Virtual Shared Workspace for Smart Spaces and M3-based Case Study

Dmitry Korzun*†, Ivan Galov*, Alexey Kashevnik‡ Sergey Balandin§¶
*Petrozavodsk State University (PetrSU), Petrozavodsk, Russia
†Helsinki Institute for Information Technology (HIIT) and Department of Computer Science and Engineering (CSE), Aalto University, Helsinki, Finland
‡St.Petersburg Institute for Informatics and Automation RAS (SPIIRAS), St.Petersburg, Russia
§FRUCT Oy, Helsinki, Finland
¶University ITMO, St.Petersburg, Russia
{dkorzun, galov}@cs.karelia.ru, alexey@iias.spb.su, sergey.balandin@fruct.org

Abstract—**Lack of practical development platforms and specific methods of application programming delays extensive real-life deployment of smart spaces. Virtual shared workspace is a reasonable scenario for evaluation of the smart spaces paradigm maturity. In this paper we consider SmartRoom system, which is Smart-M3 based open source implementation of virtual shared workspaces. Such collaboration activity as conference or meeting is performed in a room equipped with computing and presentational devices as well as accessing Internet services. Personal mobile devices are primary tools for users. Although the Smart-M3 platform is still a research prototype we show that its existing capability is sufficient for developing certain services for practical use. Functionality of SmartRoom services is not finely tuned and not strictly limited by activity domain. Advanced service construction with context awareness, personalization, and augmentation is possible. We illustrate these properties by introducing e-Tourism services for use in SmartRoom collaborative activity.**

I. Introduction

Over the last few years we heard a lot of predictions and comments on importance and future perspectives of the smart spaces paradigm. Despite of its elegance for programming service-oriented applications, the paradigm still suffers from the lack of practical development platforms, specific methods and models of programming [1], [2]. Emerging technologies of Internet of Things (IoT) also bring challenges and new opportunities for smart spaces deployment in real-life settings.

A popular example scenario for smart spaces is virtual shared workspace supporting collaboration activity. The new generation of personal devices (smartphones, tablets, etc.) allows people to effectively communicate with colleagues when working together, to flexibly provide own resources to the collective solving process, and to intelligently access assisting services. The next level of collaborative work requires deploying virtual shared workspaces. The current vision suggests that such a workspace is built on the IoT-aware environment localized in physical spatial-constrained space, e.g., within a room or a set of them [3]. The environment consists of locally equipped devices (WLAN connectivity) and allows accessing external services when needed.

This paper enhances our previous work [4] and reports on the recent development of SmartRoom system. The latter implements a virtual shared workspace scenario where personal mobile devices are primary access and control points for users to participate in such collaboration activity as conferences or meetings. The core services aim at support for intensive in-room collaboration using surrounding devices for hosting the system. The SmartRoom design is not oriented to finely tuned services for in-room activity. An essential target that our M3-based study achieves is to make the service set flexibly augmentable.

We propose advanced scenarios when e-Tourism services, operating in a different domain than SmartRoom, become included into the SmartRoom service pool and interleaved with other services. The e-Tourism services for SmartRoom support context-aware recommendations on the best way to reach the room and on nearby points of interest for the participants during their free time. The services also focus on the use of personal mobile devices for user-centric management during and after the collaboration activity.

Our development is based on Smart-M3 platform [5], where M3 stands for Multidevice, Multidomain, and Multivendor. The platform provides means for creating and deploying a smart space in given computing environment. The smart space realizes a shared knowledge base for this environment. Smart-M3 Semantic Information Broker (SIB) provides read&write access to the shared knowledge. Software agents, called knowledge processors (KP), interact via information sharing in the smart space, using the known interaction models: blackboard and publish/subscribe. Recently the Smart-M3 platform is a research tool for prototyping smart spaces applications—M3-based service systems. Nevertheless we show that its existing functionality is sufficient for implementing certain services for practical use.

We expect that our SmartRoom development presents a practical M3-based case study on construction of virtual shared workspace for smart spaces. Our architectural solutions make such a system deployable in IoT-aware settings. Many heterogeneous devices are included into interaction using wireless network communication in the local area. Our design solutions accent the “smartness” property of services. We identify the key components in service design for this property. Our study provides several reference solutions for implementing similar workspace scenarios based on the existing technology.

The rest of the paper is organized as follows. Section II describes related work. Section III summarizes our architectural solutions to implement and deploy the SmartRoom services. Section IV discusses the term “smart service” and provide its design formalization. Section V considers the service augmentation using e-Tourism services as a case study. Section VI concludes the paper.

II. Related work

Advances in software/hardware and Internet technologies have led to digital environments where collaborative activity can be effectively assisted with multimodal “smart” equipment. The concept of virtual shared workspace has emerged to address the need for collaboration when people access services to communicate with other people, analyze existing facts, create new knowledge, and share findings, either in face-to-face or remote scenarios.

An early system to broadcast, record, and remotely view meetings was studied in [6]. Participants from different geographical sites can have proper workspace for collaborative work, similarly as if they would be in the same room. The issues of this kind of collaborative work are carefully discussed in [7]. Many supporting technologies are recently available on the market. For instance, BeHere (http://www.behere.com) provides 360° Internet video for remote users to control personalized camera angles (independent of other viewers) and to gain a “be here” experience.

Kim and Fox [8] considered a ubiquitous collaboration framework for floor control in multimedia conferencing and collaboration work. Cell phones are primary end-user devices. A virtual shared workspace (conference room) is constructed for local and remote participants. Specialized coordination and sharing mechanisms are designed, see Community Grids Lab (CGL, http://communitygrids.iu.edu). Solutions for automatic control in such a system are discussed in [9].

