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CONTEXT AWARENESS IN MOBILE SOFTWARE AGENT NETWORK

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Summary

The paper deals with context awareness in information, communication and computing systems and context introduction in mobile software agent network. Mobile agent network is a formal system that includes a multi-agent system residing in a network of interconnected nodes, which hosts agents, allowing their operation, communication and migration. Software agents can help in managing complex relationships between information and communication service users and service providers. The role of intelligent and mobile agents representing service users and service providers in the network and supporting context awareness is considered. Context is defined as any information that can be used to characterize the situation of an entity respecting its physical, social, communication and computing environment. A unified treatment of context information contained in the user profile, presence service and those relevant for general context-aware systems is proposed in order to preserve the functionality and performance evaluation capabilities of the mobile agent network. The approach elaborated in the paper is based on conceptual context representation, system services and agent operations required for supporting context-awareness in the mobile agent network. Case study on agent-based ad-hoc social network service is included.

Keywords: context model, mobile context, context awareness, software agent, multi-agent system, presence service, social network service

1. INTRODUCTION

Ubiquitous communication, computing and especially the mobility of users and user equipment set new requirements on services and applications. The variety of circumstances in which communications and computing should be provided, while respecting the service user and service provider needs, is growing, as well as is the number of networked devices and systems. Different aspects of man to man and man to machine communication today involve over six billion users of mobile devices. A significant growth reaching fifty billion devices is expected in the next few years, and this is primarily due to the machine to machine interaction. The Internet of people extends to the Internet of services and the Internet of things. Service provisioning should remain manageable for both service users and service providers.

When considering the user-centred approach, it is important to take into account social, physical, communication and computing environments where the user resides and acts, and communication and computing make context-aware.

There are many general definitions of context in different dictionaries, such as "the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood"[1], "the situation in which something happens and that helps you to understand it"[2], or "the set of facts or circumstances that surround a situation or event"[3]. For the topic under consideration context will be defined as any information that can be used to characterize the situation of an entity respecting its physical, social, communication and computing environment.

Context awareness became a research topic twenty years ago, when Mark Weiser announced ubiquitous computing [1,2]. The term "context-aware computing" was used for the first time in 1994 [3], "context-aware communication" and "context-aware service" a few years later [4-6].

Context awareness is a promising and challenging issue, as stated by many researchers, because it influences system functionality and efficiency, as well as its complexity. The paper considers the role of software agents representing service users and service providers in the network and supporting context awareness. The major feature of an intelligent agent is its autonomy when performing certain tasks on behalf of its owner, not only upon direct and explicit request, but also following some general requirements and predefined goals. Such agents can help managing complex relationships between information and communication service users and service providers.

Besides intelligence, two additional characteristics are considered in the paper: the agent social ability and mobility. Social ability describes the agent's capabilities of communicating and co-operating with other agents when performing assigned tasks, or competing with them in favour of its owner. Mobility allows an agent to move permanently or temporarily to a specific network node, and to migrate through the network in order to perform assigned tasks.

[1] Oxford Dictionnaries (oxforddictionaries.com)
[2] Oxford Advanced Learner's Dictionary (*www.oxfordadvancedlearnersdictionary.com*)
[3] WordNet (wordnet.princeton.edu)

The paper deals with context awareness in mobile agent network. Mobile agent network is a formal system that includes a multi-agent system residing in a network of interconnected nodes, which hosts agents, allowing their operation, communication and migration [7]. Intelligent, social and mobile agents forming such a multi-agent system act as user agents, representing users and service agents, offering service capabilities. The intention is to treat in a unified way context information contained in the user profile, presence service and context-aware systems. A part of context information can be entered by a user; a part can be derived by observing and sensing environment, and a part created implicitly by reasoning and learning about user behaviour and environmental changes. An additional dimension of context information is time because most of context information changes dynamically. Therefore, when introducing context, an overhead of considering context should be taken into account, as well as the complexity/efficiency ratio achieved. A specific issue is context information generated by the agents and used by the agents exclusively, such as those related to communication and computing environment.

The rest of the paper is as follows. Related work on context awareness in information, communication and computing followed by context awareness in agent and multi-agent systems is presented in Section 2. Mobile agent network is described in Section 3. The description includes its formal definition, agent operations, inter-agent communication and coordination, intelligence and mobility issues. Section 4 elaborates the introduction of context in mobile agent network. The approach proposed in the paper is based on conceptual context representation, system services and agent operations required for supporting context-awareness. Case study on agent-based ad-hoc social networking is included.

