Post Ubiquitous Society: Problems, Proposals and its Applications

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Abstract -

Envisioning the next generation ubiquitous era when the advancement of computer and communication with its several boons may also bring some anxiety and inconveniences of various types to the society. To overcome these problems and to close the gap between human and computer we proposed a new information and communication paradigm, called *Symbiotic Computing*. Traditional ubiquitous computing environment can be considered as consisting of two computing aspects: *Mobile Computing* and *Pervasive Computing*. We then define the two axes of advanced ubiquitous computing: *Traditional Ubiquitous Computing* and *Web Computing*. To realize a symbiotic society, where human and computer will co-exist in a cooperative manner to the betterment of life and society, we proposed a new *3rd axis* to alleviate the predefined problems and by integrating these three axes, we created the *Symbiotic Computing* paradigm. In this paper we discussed about the concept, architecture and different applications based on this novel idea.

Keywords: symbiotic computing, ubiquitous information environment, mobile computing, pervasive computing, next generation network, S-gap

1 Introduction

Proliferation of computing into the physical world promises more than the ubiquitous availability of computing infrastructures. By the end of the decade, the number of PC users is expected to hit or exceed 1 billion by 2010, according to Microsoft CEO steve Ballmer, fueled primarily by new adapters in developing nations such as China, India and Russia, according to analysts, out of estimated world population of around 6.8 billion.

With the existence of large number of computers, with high processing power, coupled with wireless communication, next generation wireless is moving toward ubiquitous wireless communications systems and smooth high-quality wireless services. Computers will gradually become proficient at a wider range of activities previously requiring human intelligence, including their own design, and thereby introduce positive feedback into the development loop. This, coupled with currently expected progress in nervous system connection, may accomplish a direct machine-human brain link by 2025 [1]. The author here has predicted that in future processing capability and intelligence will be ubiquitous. The vast majority of processing devices will be transparently integrated and unidentifiable as individual machines.

Focusing towards next generation ubiquitous age we have been pursuing research on Symbiotic Computing from as early as 1994 [2]–[4]. In [5]–[8] we first define the concept of traditional ubiquitous computing environment with two computing aspects: *mobile computing* and *pervasive computing* [9]. Traditional ubiquitous computing enhances accessibility to the services using wireless network and embedded device technologies [10]–[13]. At the same time, web computing is emerging as very powerful tool to extend availability and usability of information which is widely distributed in the world [14]. Now, to define advance ubiquitous computing, foreseeing the situation around 2025, we integrated two computing axes: *traditional ubiquitous computing* and *web computing*. The advance ubiquitous computing is expected to contribute and enhance the Information Technology (IT) environment; however, at the same time, human and social aspects also need be considered. Otherwise a social imbalance with its related inconveniences and anxiety will grow up. To overcome such a situation and to strengthening the power of advance ubiquitous computing environment, we introduced a third new axis to define a new value, and by integrating these three axes, the new paradigm, called Symbiotic Computing is created. Based on this novel idea of Symbiotic Computing, symbiotic society will be realized, where human and ubiquitous information environment can cooperatively coexists and close the gap between these two entities.

Symbiotic computing is a basic idea that achieves an information processing environment, that can autonomously supports human activities, by understanding human behavior and sociality in the real world [15].

In symbiotic computing, human society and digital space interact with each other, based on “basic principle of symbiosis”, where they increase information precessing ability, activity, and stability by offering information and supports each other. As a result, it creates new relating for co-existence and co-propriety based on mutual understanding between them.

Symbiotic computing will enable digital space to provide advanced and intelligent services progressively and solve various problems that present Information Technology (IT) has, for example, the gap in the symbiosis world, and we named it as *S-gap*. The detail explanation of S-gap is given in Sec-

tion 2.3.1. This contributes to the next generation information processing environment, where everyone can easily get necessary information and services from digital space for *anyone, anything* in addition to at *anytime* and in *anywhere*.

We construct a symbiotic computing model and an architecture of symbiotic space for achieving the concept of symbiotic computing. We also develop basic technologies for realizing the model and architecture. Moreover, these are used to establish the next generation information platform and we evaluate our proposal through application developments and trial experiments.

The organization of the paper is as follows. In Section 2, Ubiquitous Environment for Improved Human-Computer communication has been discussed, focusing on Ubiquitous computing, Ubiquitous networking and Symbiosis process, where we state the problem elaborate about our motivation. Our proposed symbiotic computing architecture, where we explained about the General, Network-ware, Social-ware and Perceptual-ware is described in Section 3. Section 4 consists of Evaluation of Symbiotic Computing Architecture, where we discussed about the systems we have developed as novel application of Symbiotic Computing and the envisioned scenario of revolutionary effect of Symbiosis around year 2025. The paper is concluded in Section 5.

2 Ubiquitous Environment for Improved Human-Computer Communication

Ubiquitous computing has as its goal the nonintrusive availability of computer throughout the physical environment, virtually, if not effectively, invisible to the user [16]. Unlike virtual reality, ubiquitous computing will integrate information displays into the everyday physical world. It proponents value the nuances of the real world and aim only to augment them. In ubiquitous computing it will be a world of fully connected devices, with cheap wireless networks, available and accessible everywhere, anytime.

2.1 Ubiquitous Computing

The basic concept of human-computer symbiosis was first found in an article written by J.C.R. Licklider in 1960 [17], where he imagined a very close coupling between the human and the electronic members of the partnership. Computer technology was at its early stages and he had given a general idea of Symbiosis computing; abstraction level was very high. The main aim for this partnership are two-folds, (i) to let computers facilitate formulative thinking as they now facilitate the solution of formulated problems, and (ii) to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on the predetermined programs.

Ubiquitous computing began in the Electronics and Imaging Laboratory of the Xerox Palo Alto Research Center in the late 80s by Mark Weiser [18], [19] and his group. The inside story can be found in [20]. He had proposed a ubiquitous computing called Calm Computing, where the computing concept was to provide services naturally without disturbing human activities and thinking in the environment. Challenges in deploying ubiquitous systems is discussed in [21].

Way back in 1994, we proposed the idea of Symbiosis in [2], where we concretely defined the architecture and functionality of each part. In Figure 1 we have shown the concept of Ubiquitous computing which is based on two axes: Pervasive computing and Web computing. The extension of these two fields will bring us the Advanced Ubiquitous computing environment.

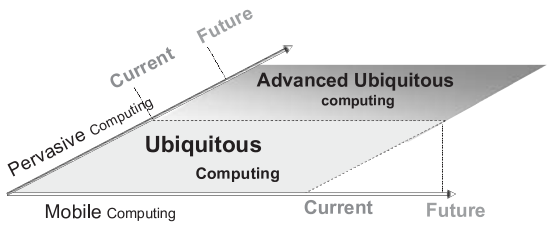

Figure 1: Two axes of computing that shapes Ubiquitous Computing field

2.1.1 Mobile Computing

The appearance of full-function laptop computers and wireless LANs [22] in the early 1990s led researcher to confront the problems that arise in building a distributed system with mobile clients [23]. The field of mobile computing was thus born. Although many basic principles of distributed system design continued to apply, four key constraints of mobility forces the development of specialized techniques: unpredictable variation in network quality, lowered trust and robustness of mobile elements, limitations on local resources imposed by weight and size constraints, and concern for battery power consumption.

