Multilevel Self-Organization in Smart Environment
Service-Oriented Approach

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Abstract: Self-organization of distributed devices of a smart environment requires development of self-organisation mechanisms. However, uncontrolled self-organization can often lead to wrong results. The presented approach utilizes the “top-to-bottom” configuration principle to solve this problem. The device heterogeneity problem is addressed via proposed service-based architecture, enabling replacement of the organisation of the smart environment with that of distributed service network. Application of the approach is illustrated via a museum smart environment case study.

1 INTRODUCTION

The expanding capabilities of mobile devices let them to be used in the growing number of human activities. However, such trend requires a significant increase of information sharing. Smart evironments are aimed to assist in solving this problem. They assume presence of a number of physical devices that use shared view of the resources and services provided by them (Smirnov et al., 2009).

In order for such systems to operate efficiently, they have to be provided with self-organisation mechanisms and negotiation protocols. Self-organising systems are characterised by their capacity to spontaneously (without external control) produce a new organisation in case of environmental changes. These systems are particularly robust, since they adapt to changes, and are able to ensure their own survivability (Serugendo and Gleizes, 2006).

The process of self-organisation of a network assumes creating and maintaining a logical network structure on top of a dynamically changing physical network topology. This logical network structure can be used as a scalable infrastructure by various functional entities like address management, routing, service registry, media delivery, etc. The autonomous and dynamic structuring of components, context information and resources is the essential work of self-organisation (Ambient Networks Phase 2, 2006). The network is self-organised in the sense that it autonomically monitors available context in the network, provides the required context and any other necessary network service support to the requested services, and self-adapts when context changes.

The key mechanisms supporting self-organising networks are self-organisation mechanisms and negotiation models. The following self-organisation mechanisms are usually selected (Telenor, 2007): intelligent relaying; adaptive cell sizes; situational awareness; dynamic pricing; intelligent handover.

The following negotiation models can be mentioned (De Mola and Quitadamo, 2006):

- Different forms of spontaneous *self-aggregation*, to enable both multiple distributed services / agents to collectively and adaptively provide a distributed service, e.g. a holonic (self-similar) aggregation.
- *Self-management* as a way to enforce control in the ecology of services / agents if needed (e.g. assignment of “manager rights” to a service / agent.
- *Situation awareness* – organization of situational information and their access by services / agents, promoting more informed adaptation choices by them and advanced forms of stigmergic (indirect) interactions.

The multilevel self-organisation has not been addressed yet in research. This approach would enable a more efficient self-organisation based on the “top-to-bottom” configuration principle, which assumes conceptual configuration followed by parametric configuration (Figure 1).

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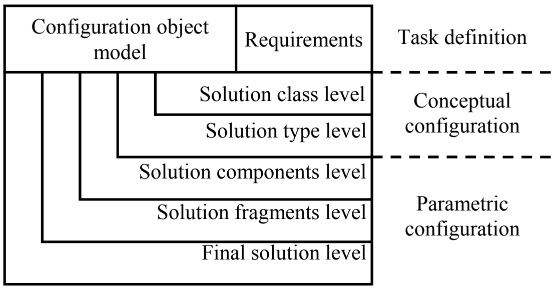

Figure 1: Multi-level configuration.

2 RELATED WORK

The approaches to creating systems of autonomous elements are currently being widely developed in the areas of context-dependent decision support systems (sponsored by DARPA), forming self-contextualized networks (IST-2004-2.4.5 Ambient Networks, FP 6), creation of self-organising systems (ICT-2007.1.1 Self-optimisation and self-configuration in wireless networks, FP 7) and other.

DARPA ITO Project S3: Scalable Self-Organizing Simulations (ITO Project S3, 2000) addresses development and distribution of Scalable Simulation Framework (SSF) and the SSFNet Internet modeling tools.

Another DARPA sponsored project Self-Organizing Sensor Networks (Institute for Reconfigurable Smart Components, 2003) assumes that self-organizing sensor networks may be built from sensor nodes that may spontaneously create impromptu network, assemble the network themselves, dynamically adapt to device failure and degradation, manage movement of sensor nodes, and react to changes in task and network requirements. Reconfigurable smart sensor nodes enable sensor devices to be self-aware, self-reconfigurable and autonomous.