2. RELATED WORK

Two aspects are considered: context awareness in information, communication and computing systems and context issues related to software agents.

2.1. Context awareness in information, communication and computing

Context definitions relevant for the information, communication and computing domain are many, starting with the one by Schilit, Adams and Want "where you are, who are you with and what resources are nearby" [3] and by Pascoe "the subset of physical and conceptual states of interest to a particular entity" [8]. Dey tried not to give too specific definition in the following way: "Context is any information that can be used to characterize the situation of an entity. 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" [9].

The major issue is how to understand and use situational information in order to take advantage of using context in information, communication and computing systems, including human interaction with systems. Dey extended his definition from the concept to the system as follows: "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [9].

There are different approaches to context representation and reasoning [10, 11]. They include conceptual, logic, ontology and case-based models. The basic model used for introducing context into mobile agent network is a conceptual one, with origins in two broader context categories, the human user and physical environment proposed in [12].

The mobility of users, user equipment and the ambient where they reside, as well as services within or through the network boundaries, widened the concept of context because of dynamic environmental, situational and social changes in personal and group spaces. An interesting empirical study is presented in [13], a software framework for the development of context-aware mobile applications in [14], while some developments in context-aware middleware enabling services in heterogeneous networks and disconnection tolerant applications are given in [15-17]. A common trait for all of them is a very careful evaluation of context awareness and focussing onto specific use case.

2.2 Context awareness in agent and multi-agent systems

Research on context awareness in agent and multi-agent systems includes the following: a) general issues related to framework, platform and middleware [18]; b) context-aware systems for smart environments [19-21], including some specific application domains such as e-health [22-25]; and c) an agent-oriented approach to context-aware information and communication services and applications.

For the topic under consideration, relevant are models that cover intelligent, social and mobile agents forming a multi-agent system suitable for context-aware information and communication services and applications. Such agents should be capable of context discovery, interpretation, aggregation and dissemination, and of using context in both a reactive and a proactive way, as well as for coordinating their activities [26].

A survey on agent-based middlewares for context awareness given in [18] includes AMASE, an experimental mobile agent system with context features related to communication services developed in 1999. The proposed context includes the type and status of the user terminal, the quality of service, changes in network connectivity and user location and preferences related to notification and security [5]. When relating agents and context now, it is important to consider both theoretical and practical issues, taking the implementation perspective into account, i.e. the ongoing standardisation efforts[4] and developed agent platforms, such as JADE[5].

The paper proposes a multi-agent system combining user agents and system agents for handling context. Most of the related work deals separately with user agents and system agents. Two examples follow.

An agent-based approach for context-aware communication is proposed in [27]. User agents called *Personal Communication Managers* represent users and make decisions about communication activities based on personal policies, presence information and current context information. The *Personal Communication Manager* consists of three components: *Personal Information Manager* (presence and context aggregator); *Presence Directory* (repository of known and deduced presence information); and *Policies and Preference Manager* (preference logic and rule manager). The context-aware system follows a Belief-Desire-Intention architecture, where beliefs correspond to the perceived presence and context information, desires to the defined policies and preferences, and intensions to the communication actions [28]. User agents are intelligent, but independent of each other, sharing context information and policy space, without explicit inter-agent communication or coordination. Therefore, multiple agents do not form a multi-agent system.

A model of a multi-agent system supporting context awareness is given in [29], where the agents play the role of system agents. Multiple agents that reside in a single domain deliver context to the system.

3. MOBILE AGENT NETWORK

Mobile agent network as a formal system that includes multi-agent system residing in a network of interconnected nodes, which host agents allowing their operation, communication and migration is introduced in [7]. The model is further developed having in mind functionality, as well as performance issues related to multi-agent systems and mobile agent networks.

[4] FIPA - The Foundation of Intelligent Physical Agents (www.fipa.org)
[5] JADE – Java Agent Development Framework (jade.tilab.com)

3.1 Definition

A mobile agent network is represented by the following three items:

MAN = {A, S, N}

where:

- A – a multi-agent system consisting of co-operating and communicating stationary and mobile agents operating in an environment defined by S and N,
- S – a set of processing nodes in which the agents perform services,
- N – a network that connects processing nodes and allows agent communi cation and agent mobility.

