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Framework Design of Pervasive Computing System for Inter Space Interactions between Private and Public Smart Spaces

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Abstract

In this paper, design of framework architecture of pervasive computing system providing seamless inter space interactions between private and public smart spaces is presented. The seamless inter space interaction issues are related to establishing user's service environment by allocating relevant resources in a new location where there are no prior settings for the user or where there are current users already being served in the new location. In the realm of pervasive computing, we can have different types of smart spaces, offering proactive and intelligent services, which are islands of smart spaces independent from each other. As users move about, they will have to roam from private smart space to public smart space and vice versa. When they enter a new island of smart space, they will have to setup their devices and service manually to get the same or different services they had at the previous location. Users might be living in a non-pervasive computing environment because this manual operation is inappropriate to its generic features of proactive and intelligent services of pervasive computing. The framework architecture will provide seamless inter space interactions initiated by changes in users' location to acquire negotiations of resources for new and current residents regarding service provision with limited available networked devices.

Key Words : pervasive computing, human computer interactions, intelligent agents, context-aware computing, interactive systems

1. Introduction

Pervasive computing systems provide users with proactive and intelligent services by sensing space, interpreting context, and connecting best available sets of service and resources [1]. A large number of research and development projects called smart spaces in home, office and workplace has been brought feasibility in realizing smart space [2-8]. However, it is still one of crucial aspects in pervasive computing system to provide users with seamless service at right time and right place. Even though when users enter into a smart space where current residents are occupying the space and being served by the pervasive computing system, the system should perform relevant features to provide new users with seamless services [9]. As we know, users usually move randomly and unpredictably around different smart spaces and in each smart space, there might be number of residents already occupied the smart space and being served by the system, which means the system is unable to provide relevant service according to users' needs in their new locations. When a user changes his/her location, a smart space will provide the user with best available services in the space with no prior settings as well as with conflicts of accessing same networked devices for different services. Then, the pervasive system faces the issues of seamless inter space interactions between two different spaces, i.e., user's previous space and new space [10]. For successful implementation of pervasive computing system, design of system framework architecture as well as developer's environment should be compatible and scalable to bridge other pervasive computing systems [11] [12] [13].

The user service environment of pervasive computing system is quite different from the traditional computing system regarding uncertainty in users' locations, user's preferences, and status changes in networked devices, terminals and other appliances. We categorize these kinds of context of uncertainty as 'dynamic'. Contrarily, system resources, *i.e.*, memory, process, I/O, network bandwidth and user's profile are categorized as 'static' properties. In this paper, user context means integrated data set of user profile and user preference. Therefore, we can assume that the seamless inter space interaction issue is generated when the system make best available sets of context and service by interacting user's previous and current spaces regarding change in user mobility, *i.e.*, dynamic property, and available system resources, *i.e.*, static property. We have updated idea and designed system framework architecture of pervasive computing system with

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these assumptions and our previous publications [14]. The remainder part of this paper consists of related work, problem statements, architectural requirements, and features of framework architecture in resolving inter space interaction issues followed by working scenario.

2. Related Work

One of the most similar approaches to resolve inter space interaction issues is MIT's 'Follow-Me' applications in ubiquitous computing environment [15]. The 'Follow-Me' is focused on migration mechanisms for agent software which are secure against masquerade as owner of the agent software. It provides users with seamless desktop computing environment along to other computers. There have been different approaches of pervasive computing middleware for enabling active spaces and services which are also focused on specific service features of the pervasive computing system [16-19].

The other research on the flexible middleware for service provision over heterogeneous pervasive networks shows adaptation of middleware and its applications linked to the different protocols for discovering and accessing services in heterogeneous pervasive networks [20]. This research introduces the architecture of the Wings pervasive computing middleware that holds context, service and peer.

