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Self-Improving Personal Smart Spaces for Pervasive Service Provision

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Abstract. Current research in pervasive computing, as well as in the fields of mobile telecommunications and device manufacture are opening the way for convergence between mobile telecommunications and the traditional Internet towards the Future Internet. The ubiquitous computing paradigm integrates information processing into the objects that surround us in our environment and permits both global control of these objects and global access to the information they can provide. One aspect of this is the notion of smart spaces where the integration of communication and computational devices is being used to create intelligent homes, offices and public areas, which provide intelligent support for the user. The Persist project (PERsonal Self-Improving SmarT spaces) is investigating a novel approach to this convergence through the introduction of the concept of self-improving Personal Smart Spaces.

Keywords. Personal Smart Spaces, Pervasive Services, Context-awareness, Learning & Reasoning, Self-Improvement, Proactivity, User Intent prediction

1. Introduction

The first basic paradigm for computer usage was that of a single computation device, originally the mainframe and later on the desktop computer. However, over the past two decades [1], the notion of ubiquitous or pervasive computing [2] has evolved to capture environments where humans are surrounded by a large number of different devices and technologies that "weave themselves into the fabric of everyday life until they are indistinguishable from it". These technologies support a range of services, which capture processes and exchange information to serve the needs of humans. Recently, the term "everyware" has been used to describe these [3]. The importance of this new paradigm has been recognised both by the academic/research and the industrial community; and the area of Ubiquitous Computing has been identified in two of the seven major global challenges for Computer Science over the next decade [4].

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Thus, much research has been devoted to the development of ubiquitous or pervasive systems over the past decade. One class of system that has emerged from this process is that of fixed Smart Spaces, which aim mainly to create intelligent buildings. Here research has focused on developing techniques to support building automation (or domotics), such as intelligent light controls, window shutters, security systems, kitchen appliances, etc. In particular, there has been considerable interest in developing intelligent smart homes that can provide support for elderly and disabled residents, making it safe for them to live at home. This approach is basically concerned with a fixed space that is required to provide intelligent features that adapt to the user's needs.

Another class of systems that has emerged aims to address the needs of mobile users. This introduces different and more challenging problems. In this case there are strong requirements regarding the delivery of services irrespective of the user's location and the devices that are accessible to him/her. A ubiquitous system is expected to provide access to devices and services in the user's current environment, no matter what time it is, or where the user is located. A typical example is that of the use of personal biometric sensors that might communicate with home controls for illumination, heating or air conditioning in a room to provide the ideal environment for a user or the best compromise for a group of users. Likewise, a user's location might be used to select different network options and services when the user is at work from those selected when he/she is at home. This is also applicable to situations where the user is travelling in a car or walking outdoors.

However, these two classes of systems are generally completely disjoint, as research in the domain of fixed smart spaces is associated with buildings and is quite independent of ubiquitous or pervasive systems for mobile users. This has resulted in the existence of "islands of pervasiveness" within which fully functional pervasive services are provided, but outside of which there is limited (if any) support of pervasive features. This makes it very difficult to combine these two classes of system. For example, Smart Homes control devices and services within their physical boundaries, but they cannot easily share these with the mobile networks of the residents or of visitors.

Persist (PERsonal Self-Improving SmarT spaces) (http://www.ict-persist.eu/) is an EU funded project, which aims to overcome this problem through the notion of self-improving Personal Smart Spaces (PSSs). PSSs aim to couple the facilities offered by next generation mobile communications and the Future Internet with the features provided by static smart spaces to support a more ubiquitous and personalised smart space that is able to follow the user wherever he/she goes.

This chapter presents some of the concepts, features and approaches underpinning Personal Smart Spaces. The rest of this chapter is structured as follows. Section 2 elaborates on the nature of Personal Smart Spaces and provides some concept definitions. Section 3 describes an illustrative PSS use case scenario that highlights some of the main features and capabilities of Personal Smart Spaces. Section 4 presents the PSS architecture and describes the roles and functionality of its core component blocks. Section 5 investigates how Personal Smart Spaces contribute to the Future Internet and benefit from it. Finally, in Section 6 conclusions are drawn and future plans are exposed.