An agent $agent_k$ from the multi-agent system A = ($agent_1$, ..., $agent_k$, ..., $agent_n$) represents its owner (service user or service provider) and performs some tasks on behalf of its owner. It can communicate with other agents and migrate autonomously from node to node to perform some service. Agent intelligence and mobility influence its service capability from the functionality and performance point of view. An agent performs some services requested by its owner alone, or as a member of an agent team operating within a multi-agent system. When necessary, agents communicate and co-operate, or compete in order to serve their owners.

The functionality of a multi-agent system is defined by a set of elementary services supported by the system as follows:

$$ES = \{es_1, es_2, ..., es_j, ..., es_{nes}\}$$

The same elementary service, es_j, can be provided by multiple agents. A single agent can provide multiple elementary services. Therefore, agents are considered as multiservice ones. An agent is defined by three items:

$$agent_k = \{name_k, address_k, service_k\},$$

where:

$name_k$ – unique agent identification,
$address_k$ – agent's actual location, i.e. a node where it resides and
$service_k$ – functionality the agent provides, i.e. a set of elementary services from ES assigned to $agent_k$, $service_k = \{es_{k1}, es_{k2}, ..., es_{ki}, ..., es_{kn}\}$.

The set of processing nodes is denoted as $S = \{S_1, S_2, ..., S_i, ..., S_{ns}\}$. Each node, S_i, provides operating environment for the agents. It is characterised by a set of elementary services from *ES*. It supports as follows:

$$s_i = \{es_{i1}, es_{i2}, ..., es_{ij}, ..., es_{in}\}.$$

The same elementary service can be supported by multiple nodes, and one node can support multiple services. For $agent_k$ hosted by node S_i or directed towards it, $address_k = S_i$. $agent_k$ can execute at S_i elementary services from the intersection $service_k \cap s_i$.

A network *N* connecting nodes from *S* is represented by an undirected graph, $N = (S, E)$. *E* is the set of links, $E = \{e_1, e_2, ..., e_m, ..., e_{ne}\}$, where $e_m = \{S_i, S_j\}$ represents a link between nodes S_i and S_j .

3.2 Operation, communication and coordination

From the operation point of view, agent owners define and generate requests to be served by the agents. In general, each request requires an ordered set of elementary services to be executed by the agents at some nodes. Agents involved in serving some request communicate by using agent communication language[6] and cooperate by taking specific roles in an agent team [30-32].

The request is represented by a directed acyclic operation graph $G = (T, L)$. *T* denotes the set of elementary services required to serve a request with the address of the node where they should be executed, $\{es_i, address_i\}$. If the address is not defined, then es_i can be executed on an arbitrary node S_j that supports es_i, i.e. $es_i \in s_j$, and the agent, according to its knowledge and intelligence, decides where the elementary service will be executed. *L* denotes the set of directed edges that define precedence relations between elementary services. An edge is described by the quadruple $\{es_i, o_i, es_j, i_j\}$ where o_i represents the output of es_i and i_j the input of es_j, defining that if $i_j = o_i$ then es_i precedes es_j.

From the functionality point of view, a request can be served by a single agent if and only if at least one $agent_k$ exists for which $T \subseteq service_k$. In all other cases, a team of agents should be formed taking into account defined performance metrics, such as minimum response time, smallest number of nodes involved, lowest inter-agent communication or others. The process of assigning elementary services includes determining the number of agents in the team, as well as deciding which agent will execute which elementary service. Consequently, intelligent

[6] FIPA Agent Communication Language (ACL)

agents can choose different distributions depending on their knowledge of the service execution ability, network topology, current network and node load, etc.

The problem of assigning a set of elementary services T to an agent team according to some performance requirements includes three relations: agent – elementary task; agent – agent; agent – node. In order to serve a request, agent coordination and communication is required. The only exception is the case when $L = \emptyset$, i.e. all elementary tasks are mutually independent and therefore no agent communication is required.

