Community Context Management Research and Challenges in Pervasive and Social Computing

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***Abstract*—Context-awareness is one of the main aspects of pervasive computing environments. Recently, some social networking systems have also started to exploit context information. These two paradigms serve different purposes. Pervasive computing systems have been designed mainly to address the needs of individual users, thus neglecting the social nature of humans. On the other hand, social computing focuses on exploiting the social relations between users, on promoting their interactions and on supporting the sharing of digital resources among them. However, the recent development and popularity of social networking systems has happened in isolation from the developments in pervasive computing. This paper elaborates on the role of context in both pervasive and social computing environments and introduces the approach of the SOCIETIES project that integrates full scale pervasive functionality in social networking systems to develop the next generation of social media systems. Finally, it discusses the new research challenges that emerge in pervasive social media regarding community context-awareness and the respective benefits that the end users may experience.**

Keywords-community context management; Cooperating Smart Space; social networking; pervasive computing; innovations

I. Introduction

Pervasive computing [1] introduces the third era in computer science. Exploiting the miniaturisation of computing equipment, pervasive computing assists users in their everyday tasks in a seamless unobtrusive manner, by transparently and ubiquitously embedding numerous computing, communication and sensing resources in the users' surrounding environment, as well as in their mobile devices. Up to now, pervasive computing systems have been designed mainly to address the needs of individual users. This neglects an important part of human behaviour; socialising, and might partly explain the slow take-up of pervasiveness in commercial products. On the other hand, social computing [2] has enjoyed meteoric success in bringing people together online. Products in this area, however, do not integrate well with any but a few of the many devices and services to which their users have access.

The time is ripe for the two paradigms to converge. The SOCIETIES project (http://www.ict-societies.eu/) investigates approaches to enable this convergence. Integrating current pervasive computing systems with social networking services allows users to communicate and socialise, while it facilitates their everyday activities by supporting their interaction with other users that have similar interests, preferences and expectations, and in general, the same or similar context. A necessary step towards this integration is the employment of group or community context awareness. The need to utilise group context information in pervasive systems is not new, as the first approaches have been marked as early as the year 2000 [3]. On the other hand, the context-aware concepts are gradually gaining momentum as means to improve the user-experience in social networking systems (SNSs). The most popular SNSs do not exploit the contextual information explicitly, but rather rely on the users' actions and intentions on describing their situation, their relationships with the other users, their preferences, etc. Nevertheless, lately there have been observed some social networking services (e.g. Foursquare, Facebook, Google+) that gradually exploit location information. But this is still a very limited usage of a single type of context information. Thus, merging the two domains introduces imperative requirements, as well as various research challenges regarding community context.

The rest of this paper is structured as follows. In Section II, a short state of the art review is presented with regards to context awareness in pervasive systems, as well as in social networking services. In Section III, the SOCIETIES vision and concepts are presented. In Section IV, the context-related innovations that arise in integrated pervasive social computing systems are presented. In Section V, these innovations are mapped to the components of the SOCIETIES context management architecture. Finally, in Section VI the paper conclusions are drawn.

II. State of the Art Review

In this section, the community context modelling, management and inference state of the art research work is briefly presented, both for pervasive computing environments and for social networking systems.

A. Community Context in Pervasive Computing Systems

The heterogeneity of context data, combined with the introduction of the community context information that is collected from different sources, further increases the complexity of processing these data. In order to reduce this complexity, numerous research initiatives focused on the design and implementation of suitable context modelling techniques.

In [4], the authors propose a method for constructing dynamic groups based on their movement. Nodes are considered part of the group if their movement is evaluated, using

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a qualitative model, as correlated. The paper presents two lightweight and efficient methods for extracting location and movement information and analyses the advantages and disadvantages of each one. Thus, although the context information processed is not complex or modelled to cover diverse kinds, such as temperature, activity, etc., the location grouping approach reveals an interesting application of group context awareness in wireless sensor networks.

In [5], the authors propose a \ model for spatiotemporal community context, based on the ontology approach. They envision communities in terms of groups of people who have something in common and propose community reasoning based on the stored facts of users' personal profiles, contact information and movement. However, they don't use social networks in order to enhance the creation of communities.