2. Personal Smart Spaces (PSSs)

In order to explain what a Personal Smart Space (PSS) is, this section first discusses what a smart space implies, and then elaborates on the key features of a PSS. Smart

Spaces usually target real physical spaces as in HP's Cooltown project [5], rather than "Smart Places". A common definition from this point of view is the following: "*A smart space is a multi-user, multi-device, dynamic interaction environment that enhances a physical space by virtual services*" [5][6]. The services are the means of interaction between participants, objects and the smart spaces. Another definition describes them as "*ordinary environments equipped with visual and audio sensing systems that can perceive and react to people without requiring them to wear any special equipment*" [7], which is more or less the vision in several projects and prototypes [8][9][10][11][12]. The common aspect in these definitions and most approaches to smart spaces is the need for infrastructure and sensor-equipped rooms. They neglect the costs of installation and maintenance and the difficulties related to a market entry. If Smart Spaces are to have a wider impact they must be enabled to work without sophisticated infrastructure in specially enhanced rooms and to allow for user mobility. This leads us to one of the key features of PSSs.

A PSS is able to interact with other PSSs, fixed or mobile, in its vicinity, and thereby share information and services. Thus, as the owner of a PSS moves to different locations, his/her PSS interacts with other PSSs in the surrounding environment, offering services to these other PSSs or accepting services from them, thereby offering a unique support for pervasive service provisioning. In a nutshell, a Personal Smart Space can be defined as *a set of services within a dynamic space of connectable devices, where the services are owned, controlled, or administered by a single user* [13]. It facilitates interactions with other PSSs, it is self-improving and is capable of pro-active behaviour. Thus, a PSS is user centric and controlled by a single user; it is mobile, it allows for interactions with other PSSs and is capable of self-improvement and proactive behaviour.

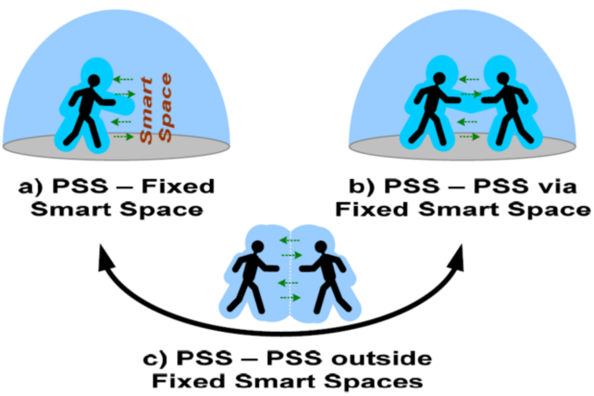

Figure 1. Interaction between PSSs: a) a PSS interacts with a fixed Smart Space, b) two PSSs interact via a fixed Smart Space and c) two PSSs interact without the intervention of a fixed Smart Space.

The Persist vision is of a Personal Smart Space that will provide an interface between the user and the various services and sensors which are, or will be, available globally via the Internet. PSSs will be able to interface to local devices and sensors even when no Internet connectivity is available to the user. Moreover, PSSs will be able to interact with one another to create a more powerful and flexible environment for users, enabling them among other things to obtain indirect access to the Internet by chaining from a user who does not have Internet access through to a Personal Smart Space which can supply such connectivity. In this framework, three main PSS interactions will be supported (Figure 1), i.e. PSS interactions with fixed Smart Spaces, PSS to PSS interactions via fixed Smart Spaces and PSS to PSS interactions without the intervention of fixed Smart Spaces or infrastructure in general.

