Distributed Autonomic Inference Machine for Wireless Sensor Networks

Nídia Glória da Silva Campos, Danielo G. Gomes
Department of Teleinformatics Engineering
Federal University of Ceará - UFC
Fortaleza, Brazil
e-mail: nidia@great.ufc.br, danielo@ufc.br

José Neuman de Souza
Department of Computer Science
Federal University of Ceará - UFC
Fortaleza, Brazil
e-mail: neuman@ufc.br

***Abstract*— Wireless Sensor Networks (WSNs) offer data to Intelligence Ambient system, but, due the big number of sensor nodes and data heterogeneity, it can be overload by them. This paper proposes MIAD, a distributed autonomic inference machine which uses fuzzy logic to make ambient context and to self-configure sensing and dissemination rates and minimize redundant context of WSN. Tests with Crossbow micaz motes and temperature and relative humidity sensors show that MIAD sends more relevant risk fire context messages to final system while it saves WSN energy. It presents better results than distributed WSN application without self-configuration and an autonomic engine based on crisp rules.**

Autonomic Computing; WSN; Fuzzy Logic; Self-Configuration

I. INTRODUCTION

Ambient Intelligence involves an environment enriched of technology and a system which takes decisions based on information obtained in real time and/or of the environment historical data bringing benefits to its users. Sensors and devices interconnected in network supply with data the information creation of decision system. Ambient Intelligence can be defined as a digital ambient which gives support to people in their daily life helping them in a sensible way. In this context, "sensible way" means the system not only recognizes the user, as well, it learns with him and it knows his preferences to provides services more personalized to him [1].

The concept of Ambient Intelligence comprehends other ones, like ubiquitous computing, pervasive computing, context awareness and embedded systems, but, with some differences [2]. Context can be any information used to characterize the situation of an entity (person, place or object). Such entity is relevant to the interaction between a user and an awareness application/system which adapts its behavior according to the processed context [3]. Contexts can be obtained through data from a wireless sensor network (WSN) installed into the ambient, for example. For user benefits himself with Ambient Intelligence, context must be employed with inference and learning techniques, which will allow system to take decisions, like turn off lights or regulates air-conditioning temperature from a place.

The feature Self-Management of Autonomic Computing can be employed to build these kinds of ambient, because it intends to liberate system administers from operations and maintenance details and provides systems which are able to work 24 hours per day and 7 days per week. Like biologic systems, autonomic systems will keep and adjust its operation according to changes of components, workloads, external demands and conditions and also malicious fails, or not, in its hardware or software [5].

This work proposes a distributed autonomic inference machine (MIAD) for WSN which is embedded in each sensor node to produce high level context information using both local and neighborhood sensor data while it self-configures sensing and dissemination rates as well the redundancy of WSN data using fuzzy logic. Context can be consumed by an environment monitoring system to support decisions about the execution of services to satisfy Ambient Intelligence users.

II. RELATED WORK

e-Sense was a project integrated to European Commission and it aimed to capture Ambient Intelligence to mobile communications through WSN until 2007. In this project, techniques were researched to join information from several wireless sensors scattered in ambient to deduce user current emotional state and as well configurations to search social well-being and general information of monitored ambient. Applications connected to this kind of ambient will can use these information to provide its services in an intelligent way. In Fig.1, WSN heterogeneous data of houses, people body, and several ambient can be joined and processed to provide context to applications in servers, as example, triggering alarms to supervisor of system.

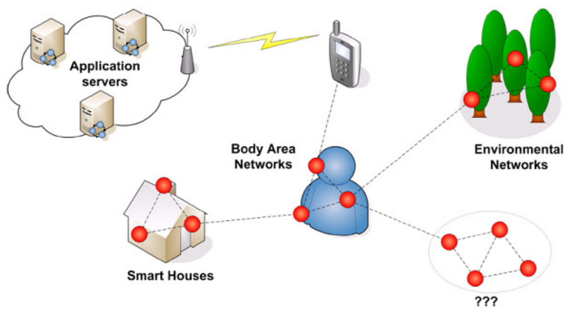

Figure 1. e-SENSE scenery [7]

e-SENSE vision continues be explored in an audacious way in an European consortium called SENSEI since 2008. Its principal objective is the integration of physic world with digital world in a network from future. One of its principal approaches is Context-Aware Systems which use heterogeneous wireless sensor and actor networks (WSAN) for development of intelligent cities as shown into Fig. 2. Intelligent cities give a better connectivity and interactivity between individuals and organizations, secure networks, intelligent transports that always search the better route, and also minimize the emission of carbon monoxide due a system which monitors them constantly. An expected result is an open service interface and a semantic specification relevant to unify context information access and performance services offered by services systems and applications [12].