In order to follow the concept of multi-agent system autonomy, an agent responsible for planning team activity, *p_agent*, is added to system A:

$$A = \{p\_agent, agent_1, ..., agent_k, ..., agent_n\}$$

The task of the planning agent will be described by using an example of operation graph shown in Figure 1, for which mobile agent network is defined as follows:

$$MAN = \{A, S, N\}$$

$$A = \{p\_agent, agent_1, agent_2, agent_3\}$$

$$service_1 = \{es_1, es_2, es_3, es_4\}$$
$$service_2 = \{es_3, es_4, es_6\}$$
$$service_3 = \{es_5, es_7\}$$

$$S = \{S_1, S_2, S_3, S_4\}$$

$$s_1 = \{es_1, es_6\}$$
$$s_2 = \{es_2, es_3, es_6\}$$
$$s_3 = \{es_4, es_6\}$$
$$s_4 = \{es_5, es_7\}$$

Consider the following plan that gives the minimum response time: $agent_1$ executes es_1 at S_1, sends result o_1 to $agent_2$ at S_3 and migrates to S_2 in order to perform es_2 and es_3. $agent_2$ operates in parallel with $agent_1$, executes es_4 at S_3, and decides about es_6, because this elementary service is supported by the three nodes, S_1, S_2 and S_3. $agent_3$ waits for collecting results (o_3 from $agent_1$, o_4 and o_6 from $agent_2$) in order to proceed with es_5 and es_7.

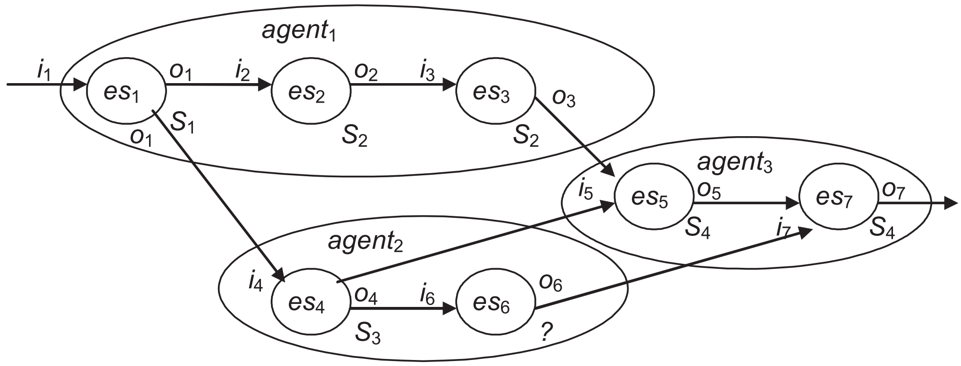

Fig. 1. Operation graph and assignment of tasks to agent team
Sl. 1. Operacijski graf i dodjela poslova agentskom timu

Besides the parallel execution of elementary services by $agent_1$ and $agent_2$, single agent migration ($agent_1$ from S_1 to S_2) also contributes to the minimum response time. Regarding the execution of es_6, $agent_2$ has several options: a) to stay at S_3 and execute es_6 if the node is not overloaded, and send the result o_6 to $agent_3$ at S_4; b) to move to S_4 if the network is not congested, execute es_6 there and exchange o_6 with $agent_3$ locally, at the same node. Migration to S_1 is not the preferred choice because it requires agent migration, as well as agent communication through the network.

For performance evaluation purposes, mobile agent network is described by three sets of parameters related to the multi-agent system (A) and the computing and communication environment (*S* and *N*). Mobile agent network is described as a queuing system where the agents from *A* represent information units to be served by *S* and *N*. Stochastic input flow of service requests is transformed into input agent flow consisting of agents with assigned elementary services required to serve a request. Basic parameters describing agent flow are the following: agent team arrival intensity, mean agent team interarrival time, a number of agents per team, and a number of elementary services per agent [33-35].

3.3 Intelligence and mobility

Mobile agent network allows different approaches to the agent's intelligence according to the relationship between the agents and the environment, specified by the networked nodes and their functionality. The basic distinction is between reactive and deliberative agents as deterministic entities in a nondeterministic environment [36, 37]. An agent is a reactive one if it responds to changes perceived in the environment, i.e. if its intelligence depends on the continuing interaction with the environment. The deliberative agent operates by using symbolic representation of the environment and reasoning as the basis of its intelligence. Previously mentioned implementation issues lead to the Belief-Desire-Intension model for deliberative agents used for planning and making decisions.

It should be noticed that the multi-agent system operations are started by explicit requests where the owners instruct agents what to do their behalf. Instructions of different complexity require actions based entirely on the actual situation, with no reference to the history, or history dependent, determined by the earlier interactions with the environment and previous actions. In the last case, agent's knowledge and learning capabilities offer additional triggers for its actions (implicit requests).

