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Agent-based Framework for Sensor-to-Sensor Personalization

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Abstract

In Wireless Sensor Networks, personalization has been seen by researchers as the process of tailoring services to fulfill requests of different users with different profiles. This vision ignores that individual sensors commonly have different profiles and contexts and therefore different needs. In this paper, we aim at extending personalization by allowing sensors to support each other with services that mutually fit their differences. To this end, we propose an agent-based framework where sensor nodes delegate software agents (static or mobile) to collect valuable data about the neighboring sensors and the spatial characteristics of their surrounding environments. We also show how this framework may be used to make the routing and relocation processes more personalized.

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Keywords: sensor network; personalization; software agent; mobile agent; routing; relocation.

1. Introduction

Personalization has been addressed and implemented in a variety of fields. Technological advances have been very beneficial in getting closer to users, acquiring their explicit and implicit data, as well as acquiring relevant data on their surroundings. In this context, Wireless Sensor Networks (WSNs) can improve and expand the quality of services across a wide variety of settings. This is particularly possible thanks to the context awareness ability of sensors and their ability to adapt and support new events of interest. Several research works (discussed in Section 2) have benefited from those capabilities to deliver personalized services to the end-user.

In this paper, we argue that further benefits could be obtained, not only by delivering personalized

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services to the end-user, but also by adding personalization within the sensor network itself. This means that sensors should not only sense/process/forward/move according to their own capabilities and/or the end-user's preferences. They have also to maintain one-to-one relationships with their neighbors, by understanding their mutual needs. Sensors have thus to offer personalized services to their next hops to achieve sensor-to-sensor personalization. For instance, a sensor node S would only send to its neighbor R data in the format that R can process while making sure that R is trustworthy and has enough resources. This requires from sensor S to have an updated knowledge about its neighbors' status, capabilities, and context. This implies exchanging an important volume of messages that may not be supported by the available bandwidth and the current level of energy and processing capabilities of the sensors. It may also require collecting contextual data (e.g. characteristics of the space where these neighbors are operating) which are not necessary available at any of these neighbors. To this end, we believe that it is important to endow sensors with autonomy and intelligence allowing them to provide peers with the right data at the right time. Agent technology appears then as a serious candidate for this task.

An agent is a computer system which acts autonomously in its environment to meet its design objectives [1]. Thanks to their autonomy, agents can operate in an environment which is open, highly dynamic, uncertain, or complex [1]. Similarly, sensors are required to behave autonomously within a distributed network and adapt their behaviors to the changing environment without human intervention. In addition, sensors have to collect data about their neighbors (to provide them with personalized services) without compromising the overall performance of the network. In this context, the agent community has an adequate set of formalisms, algorithms, and methodologies which can address these challenges [2].

In the reminder of this paper, Section 2 explores the related works in personalization and agent use in WSN. Section 3 presents our agent-based framework which provides sensor-to-sensor personalization by allowing sensors to act autonomously and more intelligently. Section 4 outlines our proofs of concept. Finally, Section 5 summarizes our contributions and future works.

2. Related Works

Several research works, particularly in healthcare applications [3], smart-spaces [4], and mobile applications [5], have benefited from WSN capabilities to provide users with personalized services. For example, in order to achieve pervasive healthcare environments, sensor networks were used for a variety of purposes that range from simply setting an alarm volume according to the user's hearing abilities and the ambient noise level, to the complex tailoring of the user's entire eHealth environment [6].

Furthermore, thanks to the micro-nano technologies, the recent types of biomedical sensors are allowing personalization to be achieved more efficiently by maintaining and updating user's profile and data related to his/her context, general and specific preferences, physical and mental abilities, and other relevant parameters [6]. In smart environments, applications generally require situated, individualized, and personalized information to give optimal support to the user [7]. In addition to the information stored beforehand about the user, data on the current situation and user's activities are commonly acquired by on-body and off-body sensors. On-body sensors (e.g., biological signal sensors) are helpful to get the implicit feedback of users while off-body sensors have been used to acquire data on a variety of issues, including persons' identities, locations, gestures, focus of attention, and emotion.