Other related work on inter space interactions is the research on the adaptive middleware for context-aware applications in smart-homes [21][22]. This research introduces autonomic computing in a middleware for context-aware applications consist of Quality of Context (QoC) and Service Discovery protocol (SDP) [23]. In this research, context providers (CP) are assumed to estimate their QoC by adopting application weights and the role of authentication to each context. Current work on resolving seamless inter space interaction issues have been partially focused on relationship between user mobility and intention. Therefore, now it partially suggests a method of relevant service for an individual person's needs for seamless inter space interaction. Each of the current works is partially devoted to user mobility not devoted to overall issues on seamless inter space interactions.

The challenges of framework architecture of pervasive computing system for resolving inter space interaction issues can be summarized as binding resources and quality of service. As people get used to new technology, they come to expect its availability and dependency. This is especially true of smart spaces because their goal is to embed technology into living environments, which can greatly impact activities of daily living (ADL). Regarding challenges in seamless inter space interactions, we briefly summarize two of open issues in seamless inter space interactions for bridging islands of smart spaces: Binding of resources and QoS issues [24].

Binding refers to the attempt of migration a service running in one pervasive space (usually owned space) to another pervasive space (usually temporary, visited space), as well as reconnecting user's preferences to this visited space. Resolving inter space interactions issues should also involve identifying the factors that affect where binding should occur for particular architectures or applications. Device descriptions, service/application descriptions and user preferences are some of the crucial information in specifying and coordinating how a smart space works. In semi-private setting, such as paying visits to a friend's smart home, some sort of rules have to be established to accommodate the visitors' needs including privacy while maintaining the control and preference of the space owner to ensure continued integrity and security of the space owner's resources [25-28]. How to characterize each person, device and service, and authenticate them and identify their ownership is one of the key concerns in inter space interaction issues [29][30][31].

QoS of pervasive computing systems is influenced by many factors, for instance, the bandwidth of different types of networks, the number of migrating services, the specifications of networked devices, the priority of services and pattern of user's mobility. Conflict resolution can be regarded as another facet of the authentication and ownership, but it is important enough to be considered separately. How do we decide which of the conflicting commands issued by different applications should overwrite all the others? How do we decide the priority of conflicting preferences of users? For instance, when the user goes back and forth for a series of tasks or changes in intention, the pervasive computing system should provide seamless inter space interaction service to meet the changes of context in terms of different situations and user's environments. It means the static characteristics of the pervasive computing system resources should be seamlessly interactive at the time of changes in dynamic characteristics caused by changes in user's location, intention and his/her environments. There have been different types of mechanisms to solve interferences or conflicts in contextual information [32]. While processing the seamless inter space interaction service, there are conflicts regarding managing resources and service priority.

The diversity and impact of smart space on its occupants and the spaces are much larger than networking services or traditional systems. What are the quantifications needed to be considered in addition to the traditional QoS measures such as response time, throughput, service level or degree of jitter? How do we maintain the acceptable QoS in face of missing components, such as delayed/lost user profiles, differences in specifications of networked appliances, incompatible service descriptions and missing sensors or actuators? A flexible and adaptive mechanism need to be in place to guarantee certain level of QoS.

3. Problem Statements

For seamless inter space interactions, pervasive computing systems should provide users with interactive features of static and dynamic properties in pervasive computing system resources. We describe problems of inter space interactions by conceptualizing a user's moving around smart spaces in figure 1.