A multi-agent system formed of deliberative agent *p_agent* performing planning tasks and working proactively (goal-directed behaviour) and a team of reactive agents $\{agent_1, ..., agent_k, ..., agent_n\}$ for executing tasks is a reasonable solution respecting the complexity and the performance.

Agent mobility includes three major steps: termination at the actual node, transport to the next node and activation at it. Besides user's location, reasons for transferring an agent to a specific node are primarily its service capability, the replacement of agent communication over the network with local communication of collocated agents and migration towards better execution environment (not overloaded nodes and/or links, higher speed available, ...)[38].

4. INTRODUCING CONTEXT IN MOBILE AGENT NETWORK

Intelligent and mobile agents operating as mobile agent network play the roles of user agents (requesting services on behalf of users), and service agents (offering service capabilities on behalf of service providers). As stated in the Introduction, the unified treatment of context information contained in user profile, presence service and context-aware systems will be elaborated. There are four different sources of context information: i) context information entered explicitly by a user, ii) context information derived by observing and sensing the environment, iii) context information created implicitly by reasoning and learning about user behaviour and environmental changes, and iv) context information generated by the agents and used by the agents exclusively, such as those related to communication and computing environment.

An additional requirement is to introduce context in mobile agent network while preserving its performance evaluation capability.

Context-aware mobile agent network extends the concept of mobile agent network defined in Section 3 with a set of context types, $C = \{C_1, C_2, ..., C_m, ..., C_{nc}\}$, relevant for mobile agent network functionality, i.e. tasks and goals of the multi-agent system:

$$\text{CA-MAN} = \{\text{MAN}, C\}$$

In order to introduce context in mobile agent network the following issues are addressed: context representation, system services required for implementing context awareness, and the extended functionality of multi-agent system.

4.1 Context representation

There is no generally accepted conceptual structure of context to be followed when defining context-aware mobile agent network formally [10, 11]. Therefore, following generic context categories are considered:

- *Person*: context information describing the human user, such as his or her privacy requirements, knowledge and competencies, interest and preferences, habits and mood;
- *Machine*: context information describing any kind of device capable of observing and sensing environment or performing some action in it;
- *Status*: context information describing the actual activity of a person and person's role in some activity;
- *Social environment*: context information describing a person's social relationships such as proximity to others, group activities and collaboration;
- *Location*: context information describing the absolute or relative location and characteristics of the place;
- *Communication and computing environment*: context information describing the devices, systems and services used for/in communication and computing and the conditions in communication networks and computing systems;
- *Physical environment*: context information describing the conditions in the physical environment;

The context categories *Person*, *Status* and *Social environment* define the human user-related context, while *Location*, *Communication and computing environment* and *Physical environment* define the environment-related context, according to the basic taxonomy by Schmidt, Beigl and Gellersen [12]. It has to be underlined that the category *Communication and computing environment* includes specific context information related to agents.

Context categories cover mobile context and overlap with two other information sets developed within different, not (enough) connected research communities: user profile and rich presence information.

User profile is a collection of personal data characterising a person. It is used in social networking and personalised information and communication service provisioning. The context categories closest to the notion of user profile such as one proposed in [39] are *Person* and *Social environment*.

Rich presence information is a collection of information representing presentity, an entity that uses presence service [40]. Presentity provides presence information for notifying its state and changes in its state, and for communicating according to the state. All proposed context categories are included in the rich presence information data format [41], with an ecosystem proposed in [42].

Table 1. Context category, types and values – an example

Tablica 1. Primjer kategorija, tipova i vrijednosti konteksta

Context category	Context types	Context values

Person	`Identity`
	`Privacy`
	`Profession`
		`(name, symbolic name, ...)`
		`(no_com, voice, text, ...)`
		`(physician, engineer, ...)`

Status	`Activity`	`(meeting, travel,   )`
Social environment	`Relationship`	`(colleague, friend, ...)`

Location	`Absolute_location`
	`Relative_location`
	`Virtual_location`
	`Building`
	`Place`
		`(geo_coord, address, ...)`
		`(nearby, close_to, ...)`
		`(IP-address, ...)`
		`(office, home, ...)`
		`(indoors, outdoors)`

Communication and computing environment	`Device`
	`Network_access`
	`Computing_system`
		`(on/off, application, ...)`
		`(high_speed, congestion, ...)`
		`(overload, ...)`

Physical environment	`Condition` `Sound`	`(noisy, dark, hot, ...)` `(silent, moderate, loud)`

Specific context information belonging to a generic context category will be defined with a context type, $C_m \in C$, as an atomic context abstraction described by one or more context values, cv_{mi}. In order to avoid an overload when considering context, it is important to define context atoms at an abstraction level required for context awareness, i.e. depending on context use. The problem of abstraction level is illustrated by some examples given in Table 1.