In [6], group context is modelled and used in order to provide group recommendation services. The group context information employed can be of any nature, while the most important attributes are estimated in order to perform the aforementioned recommendations. Thus, the service "decides" which context information of the group members is required to be adapted and employed, based on its functional and non-functional requirements.

In addition to context modelling, an equally important aspect that has the potential to reduce the complexity and improve the efficiency of context-aware systems for communities of users is the management of context information.

In [7], the Active Surroundings middleware is presented that aims to address the problem of grouping users with regards to their preferences. This work recognises that the users might have conflicting interests because of their number and diversity. For this reason, the proposed middleware attempts to harmonise the preferences of the various users based on their status and resolve potential conflicts among them, thus forming the so called group of users with resolved preferences. In this case, the solution is provided only for the resolution of conflicting preferences among users and does not deal with the group context awareness in its original form. Therefore, it can be characterised more as preference resolution and less as group context aware middleware.

In [8], the authors formally describe what a group is and how cooperation can be achieved between members of this group. Thus, they focus on communication issues between collaborative entities that belong to the same organisation and enrich their interactions with trust characteristics. However, this work is far from dealing with actual group context awareness, as further functionality characteristics should be present and shared between the members of the group, albeit the result is surely an adequately structured group with definite rules for its members.

In [9], group context is defined as an important parameter of recent service technologies. The group is formed by exchanging in-range control packets and afterwards group context packets become part of the group in order to inform each member of it. The platform then takes over the responsibility to resolve various requests of services, which are group-based ones. Finally, the platform supports a certain level of privacy when messages between members are exchanged and when services are employed.

A semantically assisted group context synchronisation mechanism is described in [10]. In this paper, the author describes a formally modelled mathematical approach that aims to detect contextual changes of the users of a group, so that they become efficiently shifted into other group formations or are dealt with other options. The ontology is not modelling the context of the groups, but the contextual dynamic of them in action, as it performs a mapping of the context regarding the users' actions based on specific metrics that are described, in order to perform the synchronisation in a web-like environment with hypertext, hyperlinks and the relevant content.

B. Context-Awareness in Social Networking Systems

On the Social Networking domain, there have been some attempts to exploit the potential of context-awareness. For example, the Social Network Service (SNS) described in [11] is inherently built with a number of context-awareness properties. The authors present the Context Watcher, a mobile application built atop Mobilife [12] that enables mobile phone users to share personal context data (location, heart rate, speed, view) with their mutual consent. These data can also be used as input for information services, to adapt applications to the context, or to automatically derive daily patterns and situational information. Solutions that integrate location and physical activity information of the users have been presented also in [13] and [14].

A novel approach for modelling and exploitation of social context is presented in [15], where context information is treated as a composition of roles, location and interactions of users. These characteristics are closely monitored and variations are used to update accordingly the situation of the users. It is worth mentioning that each user is engaged with a specific role in a form of contract against the adjacent ones and based on this role he/she is responsible to fulfill the contract terms.

Another approach, which identifies opportunities to improve the social networking experience of users by attaching context-aware characteristics, is presented in [16]. It is based on the fact that social communication is coherent to the sharing of contextual data, and thus, the users can focus on the communication rather than on the sharing process itself. In essence, what is done is based on the realisation that the users that share information can be classified as having certain common interests and automatically be parts of a communication channel. However, more work towards this direction is required in order to surpass the limitations imposed.

The authors in [17] recognise the importance in the existence of a taxonomy that takes into account social context. They introduce the STIP taxonomy that is based on a four-dimensional design space, where each definition of social context is characterised by its spatial, temporal, inference and target people's characteristics with respect to groups.

A context-aware middleware for Anytime, Anywhere Social Networks is introduced in [18]. The authors take into account several support mechanisms and tools, including location and proximity systems, expressive representation models of physical place and user characteristics, and effective social-matching algorithms. The proposed middleware integrates a set of common management facilities for personalising location-dependent social networks and for propagating social networks' visibility up to the application level.

