Towards a Collaborative Sessions' Management Tool for WSNs

Laura M. Rodríguez Peralta, Lina M. P. L. Brito, and João F. F. Santos
Exact Sciences and Engineering Centre (CCCEE)
University of Madeira (UMa)
Centro de Ciências Matemáticas (CCM)
Madeira, Portugal
{lmrodrig; lina}@uma.pt; joao_santos87@hotmail.com

***Abstract* - In Wireless Sensor Networks (WSNs), the sensor nodes are typically resource limited. This fact forces nodes to collaborate in order to implement their tasks. In this paper, we propose and implement a model that represents the various types of collaboration relationships that can be established in a WSN. This involves identifying and analyzing the different types of collaboration that may occur in any WSN. As a result, we propose a hierarchy composed by different types and levels of collaboration, and we propose a collaborative session management tool, called WISE-MANager. This tool allows bringing these concepts into practice, more precisely to the establishment of collaborative sessions. WISE-MANager optimizes the WSN operation and increases the user control on the network monitoring.**

Keywords: Wireless Sensor Networks; Modeling; Collaboration Hierarch; CSCW; ZigBee.

I. Introduction

In WSNs, sensor nodes are resource restricted; i.e., they have limited memory and processing capabilities, short transmission range (thus, nodes can only communicate with local neighbors [1]. As a result, nodes need to collaborate to be able to accomplish their tasks: sensing, computing, routing, localization, etc. Therefore, WSNs are, inherently, collaborative networks [2].

In this paper, we provide an enhancement of the CWSN model by proposing a hierarchy of collaboration for WSNs. Another contribution is bringing the main CSCW (Computer Supported Cooperative Work) concepts into the area of WSNs, which includes identifying and describing the different types and levels of collaboration, as well as the collaborators that can exist within a WSN

By collaboration we refer to any interactions that may be established between two components of a WSN. These interactions can simply refer to: i) data transmission, or ii) collaboration between sensor nodes to carry out a specific task, or iii) the transmission of control information and commands necessary for essential procedures, such as configuration/reconfiguration of nodes, clusters, or the network itself.

Aiming to bring these concepts into practice, we have implemented a tool that allows creating and manipulating collaborative sessions in a real WSN.

This paper is organized as follows. Section 2 briefly describes the related work. In section 3, the different types of collaboration are identified and described, and a hierarchy of collaboration is proposed. Then, a definition of session and its classification is proposed. Section 4 describes the WISE-MANager tool and its implementation. Section 5 provides some conclusions and some perspectives of future work.

II. Related Work

We have observed that the great majority of works on WSNs' modeling focus on modeling connectivity or mobility problems, or even both problems. Nevertheless, we have identified other modeling concerns, such as: communication, interference, data aggregation, coverage, and signal processing. On the contrary, the CWSN model intends to model a whole WSN, i.e., it tries to consider the most complete set possible of entities that can exist in a WSN, and their respective attributes.

Regarding the works focusing collaboration in WSNs, the great majority of them covers a specific type of collaboration, which is associated with the accomplishment of a certain task, such as: signal processing [4], sensing [5], computing [6], routing [7], localization [8], security [9], task scheduling [10], heuristics [11], calibration [12], resource allocation [13], time synchronization [14], transmission [15], etc., and also works concerning collaboration between wireless sensor nodes and other kind of devices (heterogeneous groupware collaboration) [16] to support some specific applications (for example, collaboration between sensor nodes and PDAs, in a fire fighting scenario).

According to the literature available, the only work that presents a model for collaborative work in sensor networks has been proposed by Liu et *al.* [18]. It is the SNSCW (Sensor Networks Supported Cooperative Work) model, a hierarchical model that essentially divides cooperation in sensor networks in two layers; the first one relates to cooperation between humans and sensor nodes; the second one relates to cooperation between the sensor nodes. This model was designed for sensor networks.

However, the SNSCW model only allows the modeling of collaboration itself. On the contrary, the CWSN model, which has been presented in [3], is a formal model that was created specifically to describe WSNs. However, the CWSN model allows not only the modeling of collaborative work (based in CSCW concepts), but also the modeling, formalization and graphical representation of the entities that can constitute a WSN (different types of nodes, clusters, relationships, sessions, obstacles, etc.), as well as its attributes. Moreover, it allows the representation of the WSN's hierarchy and the network evolution.