3.1. Smart Space: Possible Inter Space Interactions

We assume a user is moving about smart spaces where current residents occupy the smart space and are using a few networked devices as a consequence of the user's needs. We divide smart spaces into five small smart spaces which is called 'virtual cell'. We also assume that there will be four different inter space interactions such as entering the smart space, leaving the smart space, interacting current resident(s) and bypassing the smart space. Other interactions such as fetching some devices or bringing something in the smart space fall into bypassing the smart space category. Figure 1 describes four different types of possible inter space interactions. In the figure 1, there is a networked assistive robot that represents software agents, which is a tangible entity of the pervasive computing system, perform sensing space, interpreting context and connecting best available resources for seamless inter space interaction services. When the user is entering the smart space, then the system will initiate user's authentication, resources allocation and migrating user profile. It accompanies authenticating user, context and services for the new user. When the user is leaving the smart space, then the system will terminate user's services by releasing the resources, interrupting the services, and reporting the user's leave to the computing system. When the new user is interacting with current user(s) in the smart space, *i.e.*, a virtual cell, then the system will perform a series of operations such as negotiating, adjusting, compensating and binding appropriate resources in the pervasive computing system. And when the user is bypassing the virtual cell, then the system will only have to identify the new user's identification.

3.2 Architectural Requirements

We adopt one of our outcomes of requirements for middleware design of ubiquitous pervasive computing [14] in developing architectural requirements for seamless inter space interactions. The key aspects on real time re-configuration of pervasive computing system resources to provide user with seamless inter space interactions are architectural adaptation and compatibility with legacy systems of pervasive computing services. The following subsections are architectural requirements for seamless inter space interaction services:

3.2.1 Verifying User's Identification and Location

The user in the service scenario does not have to carry any device or appliance for identifying his or her location in the indoor space. The only thing the user should carry for identifying his or her identification and location in the other smart space is his or her RFID tag. It can be put on the user's clothes. The system should have flexible interfaces handling different kinds of sensor information of user's new location. When the user leaves his or her private space, the RFID reader located at the entrance of other smart space will detect his or her entering the other smart space, *i.e.*, public smart space or other person's private space.

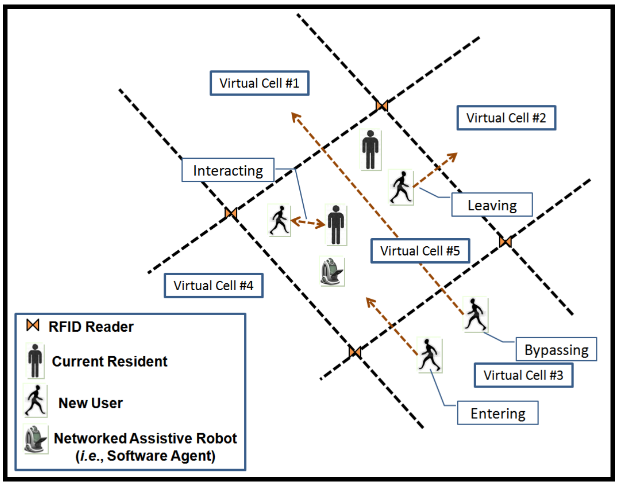

Fig. 1 Possible Interactions with Virtual Cells and users

3.2.2. Criteria of Quality of Service (QoS)

For the seamlessness in user's moving about the smart spaces, the quality of service should be kept in the range of threshold regarding the user's location, preference and environment changes after entering into new smart space. It means the user will not lose the privilege of acquiring high quality of services no matter where the user enters into different smart spaces. It also means QoS of each layer in the system architecture should communicate each other on resource allocation and its appropriate QoS of the set of {service-tasks}.

3.2.3. Best Available Set of Service-Resources

The real time re-configuration of pervasive computing system resources is directly related to binding variables and parameters of system resources and QoS parameters of each layer in system architecture for a specific service. The process of binding the variables and QoS parameters is also related to optimization not only system resources for a specific service but also other factors affecting QoS parameters and data. For instance, if the user changes location, alternative resources are required for initiating the same service that was being invoked at the previous smart space.

3.2.4 Device and Appliance Adaptation

While reconfiguring the resources for new smart space, networked devices and their application software should be adaptive according to the quality of service. For instance, when a user watches a TV drama with a 63 inch plasma TV monitor in the previous smart space, and the user enters into a new smart space where there is a 12 inch color monitor available for the user's service, then the system will provide the user with seamless service of viewing TV drama after device/appliance adaptation by reconfiguring resources in each framework architecture layers of the system.