Many other examples can be found in the literature. However, most of personalization efforts have been performed at the level of services delivered by the sensor network to the end-users. To the best of our knowledge, no research work has tackled the issue of personalization within the sensor network at the level of sensor-to-sensor communications. This could be explained by the fact that personalization has been always seen as an effort aiming to deliver services to a human being (as an end-user).

Regarding the use of software agents, many agent-based approaches have indeed been proposed to solve various problems in sensor networks [8]. More recently, powerful mote platforms have been developed by using intelligent Wireless Sensor Networks (iWSNs) [8]. As energy conservation is one of the main concerns in WSN, most agent-based approaches in WSN aim at enhancing the node life, in particular by introducing mobile agents. Indeed, mobile agents, when used in WSN, reduce the message traffic and thus save energy [8]. For example, in [9], mobile agents are used to reduce the communication cost by moving the processing function to the data rather than bringing the data to the sink. Each mobile agent has to carry a code to the source nodes and brings back aggregated data to the sink. In [10], the authors propose to reduce energy consumption of the WSN –to forecast water quality- by using data aggregation algorithms whereby mobile intelligent agents act as dynamic clustering points in the network. In [11], mobile agents store and gather metadata from nodes while minimizing route cost and maximizing battery level of sensors. The use of agents (particularly the mobile ones) does not only save energy. They may also allow a more efficient use of sensors' memories [8]. Indeed, since running all codes on a given node is often expensive and sometimes infeasible due to restrictions on local memory and processor, mobile agents can be deployed to support code distribution between sensors [12, 13]. In terms of conceptualization, several research works have modeled sensor nodes as software agents (not mobile) to achieve adaptive data sampling (e.g., [14]), improve task assignment (e.g., [2]), and make data routing more efficient (e.g., [15]). In the next section, we propose a framework where each sensor can delegate some of its tasks to a mobile agent. This latter migrates to other nodes/platforms to collect relevant data which are needed to offer personalized services to next hops.

3. Agent-based Framework

3.1. General Concepts

Fig. 1 shows a layered framework which design philosophy has been inspired by the layered simulation model in [16]. The framework builds a parallel between a Real World (where the WSN is deployed to manage/monitor real resources) and a Virtual World (where software agents can behave/act on behalf of the real sensors).

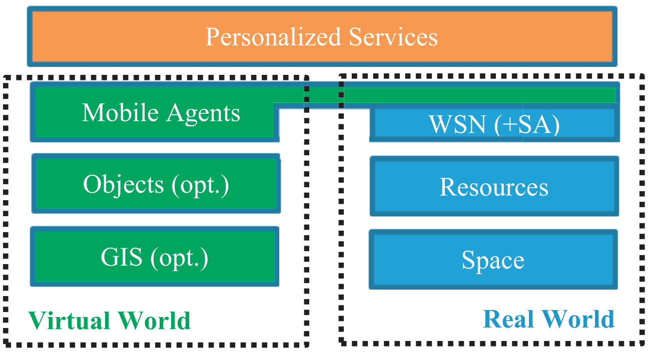

Fig. 1. General view of our agent-based framework

In order to offer a personalized service to its neighbor, a sensor node has to take into account the environment context, the requirements and constraints of its neighbors, as well as its own goals and restrictions. To this end, and under such circumstances, the Real World environment is not necessary the best place for the following four reasons:

- The process may involve the collaboration of several sensors with a high volume of exchanged messages. Communication is the main energy consumer function of a sensor.
- Offering a personalized service to the other nodes may require from a given sensor more processing. This is often very difficult if not unfeasible due to its limited memory and CPU.
- The decision/action of each sensor may depend on the spatial characteristics of the surrounding space (elevation, slope, etc.) and the location of the other resources/sensors. These data are, at best, partially available for a single node in the real world.
- Individual sensors have only a partial vision of the overall environment (status of the global network, context, etc.). As each sensor is only aware of its neighborhood, the undertaken actions are not necessary positive for the overall network.