The Access Grid (http://www.accessgrid.org) provides resources and technology to support group-to-group interactions. It can be used as an advanced type of videoconferencing facility that allows participants from multiple locations to interact in real-time. In addition it provides mechanisms to share data, collaborate using a variety of shared applications (such as sharing presentation material), utilize large-format displays, and employ multiple video sources to allow room-to-room conferencing capabilities. Similar ideas were elaborated in the Global-MMCS Project (Global Multimedia Collaboration System, http://www.globalmmcs.org), which builds a service-oriented collaboration system to integrate various services including videoconference, instant messaging, and streaming.

Although many problem-specific platforms and supporting technologies exist for creating virtual shared workspaces, to the best of our knowledge, only Smart-M3 [5] provides a general-purpose open-source platform for smart spaces. It supports interoperable ontology-driven knowledge representation, sharing, and reasoning. Methodological aspects of M3-based development of service-oriented systems are discussed in [10], [11], [2]. At present one of key contributors to the Smart-M3 platform is the Smart Spaces team of EIT ICT Labs (http://www.eitictlabs.eu/innovation-areas/smart-spaces/). A lot of relevant material can be found in the proceedings of Open International M3 Semantic Interoperability Workshop (http://www.fruct.org/eit-m3).

Smart Conference system [12] is predecessor work to ours. That system is a proof-of-the-concept prototype, which has elaborated the M3-based concept of assistance in conference activity. SmartRoom system further evolves the concept by introducing advanced architecture and service set. The focus is on intensive in-room collaboration using IoT-aware surrounding devices for hosting the services. Personal mobile devices are primary user tools. Participants are either locally present in the room or remote. SmartRoom covers wider area of collaborative activity, expanding to meetings and lectures.

III. SmartRoom System

The system consists of software agents that construct and deliver services in a shared smart space—*SmartRoom space*. It makes localization and relation of information in regard to spatial area of the room and to information sources of participants. The room is equipped with electronic devices to create a virtual workspace for such collaborative activity as conferences, meetings, or lectures. Devices are media information interfaces (projector–computer pairs, TV panels, interactive boards), sensing (physical sensors and actuators, activity detectors, microphones, cameras), user access and control (laptops, netbooks, smartphones), WLAN infrastructure.

A. Services and Users

The SmartRoom system scope was presented in [4]. A schematic view is depicted in Fig. 1. The services simplify

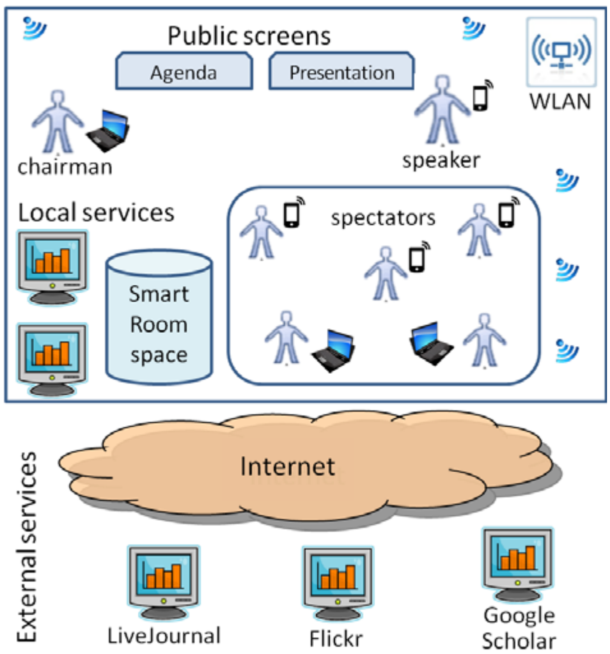

Fig. 1. SmartRoom system scope: Spectators are mobile users, services are constructed locally and accessing the Internet

organization (e.g., agenda management), user information presentation (e.g., slide show), and interactions (e.g., online discussion). Routine procedures of information search, retrieval, transformation, and sharing are automated. This intelligent assistance allows the people to concentrate on the problems the activity is devoted to, not on technical details of information manipulation.

Spectators participate in the activity and most of them are present physically in the room. Among spectators there are speakers who make presentations using Presentation screen (one of the two public screens). Every active speaker (in turn relay manner) and the chairman control the slide show and other multimedia visualization. The activity program is visualized on Agenda screen (another public screen). The program is a dynamic information entity, and the chairman is responsible for its control. The public screens are large-format displays visible to all participants in the room.

The core SmartRoom services are Presentation-service and Agenda-service: they are responsible for information visualization on Presentation and Agenda screen, respectively. Content-service keeps multimedia content which is used in activity (e.g., presentations, pictures, video) and provides the content to other SmartRoom components on request. For example, Presentation-service needs a recent slide to visualize on the public screen.

Other local services provide specific pieces of information and assistance for spectators. For instance, Conference-service constructs and dynamically maintains the activity program when the activity is a conference. Similar services are for other activity types (e.g., Meeting-service or Lecture-service), since properties of activity program (plan, recent state, history) differ. Other examples are services for browsing spectators' profiles and available presentations, discussion of ongoing activity, manipulation with camera angle/focus.

Each spectator can become a SmartRoom user via her SmartRoom client, which is a software agent running on her personal mobile device. On behalf of its user the client interacts with services, taking into account the recognized user needs and context. For instance, such a client provides personalized visualization of received information from services.

SmartRoom has a multimodal interface. Its basic UI elements are public screens and personal mobile devices. Computational part is delegated to local services, which access external services from the Internet if globally available information is required. For instance, the discussion service forms a blog based on the activity program on LiveJournal, and users discuss any presentation in this blog online. Another example is association of personal citation indexes (e.g., from Google Scholar) with particular spectators. Then the indexes can be visualized by Agenda-service or in SmartRoom client while browsing the list of spectators.