For instance, context information related to the location can be expressed as context type `Absolute_location` described by geographic coordinates `(geo_coord)` or civil address `(address)`, or `Relative_location`, or `Virtual_location`, or as context type `Building` described by `office`, `home` and others, or simply `Place` defining just `indoors` or `outdoors`.

Context information related to the physical environment can be expressed as a general context type `Condition` described by values such as `noisy`, `dark`, `hot` and others, or as more specific context type `Sound` having values `silent`, `moderate` and `loud`. Context values `noisy`, `dark` and `hot` do not exclude each other, i.e. it can be `dark` and `hot`, or `noisy`, `dark` and `hot`. On the contrary, context values describing Sound are mutually exclusive.

The granularity of context types, as well as the context values should be defined according to the context use. For somebody being `outdoors` in a `noisy` environment, it would be better to receive a `text` than a `voice` message if he or she has not declared `Privacy` requirement as no communication `(no_com)`. On the other hand, for somebody listening to the music in his or her `office`, relevant context type is `Sound` and the context value `moderate`.

Context types combined together represent higher level context. For instance, context-based decision about `voice` or `text` communication is driven by the context types `Place` and `Condition`, and values `outdoors` and `noisy`, respectively, i.e. if `outdoors` and `noisy`, then send a `text` message.

4.2 System services for implementing context awareness

Context information producers are human users, other users (devices or "machines") and agents themselves, while content information consumers are agents only. At the conceptual level, system services for exchanging context information between producers and consumers will be based on the subscribe/publish/notify paradigm. The approach is similar to the one used in presence service [40].

Three system services for implementing context awareness are the following:

- Context subscription: subscribed context value cv_{mi} for context type C_m or subscribed context type C_m is defined by the context consumer;
- Context publishing: published context value cv_{mi} for context type C_m is presented by the context producer ($C_m = cv_{mi}$);
- Context notification: published context value cv_{mi} for context type C_m matching subscribed context value cv_{mi} for context type C_m or published context value cv_{mi} matching subscribed context type C_m is presented to the context consumer. Notifications are presented to the consumers when a new context is published.

Context information producers are publishers of context values for context types assigned to them. For instance, a person can define explicitly `Privacy` as `no_com` that should be notified to interested consumers. An acoustic sensor can measure sound, express it in decibels, or as `noisy` or `loud`, depending on the context type used, and publish it.

Published context information is stored and distributed to consumers via notifications, according to the subscriptions. An agent deciding about `text` or `voice` messaging can be subscribed to context types `Place` and `Condition` in order to receive context values it needs to know or check in order to define if `outdoors` and `noisy`. If it is subscribed to context values `Place = outdoors` and `Condition = noisy` it will be notified about matched subscription.

It is obvious that there is no (big) difference between presence service and more general context-aware service when considering human users and their communication. Differences become more evident when other types of users, i.e. devices ("machines") are involved in man to machine, machine to man or machine to machine communication and related computing. The same is with the agents. An example follows: an agent situated at a node or mobile agent migrated to it can detect and publish context information of `overload` at `Computing_system` or `congestion` at `Network_access`. Agents subscribed to `Computing_system = overload` will exclude such a node from server operations and their migration path.

4.3 Context-based agent actions

The two basic types of context-based agent's actions are actions triggered by the matched context and actions planned or decided upon context. The first type is characterised by reactive agent behaviour. In the previous example, that means that the operation graph has a context-related input i_1. For the second type, agent behaviour is deliberative, such as of planning agent having model of communication and computing environment and being subscribed to context types `Network_access` and `Computing_system`. For instance, after recognizing `Computing_system = overload_at_S3`, the planning agent can instruct $agent_3$ to move to S_4, execute es_6 there and exchange o_6 with $agent_3$ locally, at S_4.

