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Inter-space Interaction Issues Impacting Middleware Architecture of Ubiquitous Pervasive Computing

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Abstract

We believe that smart spaces, offering pervasive services, will proliferate. However, at present, those islands of smart spaces should be joined seamlessly with each other. As users move about, they will have to roam from one autonomous smart space to another. When they move into the new island of smart space, they should setup their devices and service manually or not have access to the services available in their home spaces. Sometimes, there will conflicts between users when they try to occupy the same space or use a specific device at the same time. It will also be critical to elder people who suffer from Alzheimer or other cognitive impairments when they travel from their smart space to other visited spaces (e.g., grocery stores, museums). Furthermore our experience in building the Gator Tech Smart House reveals to us that home residents generally do not want to lose or be denied all the features or services they have come to expect simply because they move to a new smart space. The seamless inter-space interaction requirements and issues are raised automatically when the ubiquitous pervasive computing system tries to establish the user's service environment by allocating relevant resources after the user moves to a new location where there are no prior settings for the new environment. In this paper, we raise and present several critical inter-space interactions issues impacting middleware architecture design of ubiquitous pervasive computing. We propose requirements for resolving these issues on seamless inter-space operation. We also illustrate our approach and ideas via a service scenario moving around two smart spaces.

Key Words : Ubiquitous pervasive computing, Human computer interactions, Intelligent agent, Context aware computing, Middleware

1. Introduction

Ubiquitous pervasive computing systems are pervasive systems that exist everywhere to provide users with intelligent and needed services. The high demand of automatic and customized services for home and office residents leads us to believe that smart spaces, where pervasive computing services are available, will become much more widespread in the near future. Overcoming the technical issues of implementing pervasive computing systems require an interdisciplinary approach to bridge each island of technical components consisting of different types of ubiquitous and pervasive computing system resources. Advances in context aware computing, sensor networks, pervasive computing and ubiquitous computing have led to a proliferation in R&D of so called smart spaces on intelligent environments. For instance, smart homes are widely researched and developed [1-23]. Such outcomes promise the future image of intelligent living at homes and offices.

However, we still have to bridge some of technical components to build seamless ubiquitous pervasive computing services those will bridge islands of smart spaces. For instance, as shown in the figure 1, when an elderly person with early-stage Alzheimer's, whose independent living depends on a medicine reminder and a vision-based gait monitoring/analysis services in her home leaves home to go to a super market near her home, she will lose the benefits of these critical services if she leave her smart home [24] [25] [26]. That is one of the clear examples why we should provide seamless inter space interactions in ubiquitous pervasive computing systems.

In this paper, we focus on the issues regarding seamless inter space interactions in middleware of ubiquitous pervasive computing systems that is regarded as one of the major issues of bridging islands of smart spaces. For successful dissemination of ubiquitous pervasive computing technology, the architecture of the system should be open to other ubiquitous pervasive computing systems and the development environment should be

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compatible and scalable [27] [28] [29] [30].

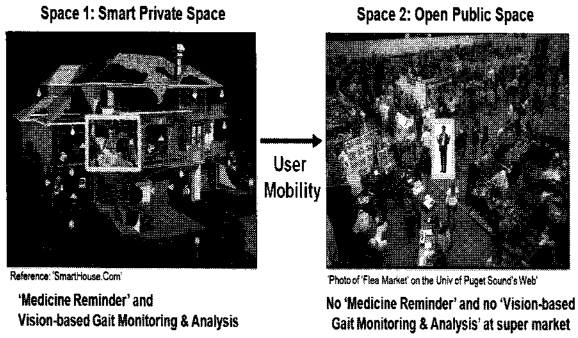

Fig. 1. Example of Seamless Inter Space Interaction of User Mobility

When ubiquitous pervasive computing systems try to establish user's service environments after the user's location is changed to where there are no prior settings and when users try to occupy same networked device with different service requests, then the systems meet the issues of seamless inter space interactions [31] [32] [33]. The user service environment of ubiquitous pervasive computing is quite different in regard to changes in users' locations, user's preferences and status changes of networked devices, terminals and other appliances. We categorize these kinds of properties as '*dynamic*'. Contrarily, system resources, *i.e.*, memory, process, I/O and network bandwidth and user's profile are able to be categorized as '*static*' properties.