III. COLLABORATION HIERARCHY IN WSNS

In this paper, we present a new approach that brings some of the fundamental CSCW concepts into the world of WSNs. The CWSN model is, then, improved in order to represent not only the entities that can compose a WSN and its attributes, but also to represent collaboration in a WSN. So, on one hand, we enrich the CWSN model with the most important CSCW concepts, such as: participants, relationships, roles, tasks, sessions and groups. On the other hand, we identify several levels of collaboration, going beyond the two levels defined by the SNSCW model [17]. Thus, we extend the CWSN model with a hierarchical collaboration representation. As a result, the CWSN model evolves into a hierarchical model of collaboration.

By collaboration we denote any interactions that may be established between any two entities of a WSN. It may refer to collaboration involved in transmission of data between any two entities of the network, or to the collaboration required so that nodes can perform the majority of their tasks, which is a consequence of their severe resource limitations. However, the types of collaboration are determined by the types of nodes that exist in a WSN, since each type of node has its specific tasks. Consequently, the different types of collaboration that exist in a WSN are a natural result of its inherent hierarchy. For example, only the sink node can send data to the user; consequently, all the other nodes have to forward data towards the sink node; therefore, the sink node is naturally on the higher levels of the WSN hierarchy.

In a WSN, each participant in collaboration plays its own role. We define the possible roles that the participants can play in a WSN, as: user, sensor node, anchor node, cluster head, or sink node. A sensor node, for example, can simply play the role of a sensor node, or it can play the role of an anchor node or of a cluster head.

A. Tasks of the Participants

The tasks of each participant depend on its type, that is to say that it strongly depends on its role, and also on the characteristics of the intended application. Thus, most tasks are application-specific. However, in a WSN, tasks of the participants can be generally classified in two categories:

- Supporting tasks: these are tasks usually related to management, communication and maintenance functions (typically associated with the protocols in use).
- Information processing tasks: Data collected by sensor nodes can be processed depending on the application (data may have to be compressed, correlated, ciphered, etc.) and/or depending on the tasks of each node in the collaboration relationships established.

B. Sessions

In this work, we propose a definition of session as the essential unit of a collaborative activity in WSNs. Basically, this means that each time the user has a new objective (new type of phenomenon to monitor, new geographical area to monitor, new monitoring period, etc.) he can create a new session

In the context of WSNs and considering CSCW definitions, sessions are composed by participants, the collaboration relationships and data flows established among them, and the tasks of each participant. In a session, different types of collaboration relationships can exist; therefore, several different collaborative groups can be established inside a session.

Concerning the state of the nodes that constitute a session (regardless them being organized into groups or not), a session can be classified in one of four states:

- Created – The session has been created but not initiated; that is, the session is not in the open state yet. This is the first state of a session.
- Open – While the objective of the session is not fulfilled and some nodes are active, the session maintains its activity.
- Close – A session can become inactive due to one of two possible motives: 1) when all the nodes go into sleep mode; or 2) when all nodes are damaged or fail (for example, due to battery depletion); or 3) when there is a temporary interruption in the session (i.e., the session stops for a certain time interval that is settled by the user).
- End - A session ends due to one of three possible causes: 1) when the objective of the session is fulfilled; 2) when the predefined lifetime of a session comes to an end; or 3) when the session is aborted by the user (through the transmission of some command).
- Deleted – This state occurs when the user deletes the session and its respective data.

These session states and session evolution are represented in Fig. 1.

Depending on the WSN specific application, sessions can be classified according to their temporal characteristics: sessions can take place in parallel or in sequence; and they can be synchronous or asynchronous.

- Parallel sessions – Sessions that occur at the same time.
- Sequential sessions – A particular session starts only after the end of another session.
- Synchronous sessions – The occurrence of these sessions is planned by the network manager. Parallel and sequential sessions can also be classified as synchronous sessions.
- Asynchronous sessions – The occurrence of these sessions is not planned by the network manager. Rather, they can be started by some action (user

initiated or node initiated), by the detection of an unexpected change in a particular phenomenon, etc.

Thus, in a certain moment, there may be several collaborative sessions in a WSN.