The rapidly expanding technology of cellular communications, wireless LAN, and satellite services promises to make it possible for mobile users to access information anywhere and at any time. Regardless of size all mobile computers is equipped with a wireless connection to information network. The resulting computing environment, which is often called mobile or nomadic computing, no longer requires a user to maintain a fixed position in the network and enables almost unrestricted user mobility [24]. Mobility and portability create an entire new class of applications and new massive markets combining personal computing and consumer electronics.

Mobile computing brings about a new style of computing, Due to battery power restrictions, the mobile clients will frequently disconnected (powered off). Most likely, short bursts of activity, like reading and sending email, or querying local data-bases is separated by substantial periods of disconnection. Also, quite often, the mobile client will “wake up” in a totally new environment in some new location far away from home. Finally, due to mobility, the client may cross the

border between two different cells (coverage areas) while being active (the so-called hand-off process). Handoffs are relatively straightforward in cellular voice communication due to a higher loss of information that can be tolerated.

Mobile computing poses new challenges to the data management community and they can be grouped into the following categories:

1. Mobility Management and Scalability
2. Bandwidth Management
3. Energy Management

2.1.2 Pervasive Computing

It was first began with Mark Weiser 1991 paper [18] that explained the vision of ubiquitous computing, now also called as pervasive computing. The basic and most important part of that vision was the creation of environments completely fill with computing and communication capable devices, yet gracefully integrated with human users. This vision was far too ahead of time, when hardware needed to achieve this goal was just not existed and naturally Weiser and his group at Xerox PARC failed in their implementation. With recent progress in hardware and ubiquitous computing technologies, broadband convergence with mobile and broadcasting networks, emergence of RFID has enhanced the accessibility of real-world objects together with information on the Internet and we are now better positioned to begin the quest for Weiser's vision. Later Garlan et al. [25] in project 'Aura' discussed about a disruption free pervasive computing.

2.1.3 Ubiquitous Computing Environment

Weiser introduced the area of ubiquitous computing (ubicomp) and put forth a version of people and environments augmented with computational resources that provide information and services when and where desired [18]. For past many years, ubicomp researchers have attempted this augmentation with the implicit goal of assisting everyday life and not overwhelming it. Weiser's vision described a proliferation of devices at varying scales, ranging in size from hand-held "inch-scale" personal devices to "yard-scale" shared devices. This proliferation of devices has indeed occurred, with commonly used devices such as hand-held personal digital assistants (PDAs), digital tablets, laptops, and wall-sized electronic white-boards. The development and deployment of necessary infrastructure to support continuous mobile computation has arrived. Now the Ubiquitous Computing environment is consists of Mobile Computing and Pervasive Computing.

2.1.4 Web Computing

With the rapidly expanding reach of Internet people in this world is becoming merely the players of it. Whether by establishing or enhancing access, or through the utilization of publishing tools, there are various resources as mentioned below, which can help us extend our arena for self-expression to the entire world.

- E-mail and Calendaring
- Network and Internet Access
- Newsgroup (Usenet)
- Internet Searches
- Telnet and SSH
- Web Publishing (blog etc.)

The world wide web is revolutionizing access to information and communication for business and individuals alike. It is evolving faster, and involving more people, than any other technology in history. Transforming the Web from primarily a document transfer system to a platform for Web applications, involves developing an architecture that supports Web objects interacting with each other. Web computing involves hence a suitable Web object model, encompassing both document publishing and distributed object communication. Web services have emerged as a standard platform for Web computing. Nevertheless Web services only provide one-way request/reply communication from client to server. Developing fully interactive applications is difficult with current Web technology. Users can only get updates by hitting some button or clicking a ling on their browsers and re-generating an entire new page. The future web is envisioned as no longer a network of connected machines, but rather the indispensable thread of human connectivity that binds together cultures, economies, and societies. Content, communication, and context will continue to form the underpinnings of human connectivity, much like they do at present.

2.2 Ubiquitous Networking

Development of technologies for *ubiquitous networking* environments on which the ubiquitous computing is constructed is in progress in the world. From our viewpoint those technologies accelerate deployment of mobile and pervasive computing, extend the field of ubiquitous computing. Now many suggested technologies are based on the Internet, and the *next* generation network based on IP is proposed as NGN. Some researches are started that focus on a totally new networking technology which called as a *new* generation network [26]. Various activities of ITU-T can be found in [27] and [28].

2.2.1 Coming Technologies of the Internet

An ubiquitous networking environment based on the Internet realizes an access to contents on the Internet in anytime and anywhere by using mobile devices. Key technologies for this purpose are 1) small area wireless communication technologies 2) seamless handover between different networks 3) secure and scalable network infrastructure. Personal networking technologies just like ZigBee/IEEE802.15.4, RFID,

and wireless ad-hoc networking technologies [29]–[31] are in 1). In 2), the standardization and development of MobileIP [32][33] is important. Many other technologies that realizes mobility is proposed for various situations [34]–[36]. In 3), IPv6 [37] is now growing to introduce absolute number of devices to the Internet, and enhances efficiency of core networks. Many researches about traffic engineering and QoS-reservation is ongoing. Ubila project [38] is assuming an ubiquitous network connecting 10 billion devices and promoting practical researches in this field. Mobile IPv6 management information base is proposed by Keeni et al. in 2006 [39].

2.2.2 NGN: Next Generation Network

There are two big problems in the Internet as an infrastructure of ubiquitous computing. The first is *vulnerabilities*, in other words, insecureness. The lack of security function forces all protocols and systems in the Internet to deploy and maintain complete secureness each other. This is quite inefficient. The second is *low reliability* in performances. The basic principle of the Internet is best-effort. By this principle, much more systems that have a critical mission can not depend on the Internet.

Now a dependability is of great interest for networking technologies. Many telephone and cell-phone operators in the world is going to replace their operating telephone network by NGN, next generation network NGN is the next generation telephone network architecture that is based on IP technologies. The transport stratum of NGN enables end-to-end QoS control and can provide multimedia services with dependable performance. Various services are provided through the service stratum and it realizes the security.

2.2.3 NwGN: New Generation Network

NGN is one solution that solves a part of many problems in the Internet. But there still remains problems. One major problem is the complexity of the network. Now many network technologies are developed and deployed in ad-hoc manner. Without sufficient arrangement, the coming ubiquitous networking environment should become quite complex. Another problem is the handling of non-IP nodes. The ubiquitous networking environment has to bring in quite large number of small nodes. These small nodes may not use IP protocol. IP based network cannot support non-IP nodes well.

Some research groups are considering totally new network architecture. These are called as NwGN, new generation network [26]. GENI [40] is the testbed for developing new generation network. Akari project [41] is considering to *reinvent* the Internet by suggesting a whole new network architecture.

Extension of Ubiquitous computing field from year 2010 to 2025 is shown in Figure 2. Year 2010 is the era of Next Internet Technology, 2015 as Next Generation and 2025 as New Generation Networking.

