UbicKids. The basic requirement is to let these co-existing networks be well integrated and not interfere with each other.

To operate these devices and process the data to/from them is based on specific software embedded to the devices and related software APIs provided. Such software is often device or network dependent, and different programming languages may be used for the low level programming of these devices and networks. The middleware is for hiding the details of such devices and networks' dependence on hardware/software so as to provide relatively more general programming frameworks and environments as well as some common services in building ubiquitous systems or applications. The middleware has been widely recognized as one of the challenging issues in ubicomp/percomp.

The block enclosed with dotted lines in Figure 2 is about real space/world model and semantics, which may not be an independent layer in the system but is one of the most important core issues not only in UbicKids but also to other smart space systems. One essential feature of ubicomp is to get physical and get real [52] in everyday life, work, etc. It is then a base to abstract real worlds with proper models and represent them with computable semantics so that the following computing can be further conducted [19], [25], [47], [50]. Whether or not a ubicomp application is truly successful and practically useful greatly depends if it is good or not to the corresponding models and semantics. A lot of models and semantic representations have been so far invented in many areas of computer science, IT fields and other disciplines. Although some of them can be used for smart spaces/environments, more work and efforts on the model and semantics are needed due to the extreme complexity and uncertainty of the real world. In the UbicKids study, we should focus on these models and semantics specifically related to kids care spaces and the hyperspace, as well as closely associated with children/parents and their activities for supporting design and development of the UbicKids environments and applications in the real physical world.

To get the physical and real are primarily necessary to get the real world contexts, i.e., semantic mapping between real and virtual spaces including users and surroundings based on real world models as well as context models [35], [39]. The context is an indispensable and important part of ubiquitous smart things [31], and its existence as one of the basic components is greatly differentiated ubicomp systems from many conventional computing systems. The key issues related to the contexts are how to acquire and process the raw contextual data from sensing devices, manage the context information from different sources, and to keep the information into some kind of database to meet various usage/service requirements. It is also a hard issue on how to dynamically handle a huge amount of context data from a number of sensing devices with many kinds of media, and efficiently keep them into the context database for current and possible later uses since context history has the same importance as the present contexts [60].

Many current computers and related technologies have been made based on the interactive mechanism, i.e., a process of request and response dialogs between human and computer. In this mechanism, a user gives commands via some input devices, and receives replies from some output devices. The user is often an activator of a sequence of computer and network actions, and the computers/devices play relatively passive roles. In contrast to this, the proactive mechanism is to let users' get out from the interaction loop and make computerized systems more active or automatic so that they can decide by themselves when to take proper actions by anticipating the users' needs with reference to the rich contexts [36], [52]. Both interactive and proactive mechanisms are needed in UbicKids, but our emphasis is on the proactive mechanism since it is among one of the main basic characteristic of ubicomp systems as compared with conventional systems.

Since proactive computing has put emphasis on human-supervised automatic operations rather than human-computer interactions, it is therefore rational and necessary to have a specific part in the UbicKids architecture to manage the corresponding supervision information that may include task, plan, policy, rule and background knowledge [3], [18]. Such information is cataloged as some kind of contexts by some researchers. However, we feel that it would be better to separate the supervision information from other contextual information since the former is usually requested and set by users, and the latter is generally acquired dynamically via sensors/monitors and/or information service providers. A variety of supervision information exists due to the diversity and heterogeneity of different applications and users, and must be clearly defined and represented for each application. The issue here is how such information will be used to guide UbicKids applications decision-making according to the contexts and their reasoning based on the real world models and semantics.

Ubiquitous applications for offering 3As functions is on the top of all as discussed above including contexts and supervisions as well as other underlying services in the architecture in Figure 2. Therefore, the architecture can be used for research and development of all UbicKids applications, and it seems also applicable to other classes of smart space/hyperspace applications. The core issue in developing each application is how to use these available information and services to precisely and promptly know the users true needs and exact surrounding situations, and then provide desired and trustworthy novel services while adapting to countless diverse and often uncertain cases in practical kids care, which looks simple to human but actually extremely difficult for computers.