The Ambient Networks EC FP6 project (Ambient Networks Phase 2, 2006) is addressing these challenges by developing mobile network solutions for increased competition and cooperation in an environment with a multitude of access technologies, network operators and business actors. It offers a complete, coherent wireless network solution based on dynamic composition of networks that provide access to any network through the instant establishment of inter-network agreements. The concept offers common control functions to a wide range of different applications and access technologies, enabling the integrated, scalable and transparent control of network capabilities.

The vision of SOCIETIES (Self Orchestrating CommunIty ambient IntelligEnce Spaces, EC FP7 project, Waterford Institute of Technology, 2013) is to develop a complete integrated solution via a Community Smart Space (CSS) which extends pervasive systems beyond the individual to dynamic communities of users. CSSs will embrace online community services, such as Social Networking, and thus offer new and powerful ways of working, communicating and socialising.

Tangible results of the project SENSEI (Integrating the physical with the digital world of the network of the future, EC FP7 project, SENSEI, 2010) include a highly scalable architectural framework with corresponding protocol solutions that enable easy plug and play integration of a large number of globally distributed wireless sensor and actuator networks (WS&AN) into a global system.

One more EC FP7 project SOCRATES (Self-optimization and self-configuration in wireless networks, SOCRATES, 2010) investigates the application of self-organization methods, which includes mechanisms for self-optimization, self-configuration and self-healing, as a promising opportunity to automate wireless access network planning and optimization, thus reducing substantially the Operational Expenditure (OPEX) and improving network coverage, resource utilization and service quality. Fundamental drivers for the deployment of self-organization methods are the complexity of the contemporary heterogeneous access network technologies, the growing diversity in offered services and the need for enhanced competitiveness.

3 SERVICE-ORIENTED APPROACH

The proposed approach is based on the idea of smart environment where all participating devices are represented via services (Johanesson, 2008). The service-oriented architecture (SOA) is a step towards information-driven collaboration. This term today is closely related to other terms such as ubiquitous computing, pervasive computing, smart space and similar, which significantly overlap each other (Balandin et al., 2009).

The proposed service-oriented approach to efficient multilevel self-organisation of services in the smart environment assumes information actualization in accordance with the current situation. An ontological model is used in the approach to solve the problem of service heterogeneity (Smirnov et al., 2012). This model makes it possible to enable interoperability between heterogeneous services due to provision of their common semantics (Uschold and Grüninger, 1996). Application of the context model makes it possible to reduce the amount of information to be processed. This model enables management of information relevant for the current situation (Dey, 2001). The access to the services, information acquisition, transfer, and processing (including integration) are performed via usage of the technology of Web-services.

Figure 2 represents the generic scheme of the approach. The main idea of the approach is to represent the smart environment members by sets of services. This makes it possible to replace the organisation of the smart environment with that of distributed service network. As it was mentioned the configuration is done based on the "top-to-bottom" configuration principle, which assumes conceptual configuration followed by parametric configuration. The information between levels is transferred through guiding from the upper level to the lower level.

For the purpose of interoperability the services are represented by Web-services using the common notation described by the application ontology. Depending on the problem considered the relevant part of the ontology is selected forming the abstract context that, in turn, is filled with values from the sources resulting in the operational context. The operational context represents the constraint satisfaction problem that is used during self-organization of services for problem solving.

4 REFERENCE MODEL OF SMART ENVIRONMENT MEMBER

The proposed reference model of the multilevel self-organization is presented in Figure 3. Below, its main components are described in detail.

Smart environment member (service, agent, sensor, etc.) is an acting unit of the multilevel self-organization process. It has **structural and parametric knowledge**, and **profile**. It is characterized by such properties as self-contextualization, self-management, autonomy, and proactiveness.

Structural Knowledge is a conceptual description of the problems to be solved by the

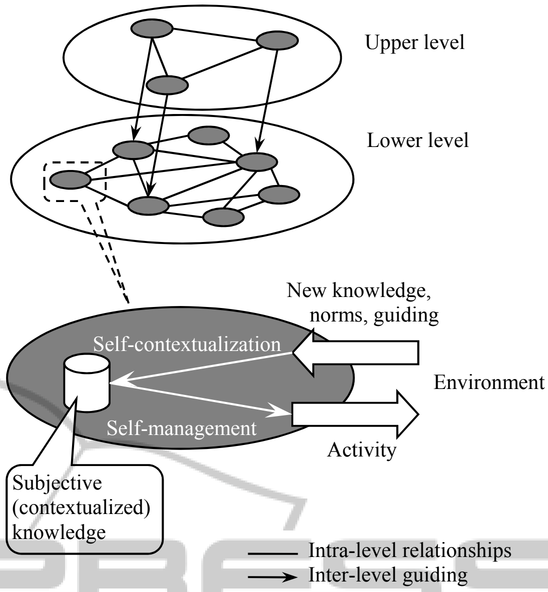

Figure 2: Generic scheme of the approach.

smart environment member. This is the member's internal ontology. It describes the structure of the member's **parametric knowledge**. Depending on the situation it can be modified (adapted) via the **self- management** capability. It also describes the terminology of the member's **context** and **profile**.