Defining a collaborative session with all its possible states, and different temporal relationships between collaborative sessions is important to allow users and managers to manipulate and control the operation of a WSN, in an optimized manner. These concepts can also help researchers to develop management tools that optimize the network management and that can make it more flexible, as will be demonstrated in section IV.

C. *Types of Collaboration*

Analyzing collaboration in WSNs from the point of view of relationships and interactions established among collaborators (or participants), we can identify essentially two main types of collaboration [17]: 1) collaboration between the user and the WSN, and 2) collaboration among nodes.

1) Collaboration between the user and the WSN: The user is the entity that interacts with the WSN, defining the application, querying the network, visualizing data, customizing the work of the sensor nodes, etc. However, depending on the application, nodes can also initiate collaboration. For instance, after analyzing some changes on the environment, nodes can notify and alert the user, and actively query the user about his needs.

So, this type of collaboration can be either initiated by the user or by the sensor nodes. From the user point of view, this collaboration can be carried out through a computer, a PDA, etc. From the WSN point of view, the collaboration is established via the sink node.

The sink node is the only node that can send data to the user; so, it controls the data transmission towards the user. Therefore, we can conclude that this collaboration established between the sink node and the user verifies the flow control property: it controls the flow of data. This CSCW property states that only one of the elements involved in a collaboration process can transmit data.

$$E_D = (S_{k,prod}, Da, User_{cons})$$

Where Da is the set of data that is shared by the S_k, the data producer, and the user, which is the consumer of data.

2) Collaboration among nodes: We consider that collaboration among nodes can be classified into several different subtypes:

- Collaboration among the same type of nodes (i.e., among sensor nodes, among anchor nodes, among cluster heads, etc.);
- Collaboration between sensor nodes and anchor nodes;
- Collaboration between sensor nodes and the sink node.
- Collaboration between sensor nodes and other type of wireless devices.
- Collaboration between other type of wireless devices and the sink node.

In relation to collaboration between sensor nodes and anchor nodes[1] it only makes sense in the case of an ad-hoc deployment, since in a manual deployment the localization of sensor nodes is known a priori. Since the application scenario that will be presented in section 4 involves manual deployment, this type of collaboration will not be covered in detail in this paper. The other types of collaboration will be described in detail further on.

In the case of heterogeneous WSNs, i.e., WSNs that are composed not only by sensor nodes, anchor nodes, cluster heads and sink nodes, but also by other types of wireless devices, like Bluetooth devices, Wi-Fi devices, PDAs, etc., more types of collaboration can occur:

- Collaboration between sensor nodes and other wireless devices.
- Collaboration between other wireless devices and the cluster heads.
- Collaboration between other wireless devices and the sink node.

In this case, wireless devices usually make use of these types of collaboration to ensure data transmission.

Fig. 2 proposes a collaboration hierarchy for WSNs that considers different collaboration levels and represents the different types of collaboration just described. The bidirectional arrows (horizontal and vertical) represent collaboration among the different participants that compose the WSN. This hierarchy can represent different types of collaboration; however, a type of collaboration that clearly verifies this hierarchy is data transmission, since it respects the hierarchy usually inherent to the participants of a WSN.

Analyzing this figure, it is rather intuitive to conclude that WSNs present a hierarchy of collaboration relationships. This hierarchy can be composed by different levels of collaboration, as represented in Fig. 2: the node level; the cluster level; the session level; the network level; and the user level. Besides, according to the types of collaboration presented above, collaboration can occur either within a certain level (horizontal collaboration) or between each two consecutive levels (vertical collaboration). However, this collaboration hierarchy intends to describe collaboration in a generic way. Therefore, this hierarchy needs to be modified and adapted in order to describe the collaboration relationships that occur in a WSN in particular.

[1] If localization of sensor nodes is unknown, it may be necessary to deploy some special nodes (anchor nodes) that will help the other nodes in the process of determining their own localization.