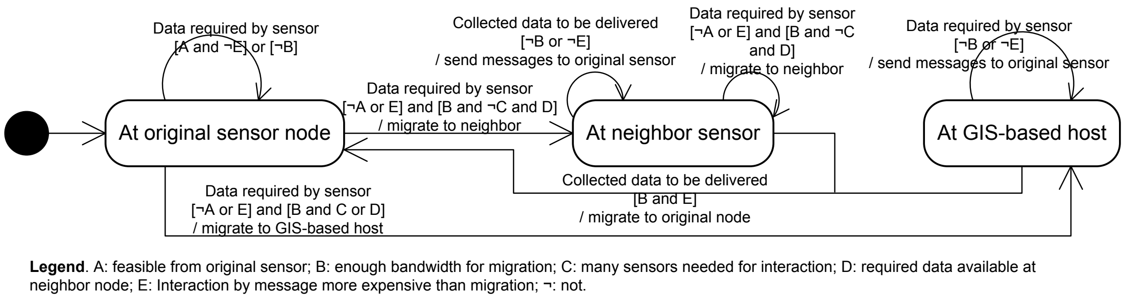

Fig. 2. State diagram of Mobile Agent (MA)

To overcome the four problems depicted above, we endow each physical sensor S with two software agents: a Stationary Agent (SA) which resides in node S and a Mobile Agent (MA) which is initially at S but can migrate to a neighbor node or to a more enhanced Virtual World depending on the situation. The state diagram of Fig. 2 depicts the different cases of MA migration. Basically, MA will leave its original node S only if personalizing a service at S would be expensive in terms of communication/energy or unfeasible for lack of data. MA may then migrate to one/few neighbor node(s) in order to collect/exchange relevant data. In some cases, when the process requires a big number of nodes and/or implies data which is not available within the sensors (e.g., spatial data), MA has to migrate to an enhanced Virtual World (mainly, a GIS-based host).

3.2. Virtual World

The Virtual World is a platform where software agents can: (i) meet (i.e. exchange local messages) each other to share data (about their original sensor nodes) and (ii) optionally, access to the GIS data to apprehend the geographic characteristics of the space surrounding the current location of their original sensors (if such data is needed to offer a personalized service) as well as the resources to be managed/monitored (represented by stationary objects or agents [16]). Concretely, if MAs aim at meeting to exchange data between them, the Virtual World could be simply a super node with extended memory and CPU capacities. However, if MAs need to access to the GIS data, the Virtual World would rather be a remote host (with extended processing and energy capacities) where a dedicated software platform provides MAs with spatial data (GIS database).

The MA, once its work is done within the remote node or platform, has to communicate with its original node S (more precisely with the SA) in order to feed it with the data required to offer a personalized service to S' neighbors. The MA has then to choose between migrating to S and sending a message to S. This choice depends on the network status and the volume of data to be sent (Fig. 2).

The selection of the Virtual World and the association of each sensor to a particular Virtual World are not discussed in this paper. We mainly aim here at demonstrating the benefits of such meeting infrastructure. We can summarize the advantages as follows:

- Most of the inter-agent messages are local (in the Virtual World environment). Even a high traffic of exchanged messages will not really affect the performance of the WSN. Agent migration, if any, is the only significant overhead. However, a well-designed agent-based middleware platform may provide basis for the good performance of WSN applications [8].
- Agents within the Virtual World can benefit from the extended capacities in terms of memory and CPU which are required to process data required later on for personalization. They can also get updated data about status/attributes of the many other sensors represented by their MAs.
- Each agent in the enhanced Virtual World (with GIS capabilities) has full access to all relevant data (needed to offer a better personalized service) including the spatial data of the surrounding space.