B. M3-based Design

SmartRoom employs Smart-M3 platform [5] to create the SmartRoom space in a given room. That smart space is maintained by Semantic Information Broker (SIB).[1] Software agents running on different devices interact with each other indirectly via communication with SIB. Network access to SIB follows Smart Spaces Access Protocol (SSAP), see [13] for details and possible extensions. Information representation uses RDF (Resource Description Framework) from Semantic Web, see [10], [11], [2] for more details on ontology-driven design and programming of M3-based systems.

TABLE I. DEVICES FOR SMARTROOM ENVIRONMENT

Devices	Role
WLAN equipment	Communication support for all devices in the local SmartRoom environment and their external access to Internet.
Media projectors, interactive boards, loudspeaker (with attached computers)	Public screens and media reproduction systems for common-interest services. Agenda screen visualizes the current activity agenda. Presentation screen visualizes speaker's slides.
Local computers	Running services related to cooperation with in-room digital equipment such as projectors, sensors, cameras, etc.
Server computers	Running SIB and admin console of SmartRoom services (for manual control if needed).
Video and audio capture devices	Sources of multimedia information flows: local recording or use of external services.
Physical data sensors	Measuring physical characteristics of the environment, (e.g., temperature, humidity, light).
Network activity sensors	Monitoring network activity in the room, e.g., for presence detection of mobile devices.
Personal mobile devices	Primary access and control tools for users to participate in SmartRoom activity.

In M3 terms, each software agent is a Knowledge Processor (KP) running on some device. Many of such devices are IoT-aware and connected using SmartRoom WLAN. Table I shows possible classes of devices and their role in SmartRoom. Any KP accesses the informational space content through SSAP-communication with SIB. The base interaction model is blackboard, through information sharing in a common store. Although direct communication between KPs is possible, it should be applied carefully due to the interoperability issue. Important extension is the publication/subscription model for interaction of KPs. The subscription operation provides KPs the way to perform persistent search queries and to detect changes of a specified subset of shared information [14].

The concept layers of the SmartRoom architecture is shown in Fig. 2. The basic programmable components are KPs: I) infrastructural KPs implement construction of services (infrastructure), II) client KPs implement personalized UI of mobile and remote users (client part). KPs associated with specific in-room equipment (including public UI elements) are also considered infrastructural.

Infrastructural KPs form infrastructure of SmartRoom that is responsible for service construction and delivery. Those KPs must process requests from client KPs in stable manner. Requests may be of explosive nature. They appear in a burst as reaction on certain events. For instance, whenever Presentation-service switches to a new slide then many clients retrieve the slide and visualize it to the users.

A service is implemented as interaction of one or more infrastructural KPs. Service design is event-driven, where the smart space reflects events as changes in informational content. This approach supports various service interleaving. Changes are made by client KPs and by infrastructural KPs themselves when they construct services. For instance, if a speaker moves to the next slide of her presentation (explicit command from

[1] Latest Smart-M3 SIB release is available at http://sourceforge.net/projects/smart-m3/ under BSD license.

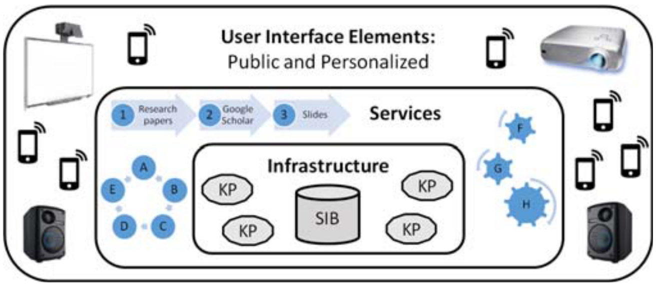

Fig. 2. Concept layers for SmartRoom components

client) then the following reaction appear in the primary scenario (conference-related activity).

- Presentation-service: showing the next slide.
- SmartRoom clients: similar reaction if their users are watching the presentation.
- Content-service: serving requests from the clients for a image file of the next slide.

The primary scenario can be augmented. The following examples of augmentation are possible.

- Timestamp is associated with the slide in the presentation history track.
- Spectators' comments for the slide appear in the public SmartRoom blog at LiveJournal.
- Camera moves to record the area in front of Presentation screen.

Service interleaving is a runtime process. Each service provides information to feed the SmartRoom space. The result is delivered to clients as well as can be used by other services. The latter option makes the informational content self-generated.

IV. Smart Services

The core services of SmartRoom system can be implemented using traditional models of distributed systems. Software modules with finely tuned functionality are developed for each system component: public screen, personal mobile device, activity control unit, etc. They have to communicate each with other using custom protocols. That approach, however, is focused on a predefined set of scenarios. More flexibility of runtime service construction and delivery is needed to "connect" many dynamic information sources with many distinguished consumers. Let us consider the smartness property of services in respect to this flexibility.

A. Smart Spaces Formalism

For service design description we apply the notation adapted from [15], [2]. From the point of view of informational content, a smart space is (I, O), where I is factual data stored and ontology O provides their logical representation structure.

Ontology is a tool to make use of the data and their semantics. For instance, ontology-aware write operations preserve information consistency and an agent specifies search queries based on the required logical structure of factual data. In the multi-agent case, the notion of common ontology for the entire smart space becomes more or less virtual. Explicit maintenance of space-wide large ontology O is impractical, and each agent may use own ontology, though partially agreed with others [16], [17].

In Smart-M3, informational content I is represented as a set of RDF triples. On a bit more abstract level of thinking I is a named collection of RDF graphs, similarly as it happens in the Semantic Web [18]. The query language is SPARQL, making an M3 smart space a SPARQL endpoint.