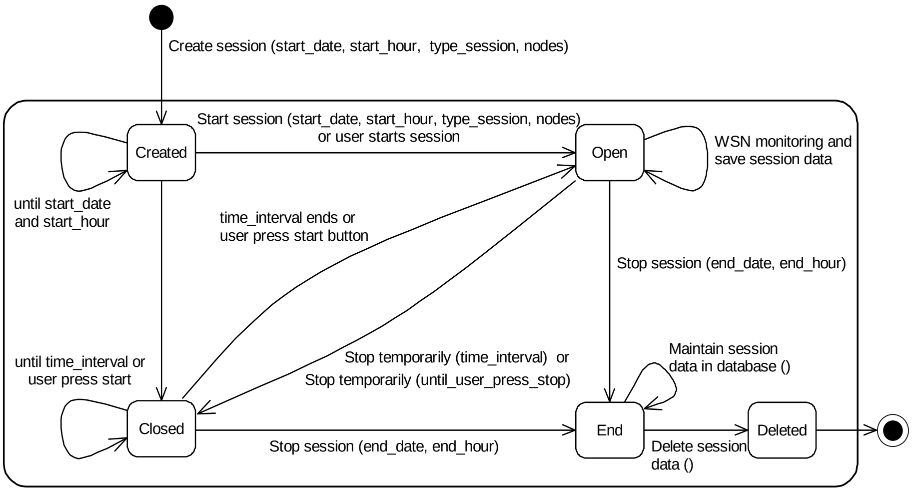

Figure 1. State transition diagram of a session.

For example, there might be the case of a WSN with heterogeneous devices, where these other wireless devices cannot communicate, and consequently, cannot collaborate with ordinary sensor nodes; they might be forced to collaborate only with the cluster heads or with the sink node. In this example, this other type of wireless devices is represented in the node level (they may even collect data like sensor nodes), but the horizontal arrows that represent collaboration between sensor nodes and these wireless devices will not exist; since they do not represent reality. Only the vertical collaboration arrows will be represented.

As mentioned before, the execution of most tasks in WSNs involves collaboration. Having a collaboration hierarchy as a framework that describes all the possible collaboration relationships that may occur in a WSN is a major advantage to researchers since they can use and adapt this framework to describe the collaboration activities of their own WSN.

a) Collaboration among the same type of nodes: As to cooperation among the same type of nodes, their relationships are uncertain, depending on the WSN's application. Nevertheless, it is possible to identify three fundamental collaboration subtypes:

- Peer collaboration [17] - The collaborators have the same roles and functions in collaboration. Peer collaboration can occur between nodes that are neighbors (so, it depends on the location of nodes), between a group of nodes in the active state, or between a group of nodes that is monitoring a common phenomenon. For example, this is the case of collaboration among ordinary wireless sensor nodes or among cluster heads.

- Master-slave collaboration [17] - In the process of collaboration, the "master" node mainly coordinates the work of the "slave" nodes, and maintains some sharing information relative to the collaboration. The slave nodes are responsible for executing specific operations. In the case of clustering being applied, master-slave collaboration is established between the cluster head and the sensor nodes that belong to the cluster.

b) Collaboration between sensor nodes and the sink node: All sensor nodes have to send collected data to the sink node. The sink node, in turn, can send queries or commands to the sensor nodes. Therefore, there is always collaboration between the sensor nodes and the sink node, unless a clustering algorithm has been implemented.

c) Collaboration between sensor nodes and the cluster head: If clustering is applied, one of the members of each cluster becomes the cluster head; the cluster head may be elected by the sensors in a cluster, or it may also be one of the nodes of the cluster that is richer is resources, or even pre-assigned by the network designer. Thereafter, all nodes in the cluster have to send collected data to the cluster head.

So, this type of collaboration involves:

- The sensor nodes send data to the cluster head.

- The cluster head receives queries and commands that the user poses to the WSN, and forwards them to the sensor nodes.

- The cluster heads can analyze received data to evaluate some parameters and take actions accordingly, sending commands to the sensor nodes; in this case, the cluster head acts as a sink node.

- Sensor nodes and cluster heads have to exchange information so that the cluster head is able to update which nodes belong to the cluster (nodes can run out of battery, or be damaged, mobile nodes can move to other clusters, etc.).