So Smart [19] is an ontology-based context model that addresses social context in a pervasive computing environment and supports reasoning of a multi-agent system made of smart objects. They envision social contexts as social groups, determined by a number of nodes in a given location, linked by some kind of relations. A set of inference rules is defined in order to accommodate context reasoning while group and user modelling analysis are expected to enhance reasoning in a group-centred perspective.

Regarding the use of social networks, CenceMe [20] is an application that uses advanced machine learning techniques to infer human presence information based on iPhone™ sensors, for example, activity, being in a conversation, noise level, location, etc. The respective inferred context information can be gathered and shared with the users' social circle via Facebook, MySpace, Twitter, and CenceMe Web without any extra effort. This is a rather simplistic approach that aims to attach real-time contextual information to the users' social media profiles.

In a similar concept, the UPCASE system [21] publishes context data to social networking sites (Hi5 and Twitter) and distributes them via instant messaging tools such as SAPO Messenger. In order to gather context information, UPCASE makes use of sensors embedded in mobile devices, as well as of external sensors that communicate with the devices via Bluetooth. The UPCASE architecture also includes context inference mechanisms allowing the usage of various context inference engines. However, the presented implementation incorporates only decision tree methods in order to learn and to identify context dynamically at run-time.

Opposed to the above systems, SocialFusion [22] is a context-aware system that gathers data from social networking web sites and fuses them with data streams from smartphones and fixed sensor networks. The authors outline a multistage architecture for achieving such fusion and describe some of the major challenges encountered, which are: mining the data for context-aware inferences of individuals and groups, generating context-aware recommendations and preserving privacy and anonymity.

III. SOCIETIES Vision and Concepts

Current pervasive computing systems [1] focus on addressing the needs of individual users. The heralded arrival of sensor networking and services, which form part of the smart spaces of these pervasive systems, whilst supporting multi-user operations, are targeted at people who are assumed to be only interacting with the smart space not directly with other users. This neglects the inherently social nature of humans and may be the reason why the market penetration of pervasive computing products is very low. On the other hand, social networking services [2] are very popular and are used to allow individuals to discover, communicate and share with others. However, they are just online systems that do not integrate well with the hardware resources of their users.

The SOCIETIES integrated project (http://www.ict-societies.eu/) pursues the convergence of the pervasive computing and social computing paradigms introducing new concepts that extend pervasive systems beyond the individual to dynamic communities of users. These concepts are:

Pervasive Community: It is a group of, two or more, individuals who have agreed to share some, but not necessarily all, of their pervasive resources with other members of that community [23].

Pervasive Resource: These are: (i) services (including services for controlling personal and environmental devices) and (ii) information about individuals and communities (including context, preferences, behaviours and memberships), which can be shared among community members.

Community Interaction Space (CIS): Once a pervasive community is created, it forms a CIS [23]. There is a one-to-one mapping between pervasive communities and CISs. Individuals may belong to any number of pervasive communities, and thus CISs, simultaneously.

Co-operating Smart Space (CSS): CSSs enable groups of users that demonstrate commonalities for a non-trivial period to join together in pervasive communities. A CSS is a digital representation of a user or organisation in a pervasive community. The CSS provides its owner with a suite of services which support the creation of and participation in pervasive communities, as well as a range of intelligent cross-community facilities. The latter enable community members to benefit from the information and services of the community as a whole. Individuals can participate in a CIS only via their CSSs. However, they can also interact with other CSSs without having to form pervasive communities or create CISs. Individuals may also interact with each other without using CSSs by employing more traditional mechanisms [23].

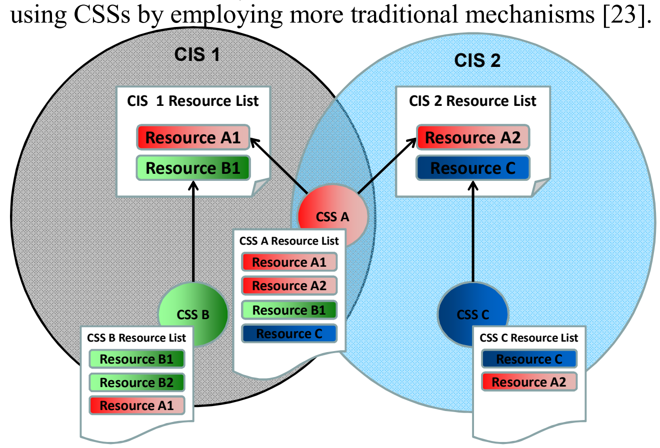

Figure 1. Sharing of resources accross CSSs in CIS domains.