3.2.5. Compatibility and Interoperability

To provide users with seamless services, the framework should have transparent interfaces to legacy pervasive computing systems for its compatibility and interoperability. For instance, the framework features needs to have transparent interfaces of different kinds of sensors and actuators to write application programs, agent software, those will run on top of different kinds of device drivers for sensors and actuators. It means bring each different pervasive computing system to place under the one umbrella of virtual pervasive computing system.

3.2.6. Privacy and Security

The framework should provide security and privacy for visitors and space owners. The privacy issue is better understood in the context of grid and cluster computing systems, however, the security issue poses several challenges that are still under investigation. Once the visitor's identification is authenticated by the remote pervasive computing system, then the resources in the hosting smart spaces will be shared by the visitor's applications, which are seamless inter space interaction services. The objective of offering robust security is to provide visitor applications, those will be granted control over the hosting platforms, such that it can be executed unaltered, unmonitored, and unrecorded by the host networked assistive robots. The security feature will include availability, integrity and authentication at the point of initiating the visitor's application and also include confidentiality and integrity in during and termination of the visitor's application.

4. Proposed Framework Architecture

Considering all the possible inter space interaction issues and architectural requirements of seamless service, we propose framework architecture, shown in figure 2, to describe a user's mobility which accompanies automatic switches of control over the networked devices and networked robots near the user's new location, especially in the public smart spaces. Figure 2 depicts flows of sensed data and control information for seamless inter space interactions in different smart spaces. The followings are brief descriptions of four components in the proposed framework architecture shown in figure 2.

4.2 Service-Task Coupling (STC) Layer

The STC layer has properties of inferring service and tasks from the changes of context regarding user, space and devices within the user's occupied space in real time manner. The context has dynamic characteristics such as changes in user location and his/her environment. The STC layer receives context of dynamic properties from the 'Space Sensing and Actuating layer' to wrap up encapsulated dynamic context data. In the STC layer, there is a repository of static context such as user context, registered devices/appliances, virtual floor plan that maps physical world floor plan and list of services that maps relevant set of tasks. With the internal loop of interaction between dynamic context and static context, the 'Service-Task Coupler' in the STC layer runs inference operations to get an optimum set of {service-tasks}. When the coupler generates the optimum set of {service-tasks}, the STC layer sends them to the CQB to produce a new Tuple for appropriate resources with the QoS information. One of the important features of the STC layer is to provide a method that prevents conflicts in service and context.