As already stated, a PSS is mobile, i.e. its physical boundary moves with the user, and thus, the availability of PSS services is determined by their reachability, and a set of rules defining admissibility to the PSS. This allows PSSs to overlap in a given physical area, and gives an intuitive way to manage the interactions between them. Furthermore, a PSS has a single “owner”, the person or legal entity on whose behalf the smart space operates. This allows any PSS to be personalised, and by extension, personalisation of transient services from another visited PSS, subject to conflict resolution between their preferences. In order to provide appropriate support, a PSS should be capable of operating in both infrastructure and ad-hoc network environments. This promotes the widest possible use of the PSS, as an integrator of devices. Additionally, applications within a PSS must be able to adapt to the current situation. To facilitate this, the PSS offers “enabling” services for context, preference, privacy, application management, etc. Each application service must interact with these “enabling” services of the PSS middleware, and react on any notified changes. A PSS facilitates applications in their interaction with the environment. Finally, a PSS can learn from previous interactions. Self-improvement is achieved by mining the information stored in the PSS to identify trends, and infer conditions when preference or user behaviour changes are manifested. This allows recommendations to be made when a PSS interacts with neighbouring PSSs, or for it to act proactively based on reasoning on user intent. A PSS can also use historic information to reason about the trustworthiness of other PSSs in order to protect the privacy of the user.

To support the PSS components involved in the decision making processes, a library based approach has been adopted, enabling them to access a collection of algorithms via a single access point. This library is open and extendible allowing for new algorithms to be added. As learning and self-adaptation are among the focal PSS properties, the library includes modular and pluggable learning algorithms. Examples of such algorithms used in the PSS prototype are Bayesian filtering for context refinement, diffusion models for proximity estimation, clustering techniques in order to discover recurring locations, as well as decision tree models, statistical analysis and markov chains in support of user intent prediction and preference learning [14]. Furthermore, in order to support the PSS recommender system, algorithms and techniques such as attribute/search based correlation, statistical summary based correlation, user-to-user correlation, item-to-item/content based correlation and hybrid approaches have been adapted to address the requirements of the PSS mobile users.

In a nutshell, a PSS supports the following functionality: context awareness; personalization; service management, discovery and composition; dependability and privacy protection; user grouping and service sharing; user intent prediction; recommender systems; pro-active behaviour; learning and reasoning; self-improvement; user, device and session mobility; ad-hoc connectivity and communication.

3. A PSS use-case scenario

This section describes an illustrative PSS use-case scenario and from this identifies the scene segments where each of the PSS features is demonstrated. It is assumed that the actors may carry various portable devices, such as smart phones, laptops and tablet PCs that constitute their PSSs. It is also assumed that communication between the devices of the same PSS or of different PSSs is supported, while third party services and sensing devices (or context information) is provided by the infrastructure that interacts with the PSSs.

3.1. Smart Conference and Reconfigurable Room use case

Mark is about to participate in a scientific conference. At the meeting venue information regarding the conference is available to the attendees via an infrastructure-fixed Smart Space that forms a digital workspace. As Mark enters the entrance hall, his PSS interacts with the fixed smart space and Mark is automatically identified as a preregistered attendee of the conference. This enables Mark to access information such as the meeting agenda, the list of attendees, the lunch menus, internet access tokens, third party services, etc. In a similar manner Mark's PSS may disclose his food preferences to the fixed Smart Space so that the meeting organizers can adapt the food they will serve accordingly. The negotiation and the respective decisions for the disclosure or not of personal information are based on trust assessment negotiations between Mark's PSS and the fixed Smart Space based on Mark's privacy preferences and the organizers' privacy policy. Attendees can also indicate their seat location on the seating map and enable other attendees to see their digital business card.

As the meeting proceeds, updated information is available via fixed displays or PSS devices of attendees. For example, Mark's PSS is updated with data regarding people sitting close to him and having similar research interests. Furthermore, Mark's PSS provides him recommendations about the rooms and the topics of the next sessions that he might be interested to attend.

The meeting's fixed Smart Space can be proactive and pre-load presentations allowing easy sharing and display. Projector services, as well as other common services, can be made available to attendees in a proactive way, based on agenda information and users' current context. For instance, the air conditioning service of the room where the presentation takes place is proactively configured according to all attendees' preferences and priorities. Potential conflicting temperature preferences are resolved by negotiation among the participants PSSs that form a group of users sharing this service.