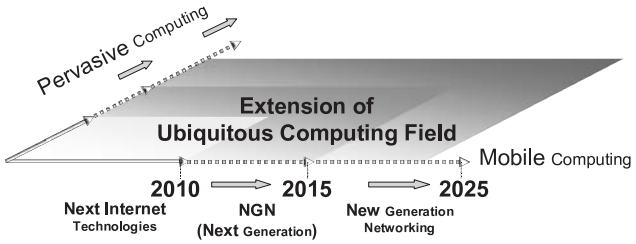

Figure 2: Networking innovations evolve axes of mobility and pervasive computing, extend ubiquitous computing field

2.3 Limitations of Ubiquitous Computing Environment

Now, in the IT society, social conveniences, security and safety that are commensurate with the cost of setting up information infrastructure and IT services, is not always available. Moreover, the information gap is getting wider and new misdeeds are coming up, which will prevent from social activation and thus creates a gap between Real Space (RS) and Digital Space (DS). We named this *gap* as S-gap and depicted in Figure 3.

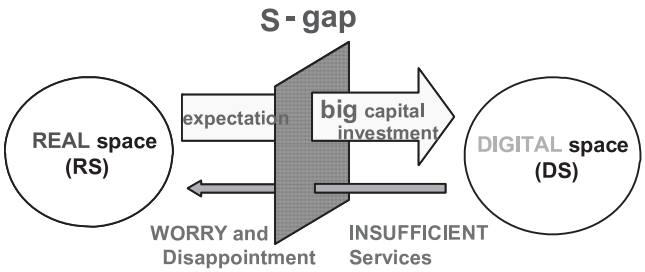

Figure 3: S-gap: Limitation of ubiquitous computing

Figure 4 illustrates the number of mobile Internet users in Japan from 2003 to 2008, of different age groups [42]. From this figure we can clearly see that the people below 10 years and above 60 years are left behind. They will not be benefited from the high-technologies and may find it difficult to cope with the changes in the society. And this is one of our primal concern and motivation to narrow this gap.

2.3.1 S-gap: Lack of symbiosis with human

The main reason of the creation of S-gap is as follows:

- Digital Divide
- Sense of Isolation
- Unease
- Distrust

In present IT society transmitting information from RS to DS is costly. Besides that, the information accumulated in DS

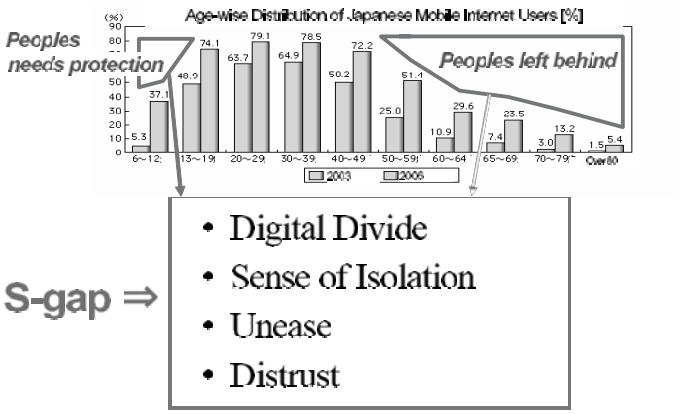

Figure 4: Utilization of Mobile Internet (Japan: 2007) WHITE PAPER Information and Communications in Japan, 2006

is not so useful in the Real Space (RS). That is, people in RS are not satisfied with the feedback received from DS, which is not so useful compare to the cost of transmission. For example, from *user's* point of view, the expectation is that the DS would solve the users' problems in RS anytime, anywhere. Also in daily life, it is supposed to give some advice and support to the user. From the *provider's* side, the information and services would be seen by many users and notified to the appropriate user at appropriate time. But these expectations are not fulfilled and as a result *disappointments* occur. Because, it the *user* is not sure what kind of service is available. Even if it is, users do not know how to use them. Also it takes time to execute them, even if they know how to use it. For the *provider*, it requires time to convert a lot of information obtained in everyday life into a certain data format. If it is too costly for the provider to supply services, the business would not work efficiently. Also, it may remain unclear to the provider whether the information is properly used or who use it.

To close the aforementioned S-gap, the concept of a new axis, the *3rd axis* comes as shown in Figure 5 and we called this 3rd Axis as S-bridge (Figure 6).

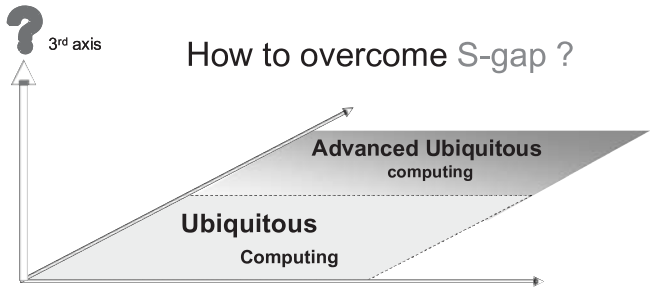

Figure 5: Towards post ubiquitous computing

Digital Divide: Depending on the closeness of the people in RS to the DS, received services also varies. The closer they live to DS more the benefits they can get. In order to get closer to DS and receive the services, they must know the architecture of DS, how to access and how to act in DS. This is an essential step where they adapt to DS, which a major impediment to DS.

Sense of Isolation: When people work in isolation, like working in a distant and separate office all by himself without any colleagues, the person can not feel the environment of the actual office and there is no one to help him out if he is any kind of trouble. Such a situation can create a sense of Isolation.

Unease: There are problems in not only RS but also in DS. It is also a serious problem that DS get expanded and complicated. The feeling of unease toward technical devices is a common phenomenon specially for elderly people due to the complexity and variety of functionalities of these devices. That makes them scared of using advanced technical gadgets and facilities and thus can not take the full advantage of the available resources and gap widened.

Distrust: People in RS can not take advantage of DS as much as they expect (S-gap). In addition, recently, people sometimes are anxious and even distrust DS. They might be wondering if their act bothers someone else, or the machines are infected with some virus, or their children access to some harmful contents, or the e-mail reaches someone who is not expected to receive. They might also worried about the hidden charges, processing of information, and so on and as a result loss the trust and dependability on the DS. We must ease this anxiety, otherwise RS wouldn't get closer to DS.

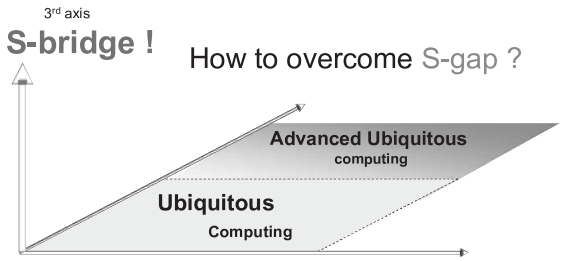

Figure 6: Towards post ubiquitous computing; S-bridge as the 3rd axis

2.3.2 Bridging the S-gap

As mentioned above, the current relation between RS and DS is still much different. Now, DS are parasitic on RS. When we ease this parasitic situation and balance DS and RS, "phenomenon to be solved" and for that we need the establish a bridge to close the gap between RS and DS, as shown in Figure 7.