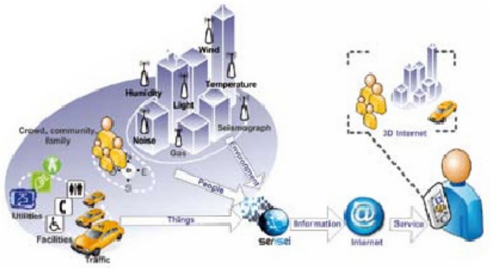

Figure 2. Scenery of an intelligent city [13]

Concrete applications that involve e-SENSE and SENSEI views, in part, are telemedicine applications. [8] and [9] proposes architectures that utilizes ontology reasoning and learning techniques applied to data provided by WSN, as shown in Fig. 1, to obtain context from monitored ambient. In these works, context is formed only by network monitor system which is overloaded when heterogeneity data augments from network. This problem was observed in [10] and [11]. In order to find a solution for it, collaboration between WSN nodes is important to WSN operates as a distributed inference system producing high level context of environment through the use of its own data sensor. Artificial Intelligence must be combined to Ambient Intelligence technologies (e.g. sensors, ambient monitoring systems) to execute ambient state interpretation tasks and to take decisions to improve its users life [4].

Fuzzy Logic is a soft technique of Computational Intelligence which can be applied to systems with memory restriction, as WSN nodes. It is a better option to represent knowledge through simple rules which can be used by nodes to lead with erroneous decisions due inaccurate or faulty sensors. In [16], each WSN node uses local and neighborhood fuzzyfied sensor data as input of a distributed fuzzy logic engine (DFLER). This method helps to decrease more false alarms than a system based on crisp rules, therefore, it is more robust. [17] uses the previous system to activity recognition during car assembly. There are WSN sensor nodes on industrial tools used in this process, as well, on assembler clothes. Sensor data are transformed in events, which are received by other network nodes, where they are processed by a fuzzy system that infers the current assembler activity. The sensor nodes send the activity to monitor system which checks if it is the right one for that assembly moment.

Fuzzy logic can be used to do tasks of control by WSN protocols. [13] proposes a fuzzy system in each WSN mote that helps to choose the better route to forwarding packets. A fuzzy controller is utilized in [14] to adapt dissemination period to the lost rate associate with data transmission from a sensor to an actor in a WSAN. Lost rate is always in a desired pre-established level that guarantees network desired QoS (Quality of Service). In [15], instead of backoff time be given after a collision in MAC layer, a fuzzy inference scheme computes this delay in a Metallic Structure Monitor WSN.

WSN should self-manages its own restricted resources (memory, communication, processing) to maximize energy when it is placed in environments of difficult human access as well to liberate WSN supervisor as much as possible of doing low level tasks as changing sensor batteries. [6] proposes an Autonomic Sensor Element (ESA) which is a model based on autonomic element of [5] with a MAPE autonomic engine (Monitor, Analyze, Plan, Execute, and Knowledge Base) that has well defined management functions to a WSN node. It was simulated in NS-2 [18] with a monoxide carbon sensor application as managed element. Based on local raw sensor data, neighborhood management messages and Knowledge Base information, ESA makes sensor node configures itself using crisp rules to control sensing and disseminations rates and its operational state to save network energy.

III. PROPOSAL

This work principal objective is development of a distributed autonomic inference machine (MIAD) composed by two principal components: an autonomic manager and a managed element. The autonomic manager is MAPE autonomic engine associated to a fuzzy system to control sensing and dissemination intervals as well redundancy of messages sent to WSN monitor system. This autonomic manager is called autonomic inference machine (MIA) which can manage a simple local sensor application as well a distributed sensor application. MIAD uses as managed element a distributed fuzzy system similar to DFLER of [16] as distributed sensor application to produce high level context information of an environment because it can help to decrease workload at WSN monitor system due the correlation of different types of sensor data is made by WSN. To illustrate, how MIAD works, distributed sensor application is presented and after MIA component.

As case study, fire risk context is based on relative humidity and temperature data obtained through Crossbow MTS400 sensorboard which is used by micaz motes [19]. In each sensing interval, these data are input of the distributed fuzzy system similar to [16]. First, they are fuzzyfied according to relative humidity and temperature fuzzy sets. Fig. 3 shows relative fuzzy set. Second, fuzzyfied data are sent to node neighbors. Both local and neighbors fuzzyfied data are used in an inference process.