After a presentation is finished, attendees can give feedback or write their comments and make them available to others. As Mark is impressed by the presentation he had just watched and he has put it down as very interesting, his PSS is automatically printing the slides and his comments. The proactive decision is based on Mark's previous behaviour, as he did the same thing manually several times in the past. Mark's printing requirements for each occasion are retrieved and addressed by the printing service.

As the conference is nearing an end, group photos of the speakers and attendees are distributed automatically by email, as well as travel information, while taxi booking/sharing services are offered to the PSSs of the attendees. The taxi sharing service provided by the fixed Smart Space has arranged for Mark to share a taxi with another person wishing to be at the airport at the same time. Mark accepts the sharing and both PSSs receive information on where and when to wait for the taxi.

When Mark arrives at the airport after the conference, his navigation service directs him via audio-visual means to the appropriate check-in counter. His buddy-finder service also notifies him that a very good friend Mary is also in the airport and that an Instant Message (IM) has already been sent to his friend stating Mark's location. Their two buddy-finder services interact with their location services to work out the most suitable meeting point. An IM is sent to both PDAs saying: "*Do you want to meet up with Mary/Mark at Murphy's Bar in departures in 15 minutes?*" Mark and Mary both respond positively. Mark's navigation service guides him to Murphy's Bar.

When Mark arrives home and enters his living room, his PSS transforms it based on his preferences. At this time of day Mark uses the room as an office. A desk and chair emerge from the floor. Filing cabinets emerge from the wall. Wallpaper appears on all the walls with various stock market movements depicted in the wallpaper pattern. A weather satellite image for the next 24 hours appears on one window pane. Three clocks appear on the wall set to London, New York and Tokyo times. Mark sits down and interacts with the tablet, which forms the surface of the table.

Later on, Mark's friend Robbie arrives. Mark is alerted to his arrival when Robbie's PSS comes into contact with his. Robbie's PSS makes two recliners emerge from the floor. Mark moves over to one of the recliners and all work related items and displays vanish. Instead, Mark's free time items and displays appear around the room. Robbie sits on the other recliner. They are going to watch the football finals. All items on the walls disappear and the wallpaper changes to display a football stadium. The lights dim and Mark and Robbie feel as though they are in the stadium.

3.2. Scenario Analysis

A Personal Smart Space provides a number of innovative features as described in detail in Section 2. In the above use case scenario, the following PSS features are demonstrated in the scene segments identified below.

- *Context awareness*: Context information is monitored and used in all the scenes that involve location, presence, proximity, personal preferences, environmental data, time, sensors, etc. For example, the system infers, based on contextual information together with data from the agenda, that a person is about to make a presentation and so the projector service is proactively configured for the presenter.
- *Personalisation*: It is used when services are adapted based on user preferences. In the scenario, temperature preferences are used to adjust the air conditioning service and printing preferences to configure the printer, while Mark's room is reconfigured based on his current needs.
- *Service Management, Discovery and Composition*: In all scenes where service provisioning is involved, the services are discovered, composed and managed automatically to address the user requirements in the best possible manner.
- *Dependability and Privacy*: This feature is demonstrated in various situations where personal information is about to be disclosed. For example, disclosure of food preferences or user's location occurs only once trust assessment negotiations between the parties involved have taken place and after the users' privacy preferences and the service's privacy policy have been considered.
- *Grouping and Sharing*: The feature of sharing a service among the members of a group of users is demonstrated in the air conditioning adaptation scene although there is also considerable potential for the formation of dynamic groups.
- *User Intent Prediction*: This feature is demonstrated at the scene where Mark's PSS automatically decides to print the session slides and again when his PSS selects the taxi sharing service. In the latter instance, his PSS predicts that he is about to depart. A sequence of Mark's actions indicates that his work in the meeting is ending and that he intends to depart by taxi.
- *Recommender Systems*: These systems are used in the scene where Mark receives recommendations about the rooms and topics of the next sessions that he might be interested to attend, based on others attendees' opinions and his personal history. This feature is also demonstrated in the selection of a specific taxi service.