Therefore, we can state that the seamless inter space interaction issue is raised when there is change in user mobility, *i.e.*, dynamic property, and the system tries to provide the user with seamless service by allocating system resources, *i.e.*, static property. The starting point of creating seamless inter space interactions is to establish clear relations of 'in-between' of dynamic and static properties of ubiquitous pervasive computing environments. As we know, users usually move unpredictably around different smart spaces, which mean the system is unable to provide relevant service according users' new locations in timely manner. The changes may include user's location and environment within user's location. Considering all of these factors of adapting the user service environment for user mobility and possible conflicts of occupying same resources, we believe that the middleware of ubiquitous pervasive computing system should provide seamless and adaptive interaction features to the user service environment regardless of changes in user location and environment within user's location.

2. Related Work

One of the prominent research projects on inter space interaction is the Internet Suspend/Resume mechanism that layers virtual machine technology on a location-transparent distributed file system. It is a rapid personalization and depersonalization approach for the transient use of anonymous hardware [65] [66] [67]. If the user carries his/her own mobile device in the space of this distributed file system, it provides an alternative way to solve some of inter space interaction issues in ubiquitous pervasive computing [39] [40]. However, if the users try to occupy same resources, for instance, a networked multimedia player, the distributed file system requires a few more functional components adding negation feature of the user, resources and service environment [65].

For the compatibility and scalability of program source code and services, there are several approaches to solve this issue by programming pervasive environments based on the context-driven and service-driven models [20] [34, 35] [52-64] [68, 69]. Both models provide developers with methods for programmable environment to solve the incompatible and scalable issues of application bundles and networked devices in smart space. These types of models will be useful if there is an interface between autonomous programmable environment and seamless inter space interactions [38].

A different approach to solving user mobility issue is QoS-aware middleware of the system [70]. The QoS-aware middleware provides application-level mobility support for user mobility. This approach assumes that user location sensing and network interface is being provided virtually. One of advantage of this approach is the adaptation of applications to the ubiquitous and heterogeneous environment. If this approach adds features of adaptive interfaces of user preferences and user profile which is part of user context related to the user mobility, it will take care of static properties of ubiquitous and heterogeneous environment.

Another approach for the inter space interaction issue is software architecture-based adaptation for handling various resources, user mobility, changing user needs, and system faults [33]. This approach illustrates an adaptation framework with three layers: task layer, model layer and runtime layer. While this model is sound from the architectural point of view, it still requires additional features for assurance of quality of service in each layer regarding user mobility.

The Service Reference Model of Working Group 2 in Wireless World Research Forum (WWRF) describes service semantic, generic service elements and service platform for mobile computing services. As the specifications are in the early stages, solving the possible conflicts of occupying same resources require additional functional features [71]. 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 [72]. 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. This research introduces autonomic computing in a middleware for context-aware applications consist of Quality of Context (QoC) and Service Discovery protocol (SDP) [73]. 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 interactions 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 requirements 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 interaction.

3. Challenges of Ubiquitous Pervasive Computing Middleware

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 many daily activity routines. When the user moves around the smart spaces, the system is supposed to provide seamless inter space interaction service to him or her. To raise issues regarding challenges in seamless inter space interactions, we present open issues in seamless inter space interactions for bridging islands of smart spaces [49] and develop a service scenario from daily living of elder people [51] with smart technology and applications [62]. In this paper, we focus on two core issues: Binding of resources and QoS issues.

3.1. Binding issues

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. We identify four sub issues with this binding.

3.1.1. Separating goals and means

Consider a medicine reminder service. Broadcasting messages on the stereo system at home is an excellent means to prompt the resident to take medicine. It may not be the most feasible modality when the person is shopping at the supermarket. Here, an alternative such as text messaging the user would be much more appropriate. In ubiquitous pervasive computing the problem has been intensified because different spaces may have drastically different resources and capabilities for context acquisition and behavior delivery.