The cluster head also verifies the flow control property, since it is the only node that can transmit the set of data produced by all nodes that belong to the cluster towards the sink node. In this case, this property can be formally described as:

$$E_D = (CH_{prod}, Da, S_{k,cons}),$$

where Da is the set of data that is shared by the CH and the S_k (or other cluster head), which are the producer and the consumer of data, respectively.

d) Collaboration between the cluster head and the sink node: If clustering is applied, the cluster head is responsible for aggregating data collected by all the nodes in the cluster and sending it to the sink node. The sink node, in turn, can send user queries or commands to the cluster heads, or it can analyze received data to evaluate some parameters and take actions accordingly, sending commands to the cluster heads.

3) Collaboration between sessions: Collaboration between sessions occurs when some information has to be passed between sessions; it can happen, for example, in the case of sequential sessions, since in this particular case one session starts only after another session ends; this type of collaboration can also take place if, for example, a session is programmed to be initiated in the case a certain phenomenon is detected in another session, or in the case an unexpected change in a particular phenomenon occurs.

IV. WISE-MANAGER

In order to implement and validate the CWSN model, we have implemented a collaborative sessions' management tool, called WISE-MANager (WIreless SEnsor networks MANager for collaborative sessions). The WISE-MANager tool allows creating, monitoring and managing collaborative sessions. The purpose of using collaborative sessions is to provide a better interaction between the user and the WSN, since the user can customize the type of monitoring to be carried out (sensor node, phenomenon, or time interval of monitoring), and query the network and its components. This way, the WISE-MANager tool increases the flexibility of the WSN.

It is important to note that the proposed tool was developed in the context of the WISE-MUSE project [18]. The nodes used in this project implement the ZigBee protocol; therefore, the WISE-MANager was tested using these nodes. Nevertheless, the WISE-MANager is not ZigBee-oriented; this tool can be used to manage collaborative sessions in WSNs composed by nodes that use any other communication protocol.

Also note that the ZigBee protocol defines three types of devices: end devices, routers and coordinators. End devices correspond to sensor nodes with sensing capabilities, routers are sensor nodes can also sense data but they are essentially responsible for routing data collected by the end devices in the their WPAN to the coordinator, and, finally, the coordinator corresponds to the sink node.

The WISE-MANager tool was implemented in Java and it is ZigBee-compliant. It is composed of two main modules: (i) Collaborative Sessions' Management; and (ii) WSN Management.

The first module, collaborative sessions' management, allows creating and managing collaborative sessions inside a WSN. Users can configure the session's parameters (id, description, etc.), the sensor nodes that will make part of that session, the monitoring period, and the phenomena to be monitored (Fig. 3).

After creating the session, the user can visualize and change the session's parameters. Moreover, he can also start and stop the session's monitoring at any moment, monitor the sessions that are in an "open" state, and delete them. Thus, sessions can be opened manually by the user or automatically according to the session's monitoring schedule.

Moreover, the user can export the session's data to a MS Word document, choosing the session and the monitoring time interval. The document will contain the session's parameters as well as the data received during the session.

In the second module, named WSN Management, the user can choose a serial port where the WSN's coordinator is connected. Using this module, the user can see the WSN information, like the PAN ID, the network channel, and the network components (routers, end devices, coordinator, etc.) and its parameters. Moreover, the user can modify the device's identifier (Fig. 4).

A. Case Study

In order to validate the WISE-MANager tool, we have applied it to a heterogeneous network, which is composed of sensor nodes and other wireless devices that detect the state of the emergency doors at the Whale Museum situated in Madeira Island, Portugal.

Several experiments were carried out to validate the proposed tool. One experiment conducted at the museum was made to test the emergency door device inside the WSN. Thus, we created two sessions inside the WSN: (i) session 3 composed of node 3; and (ii) session 4 composed of node 2 and node 6. Fig. 5 illustrates physical location of the WSN inside the museum. In this figure, the whole WSN is represented using the CWSN model.