B. General network architecture

The bridges and further integrations between the real and cyber worlds rely firstly on pervasive devices as well as their communication networks. Lots of devices will exist in a smart environment. Relatively large devices, such as disc drivers, printers, audio players, digital cameras, cell phones and so on, can do one or multiple tasks due to their available size for embedding powerful computer chips. However, some very small or tiny devices such as a single sensor or RFID may not be able to do a whole task by itself alone. For example, detecting the precise location of a user or object in the house can only be accomplished by a group of sensors/e-tags, which form a task oriented net and a dedicated distributed system. Therefore, in a smart space there may be multiple and different dedicated nets for connecting different types of devices, as shown by the general network architecture in Figure 3.

Each sense net interconnects a set of sensing devices, which collect low level context data from an environment or a user in a space/hyperspace. The possible types of sense nets related to UbicKids are:

- Sensor net to acquire ambient contexts, e.g., light, temperature, humidity, pressure, object movement, velocity, acceleration, etc.
- RFID net to sense and identify objects/users
- Various nets for indoor positioning
- GPS or cell phone net for outdoor positioning
- Camera net to capture visual information
- Microphone net to capture audio information
- Biomedical net to get human medical data
- etc.

Each action net interconnects a set of actuators or controllable devices whose states and/or working behaviors can be remotely operated by programs. The following are examples of the action nets:

- Light control net
- Temperature/humidity control net
- Door/window control net
- Home appliance control net
- Speaker net distributed over spaces
- Display net for connecting various displays
- Bio-actuator or micro-machine net
- etc.

Some devices may include both a sensor and an actuator. Such an example is a camera with zoom and tilt controls by electric signals. Many new types of micro-machines including both sensing and actuation functions are already available using MEMS, and more sophisticated ones based on NEMS technology will soon appear. These devices may use two separate nets for sensors and actuators, or both of them shares one net. For many of these low powered devices, it may be difficult or unnecessary to embed a full functional system chip able to install very heavy OS and run rich software. Special communication technologies and low level programming platforms are often used for connecting these devices. A particular device such as a RF reader is needed to interact with them and also connect to a high level network.

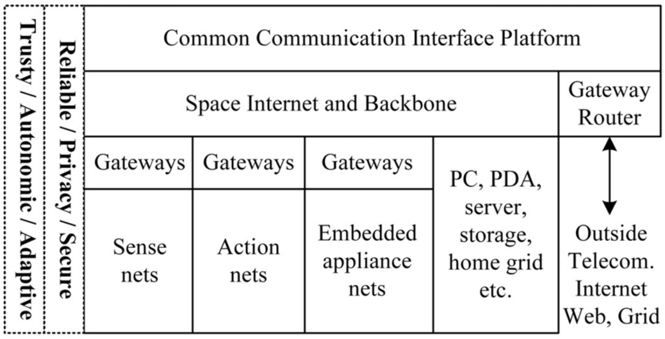

Fig. 3. General network architecture.

Some Bluetooth and Zigbee enabled devices are expected to be utilized.

A variety of electric power line networks, such as CAN, CEBus, LonWorks, X10, etc., have been used for home networking in European and North American countries in recent years. Similar power line networks have been developed also in Japan, but it is said that their practical uses are currently prohibited due to some Japanese laws and will probably be allowed in the near future. The wireless ad hoc PAN (personal area network) and BAN (body area network) possibly used for human wearing devices (not depicted in Figure 3) should be definitely used in our system.

To enable communications between devices connected in different networks, a number of gateways are often necessary. A gateway may also play a role of device management. Small computer systems can usually be embedded into many home/office appliances such as printer, TV, DVD/MD/HD player, refrigerator, etc. These embedded systems or system-on-chips are powerful enough to run a variety of software. All the frameworks and schemes of UPnP, Jini, OSGi, Salutation, SLP, Bluetooth SDP, WSDL/UDDI and so on are to support such devices. The home appliance net will not be our research focus, but the above related networking technologies, generally called service oriented architecture, should be useful in our system.

All of the above nets need to be further interconnected to form a space internet. Conventional PC, PDA, server machine, large data storage device, space high performance computational engine like a micro or home grid and so on will also connect to the space backbone network directly or indirectly. It is however unclear yet which network as a backbone is suitable for such interconnection of a variety of different physical nets. Perhaps a high speed network is required for a home as there are many different media data from various sources with diverse requirements. However, for some space such as inside a car, it will be enough to have a reasonable bandwidth network, e.g., Bluetooth. The space internet is often necessary to link to the outside telecommunication networks, Internet, Web and related grids via some gateway or router.