Figure 1 illustrates three CSSs that formulate two CISs. The sharing of resources is also depicted in this figure. One can observe that CSS B decides to share a subset of its resources with the members of CIS 1, to which it belongs. Furthermore, CSS A that is a member of both CIS 1 and CIS 2 shares one subset of its resources with the members of CIS 1 and another subset with the members of CIS 2.

IV. Context Innovations in Pervasive Social Computing

Context awareness is fundamental in pervasive environments. A context management system able to support both user and community context in pervasive social computing domains should demonstrate additional innovative features compared to traditional context management systems adequate for individual users of pervasive environments. Before analysing these new innovative features, it is necessary to define the concept of community context. As denoted in [24] and extending Dey's context definition [25], group or community context is considered to be any information that can be used to characterise the situation of a community and that is relevant to the interaction between the community members and an application. This is in fact more than just a collection of the common or similar context information of all or most of the individual members of a given community. The complexity of modelling the various community context types varies greatly. In the remainder of this section, the main innovations that are introduced in order for context-awareness to be supported in pervasive social environments are presented.

A. Community Context modelling and management

Context information is one of the main criteria that can be used to identify which users are relevant to which individuals, resources and communities. Hence, a community context model should be able to assist in the management of dynamically formed communities of people, for both digital and physical worlds in which users discover relevant entities. A community can be seen as an individual entity with its own community attributes that are derived from the individual community members attributes. However, a filtering of user's context attributes should take place in order to extract only the meaningful types of information that will be translated as community attributes. The community context model assists community management, helping people in both the digital and physical world to discover people, services and devices that are of interest.

Additional innovative mechanisms are introduced with regards to community context updates. Traditional context information updates can be triggered by sources such as sensors, user actions, changes in social media data, quality of context thresholds, context inference processes, community activity, community membership changes, etc. However, a change in an individual user's context information may trigger the update of one or more pieces of community context information across multiple communities of which that person is a member. Hence, keeping community context updated enhances its usefulness, but also increases the complexity of context management process.

B. Intelligent community context history management

Recording context information results to the creation of context history data sets that can be exploited in various ways. Context history provides facilities for the support of context-based discovery of communities and things in the physical and virtual worlds. Community context history supports the enrichment of pervasive communities with self-organisation features that exploit the community context information to make decisions on behalf of entire communities related to resource usage and sharing (i.e. support of context-based community decision making). To this end, the support of intelligent context history management for users and communities is a valuable tool in community context management systems as it can greatly enhance the end user perceived experience. Existing mechanisms for user context history management (i.e. data recording and forgetting, data volume management, extracting history summaries and outlines, privacy protection, etc.) should be extended in order to address the respective requirements in a community level.

C. Estimation of community context

Inferring community context values needs innovative sophisticated mechanisms. Community context estimation provides useful real-time information for community activities, and supports the connection of people with common interests or other context commonalities/bonds. Community context is estimated based on the attribute values of the individual community members. The community's attributes change more often than the attributes of the individuals belonging to the community. For example, each of the members of a community has an age which changes once in year, while the average age of the community will change more often as new members join or existing members leave the community. Estimating community context is a challenging task that becomes more difficult as the number of the community members increases and as the complexity and dynamicity of context information rises. Extraction of community context must be supported both on demand and continuously.

D. Context Similarity Evaluation

Context is one of the main criteria that are exploited in the discovery of the individuals that are relevant to specific users or communities. Thus, it is necessary to develop mechanisms for comparing context values. Evaluating context similarity is a challenging task that requires intelligent context comparison mechanisms. It is necessary to enable the evaluation of context similarity for both quantifiable and qualitative context information. The first requires arithmetic based comparison methods and is applicable for data such as location coordinates, weight or temperature. The latter requires new principles in comparing context semantics to estimate similarity and is employed for context data such as user interests, status or symbolic location.