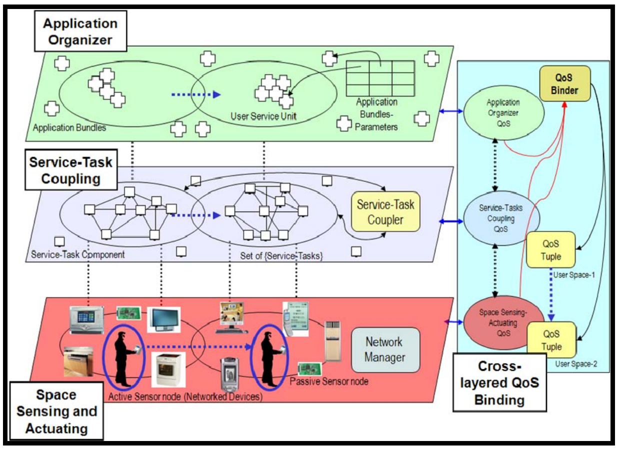

Fig. 2 Framework Architecture for Seamless Inter Space Interactions

4.3 Cross-layered QoS Binding (CQB) Layer

The CQB layer has properties of configuring appropriate resources and QoS parameters of each layer, i.e. the SSA layer, the STC layer and the Application Organizer (AO) layer, of the pervasive computing system by retrieving available resources and its parameters those are registered in each layer. To determine QoS in each layer, the CQB layer refers sets of {service-tasks} from the STC layer which is composed of the relevant tasks to perform the service. The CQB infers static resources and its parameters of pervasive computing system to perform the tasks for the service. The results of inference will be sets of resources and its QoS parameters to process a specific set of tasks. In CQB layer, these sets will be merged into sets of {service-tasks-resources-QoS} in each layer. We name this set a 'Tuple' which has control information of each dedicated resources to process a set of specific tasks. A Tuple also has control information of each set of task to provide users with service. Therefore, a set of Tuple represents QoS information of the three layers, i.e., the SSA layer, the STC layer, and the AO layer of the pervasive computing system. Once the CQB delivers a set of Tuple to the three layers, the resources of the SSA layer for the user's new location will be allocated in real time. At the same time, the STC layer and the AO layer will allocate their resources and set parameters to activate resources and applications in each layer.

4.4 Application Organizer (AO) Layer

The meaning of "organizer" is to symbolize its characteristics of reconfiguring suites of primitive application functions, i.e., application bundles. With this property of organizer, an Application Organizer (AO) represents a set of {service-tasks-resources-QoS-bundles} and a mapping table to link each application bundle to QoS parameters. An Application Organizer initiates a set of {service-tasks-resources-QoS-bundles} for each user when the user's location or his/her environment is changed. We define a term, 'Application Organizer', which has an interface of autonomous programmable features. Therefore, the AO layer will perform reconfiguration of a set of Application Organizers to provide users with a target service. For instance, a service named 'Home Security Service' consists of a set of Application Organizers such as 'sensing residents' location', 'sensing windows and devices in home', 'locking windows and doors', 'setting security level', and 'activating alarm'.

4.5. Privacy and Security Module

The privacy and security module will be offered as a plug-and-play module in the group of available packages for pervasive computing services. The security works based on an opt-in/opt-out system. Once the pervasive computing system opts-in, the module will perform an initial evaluation of the new smart space to confirm a minimal set of system capabilities and security requirements. Second, the module classifies the prospective smart space as a threat or non-threat based upon a larger set of data collected from the pervasive computing system and compared to historical data from the module. The security requirements from the go/no-go scan include requiring certain OS, up to date OS patches, specific virus scanners and specific virus scan history, among other security items. The module has active security properties those are divided into two groups. First, a set of properties are designed to ensure that the module's control flow runs without being monitored or altered by any application running on the host. The second set of properties ensures that any application data or meta-data is not accessed, altered or recorded by any non-module application running on the host. The monitoring and enforcement of the module's active security properties precedes application execution, and endures through out the life of the application. The control-flow and data protection can be achieved through secure key-exchange, key hiding, data encryption, on-time decryption, and secure context-switches.

5. Working Scenario

With all the considerations of architectural requirements and proposed framework architecture of seamless inter space interactions, we develop working scenario with the assumption as follows:

A user is moving from his/her own place, i.e., private smart space, to another place, i.e., public smart space. The user has no terminal or device while the user is at home, but when the user leaves home a networked assistive robot asks the user to take a RFID tag as an electronic identification tag to grant seamless inter space interaction services in public smart spaces. Figure 3 shows how the framework of the pervasive computing system assisits the user in seamless service when the user leaves home to go to a public smart space. The SSA, CQB, and PSM describe Space Sensing and Actuating, Cross-layered QoS Binding, and Privacy and Security Module in the framework design, respectively. The SSA, CQB, and PSM interact each other in the user's moving about.