Ontology O can be written in OWL. Let o be a particular ontology used by the agent. The latter can specify a search query $q(o)$ to I. Write $[q(o) \to I]$ to denote the fact of content retrieval. The result is either existential (yes/no) or constructive (found piece of information). Write $I{+}y$ and $I{-}y$ to denote the insertion and removal of information piece y, respectively. This ontology-aware type of agent interaction in the smart space requires specific SDK and supporting middleware [19], [17].

B. Informational Services

SmartRoom services are informational, providing multimedia content for users via SmartRoom UI. A typical scenario is visualization of ongoing processes in the room. Transfer of dynamically changing information from the smart space to SmartRoom UI elements is a simple passive form of services. It feeds the participants with information for making their own decisions in the activity.

Table II shows examples of available information sources and its delivery as a service via SmartRoom UI. Agenda screen visualizes information that is important on the two scales: i) the whole activity lifetime from the past (finished talks) to the future (planned presentations) and ii) present time (current state of speaker's presentation). Presentation screen visualizes information that the current speaker needs to present. When the main activity is not started yet then the screen can be used for announcements, such as welcoming incoming spectators. Personal mobile devices (via SmartRoom clients) can 1) make the same visualization as Public screens, 2) personalize the visualization compared to the services for public screens, 3) use other services for visualization of their information.

The multitude of information sources and publishers, heterogeneity and dynamics of space-incoming information make the reason for smartness of services and their delivery to users. Each informational service s performs the conceptual steps formalized in Algorithm 1. This solution defines a decomposition of the smartness of a service onto the intelligence of each of those steps.

Algorithm 1 Information delivery actions of service s

Require: Ontology o_s to access information content I of the smart space. The set U of available UI devices.

Await $[q_{\text{act}}(o_s) \to I] = \text{true}$ {event-based activation}
Query $x := [q_{\text{info}}(o_s) \to I]$ {information selection}
Select $d \in U$ {target UI devices}
Visualization $v_d := v_d + x$ {service delivery}

TABLE II. INFORMATIONAL SERVICES AND SMARTROOM UI

Source \ UI	Agenda screen	Presentation screen	Personal device
Activity program	Up-to-date status	Recent progress and time limits	Duplication with personalization
Presentation of active speaker	Summarized view associated with speaker's part of the program (title, authors, etc.)	Slides and other multimedia visualization	Speaker: control. Participants: slide show (duplicated or personalized)
Corpus of presentations from spectators	Summarized view for each speaker (finished or awaiting) in the program.	*Inapplicable*	Browsing presentations of participants.
Personal profiles of participants	Summarized view for each spectator.	Slides and other multimedia visualization.	Browsing profiles of participants.
Audio flows from participants	*Inapplicable*	Room-embedded audio system is a logical extension of the screen.	Microphone to input speaker's voice.
Local video from room-installed cameras	Video show in a part of screen (focus on participants in the room).	*Inapplicable*	Control (individual or collaborative) of camera focus and direction.
Incoming multimedia flows from outside world	Summarized view associated with author/presenter.	Part of speaker's presentation.	Duplication with personalization.
Online discussions of participants	Visualization of latest messages.	List of questions after each talk.	Participation in discussion: reading and commenting.
User activity (e.g., network traffic)	Current status associated with participant.	*Inapplicable*	Browsing activity statuses of participants. Control of own activity status.
Physical environment data	Summarized view in a dedicated part of the screen.	Manipulation with lighting for the screen.	Browsing recent values of sensed physical parameters.

Step 1 detects when s is needed based on the current situation in the smart space. Step 2 makes selection of information piece x to deliver to the user. Step 3 decides which UI elements are target devices; this decision may be supported with knowledge from Step 1. Finally, Step 4 updates recent visualization v_d to include x on device d.

Consider an example of informational service. In the basic from, Welcome-service is a part of Agenda-service to visualize the process how new people are coming into the room. The event for activation is the first appearance of spectator in the room. The welcome note needs personal information (e.g., her name and country) and contextual information (e.g., best colleagues already present in the room). This information is queried from the SmartRoom space. The welcome note is then visualized on Agenda screen, possibly in respect to already shown information about this spectator.

C. Control services

Informational character of SmartRoom services supports the following way for automation of routine or laborious processes and for control of ongoing activity. The SmartRoom space keeps representation of activity processes. Any change in the representation is a control action.

Conceptual steps of such a service are formalized in Algorithm 2. Step 1 analyzes the space content to detect that a control action is needed. Steps 2 and 3 are reasoning over the recent situation, and s decides what updates (possibly without human intervention) the process representation requires.

Algorithm 2 Control actions of service s

Require: Ontology o_s to access smart space information content I. The set U of available UI devices.

1: Await $[q_{\text{act}}(o_s) \to I] = \text{true}$ {event-based activation}
2: Query $x := [q_{\text{info}}(o_s) \to I]$ {information selection}
3: Decide $y := f(x, o_s)$ {formulation of control action}
4: Update $I := I + y$ {service delivery}

For instance, detection of absent speaker when the turn is coming leads to canceling her presentation, recalculating the activity agenda, and delegating the control on presentation to the next speaker.

D. Service Flexibility

In the simplest form, a service is implemented as one KP. Service consumers are KPs running on UI elements. This way is close to traditional models of distributed systems. Adding a new service introduces a distinguished scenario, making incremental effect to the system.

On the other hand, Algorithms 1 and 2 do not fix the responsibility of their steps. They may involve different KPs and interaction between these KPs over the shared informational content. For instance, recalculation of the activity agenda may require several iterations to achieve a suitable result.

In general, a service is considered as a connector between many information sources and many consumers. Service design is focused on service input and output in the smart space. Input is constructed (by control services) from different sources. There can be many services that have operated before the input appears in the smart space. Output is then shared for use by many consumers. In case of informational services, the output is visualized on UI elements. In case of control services, the output is used as input for other services.