3.3. Personalization via Sensor Enhanced Capabilities

In order to enable sensors to provide personalized services to neighboring peers, sensors (and/or their agents) have to be endowed with extra capabilities, namely, semantic-awareness, trust-awareness, and space-awareness (see Fig .3). Basically, sensor-based personalization may be carried out at three stages: data acquisition, data processing, and data communication. For instance, when a sensor, initially in an idle state, receives a request to acquire some data, it starts by assessing, if necessary, its own trust (using for example [17]) on the sender of the message. If this sender is trustworthy, the receiver starts by checking the data type requested. If this data type is not supported, the sensor notifies the sender that it is unable to acquire the requested data. Otherwise, the sensor identifies the needed data accuracy and sampling rate then collects that data. If data analysis is necessary, the sensor may carry out some processing, such as data filtering, data aggregating, and data formatting with respect to the expected level of details. Once the personalization of data processing is achieved, the sensor carries out the personalization of data communication by setting up the size of data packages while taking into account the QoS requirements of the beneficiary peer. In the three cases (data acquisition, processing, or communication), if the output is not personalized as expected, the receiver sensor may make some recommendations to the peer based upon its awareness about the current situation and its surroundings.

Fig. 3 summarizes the different capabilities of our sensors. Each sensor has the three common capabilities which are Processing, Routing, and Communication in addition to Relocation for mobile sensors. We propose to add four other capabilities to achieve personalization:

- Space-awareness: a sensor S needs to know the characteristics of the space in which it is operating in order to provide a better service to its peers. For example, knowing that a geographic obstacle (e.g., mountain or hill) is between S and its receiver, may push sensor S to move to be reachable by its receiver. Space-awareness requires data which is provided by the Virtual World (equipped with GIS).
- Trust-awareness: a sensor may need to know if a neighbor node from/to which it gets/sends a message is trustworthy or not. This implies different processing (e.g., by encrypting data) or routing (e.g., by choosing another route) if the destination node is more or less trustworthy. Data about sensors trustworthiness may be collected at the sensor itself (via its SA) based on its own experience with the targeted node or at the Virtual World (via its MA) based on the feedback of the other nodes.
- Semantic-awareness: a sensor may perform a smarter forwarding if it can understand the semantic of the data. It will then avoid sending useless data to sensors. More details are in [18].
- Mobility (of agent): this capability is supported by the MA and aims at collecting the necessary data from the Virtual World to feed all the other capabilities (as shown in Fig. 3).

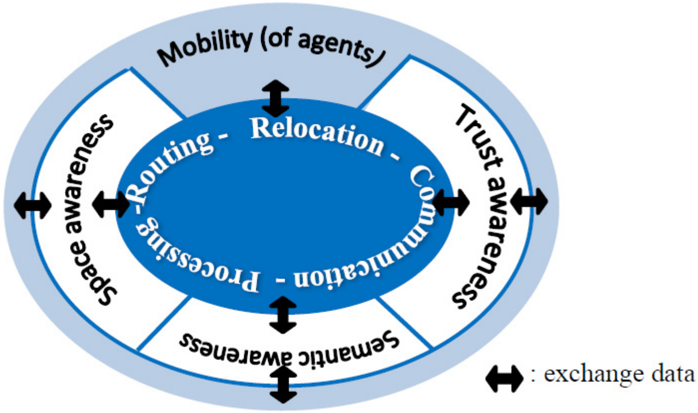

Fig. 3. Sensor endowed with extra capabilities

3.4. Discussing Enhanced Capabilities

Endowing sensors with the enhanced capabilities mentioned above requires discussing their impact on two main sensor constraints, namely, computing complexity and energy usage. In particular, agents, when embedded in devices such as sensors, must be circumspect in their use of energy since these nodes are often very constrained by nature [19]. It is here worth mentioning that mobile agents, when used in WSN, reduce the message traffic and thus save energy [8]. Several research works (see Related Works) have indeed confirmed this. In addition, in our framework, agents migrate only if this does not affect the bandwidth (see Fig. 2). Second, the Space-awareness capability implies being in a Virtual World (with GIS data) where resources (computation and energy) are relatively abundant. Finally, making sensors aware of the trustworthiness of their neighbors and the semantic of the forwarded data requires from each sensor to collect data (from its neighborhood) and performs extra processing. Nevertheless, when these tasks are performed by the MA in the Virtual World (e.g., a super node with extended memory and CPU capacities), the WSN overall performance is not really affected. The network may provide better services (by supporting trust and semantic) at a cost of installing more super nodes (if necessary), allowing agents to migrate through the network (when possible), and adding little complexity on super nodes (where resources are not as critical as in simple sensor nodes). The only case where simple sensor nodes may have to perform significant extra processing are when MAs cannot migrate (e.g., due to limited bandwidth) to the Virtual World. In this situation, a sensor which is running out of resources may suspend its personalization activities and focus on its primary functions (data acquisition, processing, and routing). To conclude here, sensors endowed with enhanced capabilities offer better services to each other and thus to the end-users. However, this implies more or less extra usage of resources (energy and processing). We think that each WSN designer, depending on the constraints and objectives, has to find a compromise between quality of service (provided by the enhanced sensor capabilities) and resource usage.