Fuzzyfication interface transforms environment data in instances of linguistic variables modeled by fuzzy sets. These instances are processed by inference component that uses fuzzy rules of knowledge base. Several rules can be activated at the same time and their results are input of desfuzzyfication interface which transforms linguistic variables in data used in a non-fuzzy control [20].

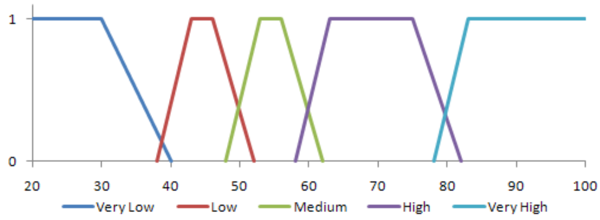

Figure 3. Relative Humidity Fuzzy Set

As it was difficult to find a knowledge base which relates temperature, humidity and potential risk fire, a meteorologist of [21] was interviewed to be possible elaborate 3 fuzzy sets and 92 fuzzy rules regarding temperature and relative humidity. Example of a fuzzy rule of fire risk inference: *If local and neighborhood temperature are high and local and neighborhood relative humidity are very low then fire risk is high*. After inference, fire risk is desfuzzyfied by method of Centroide according to fuzzy set of Fig. 4.

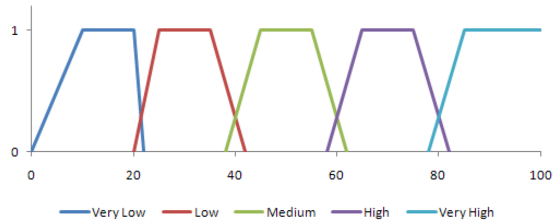

Figure 4. Fire Risk Fuzzy Set

A context message is created based on Micro Sensornet Ontology (µSONG) due its simple and flexible way to express WSN context. It has 3 principal attributes: *ContextName* is a context unique name; *ContextValue* é used with *ContextName*; *Fidelity* uses a value between 0 and 100 to indicate fidelity to *ContextValue* [22]. In this case study, a context message is sent by WSN nodes to WSN monitor system in each dissemination interval with the following values: *ContextName* = FIRE_RISK; *ContextValue* = VERY_HIGH; *Fidelity* has the value of desfuzzyfication process.

A sensor node can self-configure sensing and dissemination intervals and also take decision to send or not redundant messages to WSN monitor system through a fuzzy system, whose components are distributed between MAPE autonomic engine services of the autonomic manager. Monitor service has fuzzyfication component, Analyze service has inference process and desfuzzyfication method. The result of association is called autonomic inference machine (MIA).

The following local information is input to MIA: percentage of relevant data, sensing and dissemination intervals, number of sent bytes by the node and residual energy. In each management interval, the local information is sent to neighbors to computes percentage of neighborhood relevant data and percentage of neighborhood similar configuration which are also MIA inputs. Therefore, sensor node self-configuration is based on local and neighbors data.

In case study of [6], these inputs are employed in crisp rules for a node self-configuration decisions, but, in this present work, these inputs was modeled in 7 fuzzy sets and utilized in 74 fuzzy rules for the same purpose. Example of MIA fuzzy rule: *If local and neighborhood relevant data are low and sensing and dissemination intervals are low then sensor interval is reasonable low and dissemination is low*.

In this same way, sensing and dissemination intervals and redundancy self-configuration were modeled. Fig. 5 shows sensing interval self-configuration fuzzy set used in desfuzzyfication method of Centroide, whose result is number of seconds that must be added or subtracted from current sensor interval. In the previous example, sensor interval is inferred as low, then, Plan service gives to sensing rate an augment probability of 20% and to dissemination, an augment probability of 80%. After this, Execution service execute this action and update MIB (Management Information Base) of Knowledge Base MIB, as in [6] study case.