Adding a new service introduces a combination of scenarios to the system since the output can activate existing services. Services can be flexibly interleaved, multiplying the effect.

V. ADVANCED SCENARIOS: USE OF E-TOURISM SERVICES IN SMARTROOM

The smartness schemes for SmartRoom services that we discussed in the previous section support advanced scenarios. As a particular study let us consider e-Tourism services and their use for enhancing the SmartRoom service set.

A set of smart e-Tourism services[2] for use in smart spaces were presented in [20], [21], [22]. The services are summarized in Table III and include Attraction information service, Recommendation service, Region context service, Public transport service, and Ridesharing service.

Although at the first glance the SmartRoom and e-Tourism services are disparate, their useful integration is possible. It enhances the core functionality of the SmartRoom system, introducing a new view what kind of assistance can be implemented for collaboration activity. Let us consider the following scenarios for use of e-Tourism services in SmartRoom (Fig. 3).

[2]Client for Android OS is available for installation at https://play.google.com/store/apps/details?id=ru.nw.spiiras.tais

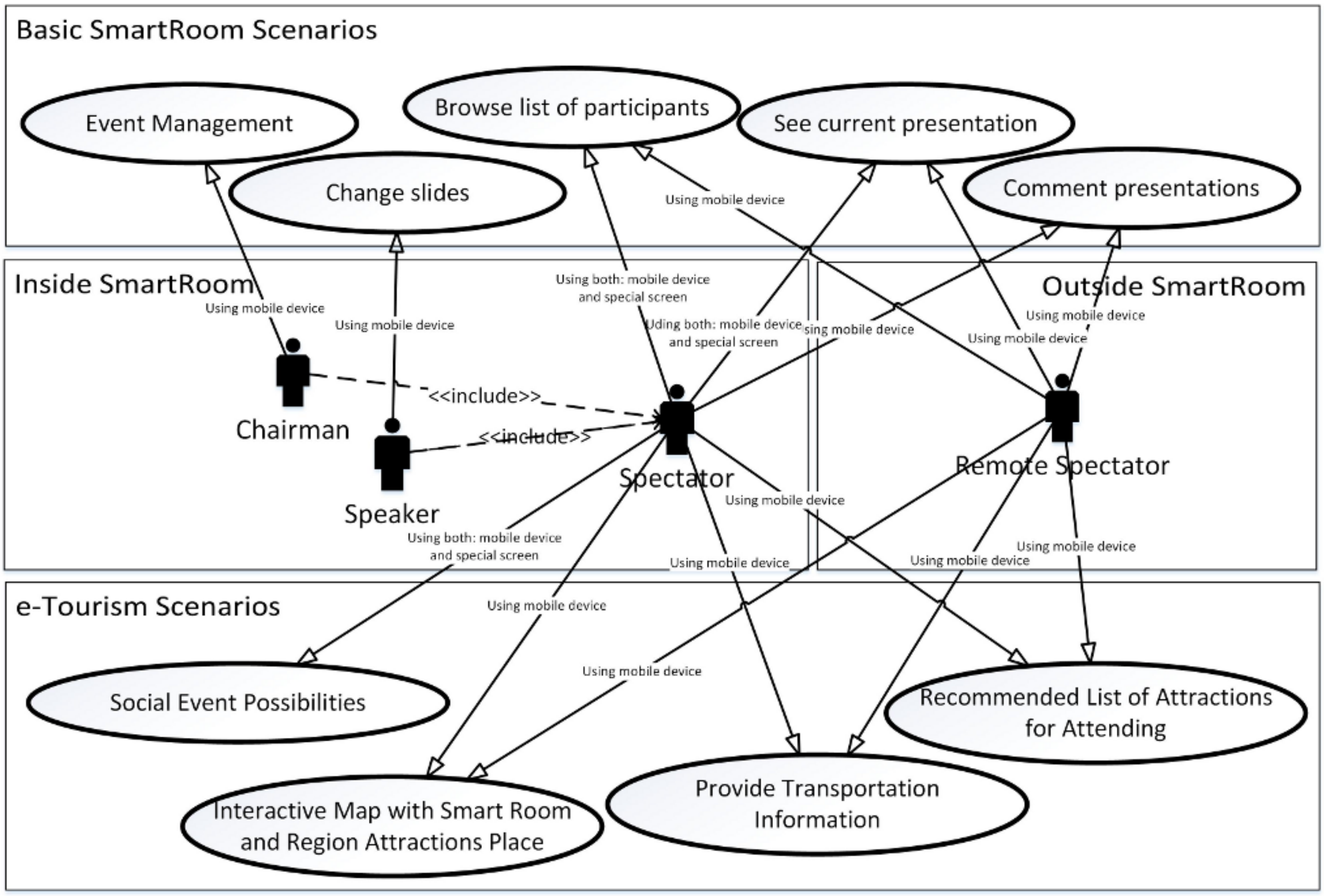

Fig. 3. UML use cases diagram: Use of e-Tourism services in SmartRoom scenarios

TABLE III. BASIC E-TOURISM SERVICES

Service	Description
Attraction information	Implements retrieving and caching the data about attractions and their locations.
Recommendation	Evaluates attraction/image/description scores based on ratings having been saved in the internal database [22].
Region context	Acquires and provides information about current situation in the region (e.g., weather, traffic jams, closed attractions).
Ridesharing	Finds matching the spectator and preferred attraction locations with accessible in the region transport paths to these locations [20].
Public transport	Finds information about public transport applicable to reach preferred attraction [21].