Parametric knowledge is knowledge about the actual situation defining the smart environment member's **behavior**. Its structure is described by the member's **internal ontology**, and the parametric content depends on the **context**.

Context is any information that can be used to characterize the situation of an entity where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves (Dey et al., 2001). The context is purposed to represent only relevant information and knowledge from the large amount of those. Relevance of information and knowledge is evaluated on a basis how they are related to a modelling of an ad hoc problem. The context is represented in terms of the smart environment member's **internal ontology**. It is updated depending on the information from the member's **ecosystem** and as a result of its **activity in the community**. The context updates the member's **parametric knowledge**, which in turn defines the. member's **behaviour**. The ability of a system (smart environment member) to describe, use and adapt its behavior to its context is referred to as **self-contextualization** (Raz et al., 2006). The present research exploits the idea of self-contextualization to

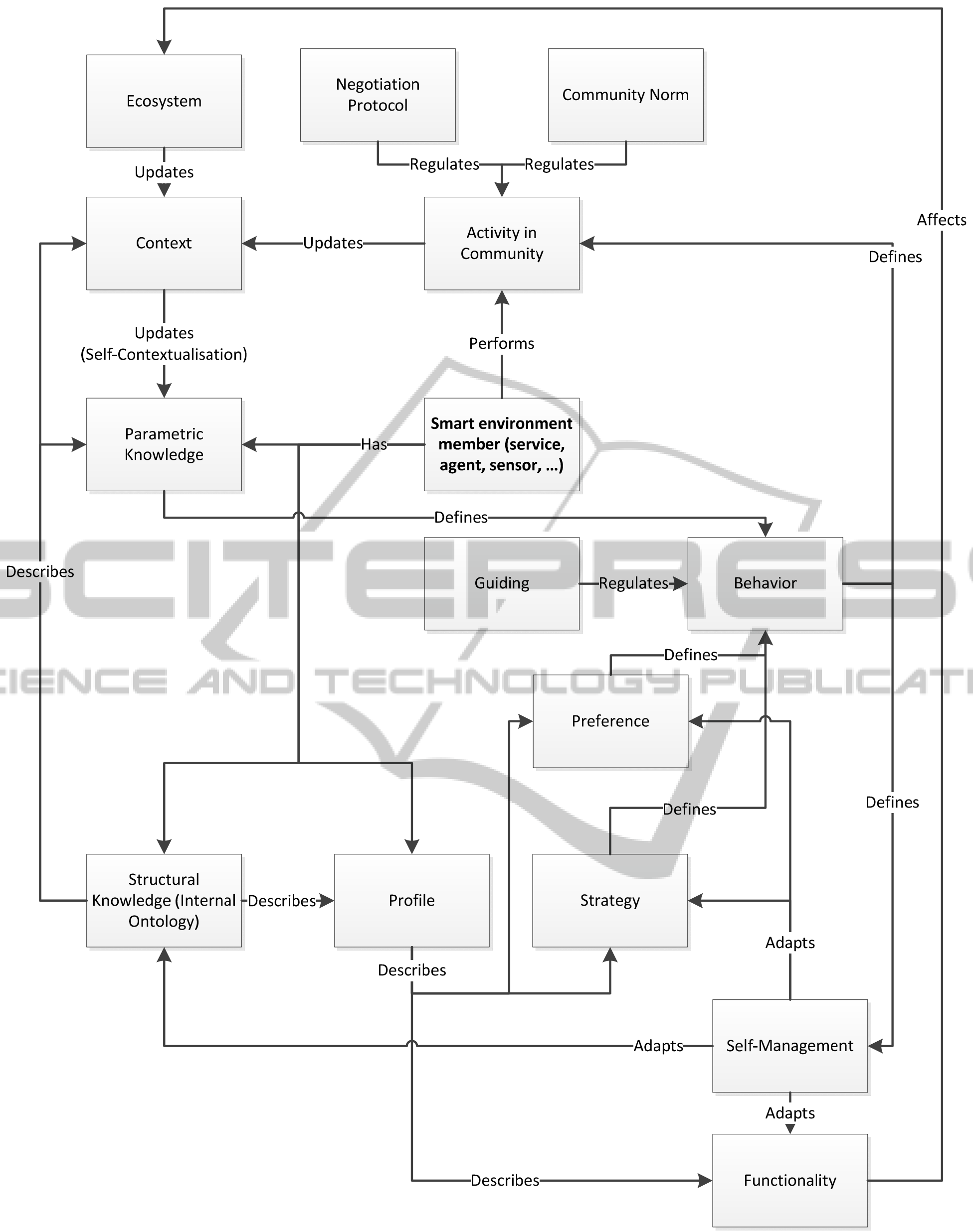

Figure 3: Reference model of multi-level self-organisation.

autonomously adapt behaviors of multiple members to the context of the current situation in order to provide their services according to this context and to propose context-based decisions. To achieve this purpose the smart environment members have to be context / situation – aware and context-adaptable.

Ecosystem is the surroundings of the smart **environment**, that may interact with its members. The ecosystem affects the members' **context**. The **smart environment member** can affect the ecosystem if it has appropriate **functionality** (e.g., a manipulator can change the location of a corresponding part).

Functionality is a set of functions the **smart environment member** can perform. Via it the **member** can modify its **ecosystem**. The member's functionality can be modified in certain extent via the **self-management** capability. The functionality is described by the member's **profile**.

Profile describes the smart environment member's **functionality** in terms of the member's **internal ontology** and in a way understandable by other members of the smart environment.

Self-Management is a smart environment member's capability to modify (reconfigure) its **internal ontology**, **functionality, strategy**, and **preferences** in response to changes in the **ecosystem**.

Behavior is the smart environment member's capability to perform certain actions (**activity in community** and/or **functionality**) in order to change the own state and the state of the **ecosystem** from the current to the preferred ones. The behavior is defined by the member's **preferences** and **strategies**, as well as by the **guiding** from a higher level of the self-organization.

Guiding is a set of principles and/or rules coming from a higher level of self-organization to direct the **behavior** and achieve rational outcomes on a lower level of self-organization.