It is important that RS and DS understand each other to achieve the symbiosis. Specifically, DS must collect a variety of information, knowledge and condition in RS like the environment info, users' info, etiquette, laws, local rules and task flows. On the other hand, RS must get the various specifications. For example, the architecture of systems, protocols and how to access to services, and figure out DS in more depth.

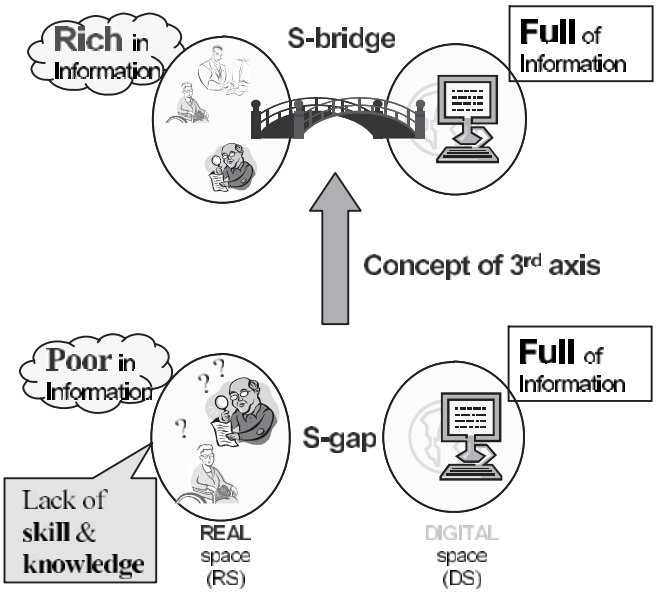

Figure 7: S-bridge: to close the gap between REAL and DIGITAL space

This mutual understanding will build the relation where RS and DS have any interactions as much as needed at the lowest cost when needed.

In the post-ubiquitous society, computing models are essential to promote the mutual understanding between RS and DS. In our project, we propose "symbiotic computing" as one of the computing models in the post-ubiquitous society. In the symbiotic society created by the symbiotic computing, RS and DS exchange their necessary information, knowledge and services to each other and the relation evolve into the real "symbiotic relation" so that we can solve the "phenomenon to be solved" and problem caused due to this S-gap will be eased by the S-bridge.

To address problems in recent IT society and to realize the Symbiotic computing, it is important to understand situations on the other side, specifically, to realize "Mutual Understanding" between Real Space (RS) and Digital Space (DS). This understanding consists of RS recognition and DS recognition as shown in Figure 8. RS recognition is a notion that the DS acquires social intelligence, individual characteristics, and environment information of the RS autonomously. This recognition is accelerated by the ubiquitous computing,. DS recognition is a notion that the DS presents and offers information, knowledge and service of the DS to the RS properly and intelligently. This recognition is enhanced by web computing. As mentioned above, mutual understanding is a state where the RS and DS can recognize each other.

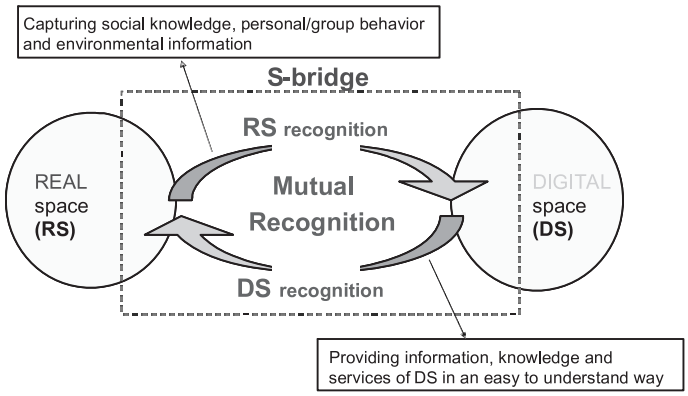

Figure 8: Symbiotic society: mutual-recognition between RS and DS solves S-gap problem

3 Proposal: Symbiotic Computing and its Architecture

3.1 Third Axis Concept: Symbiotic Computing

Symbiotic computing is realized by integrating three axes of computing: *ubiquitous computing*, *web computing* and *perceptual/social computing* - the newly added axis (value) as shown in Figure 9.

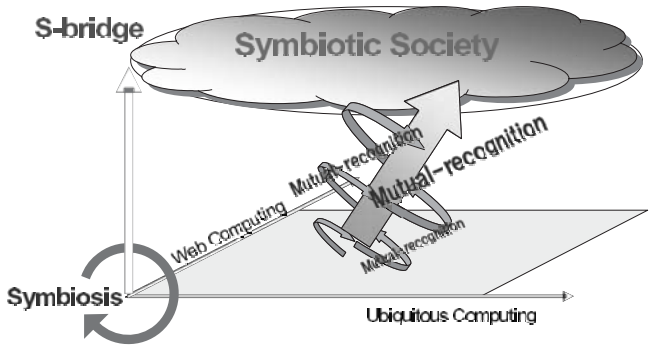

Figure 9: Symbiosis: 3rd axis concept

Definition1: Symbiosis When an autonomous and intelligent digital space (DS) and a real space (RS) are closely related to each other and human activities in RS are supported without thinking how DS works, we call this "Symbiosis" between DS and RS. Generally, "Symbiosis" means "a relationship between different types of animals or plants in which each provides for the other the conditions necessary for its continued existence". It is same as "Symbiosis" in our project in terms of providing service to each other, but different at our focus on relation between DS and RS.

Definition2: Symbiotic Computing Enhancing the autonomy and intelligence of DS leads to the symbiosis of DS and RS, where people belongs, and makes it possible that people receive DS services anytime. We call this way of information processing "Symbiotic computing".

Definition3: Symbiotic relation "Symbiotic relation" is a process in which people provide knowledge and do other things for DS so that both RS and DS develop.

The purpose of Symbiotic Computing is to make the computing model so that the human society (Real Space: RS) and the virtual society (Digital Space: DS) live symbiotically. Concretely, we will develop the technology to build an S-bridge between RS and DS, or the symbiotic computing technology.

Symbiotic computing is a basic idea that achieves an information processing environment, which autonomously supports human activities, by understanding human behavior and sociality in the real world.

In symbiotic computing, human society and digital space interact with each other, based on "basic principle of symbiosis", where they increase information processing ability, activity, and stability by offering information and supports each other. As a result, it creates new relation for co-existence and co-prosperity based on mutual understanding between them.

3.2 General Architecture of Symbiotic Computing

The symbiotic computing architecture consists of three parts; *perceptual-ware*, *social-ware* and *network-ware* (Figure 10). Each ware has both 'fundamental technology' and 'developing technology'. The former is the existing technology that would be the base of the symbiotic computing, and the later is the new technology that we proposed and developing for the symbiotic computing project.