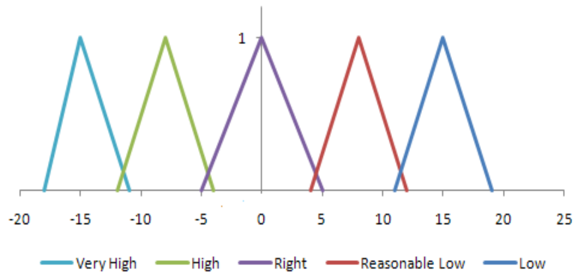

Figure 5. Sensing Interval Self-Configuration Fuzzy Set

To validate this proposal, there were developed 4 methods in nesC programming language of TinyOS operating system. ESA [6] which MAPE autonomic engine is based on crisp rules to do self-configuration of sensor node. Its managed element is a simple sensor application which sends local environment temperature and relative humidity to WSN monitoring system. MIAL which has a MIA and as managed element, has the same local sensor application of ESA. DFLER [16] is distributed sensor application which infers the level of fire risk. And MIAD, that is the proposal of this work.

Table 1 shows all types and length messages sent by the methods. ESA, MIAL and MIAD sensing and dissemination intervals start, respectively, at 20 and 40 seconds, and DFLER intervals remains constant at 40 seconds. ESA, MIAL and MIAD management interval is fixed in 200 seconds and their autonomic cycle interval is fixed in 100 seconds.

The WSN was composed by 6 micaz mote with sensorboards MTS400 [19] plus one micaz mote with a WSN sniffer application. This last one was connected to a mote interface board MIB520 to direct traffic to a computer with SerialForwarder Java application. Also a Java application keeps and analyzes received messages was developed. Each method was embedded in the sensor nodes and it ran during one hour in a test room at 18°C. With the purpose of analyze application reaction during a possible fire risk, after the first 100 seconds, a hair dryer of 1700W was turned on to modify temperature and relative humidity during 10 minutes.

TABLE I. MESSAGES TYPES

Type	Length (bytes)	Application
Data	10	ESA, MIAL
Management	22	ESA, MIAL, MIAD
Fuzzy	42	DFLER, MIAD
Context	8	DFLER, MIAD

This testbed was performed 5 times to each method. Then it was possible computing the mean of the following parameters analyzed: consumed energy, total of sent messages, total of lost messages, total of data message sent, total of relevant data messages, total of context messages, total of relevant context messages, RAM and ROM memory consume (bytes). Data is relevant when relative humidity is very low (<=40) and temperature is very high (>=30°C). Context is relevant when fidelity of fire risk is high (>=70).

IV. RESULTS

Table 2 has the mean of analyzed parameters by method. It can be observed that MIAD consumes more memory, approximately 71.4% of ROM and 25.3% of RAM. Comparing consumed energy of ESA and MIAL which both send the same type of messages: MIAL saves approximately 9.09% more than ESA. In general, MIAL sent 46.7% more data messages than ESA, but, it sent 67.22% more relevant data messages to WSN monitor system.

Figure 6 shows the arrival of ESA data messages sent to base station by each WSN node between 13h22 and 14h22. It can be noted ESA has augmented sensing and dissemination rates at hot air event, but, it make all sensor nodes stop dissemination before the event be finished. ESA autonomic engine based on crisp rules caused starvation of data messages to WSN monitor system until the final of test.

According to figure 7, the mean of sensing and dissemination intervals of ESA, as well, the mean of their final values are a little bigger than the half of their start values. It demonstrates ESA can augment the rates during events but it doesn't decrease when it disappears. Then, TinyOS sensing components are called in short intervals of 10 seconds consuming major part of WSN energy. It does not happen with other methods.

Comparing MIAD and DFLER, Table 2 shows MIAD saves 21.53% more energy than DFLER. MIAD sent 23.3% less messages in general than DFLER, 38.36% less context messages but 10.74% more relevant context messages. Figure 7 shows the mean of MIAD sensing and dissemination intervals are respectively 5.2 and 3.8 bigger than ESA intervals and the mean of final intervals are respectively 9.7 and 7.6 bigger. Figure 8 shows MIAD and MIAL intervals are more changed than ESA. Then, MIAD and MIAL can augment sensing and dissemination rates during hot air event and decrease them when the event disappears saving WSN energy and decreasing irrelevant redundant messages.

TABLE II. SYNTHESIS OF ANALYZED PARAMETERS

Parameters	ESA	MIAL	DFLER	MIAD
Consumed Energy (%)	1.1	1.0	1.30	1.02
Sent Messages	483.6	907.4	2488.4	1915.2
Lost Messages	0	0	0	0
Data Messages	88.6	507.4	-	-
Relevant Data Messages	47	143.4	-	-
Context Messages	-	-	519.6	318.2
Relevant Context Messages	-	-	121	134
Consumed ROM Memory (bytes)	23870	55666	54140	91452
Consumed RAM Memory (bytes)	1395	1622	1268	2022