Preference is a smart environment member's attitude towards a set of own and/or environmental states and/or against other states. The preferences are described by the member's **profile** and affect the member's **behavior**.

Strategy is a pre-defined plan of actions rules of action selection to change the smart environment member's own state and the state of the **ecosystem** from the current to the preferred ones. The strategy is described by the member's **profile** defines the member's behavior.

Activity in community is a capability of the **smart environment member** to communicate with other members and negotiate with them. It is regulated by the **negotiation protocol** and **community norms**.

Negotiation protocol is a set of basic rules so that when smart environment members follow them, the system behaves as it supposed to. It defines the **activity in community** of the members.

Community Norm is a law that governs the smart environment member's **activity in community**. Unlike the **negotiation protocol** the community norms have certain degree of necessity ("it would be nice to follow a certain norm").

5 CASE STUDY: MOBILE MUSEUM SMART ENVIRONMENT

Recently, the tourist business has become more and more popular. People travel around the world and visit museums and other places of interests. They have a restricted amount of time and usually would like to see many museums. In this regard a system is needed, which would allow assisting visitors (using their mobile devices), in planning their museum attending time and excursion plans depending on the context information about the current situation in the museum (amount of visitors around exhibits, closed exhibits, reconstructions and other) and visitor's preferences.

The main benefit of the presented case study is assisting visitors in the museum smart environment using personal mobile devices, which have Wi-Fi connection and possibility to show appropriate information to visitors.

Mobile devices interact with each other through the smart environment. Every visitor installs a smart environment client to his/here mobile device. This client shares needed information with other mobile devices in the smart environment. As a result, each mobile device can acquire only shared information from other mobile devices. When the visitor registers in the environment, his/her mobile device creates the visitor's profile (which is stored in a cloud and contains long-term context information of the visitor). The information storage (not computing, which is distributed among the services of the smart environment) cloud might belong to the system or be a public cloud. The only requirement is providing for the sequrity of the stored personal data. The profile allows specifying visitor requirements in the smart environment and personifying the information and knowledge flow from the service to the visitor.

Each time when the visitor appears in the smart environment, the mobile device shares information from the visitor's profile with other devices.