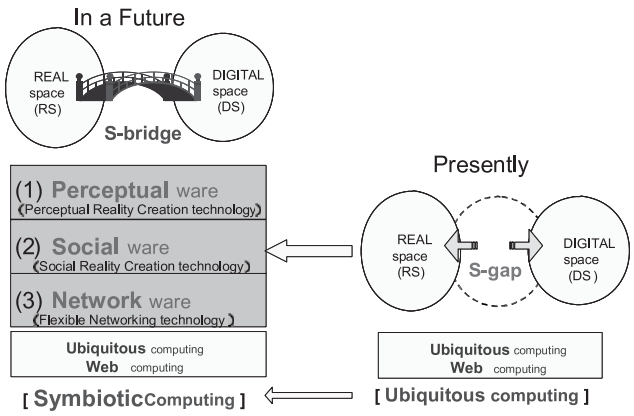

Figure 10: Architecture of symbiotic computing

Figure 11 shows a model of Symbiotic computing which realizes mutual understanding to make up a bridge to accomplish synthesis of RS and DS based on the ubiquitous, web and perceptual/social (P/S) computing. Here, P/S computing consists of Perceptual computing for perceptual reality and Social computing for social reality. These computing are based on perceptual-ware and social-ware described earlier. Perceptual computing acquires signals and data from RS and DS through the Network computing, and processes (identify, express, and operate) them by functions described in the box of Perceptual computing in Figure 11. Then it sends them to Social computing. Using such signal and data, Social computing recognizes users' activities in society based on social intelligence and individual model, using some of the functions and technologies shown in Social computing box, in order to provide such activities with some appropriate advice and information.

3.3 Network-ware

Network-ware is a device or software which removes the communication gap between RS and DS to support the communication between men, software and devices.

Fundamental technologies:

1. Flexible networking technology:
   (a) Flexible QoS control technology
   (b) Application level GW technology
   (c) Flexible network middleware organizing technology
   (d) Wireless network organizing technology
2. Ubiquitous networking technology:
   (a) Wireless ad hoc networking technology
   (b) Sensor networking technology
3. Wired and wireless seamless connection technology

Developing technologies:

1. (N1) Symbiotic Wireless and Ad hoc Networking: This technology provides channels with appropriate quality, changing the wireless ad hoc network compositions dynamically depending on requests from the perceptual-ware and social-ware. For example, it obtains the social relation between users from the social-ware, so that control QoS routing of the ad hoc network based on it.
2. (N2) Access Network Selection: This technology is for the election of access networks from the terminal providing services for users to the backbone network with considering users' communication requests, presence and locations, which are obtained from the perceptual-ware.
3. (N3) Ubiquitous Network Self-Configuration: This technology sets up ubiquitous networks at once, distributes a variety of software automatically to provide services and starts communication services. The extension of IdobataLAN for ubiquitous networks.
4. (N4) Symbiotic Application-Level Casting: This technology uses unicast, anycast and multicast effectively at application level on broadband networks based on situations of ubiquitous networks and users' social information from the social-ware so that it can keep the QoS of multiuser bidirectional communicating applications.

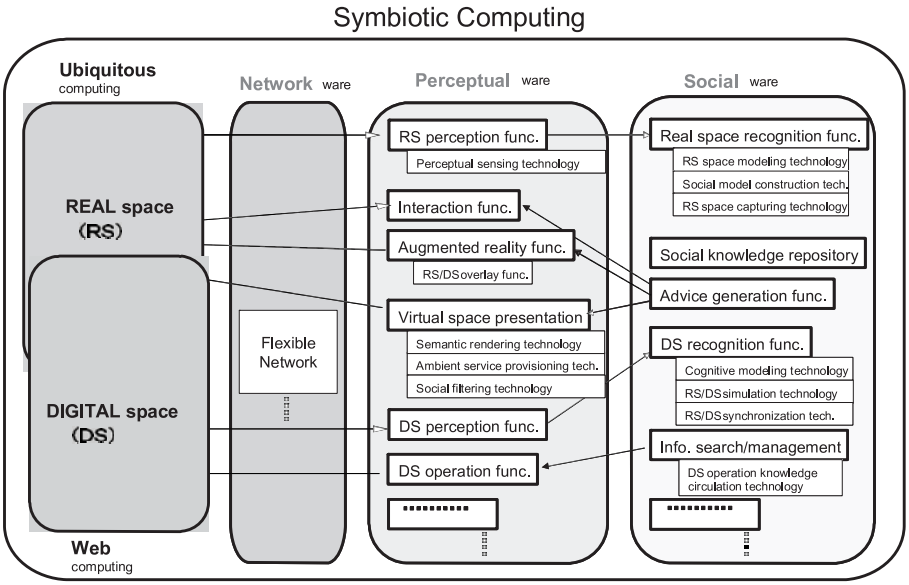

Figure 11: Model of symbiotic computing: integration of RS and DS

3.4 Social-ware

Social-ware is device or software which removes the logical gap between RS and DS to promote resolving user's problems and cooperating each other.

- (S1) Social Modeling: This technology regulates human and agent activities by recognizable model. This technology, for example, (1) forbids increasing prices unreasonably at online auction sites by the owner's making some bids, and (2) controls access with the perceptual-ware technology depending on users' age to the web sites that forbid underage accessing.
- (S2) RS/DS Simulation: This creates dynamically and simulates possible actions caused by actions of the social-ware technology. This technology, for example, predicts what kind of actions will take place by applying the social-ware technology when choosing either charging by a packets or flat rate for creating a new social model building technology.
- (S3) RS Space Capturing: This technology captures a "space" in RS as a semantic model in DS. This technology captures architectures of a real space and activities caused by those who are in the space as logical models (social model) and space models in DS. For example, this RS capturing technology allows to build a laboratory, seminar room and professor's room in DS without starting programming and establishing a 3D model.
- (S4) DS Space Modeling: This designs semantic models of "spaces" in DS. This technology enables to build logical models (social models) and space models in DS without the RS space-capture technology. For example, social networks (ex., mixi), which is mainly based on websites built in DS, are the social spaces that do not exist in the real space.
- (S5) Cognitive Modeling: This technology converts semantic models into recognizable models This technology converts logical models in DS into recognizable logical model in the social-ware. Things like URIs, e-mails, chat and changes of traffic in the existing DS are converted into formats that the social-ware can handle.
- (S6) RS <-> DS Synchronization: This synchronizes situations in RS and semantic models in DS. This technology enables, for example, to make a deal in RS, while making a deal in DS. All the things that are around you can be recognized through the social-ware.
- (S7) DS Operation Knowledge Circulation: This mechanism circulates necessary information for DS management and maintenance efficiently. For example, the management and maintenance knowledge of a video conference system, which is one of DS, or the information of unsecured web sites are converted into recognizable models by the social-ware in order to circulate them.

3.5 Perceptual-ware

Perceptual-ware is device or software which removes the sensory gap between RS and DS to accelerate obtaining and providing information.

- (P1) DS-RS Perceptual Overlaying: This technology allows to build a tangible agent environment, where images in DS are laid on those of RS with a special device so that people in RS can interact with those who are in DS (agents or remote users).