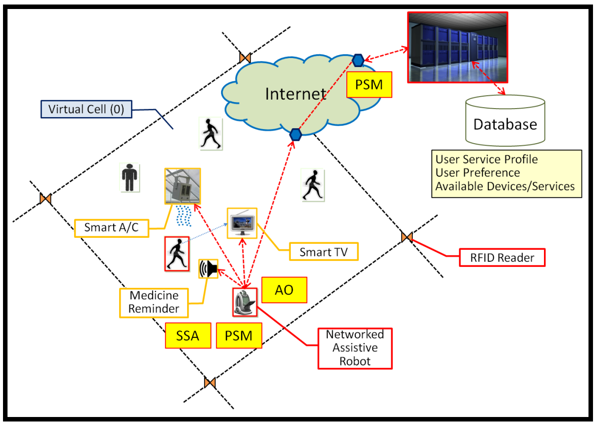

Fig. 3 Leaving a Private Smart Space

With this assumption, we describe a working scenario starting with each step of call flows for single user mobility, i.e., entering into a public smart space, which is one of dynamic context as follows:

Step 1: Initialization: The RFID reader at the entrance of the public smart space detects the user's entering into the public smart space (dynamic context), sends user's RFID data to the pervasive computing system to acquire authentication, queries the user's service profile (static context) and previous events (dynamic context) related to the service and activities as soon as the user moves into the public smart space. The networked assistive robot at the user's home will assist the pervasive computing system to authenticate the user's identification and the pervasive computing system will grant permission of sharing the resources in the public smart space to assist the user. Figure 4 depicts how the framework architecture in the pervasive computing interacts to assist the user's entering into a public smart space. The SSA, CQB, and PSM closely interact each other in initializing of the user's profile, preferene, and previous service log at the previous smart space.

Step 2: Preparation: The preparing process will involve two stages of authentication based on a multi-modal challenge response. The initial identification may happen through a system initiated detection of user presence through the RFID reader in the public smart space. The second stage authentication is user initiated confirmation based on biometric or other security credentials offered through a Near Field Communication (NFC) channel. For instance, a networked camera on the ceiling at the entrance of public smart space will take and transmit the user's photos to the pervasive computing system to take the second stage authentication. After the networked assistive robot at the public smart space gets control data from the pervasive computing system to proactively assist the user while in the public smart space, the pervasive computing system will start to predict relevant service for the user's situation in the public smart space. The networked assistive robot will send the user's location information in its virtual cell of the public smart space.

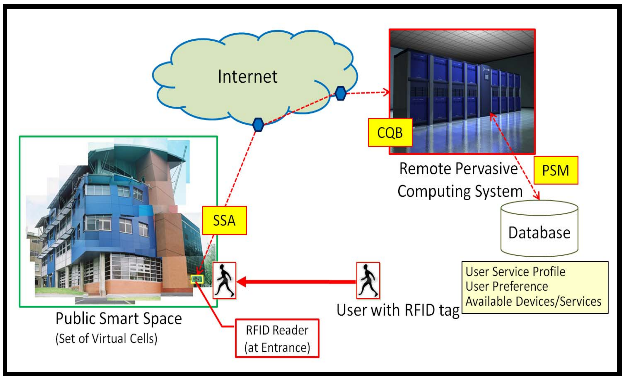

Fig. 4 Initialization and Preparation of User's Entering into a Public Smart Space

Step 3: Hand-over: After the pervasive computing system collects all the related data and information from the space, the set of {service-tasks} is determined. Once the pervasive computing system finalizes the set of {service-tasks}, then the system confirms the resources in the public smart space those are available to process the tasks. The pervasive computing system will run its QoS Binding to locate and negotiate preoccupied resources and other resources related to run the proactive service. After determining of set of {service-tasks-resources}, the pervasive computing system is ready to hand over set of {service-tasks-resources} to the networked assistive robot in the virtual cell in the public smart space. Figure 5 describes the public smart space and how the design components of the pervasive computing framework communicate with each other for hand-over and adaptation. The STC and AO mean service task coupler and application organizer, respectively. When the user enters into the virtual cell (0), then the RFID reader reads the user's RFID tag and grants authorization from the system. The networked assistive robot in the virtual cell communicates with the system to provide the user with seamless services.