By means of all the physical networks and the space backbone, all the devices are theoretically connected with each other. To let them really work, a common communication interface platform, as some kind of network middleware or framework, is necessary to enable all devices to be uniformly addressable, discoverable, communication-able, manageable, programmable, etc. It is a key but hard issue to develop such a universal platform which supports both server-client and peer-to-peer (P2P) communications. The issue is related to handling interoperability, scalability, heterogeneity, integration and transparency among different devices, networks, software, service architectures, etc.

It is very necessary to address some fundamental requirements, as noted by the blocks enclosed in dotted lines in Figure 3, in our research of UbicKids systems, networks and applications. Needless to say, the systems must firstly be secure, i.e., capable of being resilient to attack with guarantees of confidentiality and integrity covering both the data and devices. Next the systems must further protect privacy of all information [46] related to a family and all family members from other people. The third, the systems must be very reliable or dependable since UbicKids services or applications are to support the real kids care in the real world and some mistakes may result in serious consequences. The fourth, the systems must be adaptive due to great differences and heterogeneity of families in their living environments, working features/sites, cultural backgrounds, members' characteristics, etc. The fifth, the systems must be easily manageable. This is because they are (1) generally very complex with many devices, (2) usually deployed in home and other non-office sites where the ambient physical conditions of devices and networks may not be a good working environment, and (3) used daily and administrated by ordinary people who often do not have enough technical knowledge and skills [12]. The ideal solution is to make the system self-manageable, including self-configuration, self-optimization, self-healing and self-protection, which are the main focuses of the so-called autonomic computing [1], [34] or organic computing. Lastly, putting the above five together is to eventually make the systems trustworthy. The trustworthy systems are related to the emerging field of trust/trustworthy computing [17], [48], and may further cover many other technical and non-technical areas.

VI. UbicKids: Non-technical Factors and Issues

It is indeed crucial to make the UbicKids systems and applications trustworthy in terms of technical aspects. However, such technology-oriented trustworthy services are not sufficient to assure parents to adopt it for kids care. They may have lots of worries, among which, their primary concern is whether the ubiquitous care environment is harmful or not for their children's upbringing, especially on the developments of intellects, characters, habits, moods, psychology, etc. Somehow, they will expect such environment to help, or at least not reduce the development of both the children's independence and the feelings towards their parents. That is, UbicKids must be also trustworthy in terms of children's growth and development as well as other non-technical factors. Therefore, another crucial requirement to UbicKids is acceptability, i.e., being acceptable by parents as well as the children.

The acceptability requirement covers several acceptable aspects, such as predictable, controllable, and sustainable, etc. Behaviors and the consequences of the UbicKids environment should be predictable so that parents can make their own judgments if it is good or not, and which function(s) they like or dislike. The environment can be customized accordingly to adapt to family backgrounds, culture, requirements, preferences, and so on. Once the system is working, it should be fully controllable by parents i.e., they can easily stop some function/part if they find it not suitable or abnormal, request a service to change its behavior in their preferred way, and so on. A system is said to be sustainable if it includes at least two meanings. One is that it should not make parents and children always feel uncomfortable in any way maybe because the environment may look strange, annoying, unfriendly, impolite, or something else. The other is that, it should not cost too high, in other words, the underlying hardware and software system infrastructures, which usually incurs the main expense in ubicomp environments, had better be general enough to make it capable of supporting spontaneously both kids care and other family activities, such as caring the elderly and pets, household chores, home security, shopping, cooking, learning, entertainment, health, sport, travel, and many others.

Due to the very close and complex relationships between human and smart spaces as compared to those between human and desktop computers, the non-technical factors is becoming more and more important in ubiquitous smart environments [20], [30]. Technology-oriented research is necessary, but not far enough to successfully create practically acceptable ubicomp environments. Non-technical factors of human, society, culture, psychology, moral, feeling and so on should also be taken into account in designing and implementing smart spaces. UbicKids are related to the following issues:

- Common characteristics shared by many kids
- Special characteristics for individual kids
- Characteristic changes along with growing kids
- Relationships and roles of family members
- Features of kids care activities
- Heterogeneity in kids care
- Culture and laws in kids care
- Child's psychological behavior in a smart space
- Child's personality development
- Child's habit and moral cultivation
- Child's independence improvement
- Child's intelligence increase
- Feeling/love enhancement between parents-kids
- Family of single parent, with nurse, etc.
- ....