Social event possibilities: This scenario provides each SmartRoom spectator with information about possible places of social event activity. The possibilities are ranked in accordance with her preferences. Images and description are provided when the spectator clicks to a selected place. For this scenario the attraction information service, context service and recommendation services are used. All of them are developed as M3 KPs and share information in the SmartRoom space.

The attraction information service implements extraction of photos and descriptions about social possibilities available near the SmartRoom location. Location is shared in the SmartRoom space. Descriptive information is extracted from different Internet sources taking into account current situation around the SmartRoom location provided by the context service. Extracted information is shared in the SmartRoom space. The recommendation service receives subscribe notification and implements ranking of social event possibilities in accordance with personal preferences available in the SmartRoom space and current situation in the region. The scenario is used by spectators inside SmartRoom; they can see the proposed places on public screen in the room and on mobile device. Using their mobile devices participants can vote for a social event place.

List of attractions for attending: This scenario has the same procedure as the scenario for social event possibilities. The difference is that for searching social events possibilities the organizers provide predefined places of interests. This scenario is accessible for both: spectators inside SmartRoom and remote participants.

Interactive map with SmartRoom location and other interesting places: This scenario provides information to SmartRoom spectators on interesting places around SmartRoom location. Guidance on how to reach them is also provided. A list of interesting places is generated and shared in the SmartRoom space by the attraction information service. SmartRoom client shows list of these interesting places and visualizes them on an interactive map. This scenario is accessible also for both: spectators inside SmartRoom and remote ones.

Providing transportation information: This scenario allows a SmartRoom spectator to find public transport to reach

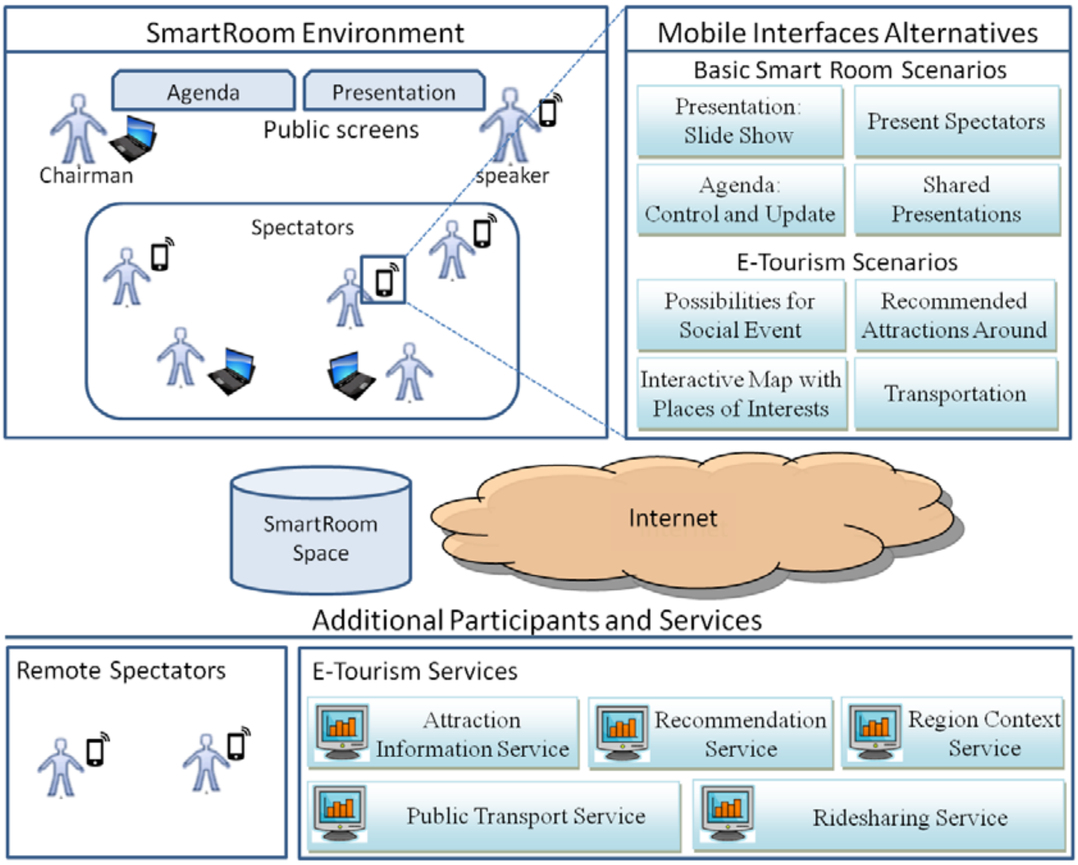

Fig. 4. Architectural scheme of augmenting the SmartRoom system with e-Tourism services

the SmartRoom destination location. Another option is to find fellow travelers who can drive her to that location. Similar information is useful for searching interesting attraction nearby or the hotel she lives in and needs to find a way to after the SmartRoom activity.

The scenario uses public transport and ridesharing services. SmartRoom client shares spectator's and destination locations. Then, public transport and ridesharing services are notified that transportation for user is needed. They calculate transportation possibilities and share them with the smart space. Then, SmartRoom client presents them to the spectator. This scenario is applicable for people present locally in the room as well as for remote spectators.

The following architecture is proposed for the above e-Tourism scenarios in SmartRoom, see Fig. 4. Personal mobile device should include both pure e-Tourism scenarios and SmartRoom-aware e-Tourism scenarios. All services share information in the SmartRoom space. Remote users have limited access to the scenarios, compared with physically present spectators.

The following e-Tourism services are information providers: Attraction Information Service, Recommendation Service, Region Context Service, and Public Transport Service. Each of them follows Algorithm 1. Ridesharing service integrates features of informational and control services. On one hand, the service provides the spectator with information about available drivers for the given destination. On the other hand, the service finds a driver for the agreed location (see Algorithm 2).