Advanced features to be supported include context specialisation[7]. In general, context specialisation includes the change, deletion or insertion of context information required for some actions. Context specialisation will be illustrated by using the previous case of overloaded node. Instructing agents to migrate from overloaded nodes will not improve the system performance if communication links towards other nodes are congested. An agent capable of monitoring and learning about the environment can specialise in communication and computing context and use it as follows: if `Computing_system = overload_at_S3` and `Network_access = high_speed_towards_S4`, then move to S_4.

4.4 Case study: agent-based ad-hoc social network service

Most of the mobile agent network research and application is related to software deployment and maintenance [43-44] and service provisioning [45-46]. These application domains serve for evaluating the proposed extension of the mobile agent network as context-aware system. Software deployment and maintenance based on intelligent and mobile agents allow software installation, modification and verification on the remote target systems taking into account network and node conditions, i.e. the communication and computing environment. On the other hand, personalized service provisioning includes social and physical environment.

In this paper, agent-based ad-hoc social networking will be used as a case study to illustrate context awareness in mobile agent network [47-48]. Social network services on the Internet support mostly permanent social relationships. A user is represented in such network by his or her profile that includes connections to other people defining social relationships and forming user's own social network called ego network. In many situations social relationships are ad-hoc i.e., set up by users located in some geographical area during a certain period in time and

[7] "One of the holy grails of context-aware computing is to have applications that do the right thing at the right time for users. While designers who have domain-specific expertise can determine part of the solution, they will obviously not think of everything that is needed to support individual users. It is the end user who is in the best position to further specialize context-aware applications to meet their individual needs." [Dey]

associated with a certain social event, or an accident or disaster having attributes of a crisis. Ad-hoc social networking service should help in using existing social relationships and building new ones in order to arrange and/or coordinate activities in such situations. The goal is to build and maintain an ad-hoc social network, ahSN, starting from the user – initiator's ego network from a permanent social network, SN.

The example shown in Figure 1 will be used for describing context awareness in ad-hoc social network service. Three agents, $agent_1$, $agent_2$ and $agent_3$, support ahSN creation and ahSN member interaction (Figure 2).

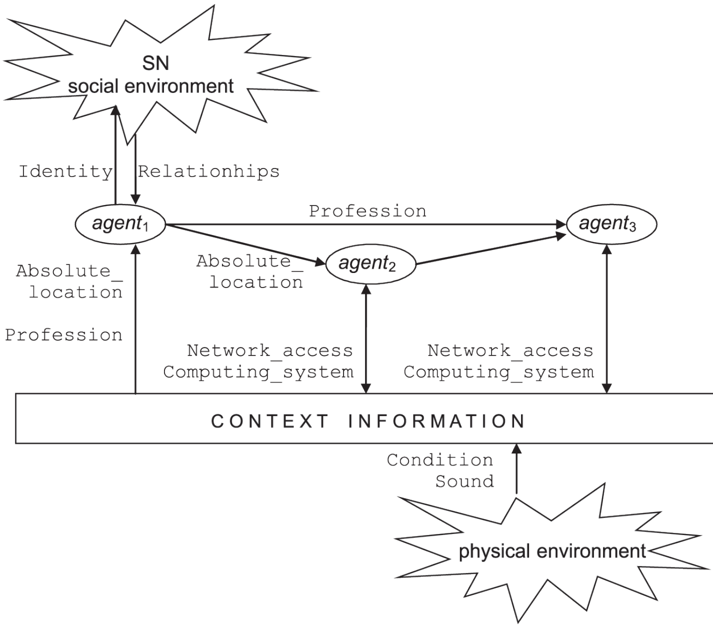

Fig. 2. Context awareness in ad-hoc social networking

Sl. 2. Svjesnost konteksta u ad-hoc društvenom umrežavanju

$agent_1$ operates as user agent and provides its owner with ad-hoc social network creation capability. It is a consumer of context types `Absolute_location` and `Profession`. On behalf of its owner, it performs following elementary services:

es1: initiation of ahSN started by user's explicit request to collect members located in the same area sharing some skills (i_1: `Absolute_location` & `Profession`, o_1: invite at `Absolute_location`)

es2: invitation of members of a user's ego network from SN being at the same location to join ahSN. The agent presents user `Identity` and collects related `Relationship` from SN. (i_1: invite at `Absolute_location`, o_2: accepted invitations from SN);

es3: acquisition of user profiles from SN for all users that joined ahSN and making of ahSN user profiles (i_2: accepted invitations from SN, o_3: members & profiles & `Profession`);