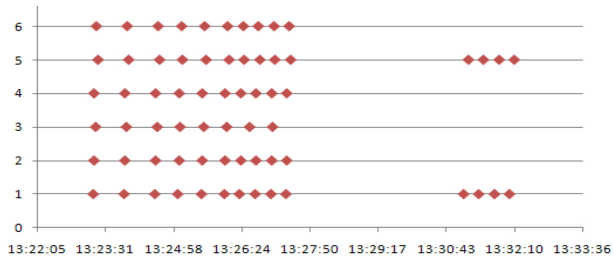

Figure 6. ESA data messages sent by WSN sensor node

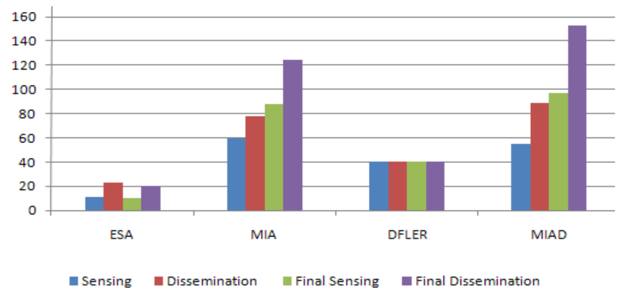

Figure 7. Mean of Sensing and Dissemination Intervals

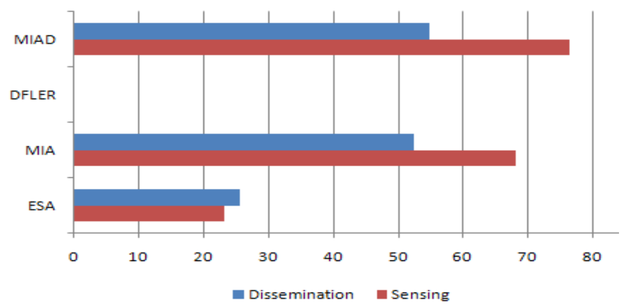

Figure 8. Mean of variance coefficient of sensing and dissemination intervals

Figure 9 shows MIAD sent 49.83% less bytes of information messages and 25.24% less bytes of relevant information messages to WSN monitor system than MIAL. It happens due context messages sent by MIAD are smaller than data messages sent by MIAL besides context messages have more semantic value than data messages because they bring WSN inference made in a distributed way.

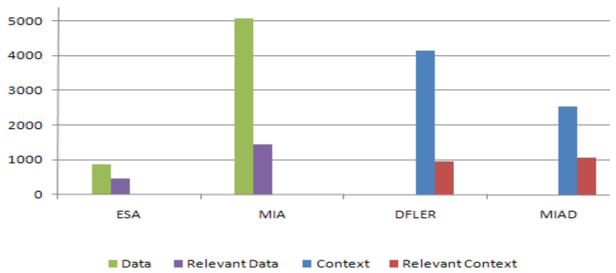

Figure 9. Mean of the total number of bytes of sent data and context messages by method

V. Conclusion

WSN can decrease the overload of data processing in Ambient Intelligence systems when WSN infers context obtained in a distributed way according data message changed between sensor nodes. Fuzzy Logic is a soft Computational Intelligence and it can be used by sensor nodes which have memory, processing and communications restrictions. Autonomic Computing through MAPE autonomic engine helps self-configuration of a sensor node, because it is based on local and neighborhood information, and it takes decisions about node operation.

MIAD is a distributed autonomic inference machine and it has fuzzy rules for a sensor node make context using ambient data and do self-configuration. Tests using Crossbow micaz motes show MIAD can reduce the amount of context messages sent to WSN monitor system in 23.3% while it can augment relevant messages in 10.74% and it saves approximately 21.53% of WSN energy without context message starvation. Context messages can augment semantic of information sent by WSN and they can help decrease the workload due different data correlation in Ambient Intelligence systems which can use more complex inference techniques using these messages. As future work, MIAD will be tested in a WSN with a major number of sensor nodes using TOSSIM, a sensor simulator for TinyOS applications and with other types of context.

References

[1] Augusto, J. C. (2007) "Ambient Intelligence: the Confluence of Ubiquitous/Pervasive Computing and Artificial Intelligence". International Journal on Computer Science and Information Systems, volume 4, number 1.

[2] Ramos, C. (2007) "Ambient Intelligence – a State of the Art from Artificial Intelligence perspective", Lectures and Notes in Artificial Intelligence Magazine. Springer Verlag.

[3] Dey, A. K. (2001) "Understanding and Using Context. Personal and Ubiquitous Computing". Springer Verlag London Ltd.