SmartRoom client integrates e-Tourism client running on the user mobile device. Other services use powerful computer systems. The main tasks of client application development are: sharing information about spectator context, profile, and actions; communication with the SmartRoom space; providing results to the user; publishing ratings of attended attractions, browsed descriptions, and images to the SmartRoom space.

The attraction information service is responsible for the four main tasks.

1) Extracting attraction titles from external sources and sharing them in the smart space.
2) Caching acquired information for quick access of users in the same location without additional requests to external sources in nearest future (lifetime of cached attraction is set by application administrator).
3) Providing internal identifiers for attractions, which are stored in Geo2Tag platform [23] (the platform provides possibilities of quick search identifiers by locations).
4) Extracting default images for attractions that are stored in internal database. Default images are defined by recommendation service as the best image for an attraction based on tourists ratings.

5) Extracting attraction details (lists of images and text descriptions) from external sources and sharing it in the smart space.
6) Setting and refreshing default images in the internal database for the attractions based on information available in smart space from recommendation service.

The recommendation service is responsible for ranking attractions, images, and descriptions for providing the tourist the best attractions to see and the best images and description of chosen attraction for acquaintance. It stores in the internal database the following mappings: (internal identifier, context $\rightarrow$ rating), (image URL $\rightarrow$ rating), (description URL, description text $\rightarrow$ rating). The internal database also keeps similarities between users, which are calculated as background process. The region context service acquire from region specific services information about tourist location area as soon as client application publishes tourist context to the smart space. Context information is published to the smart space and used by other services.

Public transport and ridesharing services provides alternatives for transportation means for reaching preferred attraction by the tourist. While public transport service provides the tourist a route that described the sequence of transportations to reach preferred attraction, ridesharing service finds a driver, which goes from the tourist location to the same direction.

VI. Conclusion

The paper presented our approach to implementation of virtual shared workspace environment. This use case has strong clear demand and is a good example for smart spaces based solutions. Emerging technologies of smart spaces and Internet of Things as well as the Smart-M3 platform allowed implementing such a workspace as the SmartRoom system. The development is publicly available[3] for deployment in a digitally equipped room. SmartRoom clients are available for installation for major mobile platforms.[4]

We expect that our design solutions can be transferred to the development of similar use cases for smart spaces, either on top of Smart-M3 or another smart spaces platform. The advantage of our solutions is in service flexibility and smartness. The semantics-oriented style of information processing, which is supported by Semantic Web technologies, allows construction of interleaving services; the variants are only limited by our imagination. The SmartRoom system is not strictly limited with finely tuned services. The service set is augmentable as we showed based on the case study with existing e-Tourism services.

At the moment an essential problem of smart spaces development and deployment is the lack of practical platforms. Nevertheless, this paper indicates that existing functionality of Smart-M3 is sufficient for practical use at least of some services. Our expectation is that in about 5 years the market will have several full-valued commercial smart spaces platforms and at least one open source alternative. In particular, Smart-M3 has certain chance to become such an open source alternative.

[3] Open source code (GPLv2) can be downloaded from http://sourceforge.net/projects/smartroom/.

[4] Android: http://play.google.com/store/apps/details?id=petrsu.smartroom.android.srclient&hl=en,
Windows Phone: http://www.windowsphone.com/en-us/store/app/smart-room/77aa6b83-d040-4839-8226-92eaa9bde01,
Symbian: http://store.ovi.com/content/444567

Acknowledgment

This joint research is financially supported by ENPI CBC Karelia grant KA322 (co-funded by the European Union, the Russian Federation, and the Republic of Finland), by grants # 14-07-00252 and # 13-07-00336 of the Russian Foundation for Basic Research, by project # 1481 (basic part of state research assignment # 2014/154) of the Ministry of Education and Science of the Russian Federation. The article was published with financial support from the Strategic Development Program of Petrozavodsk State University. This work was partially financially supported by Government of Russian Federation, Grant 074-U01.

References

[1] D. J. Cook and S. K. Das, "Pervasive computing at scale: Transforming the state of the art," *Pervasive Mob. Comput.*, vol. 8, no. 1, pp. 22–35, Feb. 2012.

[2] D. Korzun, S. Balandin, and A. Gurtov, "Deployment of Smart Spaces in Internet of Things: Overview of the design challenges," in *Proc. 13th Int'l Conf. Next Generation Wired/Wireless Networking and 6th Conf. on Internet of Things and Smart Spaces (NEW2AN/ruSMART 2013)*, ser. LNCS 8121, S. Balandin, S. Andreev, and Y. Koucheryavy, Eds. Springer-Verlag, Aug. 2013, pp. 48–59.

[3] X. Wang and P. S. Dunston, "Comparative effectiveness of mixed reality-based virtual environments in collaborative design," *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, vol. 41, no. 3, pp. 284–296, May 2011. [Online]. Available: http://dx.doi.org/10.1109/TSMCC.2010.2093573

[4] D. Korzun, I. Galov, and S. Balandin, "Smart room services on top of M3 spaces," in *Proc. 14th Conf. of Open Innovations Association FRUCT*, S. Balandin and U. Trifonova, Eds. SUAI, Nov. 2013, pp. 37–44.

[5] J. Honkola, H. Laine, R. Brown, and O. Tyrkkö, "Smart-M3 information sharing platform," in *Proc. IEEE Symp. Computers and Communications (ISCC'10)*. IEEE Computer Society, Jun. 2010, pp. 1041–1046.

[6] R. Cutler, Y. Rui, A. Gupta, J. Cadiz, I. Tashev, L.-w. He, A. Colburn, Z. Zhang, Z. Liu, and S. Silverberg, "Distributed meetings: A meeting capture and broadcasting system," in *Proc. the 10th ACM Int'l Conf. on Multimedia (MULTIMEDIA '02)*. ACM, 2002, pp. 503–512.