Visitor context accumulates and stores current information about the visitor in the smart environment (current visitor context). It includes: visitor location, museum reaching times for the visitor, current weather (e.g., in case of rain it is better to attend indoor museums), visitor role (e.g., tourist, school teacher), information about closed at the moment museums or exhibits.

To get external information for different system modules, the services are used. Four types of services are proposed:

- Positioning service (calculates current indoor and outdoor positions of the visitor based on raw data provided by visitor mobile device);
- Information service (provides visitor mobile device with needed information about exhibits, e.g., Wikipedia, Google Art Project, other services, museum internal services);
- Current situation service (provides information about the current situation in the

region, e.g., weather, GIS information, traffic information);

- Museum / exhibition (provides information related to the museum and exhibits, e.g., holidays, closed exhibits).

The proposed ontological scheme for the case study is presented in Figure 4.

Each visitor has a mobile device, which communicates with mobile devices of other visitors (shares own information to them and gets needed information), uses different services for getting and processing information, accesses and manages the visitor's profile, and processes information and knowledge stored in visitor context.

Visitor's profile and context are stored in the cloud, which allows visitors to access them from any internet enabled devices (when the visitor changes his/her mobile device it is needed only to install the appropriate software to use the new device). The conceptual level self-organization takes place in the cloud sending resulting information to the users' devices.

The visitor context is formed based on the interaction process between the visitor's mobile device and different services through the smart environment (parametric level self-organization). The context is the description of the visitor's task in terms of the ontology taking into consideration the current situation in the museums. Visitor's task in the proposed approach is a list of museums the visitor would like to attend.

The following scenario for using the proposed system is considered.

The visitor arrives to a region. His/her mobile device finds the museums the visitor is going to attend in this region (stored in the visitor's profile). The mobile device generates the context, which describes the current situation of this region. It negotiates with different services to extract information about interesting museums (working time, closed museums, closed exhibitions, statistical occupancy of interesting museums for the next few days) and propose to the visitor preliminary interested museums attending plan.

When the visitor is going to attend the museum (next day), the mobile device updates the context by current situation in the region, e.g.: weather (in case of rain it is better to postpone attending outdoor museums), traffic situation on the roads, current museum occupancy, and expected museum occupancy (based on negotiation with mobile devices of other visitors). Based on this information, the corrected museum attending plan can be proposed to the visitor.

When the visitor enters the museum an acceptable path for visiting museum rooms is built based on the museum room occupancies at the moment. Using location service and Wi-Fi infrastructure the mobile device calculates the visitor's location and shares it with other devices. Information about exhibits is acquired from the service and displayed on the visitor's mobile device. The intelligent museum visitor's support system has been implemented based on the proposed approach. Maemo 5 OS – based devices (Nokia N900) and Python language are used for implementation.

It is based on the Smart-M3 platform (Honkola et al., 2010; Smart-M3 at Wikipedia, 2010). The key idea in Smart-M3 is that devices and software entities can publish their embedded information for other devices and software entities through simple, shared information brokers. The understandability of

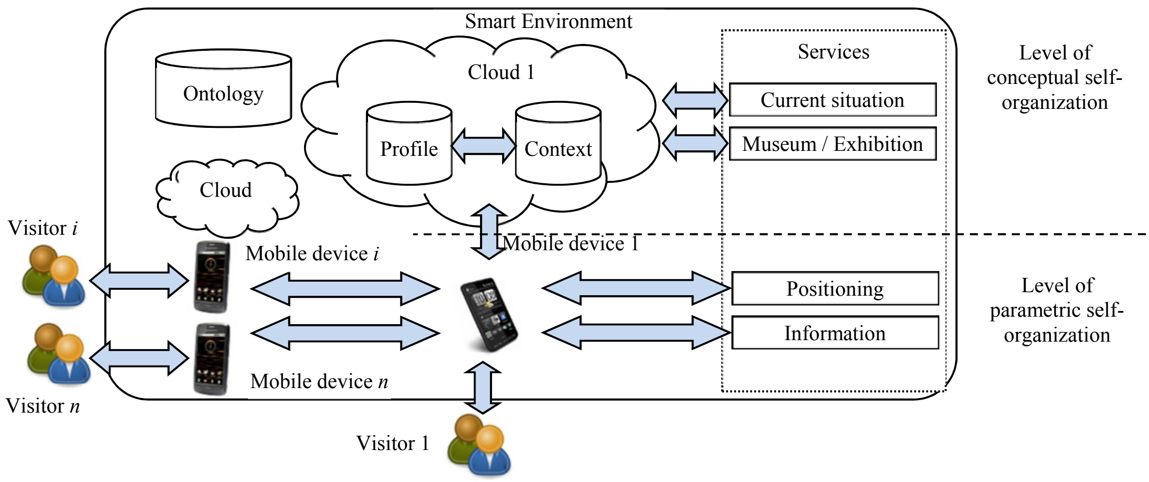

Figure 4: Ontology-based scheme of the Smart Museums Service case study.