$agent_2$ operates as ahSN membership manager providing extension of ahSN to non-SN members, as follows:

es4: invitation of other users on behalf of ahSN initiator being at the same location to join ahSN (i_4: invite at `Absolute_location`, o_4: members);

es6: making of ahSN user profiles for non-SN members (i_6: members, o_6: profiles);

$agent_3$ operates as ahSN interaction manager providing one-to-one and one-to-all communication as follows:

es5: forming operational ahSN by connecting ego networks of ahSN members and adding missing relationships, in order to reduce member distance to one (i_5: members & profiles & `Profession`, o_5: operational ahSN);

es6: selecting ahSN members according to the implicit situational information (i_7: operational ahSN & profiles, o_6: group of members with `Profession`);

Regarding context specialisation, by subscribing to context types `Condition` or `Sound` $agent_3$ would be capable to manage interactions according to situational information, for instance by instructing ahSN members with text messages if `noisy`.

Besides, $agent_2$ and $agent_3$ are consumers and producers of the context types `Network_access` and `Computing_system`. They are capable of measuring and publishing node load and link speed as well as using notified context values related to communication and computing environment in order to reach expected performance. Agent mobility offers possibility to agents to move closer to a user's location in order to reduce communication cost or avoid parts of network and systems out of operation.

5. CONCLUSION

Context awareness plays an important role in research and development of information, communication and computing systems. The variety of circumstances in which services should be provided is growing, as well as the number of mobile networked entities. When considering human user needs it is important to take into account context information related to social, physical, communication and computing environments and privacy. On the other hand, service provisioning should remain manageable for service providers as well.

The role of software agents discussed in the paper is to represent service users and service providers in the network and support context awareness, while operating on behalf of them. Context awareness in mobile agent network is provided by defining conceptual context categories, system services for handling context information based on publish/subscribe/ notify paradigm, and agent operations triggered by matched context or planned or decided considering available context information. Proposed context categories are derived from user profiles, presence service and context-aware systems. Context information can be entered explicitly by a user, derived by observing and sensing environment, created implicitly by the agents by reasoning and learning about user behaviour and environmental changes.

An agent-based ad-hoc social network service is used as a case study to illustrate context awareness in mobile agent network. Mobile agent network goal is to build and maintain an ad-hoc social network, starting from the user – initiator's ego network from a permanent social network. Agent team organization, elementary services agents provide and context manipulation related to ad-hoc social network creation and member interaction are presented.

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Svjesnost konteksta u mreži pokretnih programskih agenata

Sažetak

Rad se bavi svjesnošću konteksta u informacijskim, komunikacijskim i računalnim sustavima i uvođenjem konteksta u mrežu pokretnih programskih agenata. Mreža pokretnih agenata je formalni sustav koji uključuje višeagentski sustav koji djeluje u mreži međusobno povezanih čvorova koji udomljuju agente, omogućujući im provedbu operacija, komunikaciju i migraciju. Programski agenti mogu pridonijeti upravljanju složenih odnosa između korisnika i davatelja informacijskih i komunikacijskih usluga. Razmatra se uloga inteligentnih i pokretnih agenata koji predstavljaju korisnike i davatelje usluga u mreži te im omogućuju kontekstno svjesnu potporu. Kontekst se definira kao svaka informacija kojom se može obilježiti situacija nekog entiteta uvažavajući njegovo fizičko, društveno, komunikacijsko i računalno okružje. Predlaže se objedinjeno tretiranje kontekstne informacije sadržane u korisničkom profilu, usluzi nazočnosti, kao i one mjerodavne za opće kontekstno-svjesne sustave, kako bi se očuvala mogućnost evaluacije funkcionalnosti i performansi mreže pokretnih agenata. Pristup obrađen u radu zasniva se na koncepcijskom predočavanju konteksta te uslugama sustava i agentskim operacijama potrebnima za potporu konteksta u mreži pokretnih agenata. Uključen je studijski primjer agentski zasnovanog ad-hoc društvenog umrežavanja.

Ključne riječi: model konteksta, pokretni kontekst, svjesnost konteksta, programski agent, višeagentski sustav, usluga nazočnosti, usluga društvene mreže

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