4. Proofs of Concept and Implementation

In this section we present two different proofs of concept to the framework presented in Section 3. The two illustrations concern two main tasks of sensors, namely, routing and relocation. They show how the principles of our framework can be used to provide more personalized routing and relocation.

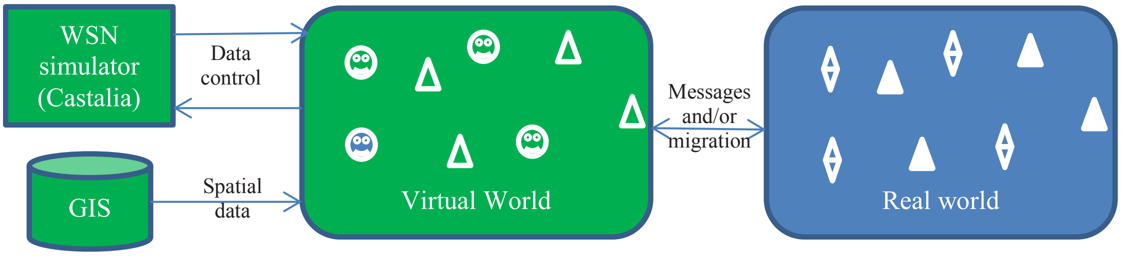

Fig. 4. Virtual World-based architecture for personalization-based routing

Regarding the routing problem, most of existing routing protocols are based on one main criterion -power consumption- at the expense of other aspects such as reliability, security, or efficiency [20]. To achieve a more sensor-to-sensor personalized routing, many requirements have to be taken into account apart from power saving, namely, sensor mobility, location, space, semantics, quality of service, and trust/security [20]. In [20] we already proposed a generic multi-criteria routing framework where the selection of the best neighbor hop (to which data should be forwarded) is personalized according to the environment (context), the end-user preferences, forwarder's requirements and constraints, and receiver's constraints and requirements (sensor-to-sensor personalization). As suggested by our framework in [20], the sender node S chooses the next hop based on –among other criteria- the data (level of energy, location, supported security level, semantic capabilities, etc.) collected about its neighbors. To support this framework, we use the agent-based framework of the present paper. More specifically, each sensor node S may use a mobile agent MA (if the conditions are met, see Fig. 2.) which may migrate to S' neighbors or to the GIS-enhanced Virtual World according to the context. MAs are thus responsible of collecting/exchanging data between each other on behalf of their original sensors. The Virtual World is implemented as a java application alimented by a GIS database to mimic the Real World space (see Fig. 4). The sensor-like behavior (e.g., routing algorithms) of agents within the Virtual World is ensured by the WSN simulator engine Castalia. Currently, agents are created at the java platform (Virtual World) as the agent migration between the Real and Virtual World is not yet coded. Our priority was in fact to prove the concept of the agent-based Virtual World as a tool to achieve sensor-to-sensor personalization. Our experiments show that routes found by agents are much more personalized than those delivered by traditional routing algorithms. When a node n receives a packet (to be routed until a final destination S1) it selects the most appropriate next hop to forward data based on the semantics, the QoS, and the security level supported at each neighbor node as well as its location. This is the sensor-to-sensor personalization facet. Node n compiles thus a lot of data (which would be collected by MA) about its neighbors in order to choose the right sensor. Moreover, depending on the end-user's requirements, node n may consider different weights of the selection criteria applied to each neighbor. This is the end-user personalization facet. Consequently, the combination of the two personalization facets determines the final routing path. This path is not necessary the shortest (Fig. 5.a). For instance, if the level of security supported at each neighbor node is the main selection criterion, the route is longer but certainly more secure. More details/results about our personalization-based routing framework and can be found in [20].