- *Pro-active Behaviour*: The system uses predictions of user intent, coupled with user preferences and other people's recommendations, to discover, configure and initiate services automatically. For example, proactivity is demonstrated when the PSS initiates a negotiation to share a taxi and when it reconfigures Mark's room when Robbie arrives.
- *Learning and Reasoning*: This functionality is demonstrated in all the scenes where inference or predictions are made. This refers to context information, user preferences, user behaviour & intentions, and service discovery, selection, composition and configuration.
- *Mobility and Infrastructure*: In all scenes of the smart conference scenario, ad-hoc network connections are established, supporting intra- and inter-PSS communication among devices, enabling user and device mobility, and a robust runtime environment is available on all devices.

4. The PSS Architecture

The PSS architecture adopts a layered approach, as depicted in Figure 2. More specifically, the architecture consists of five different layers, each addressing a well defined part of the PSS functionality. The names and purpose of these layers are presented hereafter.

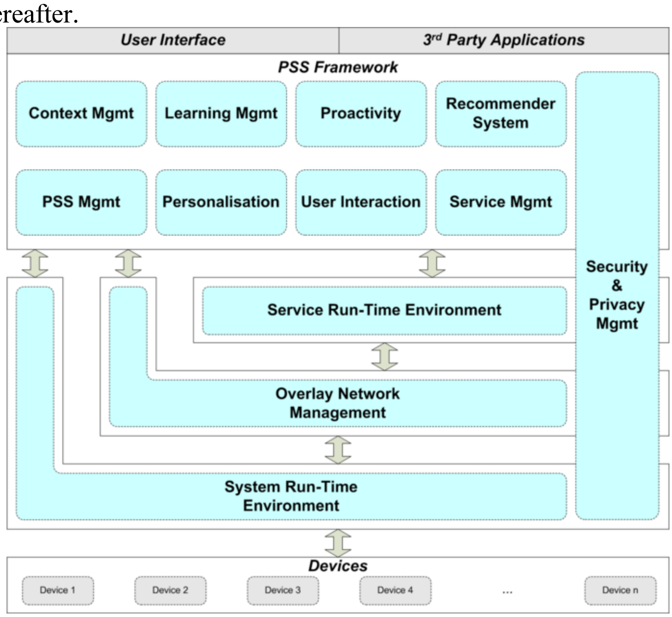

Figure 2. Functional view of the PSS Architecture.

Layer 1 - Devices

The PSS definition suggests that a single PSS can span across many different devices. Depending on their processing and networking capabilities, these devices may either implement the entire PSS stack or part of it, or simply interact with the rest of the PSS Framework. The device classification that follows, aims to identify the devices that may be part of a PSS and is based on a survey of current market-leading technologies grouped by functional/technical commonalities.

- Server: An independent computer dedicated to provide one or more services over a computer network (e.g. Windows Media Center, Apple Itheatre, PCs).
- Laptop: A small portable computer (e.g. Mac Book, Sony Vaio, Tablet PC).
- Mobile phone: A pocket-sized handheld computing device (e.g. iPhone, HTC Tytan, Nokia N90, PDAs).
- Sensors: A group of devices that can measure a physical quantity and convert it into a signal, which in turn can be read by an observer or an instrument. They can be embedded into other devices (e.g. RFID readers, GPS location estimators, accelerometers, thermometers, altimeters, barometers, air speed indicators, signal strength measurers).
- Smart object: A resource-constrained device (e.g. WiFi photoframe, Chumby, Nabaztag, home eAppliance, surveillance camera) that can be connected to the Internet or a LAN via a WiFi connection, ethernet, GPRS, 3G etc., usually intended for displaying multimedia content such as a combination of text, audio, still images, animation and video.
- Interactive entertainment electronic device: An Interactive entertainment electronic device producing a video display signal (e.g. set-top box, gaming console), which can be used with a display device (a television, monitor, etc.) to display a video game or an external source of signal (e.g. IPTV).

Layer 2 - System Run-Time Environment (RTE)

The System Run-Time layer serves as an abstraction layer between the underlying device operating system and the PSS software in order to achieve as much platform independence as possible. Essentially, this layer is what makes a device PSS-capable. Hence, employing an "off-the-shelf" implementation of a virtual machine run-time will offer PSS portability over a wide range of software and hardware platforms.