[7] Z. Yu and Y. Nakamura, "Smart meeting systems: A survey of state-of-the-art and open issues," *ACM Comput. Surv.*, vol. 42, no. 2, pp. 8:1–8:20, Mar. 2010.

[8] K. Kim and G. C. Fox, "Modeling, simulation, and practice of floor control for synchronous and ubiquitous collaboration," *Multimedia Tools Appl.*, vol. 53, no. 1, pp. 213–236, May 2011.

[9] R. M. Yusupov, A. L. Ronzhin, M. V. Prishchepa, and A. L. Ronzhin, "Models and hardware-software solutions for automatic control of intelligent hall," *Autom. Remote Control*, vol. 72, no. 7, pp. 1389–1397, Jul. 2011.

[10] S. Balandin and H. Waris, "Key properties in the development of smart spaces," in *Proc. 5th Int'l Conf. Universal Access in Human-Computer Interaction. Part II: Intelligent and Ubiquitous Interaction Environments (UAHCI '09)*. Springer-Verlag, 2009, pp. 3–12.

[11] E. Ovaska, T. S. Cinotti, and A. Toninelli, "The design principles and practices of interoperable smart spaces," in *Advanced Design Approaches to Emerging Software Systems: Principles, Methodology and Tools*, X. Liu and Y. Li, Eds. IGI Global, 2012, pp. 18–47.

[12] D. G. Korzun, I. V. Galov, A. M. Kashevnik, N. G. Shilov, K. Krinkin, and Y. Korolev, "Integration of Smart-M3 applications: Blogging in smart conference," in *Proc. 4th Conf. Smart Spaces (ruSMART'11) and 11th Int'l Conf. Next Generation Wired/Wireless Networking (NEW2AN'11)*. Springer-Verlag, Aug. 2011, pp. 51–62.

[13] J. Kiljander, F. Morandi, and J.-P. Soininen, “Knowledge sharing protocol for smart spaces,” *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 3, pp. 100–110, 2012. [Online]. Available: http://thesai.org/Downloads/Volume3No9/Paper_15-Knowledge_Sharing_Protocol_for_Smart_Spaces.pdf

[14] A. A. Lomov and D. G. Korzun, “Subscription operation in Smart-M3,” in *Proc. 10th Conf. of Open Innovations Association FRUCT and 2nd Finnish–Russian Mobile Linux Summit*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Nov. 2011, pp. 83–94.

[15] Y. Korolev, D. Korzun, and I. Galov, “Smart space applications integration: A mediation formalism and design for Smart-M3,” in *Proc. 12th Int'l Conf. Next Generation Wired/Wireless Networking (NEW2AN 2012) and 5th Conf. Internet of Things and Smart Spaces (ruSMART 2012)*, ser. LNCS 7469. Springer-Verlag, Aug. 2012, pp. 128–139.

[16] A. A. Lomov, “Ontology-based KP development for Smart-M3 applications,” in *Proc. 13th Conf. of Open Innovations Association FRUCT and 2nd Seminar on e-Tourism for Karelia and Oulu Region*, S. Balandin and U. Trifonova, Eds. SUAI, Apr. 2013, pp. 94–10.

[17] M. Palviainen and A. Katasonov, “Model and ontology-based development of smart space applications,” *Pervasive Computing and Communications Design and Deployment: Technologies, Trends, and Applications*, pp. 126–148, May 2011.

[18] C. Gutierrez, C. A. Hurtado, A. O. Mendelzon, and J. Pérez, “Foundations of semantic web databases,” *J. Comput. Syst. Sci.*, vol. 77, no. 3, pp. 520–541, May 2011.

[19] D. Korzun, A. Lomov, P. Vanag, J. Honkola, and S. Balandin, “Generating modest high-level ontology libraries for Smart-M3,” in *Proc. 4th Int'l Conf. Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM 2010)*, Oct. 2010, pp. 103–109.

[20] A. Smirnov, N. Shilov, A. Kashevnik, N. Teslya, and S. Laizane, “Smart space-based ridesharing service in e-Tourism application for Karelia region accessibility: Ontology-based approach and implementation,” in *Proc. 8th Int'l Joint Conf. on Software Technologies (ICSOFT 2013)*, J. Cordeiro, D. A. Marca, and M. van Sinderen, Eds. SciTePress, Jul. 2013, pp. 591–598.

[21] A. Smirnov, A. Kashevnik, S. I. Balandin, and S. Laizane, “Intelligent mobile tourist guide,” in *Proc. 13th Int'l Conf. Next Generation Wired/Wireless Networking and 6th Conf. on Internet of Things and Smart Spaces (NEW2AN/ruSMART 2013)*, ser. LNCS 8121, S. Balandin, S. Andreev, and Y. Koucheryavy, Eds. Springer-Verlag, Aug. 2013, pp. 94–106.

[22] A. Smirnov, A. Kashevnik, A. Ponomarev, N. Shilov, M. Schekotov, and N. Teslya, “Recommendation system for tourist attraction information service,” in *Proc. 14th Conf. of Open Innovations Association FRUCT*, S. Balandin and U. Trifonova, Eds. SUAI, Nov. 2014, pp. 148–155.

[23] K. Krinkin and K. Yudenok, “Geo-coding in smart environment: Integration principles of Smart-M3 and Geo2Tag,” in *Proc. 13th Int'l Conf. Next Generation Wired/Wireless Networking and 6th Conf. on Internet of Things and Smart Spaces (NEW2AN/ruSMART 2013)*, ser. LNCS 8121, S. Balandin, S. Andreev, and Y. Koucheryavy, Eds. Springer-Verlag, Aug. 2013, pp. 107–116.