Concerning the relocation problem, we pointed out in [21] that relocating sensors in a dynamic large-scale environment, such as a forest in fire, is not an easy task and thus has to be planned carefully. To deal with this problem, we proposed to plan the relocation in a Virtual World, which is synchronized with the real environment. In this Virtual World, we combine both simulation-based planning and agent-based planning to conduct relocation. We used, as Virtual World with GIS capabilities, the MAGS platform [22] which enables thousands of space-aware agents to interact in a virtual geographic environment (in 2D and

3D). However, we did not implement the agent migration process yet. Our aim was only to prove that within an enhanced Virtual World agents are capable of finding much better relocation plans than what sensors would have done.

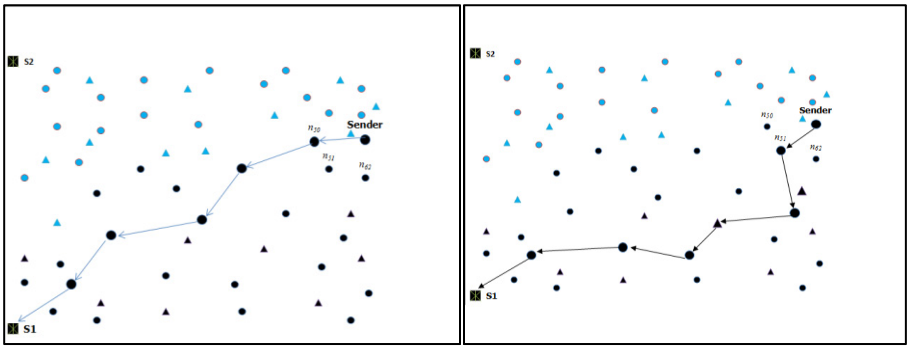

Fig. 5. (a) Shortest routing path (b) Most secure routing path

5. Conclusion and Future Works

In this paper, we proposed an agent-based framework for WSN where sensor nodes delegate software agents (static or mobile) to collect valuable data about the neighboring sensors and the surrounding environment. It also gives accessibility to more refined data (GIS). All this data can then be used by sensor nodes to provide personalized services to each other. Our framework also shows the complementarity between physical sensors and software agents: while sensors are getting data from the field (Real World), agents are collecting data from the Virtual World. Putting both types of data together makes sensor nodes more intelligent and more autonomous.

We have already showed, in previous research, how sensor-to-sensor personalization can be achieved for specific tasks such as routing and relocation. The present work actually gives the supporting framework for these applications. We are currently working on defining other aspects and applications for the sensor-to-sensor personalization. We are particularly interested in endowing sensors with a stronger trust and reputation model so that they can provide more secure services to their neighbors, with more semantic awareness to avoid forwarding useless data to the other sensors, and with more space awareness to provide services which can take the geographic characteristics into account.

Regarding the agent technology, we are working on building our own platform which will be able to provide agents with mobility, space awareness, and efficiency. We are indeed confident about the importance of this technology to solve many WSN issues. Indeed, even experimental sensor agent technology has become sufficiently reliable for operational use in the field. We do believe that the permanent deployment of sensor-agent networks is close.

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References

[1] Gerhard W. *Multiagent systems: A Modern Approach to Distributed Artificial Intelligence*. MIT Press, Cambridge, 1999.

[2] Rogers A, Corkill D, Jennings N. Agent Technologies for Sensor Networks. *IEEE Intelligent Systems* 2009; 24 (2): 13-17.

[3] Miao F, Miao X, Shangguan W, Li Y. MobiHealthcare System: Body Sensor Network Based M-Health System for Healthcare Application. *E-Health Telecommunication Systems and Networks* 2012; 1: 12-18.

[4] Byun J, Jeon B, Noh J, Kim Y, Park S. An intelligent self-adjusting sensor for smart home services based on ZigBee communications. *IEEE Transactions on Consumer Electronics* 2012; 58(3): 794-802.