Layer 3 - Overlay Network Management (ONM)

The Overlay Network Management layer provides the PSS architecture with a Peer-to-Peer (P2P) management and communication layer. The services within this layer provide functionality for PSS peer group management, peer discovery and message routing between peer networks.

Layer 4 - Service Run-Time Environment

This layer provides a container for the PSS services. It supports service life cycle management features and provides a service registry and a device registry. Moreover, it allows for service management in a distributed fashion among multiple devices within the same PSS. In this context, it delivers fault tolerance as well as device resource management. The Service Run-Time Environment also provides advanced information management features for achieving high data availability and addressing storage requirements of PSS services.

Layer 5 - PSS Framework

The PSS Framework layer is the core of the PSS architecture. Its functions include discovering and composing PSS and 3rd party services, as well as managing context data and user preferences. Moreover, the PSS Framework layer supports automatic learning of preferences and user behaviour, as well as inference of context data & user intentions. This information, together with data from recommender systems, enables the proactive behaviour of the PSS platform. Grouping of context data and preferences as well as conflict resolution and resource sharing are also provided by this layer.

5. Personal Smart Spaces in the Future Internet

The Internet was designed to enable computers to communicate and this is reflected in the way humans interact with it. Technical details are still predominant in the Human-Internet interaction: firstly a connection has to be made, then services have to be identified and located, and finally accounts must be created for each service to be used before one can run them. Moreover, the main interaction device is typically a full-blown computer that is not usually portable or constantly at hand and provides a primitive "point-and-click" interaction style. The Future Internet (FI), on the other hand, will focus on end-user needs, providing pervasive and seamless access to services and the information that will represent each of us in the digital realm. The FI will be ubiquitous and transparent so that one is only aware that it exists when it is unavailable.

As we have seen, a PSS provides a cocoon around a user through which all their interactions with pervasive systems are mediated. The PSS is able to assess the trustworthiness of services and resources which are offered by pervasive environments and negotiate the disclosure of personal data to entities in that environment. The philosophy underlying PSSs could be extended to encompass all of a user's interactions with digital entities, providing them with a Personal *e*Space [15]. A Personal *e*Space would extend into the logical space of the Internet wherever the user goes. It would be the arena in which they undertake all their computer mediated contact. It would stand between them and the people and services with whom or with which they make contact. It would be aware of a user's history, context and preferences and use them to assess the contacts they make and the situations in which they find themselves.

Another extension of the PSS paradigm offers a way to meet the future demands of a particular use of the Internet that has seen a meteoric rise in popularity in recent years: social networking. We are already witnessing the first tentative steps towards a convergence between social and pervasive computing. An example of this is Twitter's geo-tagging location feature launched in November 2009 [16]. We can expect future social networking users to demand the context-aware and more highly personalisable "everyware" services which pervasive systems aim to provide anywhere at any time. In order to address this demand the SOCIETIES international consortium is being formed to develop the concept of a Community Smart Space.

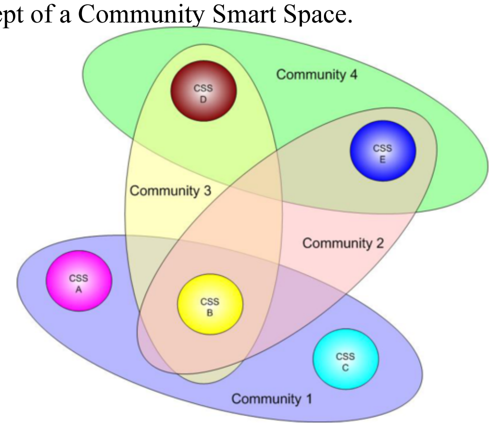

Figure 3. Five individuals using their CSSs to form four communities.