The study of the above non-technical factors must be taken from the grounds of a broad and deep knowledge in child psychology, physiology, behavioral science, education, etc. Parent psychology, whenever available, will be needed as well. It is such knowledge that can give us real insights on the non-technical issues and lead our research into truly useful, trustworthy and acceptable UbicKids applications.

Although UbicKids is a promising computer technological innovation for child's care, like any other evolving technology, will face numerous questions and queries on its implications, the pros and cons on the subject and its environs. The following cites some instances.

For generations, we oftentimes heard, "Mothers knows best!" It should be noted in the first place that UbicKids is not aimed to replace parents' role in child rearing but rather as an alternative and/or to provide assistance towards accomplishing the goal. Working mothers or large families with no house helper or servants will find UbicKids to be particularly useful. UbicKids will somehow assist Mom or Dad to accomplish their work easily and on time without worrying too much on the status of their kids, and will therefore give the family more time to spend with each other. Likewise, it is to the child's welfare if the mother can watch her growing child closely with her own eyes. This will enable the mother to learn the child's learning skills and abilities, and establish a strong mother and child binding through close communication. But with the increasing fast lifestyle in the e-society and with the very soon readily available smart things, using the technology in child rearing and in our everyday lives is indispensable.

This technological innovation, in UbicKids, is primarily aimed to foster accomplished parenthood, but somehow parents may become lazy on the process and may hamper the child's growth and development. While we consider all possible outcomes that may arise with this technological innovation, it is our utmost understanding that its useful contributions and novel objectives outweigh the negative aspects.

VII. Summary and Concluding Remarks

This article is primarily focused on our fundamental thinking of ubicomp/percomp and our current research in this field, i.e., the smart hyperspace called UbicKids. We attempt to clarify our views and research from the following three aspects.

The first is about our views on foreseeing the future world and identifying the most basic characteristics and the most essential elements of ubicomp. We envision that the future world would be a highly computerized physical world known as the smart world, a graceful and seamless integration of the physical and virtual e-worlds, built on both real and cyber spaces. It is mainly characterized by ubiquitous intelligence pervaded in ambient environments and residing in a variety of numerous smart real things including smart objects, smart spaces and smart systems, which are essential elements of ubicomp and components of the smart world. We have indicated the great difficulties in making ubiquitous things truly smart and trustworthy due to both the technical and real world complexities. A series of grand challenges exist to move from the ubiquitous world with universal services of any means/place/time to the smart world with trustworthy services with the right means/place/time.

The second is about our views on the smart space, one of the most important elements in the smart world. Many definitions of a smart space have been given by different groups, we have figured out their common features and given a taxonomy to classify the diverse smart spaces in the smart world. Although various smart spaces or environments have been so far researched and developed, many of them are usually enclosed and independent small spaces which look like isolated islands in an ocean. As people's activities are often related to a set of associated spaces, we therefore argue that such spaces need to be interconnected and collaborated with each other to form a higher level super space, i.e., hyperspace or hyper-environment. It treats a set of related space as a whole while emphasizing the possible situational, spatial, and temporal relationships between spaces for further understanding of users and thus providing better services to them.

The third is about our views and research on UbicKids, a ubiquitous kids care system, for helping parents in taking care of their children. As multiple related spaces are usually involved in caring kids, the UbicKids system is naturally formed as a representative smart hyperspace to deeply probe and research on the novel issues, models and technologies towards general hyperspaces. For now, it looks like there are not yet enough ubicomp researches specifically for kids, and UbicKids seems to be the first project specially focused on kids care. Many functions are needed for kids care and they can be classified into three categories corresponding to 3As, i.e., awareness, assistance and advice. We have listed many necessary functions, and showed several typical scenarios in kids care. UbicKids looks trivial and simple but actually it involves a series of hard issues also existing in many other ubicomp systems and applications. To guide the next wave of research and developments of UbicKids environments and applications, we give the general system and network architectures and discuss their relevant fundamental technical issues. The basic requirements, issues and problems related to non-technical factors are also explained.

Kids learn from their everyday interactions with the environments that play vital roles in forming their characteristics, behaviors, habits, personalities and so on, which may largely influence the rests of their lives. Both positive and negative impacts of ubicomp on kids need to be seriously and deeply investigated, and solutions to overcome the negative aspects must be discovered. We expect more researchers to join us to create a variety of hyperspaces towards the smart world and also let the children greatly benefit from the product of information technologies, especially ubicomp or percomp. After all, the children are our future!

Knowing more children, know more the world.

The betterment of children, the better world.

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