3.1.2. Deciding where binding occurs

When a user arrives in a new smart space, at which level are the user's preferences bound to the space's configuration? One idea is to bind at the *device level.* With this approach, each device is associated with particular domains, and services bind to the devices that support their needed domains. For instance, a climate control service, which affects the "temperature" domain, can be bound to devices such as an air conditioner, electric heater or ceiling fan. Another alternative is to bind at the *user profile level.* Here, the user's preferences are adapted and converted to conform to the protocols of the new space. Resolving inter space interactions issues should involve identifying the factors that affect where binding should occur for particular architectures or applications.

3.1.3. Interoperability and compatibility

Device descriptions, service/application descriptions and user preferences are some of the crucial information in specifying and coordinating how a smart space works. The *syntactic and semantic grammars* have to be well defined for the entire smart space to work properly. On top of this, the difference in programming models may also cause incompatibility. Many researchers have looked into extensive use of *ontology and standardization* of service description, but no definite conclusion has been reached yet. While this issue exists in single-location smart spaces, it is relatively easier to ensure compatibility of entities under the same roof than roaming around to different locations between systems, possibly internationally.

3.1.4. Ownership of space and authentication of entities

When users and devices move in and out of smart spaces, issues related to authentication and ownership take the central stage. In the *private* setting of a smart home, the owner of the house would naturally have the full control of the dwelling. Any device and service brought in or approved by the owner can be trusted and integrated into the environment. In the *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 his resources. 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.

3.2. Quality of Service (QoS) issues

QoS of ubiquitous 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. The characterizing criteria and quantification of QoS in ubiquitous pervasive computing remain to be investigated and define.

3.2.1. Conflict resolution: priority and scheduling

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? When including time dimension in the consideration, how do we schedule the execution of the commands so as to handle emergency situations promptly and preserve the quality of service in general.

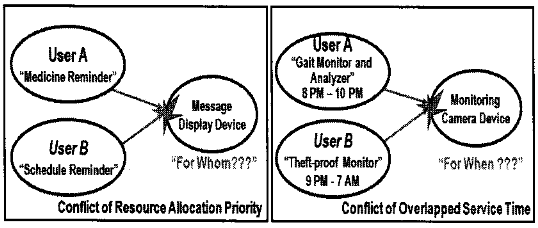

Fig. 2. Possible Conflicts of Seamless Inter space interactions

Context in ubiquitous pervasive computing usually accompanies information of user's location and intention at a specific time in real world space. For instance, when the user goes back and forth for a series of tasks or changes in intention, the ubiquitous 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 ubiquitous 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. Figure 2 depicts possible context conflicts when users move around to meet in the same smart space and the system tries to activate prior user services at the same networked device. For instance, 'user A' who suffers from Alzheimer needs services of 'Medicine Reminder' and 'Gait Monitor and Analyzer' in his/her new smart space. But 'user A' will be in critical situation if 'user B' preempts the resources, *i.e.*, message display device and monitoring camera device, then, 'user A' may not use his/her prior services for caring Alzheimer. There have been different types of mechanisms to solve interferences or conflicts in contextual information [34] [35] [36] [37] [38].

While processing the seamless inter space interaction service, there are conflicts regarding managing resources and service priority. We can categorize four different types of conflicts as follows:

Type 1: A user moves around and tries to occupy different types of devices for the same service

Type 2: Multiple users move around asking for each individual service with the same device simultaneously

Type 3: Multiple users request the same service with different devices simultaneously

Type 4: Hybrid combination of Type 2 and Type 3

3.2.2. Criteria of QoS

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.

3.2.3. Service level agreement

Not all services are created equal. Some are inherently more important than others. When moving from one smart space to another, how do we classify services into appropriate levels, and how do host smart house negotiate with visiting users and entities in terms of the service level, pricing and resource contention. For instance, service interactions occur when the user requests are directed to the same device or are being influenced by the other request: one for the 'called' request and the other for the 'caller' request.