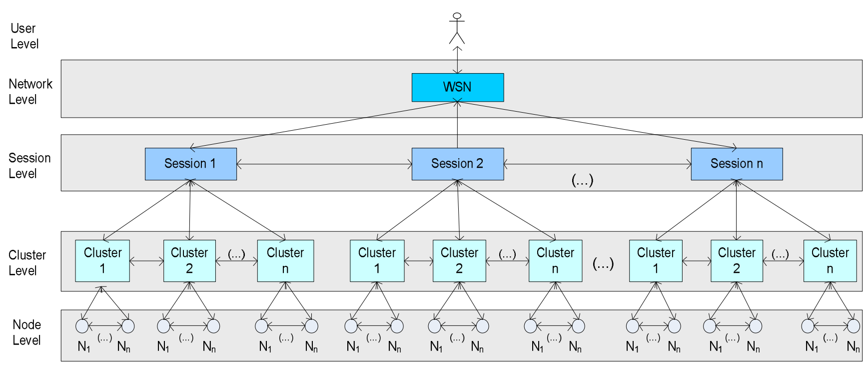

Figure 2. Multi-level collaboration hierarchy within a WSN.

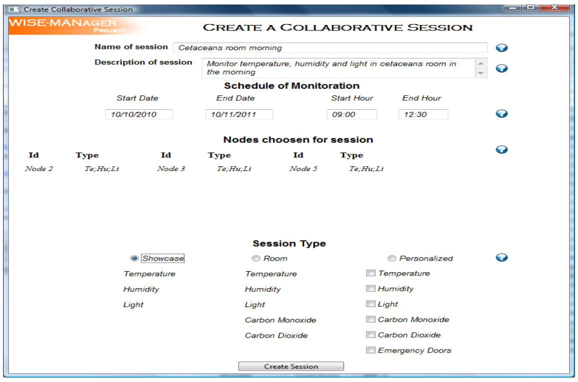

Figure 3. Creating collaborative sessions using the WISE-MANager tool.

In this experiment, both sessions were executed in parallel, monitoring two different exhibition rooms. Session 3 monitored temperature and humidity, while session 4 monitored temperature, humidity, light, and the emergency door state changes (emergency, open or close) from node 6, which was installed inside the emergency door's blocker. Data collected in this experiment is depicted in Fig. 6.

To evaluate the performance of the tool, a test was performed during 9 hours in order to check if the tool was receiving the correct packets for each session. This test was also used to analyze packet loss. It was verified that all data sent by the sessions was collected by the tool without any packet loss. After these experiments, we verified that the WISE-MANager tool was able to create, start, close, end and delete sessions.

B. Advantages and disadvantages

Analyzing Table 1, we can verify that in terms of querying the WSN, most of the tools are able to do it. On the other hand, none of these tools can create or use collaborative sessions to manage the WSN. The WISE-MANager tool allows customizing the monitoring activity and defining the session's parameters.

Moreover, the WISE-MANager tool, allows the user to control the network and inquire the WSN, getting information like communication channel, network ID, PAN ID, etc. It is also possible to detect the network's devices and change their identifiers.

Through collaborative sessions, the WISE-MANager tool enhances collaboration between the user and the network. Thus, the network is more flexible since the user can customize the collaboration, choosing different nodes to monitor different phenomena, and the monitoring time interval. Therefore, the network topology can be dynamic, since nodes can be active or inactive, according to the collaborative session's state. Additionally, this feature allows the energy saving of the network nodes.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed a hierarchical model of collaboration that brings the CSCW concepts and properties to WSNs. We have described the roles and tasks of the collaboration participants in a WSN.

Another main contribution of this paper is the proposal of the concept of session as the main unit of a collaborative activity in a WSN. A classification of sessions regarding their timing characteristics was also presented. Moreover, we described the main requirements for creating collaboration groups in WSNs, as well as its advantages. Thus, we have enhanced the CWSN model [3] by proposing a hierarchy of collaboration that identifies the different types and levels of collaboration that might exist within a WSN.

This work allowed us to conclude that the collaboration hierarchy, which is composed by distinct collaboration levels, is a result of the distinct roles that the different entities play in a WSN. A major advantage of the hierarchical modelling of collaboration is that it can be used by other researchers as a framework to describe the collaboration relationships established in any WSN, despite its particular application.

Finally, we presented the WISE-MANager tool, which was created to manage collaborative sessions. This tool allows increasing collaboration between the user and the WSN. The user gains more flexibility in customizing, manipulating, and controlling the WSN. As for future work, we intend to implement an interface that facilitates the programming of the nodes and of the network from the user point of view.