[5] Chang C, Hsu S. Personalized Service Provision in a Context-Aware Shopping Environment. In Fourth International Conference on Computational Intelligence, Communication Systems and Networks (CICSyN); 2012, p. 103-108.

[6] Pharow P, Blobel B, Ruotsalainen P, Petersen F, Hovsto A. Portable Devices, Sensors and Networks: Wireless Personalized eHealth Services. In Proceedings of MIE'2009, p. 1012-1016.

[7] Hämmerle S, Wimmer M, Radig B, Beetz M. Sensor-based Situated, Individualized, and Personalized Interaction in Smart Environments. In Proceedings of GI Jahrestagung 2005, p. 261-265.

[8] Dagdeviren O, Korkmaz I, Tekbacak F, Erciyes K. A survey of agent technologies for wireless sensor networks. Iete Technical Review 2011; 28, 168.

[9] Malik H, Shakshuki E. Data Dissemination in Wireless Sensor Networks Using Software Agents. HPCS, *IEEE Computer Society* 2007: 28.

[10] Garcia MS, Carvalho D, Zlydareva O, Muldoon C, Masterson BF, O'Grady MJ, Meijer WG, O'Sullivan JJ, O'Hare GMP. An Agent-Based WSN for Water Quality Data Collection. *UCAmI*, LNCS Springer 2012; 7656: 454-461.

[11] Tang Liu; Fang Feng-Cai. Mobile agent based metadata framework for heterogeneous wireless sensor network. International Conference on Educational and Information Technology (ICEIT) , 17-19 Sept. 2010; 1:V1-446-V1-449.

[12] Available from: http://www.tinyos.net/tinyos-1.x/doc/Xnp.pdf. [last accessed on 2013 January 30].

[13] Hui JW, Culler D. The dynamic behavior of a data dissemination protocol for network programming at scale. In Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems, ACM Press, New York, 2004; 81-94.

[14] Kho J, Rogers A, Jennings NR. Decentralised adaptive sampling of wireless sensor networks. In First International Workshop on Agent Technology for Sensor Networks, a workshop of the 6th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS-07), Honolulu, Hawai'i, USA, 2007.

[15] Kho J, Tran-Thanh L, Rogers A, Jennings NR. Distributed Adaptive Sampling, Forwarding, and Routing Algorithms for Wireless Visual Sensor Networks. In 3rd Int. Workshop on Agent Technology for Sensor Networks, Budapest, May. 2009, p. 63-70.

[16] Sahli N, Moulin B. EKEMAS, an agent-based geo-simulation framework to support continual planning in the real-word. *Applied Intelligence* 2009, 31(2): 188-209.

[17] Chen H, Wu H Zhou X, Gao C. Agent-based Trust Model in Wireless Sensor Networks. 8th ACIS Int Conf on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, 2007, 3: 119-124.

[18] Jabeur N, Iraqi Y, Sahli N. Semantic Routing in Wireless Sensor Networks: Challenges and Opportunities. IEEE Global Information Infrastructure Symposium. Tunisia June 2009.

[19] Shen S, O'Hare GMP, O'Grady MJ. Fuzzy-set-based decision making through energy-aware and utility agents within wireless sensor networks. *Artificial Intelligence Review* 2007; 27:165–187.

[20] Sahli N, Jabeur N, Khan I, Badra M. Towards a Generic Framework for Wireless Sensor Network Multi-Criteria Routing. In proc. of 4th Int. workshop on Wireless Sensor Network: Applications, Developments, and Trends. In conjunction with the 5th IEEE International Conference on New Technologies, Mobility, and Security (NTMS'2012; 1-6). May 7-10, 2012 – Istanbul-Turkey

[21] Sahli N, Jabeur N. Agent-Based Approach to Plan Sensors Relocation in a Virtual Geographic Environment. in Proceedings of NTMS 2011, Paris, France, 7-10 February 2011.

[22] Moulin B, Chaker W, Perron J, Pelletier P, Hogan J, Gbei E. MAGS Project: Multi-agent geosimulation and crowd simulation. In Proc. of the COSIT'03 Conference Spatial Information Theory, Ittingen (Switzerland), LNCS 2003; 2825: 151-168.