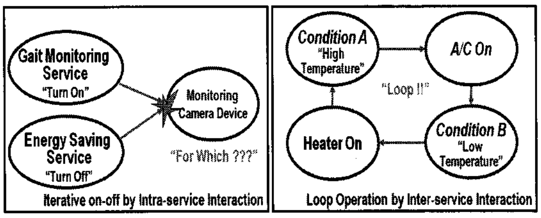

Fig. 3. Possible cases of Service Interaction in Seamless Inter Space Interaction

Figure 3 shows us feasible cases of service interaction in terms of service level agreement when the system tries to perform multiple services or multiple users' requests in open public smart spaces. The other example is environmental issue regarding service level agreement. If there are two different kinds of appliances, i.e., a heater and an air conditioner, only one of the environmental parameters affects operation of these appliances: temperature. There should be service level agreement to modulate this loop operation. We can categorize these two different types of service level agreements: intra-service and inter-service as follows [39] [40]:

Intra-service interaction: When two different services send their requests to the same device at the same time, the device will be iteratively suspended by two different services. For instance, when 'user A' wants 'Gait Monitoring Service' but 'user B' who manages the open public smart space wants 'Energy Saving Service' to save energy in the super market. The service request of a visiting user, 'user A' continues until someone manually resets the device because the other service request of 'user B' also keeps going on.

Inter-service interaction: When the hot summer comes, the home management service usually turns on the air conditioner but when the temperature drops to a certain degree the home management service turns on the heater instead. The temperature will go up and down as the home management service indefinitely turns on and off the air conditioner and the heater due to the changes of in-door temperature.

3.2.4. Mobility

When considering how to migrate from one smart space to another, we should determine what elements can be taken from projects such as Internet Suspend/Resume and what criteria are specific to smart spaces. Which *states and contexts* can be used as digital representations of users – would user profiles alone be sufficient? Can we forward the states to the target destination ahead of time to allow seamless service provision? How do we decide whether a running service should migrate, stay or terminate?

Although these open issues are not enough to cover all the issues regarding context conflict and service interaction in seamless inter space interactions of ubiquitous pervasive computing environments, we think these issues should be considered ahead as key open issues more than any issues on seamless inter space interactions.

4. Multi Spaces Service Scenario

It is very difficult to predict, adjust, negotiate and coordinate system resources to seamlessly respond to the user's mobility and changes in user environments. To respond these seamless inter space interaction, ubiquitous pervasive computing systems should provide users with interactive features of static and dynamic properties in ubiquitous pervasive computing system. We describe the service scenario in story board format and also describe the working scenario of the service with complying requirements of inter space interactions [41-48]. For better view of difference between non-seamless inter space interaction service versus seamless inter space interaction service, we describe an identical service scenario in terms of before and after seamless inter space interaction technology applies.

4.1. Synopsis of Service Scenario

Susan is an elderly woman with early-stage Alzheimer's, whose independent living depends on cognitive, physical and behavioral assistance services that cue her to finish tasks she has started [25] [50] [51]. Peter is Susan's husband who is a healthy elder living with Susan in their smart home equipped with assistive devices. Susan is going to go to super market near her home in the afternoon to buy some food for dinner. The super market has its own smart technology that allows access of customer's request of smart service. Peter, her husband, as usual, makes breakfast in the morning for her. Susan is supposed to take Alzheimer's medicine in every 6 hours.

4.2. Service Scenario: Before

Susan wakes up by the alarm sound from a clock near her bedside. Still she wants to get some sleep before she takes breakfast. 30 minutes later, Peter comes to her bedside and wakes her up. Susan goes to kitchen to take her Alzheimer's medicine. As soon as she comes to the kitchen, she hears sound of TV from the living room. Now, she goes to the living room without taking her medicine because she wants to watch TV. She watches TV with Peter for a couple of minutes. Peter thinks she has already taken her medicine. In the living room, while they are watching TV, Peter asks Susan to have her breakfast. Even though she wants to watch TV, she has to go to the kitchen to have her breakfast. There is a small TV monitor attached to the sideboard. She goes to the sideboard and turns on the TV because she still wants to watch TV. She is so excited about the drama and she keeps standing and watching TV. When Peter comes to the kitchen to find her watching TV while standing near sideboard, he decides he has to help her breakfast. After the breakfast, Peter helps her to go to super market. Peter has to be with her in the super market. Still Peter is unaware of her taking medicine because he is too exhausted to remember the doctor's order of taking her Alzheimer's medicine regularly. Susan seriously worsens her health due to her irregular taking Alzheimer's medicine.