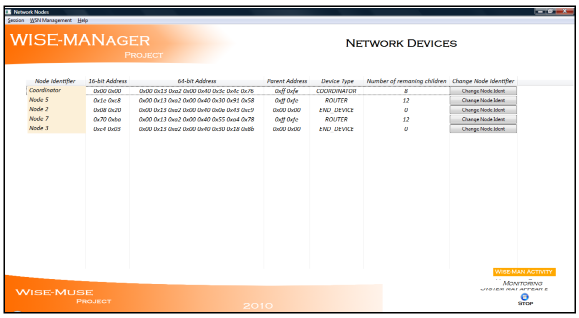

Figure 4. Detecting WSN devices.

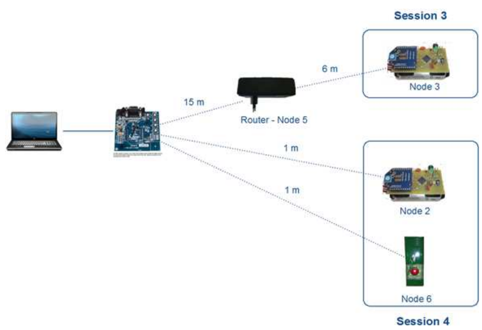

Figure 5. WSN devices for the second experiment conducted in the Madeira Whale Museum

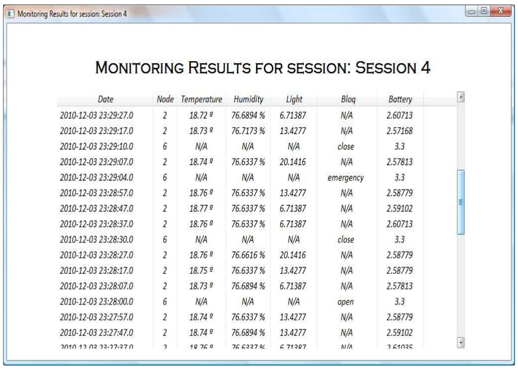

Figure 6. Data collected by Session 4.

Table 1. COMPARING WISE-MANAGER WITH RELATED SOLUTIONS

Tools	*Query WSN*	*WSN Management*	*Create Sessions*	*View Sessions*	*Monitor Sessions*
Tiny DB [19]	No	No	No	No	No
MonSense [20]	Yes	Yes	No	No	No
Mote-View [21]	Yes	Yes	No	No	No
MANNA [22]	Yes	Yes	No	No	No
BOSS [23]	Yes	Yes	No	No	No
WISE-MANager	Yes	Yes	Yes	Yes	Yes

REFERENCES

[1] Akyildiz, I., Su, W., Sankarasubramaniam, Y., and Cayirci, E.: A Survey on Sensor Networks. IEEE Communications Magazine. 38 (4), pp. 393-422 (2002).

[2] Römer, K. and Mattern, F. 2004. The Design Space of Wireless Sensor Networks. IEEE Wireless Communications. 11 (6), pp. 54-61(2004).

[3] Brito, L. and Rodríguez, L.: A Collaborative Model for Representing Wireless Sensor Networks' Entities and Properties. In: 3rd ACM Int. Workshop on Performance Monitoring, Measurement and Evaluation Heterogeneous Wireless and Wired Networks (PM2HW2N'08), pp. 104-111, Vancouver, Canada (2008).

[4] Ramanathan, P., Saluja, K., and Hu, Y.: Collaborative Sensor Signal Processing for Target Detection, Localization and Tracking. Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, USA, http://www.ece.wisc.edu/~sensit/publications/army02.pdf (2002).

[5] Wang, K.-C. and Ramanathan, P.: Collaborative Sensing Using Sensors of Uncoordinated Mobility. Int. Conference on Distributed Computing in Sensor Systems, LNCS, vol. 3560, pp. 293-306. Springer, Marina del Rey, USA (2005).

[6] Iftode, L., Borcea, C., and Kang, P.: Cooperative Computing in Sensor Networks, Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems. Mohammad Ilyas (ed.), CRC Press (2004).

[7] Chen, G., Guo, T.-D., Yang, W.-G., and Zhao, T.: An improved ant-based routing protocol in Wireless Sensor Networks. In: Int. Conference on Collaborative Computing: Networking, Applications and Worksharing (CollaborateCom 2006), pp. 1-7. Atlanta, USA (2006).