- (P2) Ambient Service Provisioning: This technology combines functions that are around users like PCs, appliances and cell phones, so that users can receive services that they request anytime, anywhere.
- (P3) Social Filtering: This technology filters providing services dynamically for the privacy protection at an appropriate level depending on the requests from the social-ware, when providing services.
- (P4) Perceptual 3D Space Sharing: The advanced technology of a 3D symbiotic space on PC. For example, displaying high-resolution images in a 3D space, controlling a display quality at a perceptual level, mobility of users in a 3D space and obtaining users' requests dynamically from biologic information like skin potential and line of sight.
- (P5) Semantic Rendering: People consider information in DS as "recognized spaces" and design some parts of them to display and publish them, like the existing web pages. The audiences can travel in those spaces seamlessly, browse information in DS and interact each other.
- (P5) Perceptual Sensing: This technology is for storing and managing information of environments and users from not only dedicated sensors but also the existing devices, PCs and information appliances. They are combined dynamically and semantically depending on the requests from the social-ware in order to make a variety of services, not for fixed purposes.

4 Evaluation of Symbiotic Computing Architecture

4.1 Children watch-over system

In this paper we experiment whether warning of the information extraction can be achieved. The main point of this experiment is that no user inputs his/her personal knowledge to the system. The system gets GPS information only about him/her and gets public area knowledge from web. Figure 12 shows our experiment model of knowledge flow. The user does not take any action to evaluate, pushing the button or inform his/her favorites. The knowledge about ID which is assigned to the participant considering for our experiment is generated with the use of open to the public information such as web pages with the knowledge management tool. The knowledge about ID is a user model able to forecast the user's behavior. The system changes its GPS information to the position using map data and makes personal user model using knowledge management tools with the personalized schedules, social knowledge and the public regional information. For example, if an ID with GPS stays at the position for a few hours in a bookshop, the system will make a positive point to user's profile that he/she is likely to read a book. There are various existing system where a lot of warning mail is transmitted when the child is taking a different route than his/her usual one. This could create plenty of false positive warning which is annoying for the parents.

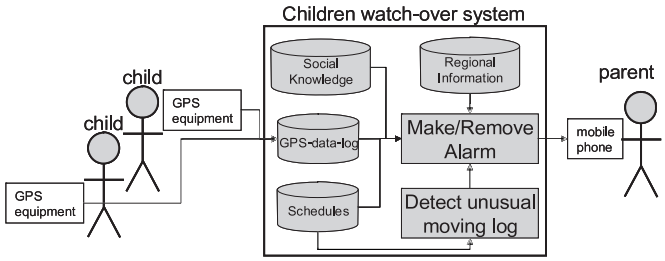

Figure 12: Children watch-over system

Figure 13 shows our demonstration area which is a typical residence area near Tokyo. We have three scenarios, (i) route-3 shows a normal going/coming-back from school to home, (ii) route-4 shows that the child go off his/her normal route to go the park, (iii) route-5 shows that the child has gone to some other place. The ordinarily services make plenty of waning messages for case (i) and (ii). But our proposed system only send warning message for case (iii). The route-4 shows that the system estimates that the child will probably go to the park.A naive position-oriented child-watch-over system makes much more warning mail for case (i), i.e. route-3 case (ii), i.e. route-4. On the other hand, our proposed system makes only send a single warning mail for case (iii), i.e. route-5.

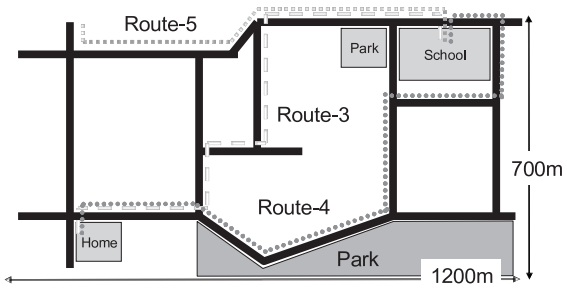

Figure 13: A Map of Watch-over Child Experiment Field

The proposed system use DB with five tables which are shown in Table 4.1.

No.	Schema
1	ID, Position, Data, Time
2	ID, Relation, ID
3	Building ID, Position, Name
4	Event ID, Position, Data, Time
5	Environment, Name, ID

Table 1: Information tables in DB

Route No.	No. of warning-mail by proposed system	No. of warning-mail by simple function
4	5	644
5	96	208

Table 2: Comparison of Number of warning mails

The proposed system shows much fewer number of warning mails compare to the existing ordinary Simple Function method as shown in Table 4.1.

4.2 Group Learning Support System

In this section, in order to evaluate the effectiveness of the Symbiotic Computing, we focus on a group learning domain consists of a teacher and several students. Group learning is a task domain of intelligent cooperative works for the purpose of educating the students, in which each student in a group effectively acquires knowledge by exchanging information with the teacher and other students.

In group learning, generally, it is effective for each student to study by oneself and discuss with group members alternatively over and over. Through self-study, every single student will be able to develop his/her own ability of thinking. In addition, through the group discussion using the result of the self-study, each student will be able to learn other solving methods about the difficult points he/she found during self-study. Thus, both the self-study and group discussion are important, and if they are executed alternately at an appropriate moment, the effect of group learning will be radically enhanced.

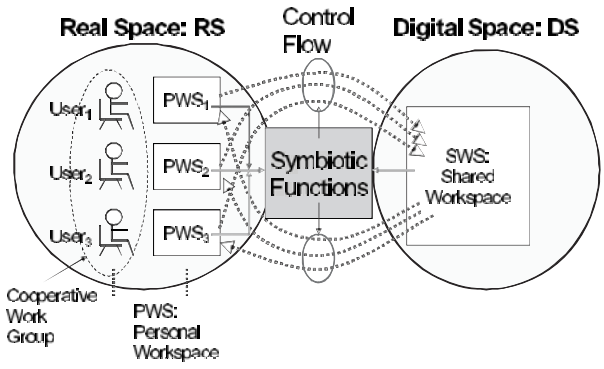

Figure 14: Symbiotic Function for group learning support system.

Based on the basic motivation mentioned above, we respectively provide the PWS (Personal Workspace) in RS as an environment for self-studying, and the SWS in DS, which is shared on a network, as a space for group discussion. Here, we expect the group learning to proceed effectively by shifting current space between the PWS and SWS appropriately in response to the progress of the study in RS. This shifting is performed by the "Symbiotic Function" as shown in Figure 14. The control of information flow between PWS (RS) and SWS (DS) is based on situations of the learning activities and progress in PWSs/SWS. By switching the PWS and SWS in proper timing, the group learning process can be controlled effectively to improve results of the learning.

We implemented a prototype system of the group learning support system with the Symbiotic Function, according to the Model of Symbiotic Computing. The user interface of the system is as shown in Figure 15.

For the purpose of evaluating the effectiveness of the proposed method, we conduct an experiment, applying this scheme to the group learning domain. On one session, one teacher and three students carry group learning on one problem which has multiple solving methods. The work duration for each session is 20 minutes, and the goal is to find solving methods of the problem as many as possible within the time limitation.

In this experiment, not automatically, but a teacher and students shift the PWS and SWS by determining from the progress of the study. In order to evaluate the effect of shifting the PWS and SWS, we conduct the experiment with three types of systems; S1, S2, and S3, as follows.