Context similarity evaluation outcome may influence various decisions with regards to: (i) creation, discovery, and deletion of communities, (ii) identification of community hierarchies, (iii) identification of communities that could be merged or split, (iv) community membership management (i.e. addition or removal of members), (v) prediction of user intent based on similar context, as common context often indicates similar intentions and (vi) user preference discovery based on similar context, as the same preferences may be applicable not only under a given combination of context information values, but also when similar context conditions are observed.

E. Context inheritance

The representation of user communities in pervasive computing introduces hierarchical structures that often exist among various communities. This concept can be particularly useful, as it allows the inheritance of context information across the community hierarchy and especially in automated creation of sub-communities. For example assuming that the first year students of computer science department form a community, then various sub-communities could be formed based on criteria such as student's food preferences, sports, hobbies, area of residence etc.

Context inheritance needs to support the inference of currently unavailable context based on information available from a parent community. The context inheritance mechanisms need to be able to deal with the potential conflicts that may arise, given the fact that anyone can be a member of multiple communities or sub-communities. However, it is worth the effort to find efficient mechanisms for conflict resolution in context inheritance, as there are multiple real life applications where speed is critical, while best-guess values are also better than no value at all for some types of context.

F. Community context prediction

Context data prediction is a feature that greatly enhances the overall system efficiency, especially in terms of proactivity. Many modern context management frameworks embed sophisticated prediction algorithms achieving context forecasting with increased accuracy. Community context allows further enhancement of existing prediction techniques and also imposes new challenges in context prediction research area. Community-based context prediction models may be particularly useful for individual user context prediction. To this end, two major approaches are identified (illustrated in Figure 2) that are differentiated by what the system collects from each community member: (i) a history log containing end-user's context history data (case A in Figure 2) and (ii) a pre-learned context prediction model (CPM) for the individual (case B in Figure 2).

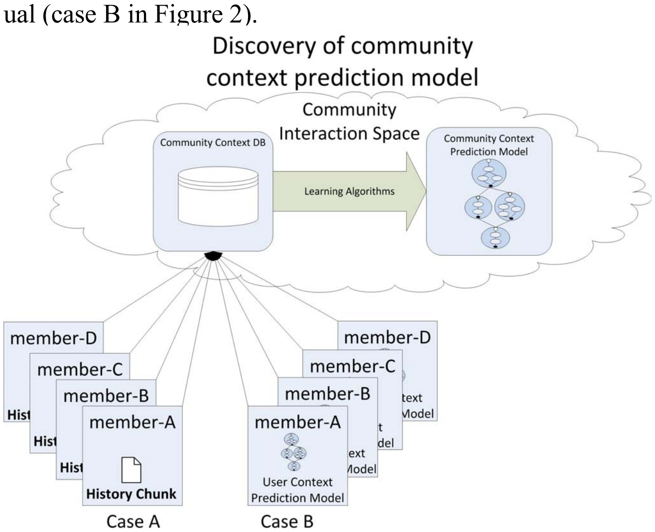

Figure 2. Two cases on community context prediction model learning.

In both approaches, the collected data are processed by a variant of the community context prediction learning algorithm that results in a community wide prediction model. In case A, the community CPM is created based on the history of the estimated community context. In case B, the community CPM is created by a process that evaluates the similarity and couples the individual users' CPMs. During the prediction process, if the user context prediction model is not providing adequate results, the community CPM is also used.

V. SOCIETIES CONTEXT MANAGEMENT ARCHITECTURE

In the previous chapter a set of innovations with regards to Community Context Management (CCM) in pervasive social computing environments was presented. As described in Section III, SOCIETIES aims to build such an environment coupling the advantages of pervasive computing with the ones of social networking systems. The community context management architecture [24] of SOCIETIES demonstrates all aforementioned innovations via dedicated mechanisms. More specifically, the following mapping of CCM components to innovations can be made:

- *Community context modelling and management:* The Context Model implements the respective data modelling features. The Context Broker provides access to current, past and future context data of both individuals and communities. Finally, there are three Context DB Management (CDBM) components that are exploited here: the User CDBM, the Community CDBM and the Multi-Community CDBM components that operate at individual user level, at community level and at cross-community level respectively.
- *Intelligent community context history management:* There is the User Context History Database that is responsible for the persistent storage of historical context data (History of Context - HoC) for both individuals and communities and is accessible via the User Context History Management and the Community Context History Management components.
- *Estimation of community context:* The Community Context Estimation component implements various mechanisms that enable the estimation of community context and are applicable either for enumerated context value formats (e.g., median value, most probable value or values of given population, selection of the values above a given probability threshold, selection of the context values that add to at least a given probability, etc.) or for quantifiable context values (e.g., average value, statistical analysis and extraction of the statistical distribution, etc.).
- *Context Similarity Evaluation (CSE):* There are three components that implement this functionality: the User CSE component that is responsible for estimating the similarity of individual user context information with given context values; the Community CSE component that is responsible for estimating the similarity of user context information for members of established communities and the Multi-Community CSE that is responsible for estimating the similarity of context information at cross-community level.
- *Context inheritance:* There are two dedicated components that handle context inheritance at individual user level and at community level, i.e. the User Context Inheritance and the Community Context inheritance respectively.
- *Community context prediction:* This functionality is implemented by the User Context Prediction and the Community Context Prediction components, which

exploit the User Context History Database and the Community Context History Database respectively.

VI. CONCLUSIONS

The research on context aware systems capable to support dynamic community management in large scale is still in early stages. While significant research has been carried out regarding community context, there is no support for resolving context conflicts or for inheritance of context information across hierarchical communities. Additionally, there are some research initiatives that have investigated the formulation of groups of people with common interests; the lifecycle management of these groups does not consider the many ongoing context changes that occur for each user. Finally, treating social networking systems as context sources and/or context consumers is still a challenging task.

This paper elaborated on the context-related state of the art work in both pervasive and social computing environments. It introduced the SOCIETIES vision and concepts that allow the integration of full scale pervasive functionality in social networking systems. It presented various innovative mechanisms that are necessary to support community context management in environments coupling pervasiveness with social networking. These mechanisms have been integrated in a context management framework that has already been designed and implemented by the SOCIETIES project. Currently, the system is under evaluation and extensive user trials are planned to take place throughout 2013 and the beginning of 2014. Three demanding user groups will be targeted: (i) computer science students with an expertise on smart devices and computing, (ii) professionals that demonstrate high organisational and interaction demands and (iii) disaster management relief workers in non-office environments. The first full scale trial will take place in February 2013. Feedback derived by the user trials will allow us to discover and address potential architectural drawbacks and to further refine the efficiency of the described user and community context management mechanisms.

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REFERENCES

[1] D. Saha and A. Mukherjee, Pervasive computing: A paradigm for the 21st century, IEEE Computer, Vol. 36, No. 3, Mar. 2003, pp. 25-31.

[2] S. Dasgupta, Social Computing: Concepts, Methodologies, Tools, and Applications, IGI Global, 2010.

[3] K. Cheverst, K. Mitchell, A. Friday, and N. Davies, "Sharing (Location) Context to Facilitate Collaboration Between City Visitors,". Proc. Workshop on Interactive Applications of Mobile Computing, (IMC 00), Nov. 2000.

[4] R.S. Marin-Perianu, P.J. Havinga, and J. Scholten, "Movement-based Group Awareness with Wireless Sensor Networks," Proc. of the 5th Int. Conf. on Pervasive Computing, May 2007.

[5] Y. Cao, R. Klamma, M. Hou and M. Jarke, "Follow Me, Follow You - Spatiotemporal Community Context Modeling and Adaptation for Mobile Information Systems," Proc. Of the 9th Int. Conf. on Mobile Data Management (MDM 2008), IEEE Computer Society, Apr. 2008, pp.108-115.

[6] T. Hussein, T. Linder, W. Gaulke, and J. Ziegler, "A Framework and an Architecture for Context-Aware Group Recommendations," Proc. of the 16th Int. Conf. on Collaboration and Technology (CRIWG'10), Springer-Verlag, Sep. 2010, pp. 121-128.