information is based on the usage of the common RDF-compatible ontology models and common data formats. It is a free to use, open source solution available under the BSD license (Smart M3 at Sourceforge, 2010). Communication between software entities is developed via Smart Space Access Protocol (SSAP).

The system has been partly implemented in the Museum of Karl May Gymnasium History (The Museum of Karl May Gymnasium History, 2013) located in St. Petersburg Institute for Informatics and Automation Russian Academy of Science building.

The visitor downloads software for getting intelligent museum visitors support. Installation of this software takes few minutes depending on operating system of mobile device (at the moment only Maemo 5 OS is supported). When the visitor runs the system for the first time the profile has to be completed. This procedure takes not more than 10 minutes. The visitor can fill the profile or can use a default profile. In case of default profile the system can not propose preferred exhibitions to the visitor.

Response time of the Internet services depends on the Internet connection speed in the museum, number of people connected to the network, and workload of the services. The average response time does not exceed one second.

An example museum attending plan is presented in Figure 5. It consists of five museums: The State Hermitage, the Kunstkamera, the Museum of Karl May Gymnasium History, St. Isaac Cathedral, the Dostoevsky museum.

6 CONCLUSIONS

The paper presents a reference model and service-oriented architecture for a multi-level self-organization in a smart environment. The proposed reference model enables a more efficient self-organisation based on the “top-to-bottom” configuration principle, which assumes conceptual configuration followed by parametric configuration. The service-oriented architecture makes it possible to replace the organisation of the smart environment with that of distributed service network. Application of the approach is illustrated via a museum smart environment case study.

The approach has some limitations. In particular, it requires the corresponding services (transportation & museums) to be available in the smart environment. At the moment, some of such services have been developed as prototypes and wrappers for existing third-party services have been developed. For development of a working application this issue has to be kept in mind. Besides, the functioning of the client’s applicatuion requires almost permanent Internet connection. Today, mobile Internet usage in foreign countries is quite expensive, however, we expect the situation to improve in the nearest future.

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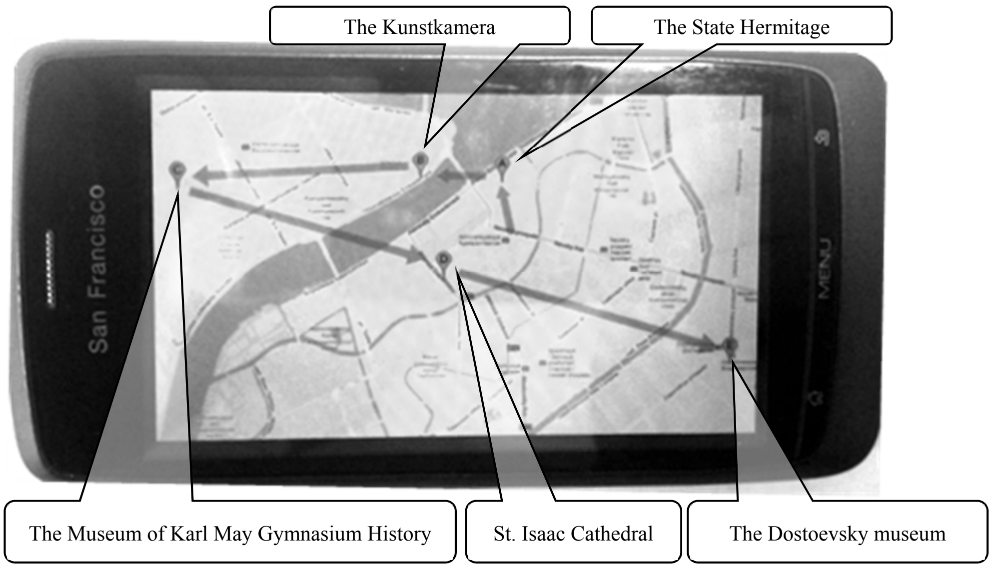

Figure 5: A sample of museum attending plan in a visitor mobile device in the center of St. Petersburg.

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