1) A system which always presents both the PWS and SWS without shifting (existing scheme: S1).

2) A system which shifts the PWS and SWS,

   2-1) on response to the request from the students (proposed scheme 1: S2).

   2-2) on response to the request from the teacher (proposed scheme 2: S3).

We carry out the experiment twice with each type of system as mentioned above. In each time, group members solve two mathematical problems related to geometry as follows:

(P1) Calculating the area of a triangle.

(P2) A problem regarding a circle and a tangent line.

We consider graduate students as examinees. As one group can carry only one session on one problem, we can not allot more than one system to a group for our evaluation. Thus, we respectively allot different groups of examinees, G1, G2, and G3 to the three types of system, S1, S2, and S3. Figure 16 shows the snapshot of the experiment.

Experimental result is shown in Table 3.

Table 3 shows number of solutions which at least one student could make it to, as a result of group learning for each question of (P1), (P2) and each situation of (S1), (S2) and (S3).

As it is indicated in Table 3, for the question (P1), five solutions can be found with (S3) which is the case when the teacher changes the SWS enabled and disabled. One solution can be found with (S2) when the SWS is changed enabled and disabled according to the order of students. One solution can be found with (S1) when the SWS is always enabled.

As for the question (P2), eight solutions can be found in (S3), seven can be found in (S2), and five can be found in (S1),

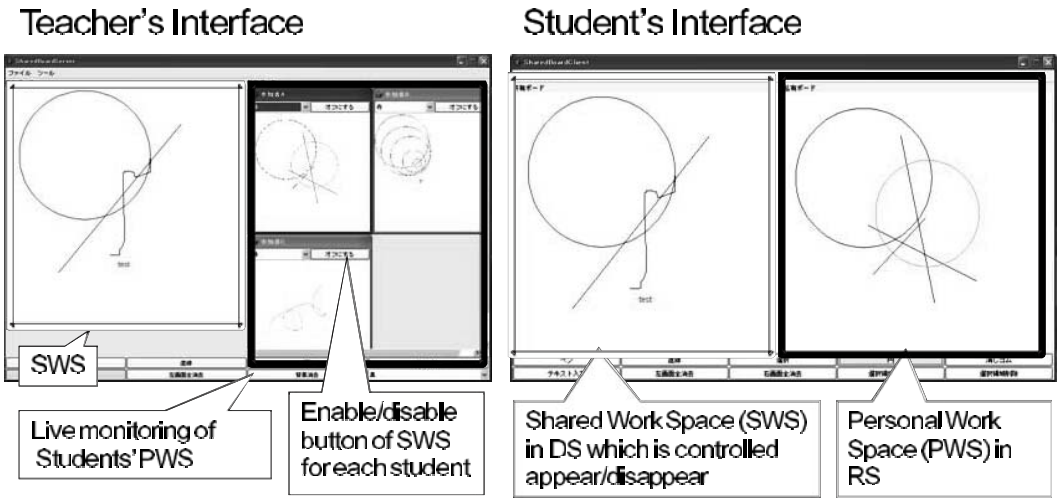

Figure 15: User interface of the group learning support system.

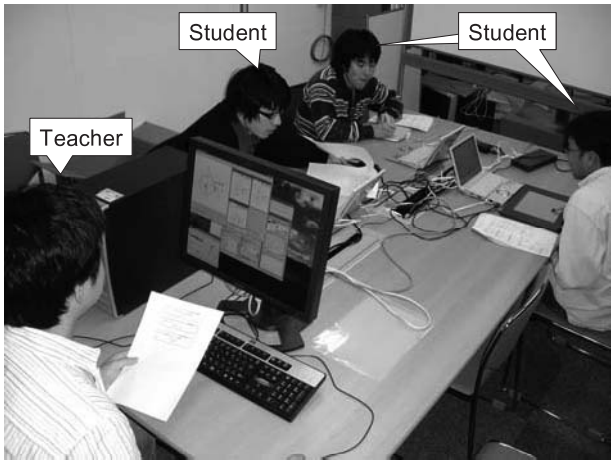

Figure 16: Snapshot of the experiment.

respectively. These results show that the cooperative work is effectively proceeded by using the proposed scheme. Finally we conclude that the Symbiotic Function with the model of Symbiotic Computing can accelerate the exchange of knowledge between RS and DS, and would improve performance of human activity in RS.

4.3 2025: Revolutionary effect of Symbiosis

In Figure 17 we have shown the futuristic situation of year 2025 and the influence of our proposed support system on the society and how effectively it can help to overcome various social and important aspect of life.

5 Conclusion

In this paper we first defined the problems that can appear in post ubiquitous society and it impact on social environments. Though the advancement of technology will bring

Given Problem	Number of acquired solutions		
	(S1)	(S2)	(S3)
(P1)	1	1	5
(P2)	5	7	8

Table 3: Number of acquired solutions compared with traditional system (S1) and proposed system (S2 and S3).

comfort but it will also create problems, and will create a *gap* between human and computers, socially to some particular group of people. To overcome these problems, we introduced a new computing paradigm called, *Symbiotic Computing*. We described the basic concept and architecture of symbiotic computing and a few applications we have developed to show the actual effect of symbiotic computing. Based on the novel concept of this new paradigm a society can be built where human and ubiquitous information environment will coexist in a cooperative manner.

REFERENCES

[1] Ian Pearson, "When I'm 64 (Technology and Telecommunications in 2025-2030)", British Telecommunications Engineering, Vol.14, Part 1, April 1995.

[2] N. Shiratori, "Post Modern Distributed System." Proc. of IPSJ symposium, 1994. pp.1-7 (Keynote Speech).

[3] N. Shiratori, "Post Modern Distributed Systems." IPSJ Magazine, Vol.36, No.9, 1995. pp. 811-814.

[4] N. Shiratori et al. "Framework of a flexible computer communication network." Computer Communications, Vol.19, 1996, pp.1268-1275.

[5] N. Shiratori, "Towards Future Development of Ubiquitous Information Society - Symbiotic Computing", Proc. of 2005 NEC Technology Forum, Symbiotic Computing for Ubiquitous Information Society. (2005) 5-20 (Keynote Speech).

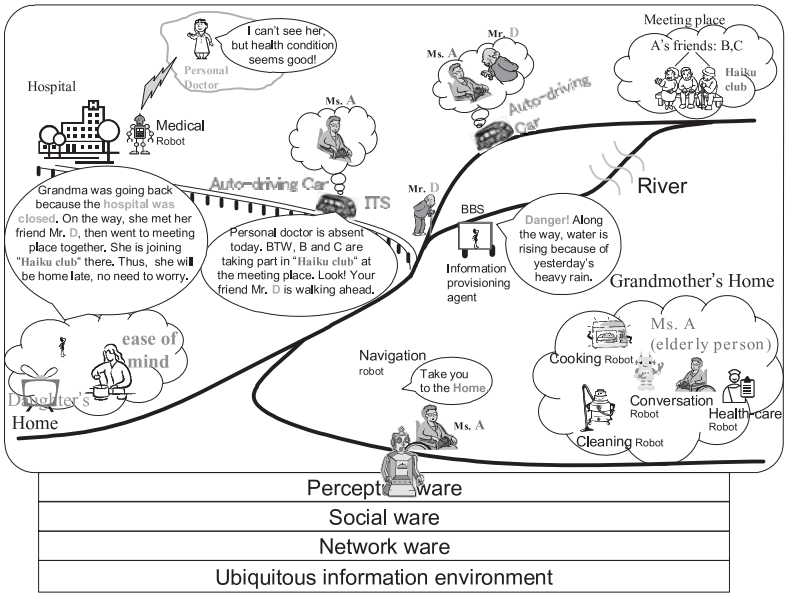

Figure 17: Towards 2025: support system for people and future society

[6] Symbiotic Computing Home Page. http://symbiotic.agent-town.com/

[7] T. Suganuma et al. "Bridging the E-Gaps: Towards Post-Ubiquitous Computing". 1st International Symposium on Frontiers in Networking with Applications (FINA 2006), pp. 780-784.