Step 4: Adaptation: The pervasive computing system will transmit the set of {service-tasks-resources} to the networked assistive robot to start the service in the virtual cell where the user is located in the public smart space. For instance, network in the public smart space needs to verify the availability and authentication of the network resources and networked devices in the virtual cell according to the set of {service-tasks-resources}. For instance, to activate the 'Medicine Reminder' service in the virtual cell, the pervasive computing system has to reconfigure parameters, i.e., display resolutions, video encoding algorithms, video image/sound noise filtering algorithms, feature extraction software packages and pattern matching software packages of the video phone devices in the public smart space.

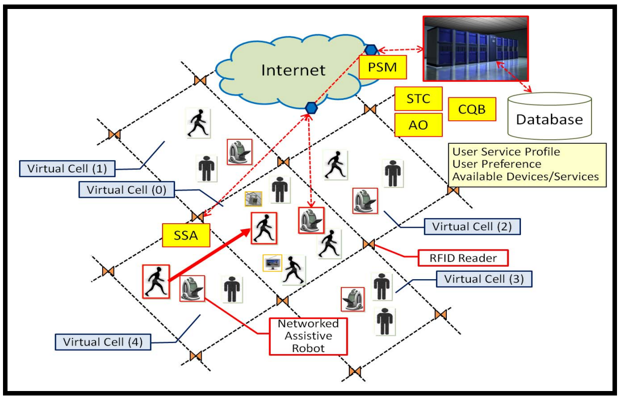

Fig. 5 Hand-over and Adaptation of Service Acquisition

Step 5: Activation: After the system finalizes the adaptation of resources at the user's new location in the virtual cell of the public smart space, the pervasive computing system performs the activation process of seamless inter space interactions by sending a tuple {service-task-resource-bundles} and control data to the networked assistive robot and then gets results of the service performance from the robot shown in figure 6. The user gets the medicine reminder service through the networked speaker near his location while watching a TV drame through networked color monitor and also having aircondition service through a networked and cell mounted A/C device.

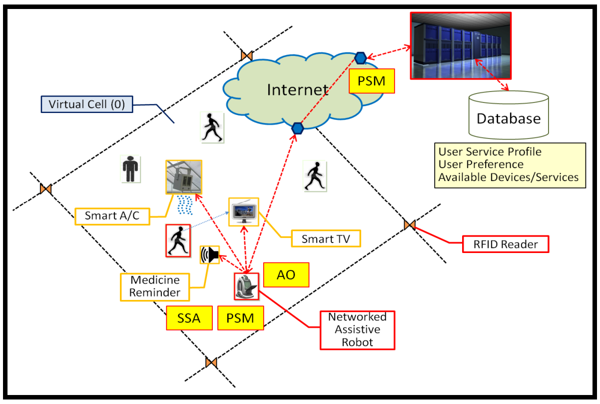

Fig. 6 Activation of Seamless Service in a Virtual Cell

6. Conclusions

In this paper, the key contributions are (1) defining problem statements of seamless inter space interactions, (2) developing possible interactions in the smart space and architectural requirements of seamless inter space interactions of pervasive computing spaces, and (3) proposing a framework architecture and working scenario of pervasive computing system for seamless inter space interactions. The framework will provide users with seamlessness in inter space interactions due to the changes in users' location and environment. With the issues and requirements in this paper, the framework design for seamless inter space interactions envisions us how to resolve the issues caused by changes in user location and user's environment. For further study of the seamless inter space interactions of pervasive computing system, functional and non-functional requirements of inter space interactions, design of middleware of pervasive computing system for seamless inter space interactions, and development of algorithms of problems in the middleware of the pervasive computing system. At this moment, we assume that the middleware might be located in the networked assistive robot platform and the pervasive computing system.

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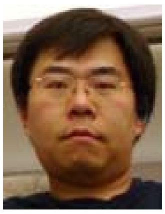

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