4.3. Service Scenario: After

Susan wakes up by the alarm sound from a clock near her bedside. Still she wants to get some sleep before she takes breakfast. 30 minutes later, *'Butler Joe'*, software agent that provides Susan with seamless service at anytime and anywhere, wakes her up with her favorite song. *'Butler Joe'* knows how long she usually wants to extend her sleep time in the morning. When *'Butler Joe'* recognizes her waking up, he, *'Butler Joe'* reminds her to take her Alzheimer's medicine in the kitchen. As soon as she comes to the kitchen, she hears sound of TV from the living room. Now, she goes to the living room without taking her medicine. But when she goes to the living room, *'Butler Joe'* reminds her to take the medicine by sending voice command on speakers near her in the living room. She goes to the kitchen and takes her medicine which is one of very important tasks. As *'Butler Joe'* recognizes she wants to watch TV, he asks her if she watches TV attached on the sideboard while she is taking her breakfast. She thinks it is a good idea and she says 'yes, Joe'. *'Butler Joe'* soon realizes Peter, her husband, has not have breakfast yet. *'Butler Joe'* also asks Peter to join her breakfast. At the moment of *'Butler Joe'* calls, Peter watches TV on different channel. He doesn't want to lose the benefit of his watching TV because it is about investment on stock market. *'Butler Joe'* finds there is a wireless palm top computer system on the dinning table. He asks if peter wants to watch TV on the palm top computer on the table. Peter thinks it sounds good and says 'yes, Joe'. They have their breakfast in the kitchen while they watch TV on the different monitors and different channels. After breakfast, *'Butler Joe'* reminds her to go to super market to buy some food for dinner and also reminds her to take her location detector with her before leaving home. She trusts her guide, *'Butler Joe'* and feels like he is one of her family members. While she is in the super market, *'Butler Joe'* sends voice/text messages to the speaker and the monitor near her in the super market to remind her taking the medicine and other appropriate real time assistive service for her Alzheimer. It is possible after *'Butler Joe'* grants permission from the super market smart system to access and use some of resources. She feels she is at home when she is in the super market because of *'Butler Joe'* can follow her in the super market. She feels very safe and secure at the idea of being taken care of by *'Butler Joe'*.

4.4. Quantitative Analysis of Service Scenario

From the multi spaces service scenario, we can analyze how many manual operations a user should do if a user moves to other smart space where there is no prior setting for his or her moving around. In section 4.2, Susan and Peter should perform seven operations which are (1) 'go to kitchen', (2) 'go to living room', (3) 'watch TV', (4) 'go to kitchen', (5) 'turn on TV', (6) 'has to help', and (7) 'helps to go to super market'. Although there are seven manual operations, Susan didn't take Alzheimer's medicine which worsens her health. As Susan has Alzheimer's, six operations are done by Peter, her husband. However, in section 4.3, there is no manual operation because Butler Joe, software agent, has already learned by rule sets and user's preference registered at the initialization stage.

5. Requirements for Middleware Design of Ubiquitous Pervasive Spaces

The key idea of the proposed framework emphasizes on the real-time dynamic configuration of service environments for the seamless inter space interaction and the architectural openness for the adaptation and compatibility with legacy systems of ubiquitous pervasive computing services. The analysis of the story board in this paper leads us to the following requirements:

5.1. Flexible Interfaces for Detecting User 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. It is assumed that user location is detected by the indoor sensors or different kinds of location detection sensors. The system should have flexible interfaces handling different kinds of sensor information of user's new location. The user location can be identified by mapping the position detected by a location detector into a virtual floor plan in the system. When the user goes out of the home, he or she is assumed to take a small wireless device for detecting the user's outdoor location.