[8] T. Suganuma, K. Sugawara, N. Shiratori. " Symbiotic Computing: Concept, Architecture and Its Applications", Lecture Notes in Computer Science, Ubiquitous Intelligence and Computing. Volume 4611/2007, pp.1034-1045.

[9] Stephen S. Yau, Fariaz Karim, Yu Wang, Bin Wang, Sandeep K.S. Gupta, "Reconfigurable Context-Sensitive Middleware for Pervasive Computing", IEEE Pervasive Computing, pp. 33-40, July-Sept. 2002.

[10] M. Weiser. "Ubiquitous Computing", http://www.ubiq.com/hypertext/weiser/UbiHome.html

[11] Ubiquitous Networking Forum. http://www.ubiquitous-forum.jp/

[12] Disappearing Computer Project. http//www.disappearing-computer.net/

[13] D.M. Russel, N. A. Streitz, T. Winograd, "Building Disappearing Computers", Communications of ACM, Vol.48, No.3, 2006, pp. 85-88.

[14] M. Hepp, "Semantic Web and semantic Web services: father and son or indivisible twins?," IEEE Internet Computing, Vol. 10, No.2, 2006. pp. 85-88.

[15] Neal Lesh, Joe Marks, Charles Rick, Candace L. Sidner, "Man-Computer Symbiosis Revisited: Achieving Natural Communication and Collaboration with Computers", Mistubishi Electric Research Laboratories, TR2004-053, Dec.2004.

[16] Yoshinori Hara and Ykiu Ebino, "Advanced Ubiquitous System Technologies for Symbiotic Evolution", NEC J. of Adv. Tech., Spring 2005.

[17] J.C.R. Licklider, "Man-Computer Symbiosis", IRE Trans. on Human Factors in Electronics, Vol.HFE-1, pp.4-11, March 1960

[18] Mark Weiser, "The Computer for the 21st Century," Sci. Amer., Sept. 1991.

[19] M. Weiser, J.S. Brown, "The Coming Age of Calm Technology," *Beyond Calculation: The Next Fifty Years of Computing.* P. Denning and R. Metcalfe, Editors, Springer-Verlag, Inc. New York (1997).

[20] M. Weiser, R. Gold, J.S. Brown, "The Origins of Ubiquitous Computing Research at PARC in the late 1980s", IBM Systems Journal, Vol.38, No. 4, 1999.

[21] Nigel Davies, Hans-Werner Gellersen, "Beyond Prototypes: Challenges in Deploying Ubiquitous Systems", IEEE Pervasive Computing, pp.26-35, Jan-Mar. 2002.

[22] J. Weinmiller, H. Woesner and A. Wolisz, "Analyzing and improving the IEEE 802.11-MAC protocol for wireless LANs", in Proc. of MASCOT, pp.200-206, Feb.1996.

[23] M. Satyanarayanan, "Pervasive Computing: Vision and Challenges", IEEE Personal Communications, pp. 10-17, August 2001.

[24] Tomasz Imielinski, B.R. Badrinath, "Mobile & Wireless Computing", Communications of the ACM, Oct. 1994, Vol.37, No.10.

[25] David Garlan, Daniel P. Siewiorek, Asim Smailagic, and Peter Steenkiste, "Project Aura: Toward Distraction-Free Pervasive Computing', IEEE Pervasive Computing, pp. 22-31, April-Jun, 2002.

[26] T. Aoyama, "New Generation Network (NWGN) Beyond NGN in Japan (Panels)", IEEE InfoCom 2007, Mar 8, 2007.

[27] Jean-Yves Cochennec, "Activities on Next-Generation

Networks Under Global Information Infrastructure in ITU-T", IEEE Communications Magazine, pp. 98-101, July, 2002.
[28] Houlin Zhao, "ITU-T NGN FG Proceedings Part I and Part II", 2005.
[29] S. Corson and J. Macker, "Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations", RFC 2501, [ONLINE]. Available: http://www.ietf.org/rfc/rfc2501.txt", June, 1999.
[30] C. Perkins and E. Belding-Royer and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing", RFC 3561, [ONLINE]. Available: http://www.ietf.org/rfc/rfc3561.txt, July, 2003.
[31] D. Johnson and Y. Hu and D. Maltz, "The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4", RFC 4728, [ONLINE]. Available: http://www.ietf.org/rfc/rfc4728.txt, Feb. 2007
[32] C. Perkins et al., "IP mobility support for IPv4", RFC 3344. [ONLINE]. Available: http://www.ietf.org/rfc/rfc3344.txt, Aug. 2002.
[33] D. Johnson and C. Perkins and J. Arkko, "IP mobility support for IPv6", RFC 3775. [ONLINE]. Available: http://www.ietf.org/rfc/rfc3775.txt", June, 2004.
[34] J. Rosenberg et al., "SIP: Session Initiation Protocol", "RFC 3261. [ONLINE]. Available: http://www.ietf.org/rfc/rfc3261.txt. June, 2002.
[35] R. Stewart et al., "Stream Control Transmission Protocol", RFC 2960. [ONLINE]. Available: http://www.ietf.org/rfc/rfc2960.txt, Oct. 2000.
[36] V. Devarapalli and R. Wakikawa and A. Petrescu and P. Thubert, "Network Mobility (NEMO) Basic Support Protocol", RFC 3963. [ONLINE]. Available: http://www.ietf.org/rfc/rfc3963.txt, Jan. 2005.
[37] S. Deering and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460. [ONLINE]. Available: http://www.ietf.org/rfc/rfc2460.txt Dec. 1998,
[38] Ubila, [ONLINE]. Available: http://www.ubila.org/e/e_index.html
[39] G.M. Keeni, K. Koide, K. Nagami, S. Gundavelli, "Mobile IPv6 management information base (2006) [Online]. RFC 4295. Available at: http//www.rfc-editor.org/rfc/rfc4295.txt".
[40] Global Environment for Networking Innovations (GENI), "National Science Foundation" [ONLINE]. Available: http://www.nsf.gov/cise/cns/geni/
[41] "AKARI", "[ONLINE]. Available: http://akari-project.nict.go.jp/index2.htm (Japanese).
[42] WHITE PAPER, Information and Communications in Japan.

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