[8] Dardari, D. and Conti, A.: A Sub-Optimal Hierarchical Maximum Likelihood Algorithm for Collaborative Localization in Ad-Hoc Networks. In: IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks (SECON 2004), pp. 425-429. Santa Clara, USA (2004).

[9] Chadha, A., Liu, Y., and Das, S.: Group Key Distribution via Local Collaboration in Wireless Sensor Networks. In: IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks (SECON 2005), pp. 46-54. Santa Clara, USA (2005).

[10] Sanli, H., Poornachandran, R., and Cam, H.: Collaborative Two-Level Task Scheduling for Wireless Sensor Nodes with Multiple Sensing Units. In: IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks (SECON 2005), pp. 350-361. Santa Clara, USA (2005).

[11] Reghelin, R. and Fröhlich, A.: A Decentralized Location System for Sensor Networks Using Cooperative Calibration and Heuristics. In: 9th ACM Int. Symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWiM'06), pp. 139-146. Torremolinos, Spain (2006).

[12] Bychkovskiy, V., Megerian, S., Estrin, D., and Potkonjak, M.: A Collaborative Approach to In-Place Sensor Calibration. In: 2nd Int. Workshop on Information Processing in Sensor Networks (IPSN'03), pp. 301-316. Palo Alto, USA (2003).

[13] Giannecchini, S., Caccamo, M., and Shih, C.-S.: Collaborative resource allocation in wireless sensor networks. In: 16th Euromicro Conference on Real-Time Systems (ECRTS'04), pp.35-44. Catania, Italy (2004).

[14] Hu, A. and Servetto, S.: Algorithmic Aspects of the Time Synchronization Problem in Large-Scale Sensor Networks. Mobile Networks and Applications, vol. 10, pp. 491-503, Springer Science + Business Media Inc. (2005).

[15] Krohn, A., Beigl, M., Decker, C., Riedel, T., Zimmer, T., and Varona, D.: Increasing Connectivity in Wireless Sensor Network using Cooperative Transmission. 3rd Int. Conference on Networked Sensing Systems (INSS). Chicago, USA, (2006).

[16] Cheng, L., Lian, T., Zhang, Y., and Ye, Q. Monitoring Wireless Sensor Networks by Heterogeneous Collaborative Groupware. In: Sensors for Industry Conference (Sicon/04). New Orleans, USA, pp. 130-134, (2004).

[17] Liu, L., Ma, H., Tao, D., and Zhang, D.: A Hierarchical Cooperation Model for Sensor Networks Supported Cooperative Work. In 10th Int. Conference on Computer Supported Cooperative Work in Design (CSCWD'06), pp. 1-6 (2006).

[18] Peralta, L.M.R, Brito, L.M.P.L., and Gouveia, B.A.T. The WISE-MUSE Project: Environmental Monitoring and Controlling of Museums based on Wireless Sensors Networks. EJSE – Electronic Journal of Structural Engineering, Special Issue on Sensor Network for Building Monitoring: From Theory to Real Application, 2009, pp. 46-57, ISSN 1443-9255.

[19] Madden S, Franklin, M.J., and Hellerstein, J.M. and Hong, W., "TinyDB: An Acquisitional Query Processing System for Sensor Networks", Massachusetts Institute of Technology, USA, 2005.

[20] Pinto, J., Sousa, A., Lebres, P., Gonçalves, G.M., and Sousa, J., "MonSense-Application for Deployment, Monitoring and Control of Wireless Sensor Networks", Faculdade de Engenharia da Universidade do Porto, Portugal.

[21] Winnie, L.L., Datta, A., and Cardell-Oliver, R., "Network Management in Wireless Sensor Networks", School of Computer Science & Software Engineering, The University of Western Australia", Australia.

[22] Ruiz, L.B., Nogueira, J.M., and Loureiro, A.A.F. MANNA: A Management Architecture for Wireless Sensor Networks. IEEE Communications Magazine, pp. 116-125 (2003).

[23] Song, H., Kim, D., Lee, K., and Sung, J., "Upnp-Based Sensor Network Management Architecture,", Proc. 2nd Int. Conference on Mobile Computing and Ubiquitous Networking, pp. 85-92 (2005).