[7] D. Lee, S. Han, I. Park, S. Kang, K. Lee, S.J. Hyun, Y. Lee and G. Lee, "A Group-Aware Middleware for Ubiquitous Computing Environment," Proc. of the 14th Int. Conf. on Artificial Reality and Telexistence (ICAT 2004), Nov.-Dec. 2004, pp. 291-298.

[8] R. Tuomela and M. Tuomela, "Cooperation and trust in group context," Mind & Society, Vol. 4, No. 1, Jun. 2005, pp. 49-84.

[9] C. Chong, and N. Nishio, "GRECOM: Group Context Management Middleware for Group Event based Services," Proc. of the 9th Int. Conf. on Ubiquitous Computing, Sep. 2007.

[10] J. Jung, "Ontology-based context synchronization for ad hoc social collaborations," Elsevier Knowledge Based Systems Journal, Vol. 21, No. 7, Oct. 2008, pp. 573-580.

[11] J. Koolwaaij, A. Tarlano, M. Luther, P. Nurmi, B. Mrohs, A. Battestini, and R. Vaidya "Context Watcher-Sharing Context Information in Everyday Life," Proc. of the IASTED conference on Web Technologies, Applications and Services (WTAS06), Jul. 2006, pp. 12-21.

[12] MobiLife Integrated Project (IST 511607), 6th Framework Programme (2004-2006), Homepage URL: http://www.ist-mobilife.org.

[13] Brightkite, Homepage URL: http://brightkite.com.

[14] Loopt, Homepage URL: http://www.loopt.com.

[15] M. Tran, J. Han, and A. Colman, "Social Context: Supporting Interaction Aware-ness in Ubiquitous Environments," Proc. of the 6th Annual International ICST Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, Jul. 2009, pp. 1-10.

[16] A. Joly, P. Maret and J. Daigremont, "Context-Awareness, the missing block of Social Networking," Int. Journal of Computer Science and Applications, Vol. 6, No. 2, Jan. 2009, pp. 50-65.

[17] M. Endler, A. Skyrme, D. Schuster and T. Springer, "Defining situated social context for pervasive social computing," Proc. of the 2nd IEEE Workshop on Pervasive Collaboration and Social Networking, Mar. 2011, pp. 519-524.

[18] D. Bottazzi, Corradi, A. and R. Montanari, "A context-aware group management middleware to support resource sharing in MANET environments," Proc. 6th Int. Conf. on Mobile data management (MDM '05), May 2005, pp. 147-151.

[19] G. Biamino, "Modeling social contexts for pervasive computing environments," Proc. of the 2011 IEEE Int. Conf. on Pervasive Computing and Communications Workshops, Mar. 2011, pp. 393-394.

[20] E. Miluzzo, N.D. Lane, S.B. Eisenman and A.T. Campbell, "CenceMe – injecting sensing presence into social networking applications," Proc. of the 2nd European Conference on Smart Sensing and Context, Oct. 2007, pp 1-28.

[21] A.C. Santos, J.M. Cardoso, D.R. Ferreira, P.C. Diniz, and P. Chaínho "Providing user context for mobile and social networking applications," Pervasive and Mobile Computing, Vol. 6, No. 3, Jun. 2010, pp. 324-341.

[22] A. Beach, M. Gartrell, X. Xing, R. Han, Q. Lv, S. Mishra and K. Seada, "Fusing mobile, sensor, and social data to fully enable context-aware computing," Proc. of the 11th Workshop on Mobile Computing Systems & Applications, Feb. 2010.

[23] K. Doolin, et al., "SOCIETIES: Where Pervasive Meets Social", Lecture Notes in Computer Science, Vol. 7281, 2012, pp. 30-41.

[24] I. Roussaki, et al., "Context-awareness in wireless and mobile computing revisited to embrace social networking," IEEE Communications Magazine, Vol. 50, No.6, Jun. 2012, pp. 74-81.

[25] A. K. Dey, "Providing Architectural Support for Building Context-Aware Applications," Ph.D. Thesis, College of Computing, Georgia Institute of Technology, Dec. 2000.