[4] Ramos, C., Augusto, J. C. and Shapiro, D. (2008) "Ambient Intelligence-the Next Step for Artificial Intelligence", In: IEEE Intelligent Systems, volume 23, number 2.

[5] Kerphart, J. O., Chess, D. M. (2003) "The Vision of Autonomic Computing", http://researchweb.watson.ibm.com/autonomic/research/papers/AC_Vision_Computer_Jan_2003.pdf, Acesso em: fevereiro de 2008.

[6] Thais Braga, Fabricio Silva, Jose Marcos Nogueira, Antonio Loureiro, Linnyer Beatrys Ruiz, "A Tiny and Light-Weight Autonomic Element for Wireless Sensor Networks," icac, pp.17, Fourth International Conference on Autonomic Computing (ICAC'07), 2007

[7] e-SENSE: Capturing Ambient Intelligence for Mobile Comunications through Wireless Sensor Networks. European 6th framework Programme for Research and Technological Development. 2006. Disponível em: http://www.ist-esense.org. Acesso 23 nov. 2008.

[8] Copetti, A., Loques, O., Leite, J. C. B. (2008) "Intelligent Context-Aware Monitoring in Home Care", IEEE 2nd International Conference: E-Medical Systems.

[9] Merico, D.; Mileo, A.; Bisiani, R. (2008) Wireless Sensor Netorks supporting Context-aware Reasoning in Assisted Living, ACM International Conference Proceedings Series. vol 282. Proceedings of the 1st International Conference on Pervasive Technologies Related to Assistive Environments.

[10] Kawashima, H.; Hirota, Y.; Satake, S. Imai, M. (2006) Met: A Real World Oriented Metadata Management System for Semantic Sensor Networks, Proceedings of the 3rd International Workshop on Data Management Sensor Networks, Seoul, South Korea.

[11] McCarthy, J. D. (2007) Using Sensor Ontologies to create Reasoning-Ready Sensor Data for Real-time Hazard Monitoring in Spatial Decision Support System, Dissertação de Mestrado. Departamento de Ciências da Terra e Ambiente. Universidade de Windsor, Ontario, Canadá, Disponível em: http://matrix.memf.uwindsor.ca/publications/theses/McCarthy-MScThesis-70917.pdf

[12] European 7th framework Programme for Research and Technological Development. 2008. Disponível em: http://www.sensei-project.eu/. Acesso em 23 nov. 2008.

[13] Azim, M. A. and Jamalipour, A. (2006) "Optimized Forwarding for Wireless Sensor Networks by Fuzzy Inference System". International Conference on Wireless Broadband and Ultraband.

[14] Xia, F.; Zhao, W., Sun, Y.; Tian, Y. C. (2007) "Fuzzy Control Based QoS Management in Wireless Sensor/Actuator Networks",Sensor 2007, www.mdpi.org/sensors.

[15] Acharjee, D. and Patel, P. (2008) "Multipath Routing Sensor Network for Finding Crack in Metallic Structure Using Fuzzy Logic", Proceedings of World Academy of Science, Engeneering and Technology, Volume 32.

[16] Marin-Perianu, M; Havinga, P. (2007) D-FLER: A Distributed Fuzzy Logic Engine for Rule -based Wireless Sensor Networks. International Symposium on Ubiquitous Computing Systems.

[17] Marin-Perianu, M.; Lombrisier, C.; Amft, O.; Havinga, P.; Tröster, G. (2008) Distributed Activity Recognition with Fuzzy-Enabled Wireless Sensor Networks. International Conference on Distributed Computing in Sensor Systems.

[18] NS (2009) Network Simulator. Disponível em: http://www.isi.edu/nsnam/ns/.

[19] Crossbow. (2010) MICAZ – Wireless Mesurement System. Disponível em: http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MICAz_Datasheet.pdf .

[20] Gomide, F. A. C.; Gudwin, R. R. (1994) Modelagem, Controle, Sistemas e Lógica Fuzzy. SBA Controle & Automação. Volume 4, número 3.

[21] FUNCEME. (2010) Fundação Cearense de Metereologia e Recursos Hídricos. Disponível em: http://www.funceme.br .

[22] Hauifeng, Q.; Xingshe, Z. (2005) Context Aware Sensornet. Proceeedings of the 3rd International Workshop on Middleware for pervasive and ad-hoc computing. ACM International Conference Proceeding Series; Vol. 115. Grenoble, France; pp. 1-7.