5.2. Seamless QoS

The system should provide seamless quality of service when the user moves around in the home or when the user's environment is changed. It means the user will not lose the services no matter where the user goes in different smart spaces. It also means QoS of each layer in the system should be generated based on resource location and its appropriate QoS for the set of {service-tasks}. For instance, if the user was supposed to take Alzheimer medicine when the user is shopping in a super market and listening to the music from the sound systems in the super market, then the system should generate relevant QoS of the resources in each layer to provide these services in timely manner. The system utilizes the sound systems in the super market to fetch voice message of taking the medicine to the user. From a color monitor in the super market that is attached to the ceiling within the user's new location, the user will be able to watch what is going on in the home. With this example, there should be adjustment of QoS in changes of user's location and his or her environment.

5.3. Optimized combination of Resources

This requirement is related to seamless QoS. It includes binding QoS parameters and information of each layer for a specific service. In the process of binding QoS parameters and information, we should consider not only system resources for a specific service but also other factors affecting QoS parameters and information. For instance, if the user changes location or intention, we should think of an alternative service that fits to the previous service. In the process of generating QoS information, it is expected that resource discovery, preempted resource recovery, negotiation, authentication of resources and their ownership, coordination and other QoS related processes for binding resources in each layer of ubiquitous pervasive computing system. The QoS process should be assistive in resolving conflicts in priority and scheduling. The QoS process will act as a mediator between the 'mandatory effort' (in critical conditions) and 'best effort' (in normal situations) to allocate resources efficiently, *i.e.*, according to their priority and scheduling.

5.4. Device and Appliance Adaptation

While doing the process of reconfiguration, adaptation of the new location environment should be considered. For instance, there was a 51 inch plasma TV monitor in the previous location but there is a 17 inch flat monitor in the new location. The system will provide device/appliance adaptation service by setting the number of resolution for reconfiguring resources in each framework layer of the system. That kind of information should be applied to the QoS in each layer.

5.5. Compatibility and Interoperability

For its openness, the framework is to provide interfaces to legacy systems of ubiquitous pervasive computing with compatibility and interoperability features. For instance, the framework features in the form of solution package of software and hardware be installed in different kinds of ubiquitous pervasive computing systems with different kinds of sensors and actuators. It means bring each different system to place under the umbrella of one virtual ubiquitous pervasive computing system. That will be the ultimate requirements of the service scenario in this paper.

5.6. Privacy and Security

The framework should provide security and privacy for the visitor and the host space owner. The latter problem is better understood in the context of grid computing and cluster computing, however, the former poses several challenges that are still under investigation. The objective is to offer portable security for the visitor application on the foreign platform such that it can be executed (a) unaltered, (b) unmonitored, and (c) unrecorded. The first property will ensure integrity of the application execution where as the second and third properties will ensure privacy during and after execution. This will be accomplished in a two step process collectively known as PCPP (Private Computing on Pubic Platforms) [75].

6. Conclusions

As Mark Weiser cited in his publication [74], the ubiquitous pervasive computing industry is growing up to be mature in the near future. The key contributions of this paper are 1) raising issues on seamless inter space interactions of ubiquitous pervasive computing spaces that will affect middleware architecture of ubiquitous pervasive computing systems and 2) proposing requirements for enabling seamless inter space operations. In this paper, we regard resources reside within the ubiquitous pervasive computing systems have *static* properties which are characterized as resources being managed as programmed and predefined. However, we regard context generated in the smart space has *dynamic* properties which are characterized as information being changed continuously and unpredictably. Therefore, we believe the issues regarding seamless inter space interactions are issues of interacting between dynamic and static properties of ubiquitous pervasive computing environments including systems, human and space. The framework will provide seamlessness in inter space interactions with *featured hardware and software packages for resolving seamless inter space interaction caused by changes in users' location and environment.* As we have witnessed so far, the ubiquitous pervasive computing industry is growing up to be mature. With the issues and requirements in this paper, the pace of growing will increase with the reason of guiding us how to resolve the issues of seamless inter space interaction caused by changes in user location and user's environment.

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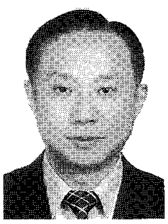

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