A Community Smart Space (CSS) is based on the PSS paradigm and aims to enable individuals to dynamically form themselves into communities (Figure 3). CSSs will inherit all of the context, personalisaton, privacy and service management functionality of PSSs and will bridge the gap between current web-based social networking and the pervasive next generation of social networking. The context-awareness of CSSs need not be limited simply to the location-awareness which is already starting to appear on mobile devices however. The sensor information available to a CSS can report a host of measurable characteristics about a user's environment, health and activities, and relay them to other members of the communities to which they belong: their work colleagues, medical centre, Twitter followers, Facebook or MySpace Friends, etc.

In its simplest manifestation, the integration of CSSs with social networks could permit the online "poke" or "nudge" to morph into an image of the poker appearing on any kind of display in the poked person's vicinity to alert them to a contact. More advanced convergence could unify the two concepts entirely. The people in one's social network will be locatable and, if in sight, identifiable, within the limits of the personal privacy policies of the individuals concerned. People with shared interests are likely to belong to a common social network group. They are likely to attend the same events or places of interest and, if at such a place concurrently, CSSs can alert them to each other's presence and enable them to meet physically. CSSs will enable people to leave messages about exhibits, restaurants, etc. which can be picked up automatically by other CSS community or social network group members who visit the same place at a later date.

CSSs also promise significant benefits in areas such as disaster management. Typically, disaster scenes attract diverse teams of international rescue experts, all of whom have to be briefed and kept up to date on the current situation as it evolves. The specialist skills of these experts need to be rapidly deployed to appropriate locations as soon as they become available. The dynamic community formation and management facilities which become possible via CSSs will enable international rescue teams to exchange multi-modal information and collaborate with each other and integrate their efforts with those of the local emergency services to optimal effect.

6. Conclusions

The industry expert group report "Future Internet 2020" [17] published in May 2009 provides a detailed overview on European expectations for the Future Internet in terms of key research challenges for Europe, key technology enablers, critical blocking points and recommendations for FI research. Rather than an evolution of the Internet, this report specifies that "*radically new approaches are needed: new architectures; ...; new ways of integrating all the different internet entities – devices, sensors, services, things and, of course, people*" [17].

The Persist project addresses the issue of Personal Smart Spaces intersecting together and with fixed (e.g. home, office) smart spaces support the FI notion of a "seamless fabric of classic networks and networked objects". The innovative PSS concept demonstrates that this vision of the FI is possible, but raises challenging technical issues. The most important one, which guides all the architectural choices, is the requirement for a "natural", hassle-free interaction with the FI. This is achieved in PSSs by context awareness and personalisation which permit customized individual experiences conditional upon situations, preferences and habits. Learning and reasoning are also employed to reduce the number of questions that the end-user is required to answer, and the capacity for pro-active behaviour ensures that actions are initiated on the user's behalf automatically whenever appropriate. Interoperability is another requirement that has had a major impact on the design decisions within the PSS framework. Network interoperability has led to the design of a Network layer based on peer to peer communication protocols, while the dynamic aspects of pervasive and mobile communications have led to support for Mobile Ad-hoc Networks. To this end, issues such as scalability and complexity prove to be among the most challenging. The PSS architecture has studied several approaches in order to deal with situations where very high numbers of PSSs interact and share services and data. The evaluation of the adopted approaches catering for the scalability of PSSs lies among our future plans. On a higher level, the need to manage a large number of services required modification of SOA-based architectures and concepts to meet the demands of the mobile realm. To maximize the perceived usefulness of PSS services, they have been augmented with semantic metadata that makes it possible for the framework to improve and orchestrate itself with the most appropriate selection of available PSS services at any given time and place. Finally, the more pervasive and knowledgeable a system is, the greater the risks to privacy and disclosure of confidential data. To avoid this, an extensive system for Identity and Privacy management has been built into the framework and a negotiation system based on trust assessments ensures that personal data is disclosed in a controlled and verified manner. The identity management components also provide a level of accountability that most business models will expect. We believe that all these features will need to be addressed to formulate and realise the FI vision. Thus, Personal Smart Spaces can be seen as a significant step towards the grand FI vision, and it is expected that future research work will build on the presented results by integrating the PSS concept with social networks and crowd computing.

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