View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Servicio de Coordinación de Bibliotecas de la Universidad Politécnica de Madrid

The Interoperability of Wireless Sensor Networks

Daniela Ballari, Miguel Angel Manso-Callejo, Monica Wachowicz

Technical University of Madrid

daniela@topografia.upm.es; m.manso@upm.es; m.wachowicz@topografia.upm.es

Abstract. The interoperability of heterogeneous sensor networks is needed for the achievement of a world integrated sensing system. The aim of this paper is to describe the results of an exploratory study which has been carried out to determine the role of metadata in an interoperability model for Wireless Sensor Networks. This model includes a description of the observations, processes, functionalities, status and configuration of a network to help improving the knowledge of a network itself, as well as to ensure the integration with other sensor networks. The results demonstrate the use of metadata to support different interoperability levels of Wireless Sensor Networks as a first step towards defining an interoperability model of Wireless Sensor Networks.

1 Introduction

Sensors and their respective networks are becoming an essential source of information for planning, risk management and other scientific applications. They support the sensing of a physical space by gathering data at a specific location of several sensors. In this paper, the focus is on WSN-Wireless Sensor Networks. These networks are composed of a large number of nodes, densely deployed within or very close to a phenomenon of interest (Akyildiz et al. 2002). They present an advantage over other sensor networks mainly because the WSN nodes are small, lightweight, and they consume less energy. They can usually be deployed with a spatial distribution that best fit the scientific requirements for gathering geo-referenced data (Werner-Allen et al. 2006). Data collected by the nodes are typically transmitted through the wireless network using a radio frequency to a node sink, which supports the storage of the transmitted data and the communication with other devices and networks outside of the WSN.

One of the current challenges of managing WSN is to develop a self-managed network (Ruiz et al. 2004). The dynamism and the self-management of WSN need to be supported by the knowledge of its own state at different periods of time. Previous research has demonstrated that self-management of computing environments can be achieved through the use of metadata (Dini et al. 2004). In the context of WSN, metadata has been defined as descriptive data used to describe the WSN system, including the environment, the nodes and their states, measurement data, and the

WSN as a whole entity. They are the knowledge of a WSN system (Zhang et al. 2006).

The metadata in WSN are also related to the allocation protocols of routing. This is particularly the case of SPIN (Sensor Protocols for Information via Negotiation). The basic operation of this protocol is that the collector of data source node spreads an advertisement containing metadata across the network. Nodes that are interested can send a request for the data source node and as a result, only them will receive the data (Heinzelman et al. 1999). Other routing protocols also using metadata are Directed Diffusion (Intanagonwiwat et al. 2003) and the extension of the protocol LEACH (Yoshitsugu et al. 2007). From the standpoint of routing protocol, metadata play an important role in improving the effectiveness of these protocols; however, from our understanding they do not provide the knowledge of the state of the network that is needed to support the interoperability of sensors.

The interoperability of sensors aims at the integration of in-situ and remote sensors to achieve an integrated sensing system (Liang et al. 2005). In terms of data interoperability it is useful to combine data from multiple heterogeneous data sources and these data must have a well-defined syntax and semantic (Balazinska et al. 2007). On the other hand, in terms of network interoperability it is also necessary an interoperability between components of the network, where the internal components must exchange and act on information provided by other components or external networks (Moe et al. 2007). The sensors interoperability has already been pointed out as an important issue by the Open Geospatial Consortium (Botts et al. 2007). In this context, metadata is essential to generate the knowledge of a sensing system and the common thread that will connect all the states and functionalities of WSN and preserve the context of the collected data (Dini et al. 2004).

The research challenge is to define a model for interoperability of WSN based on metadata, which provides a description of observations, processes and capacities, as well as their status and configuration to enable the understanding of the network itself and to ensure the interoperability with other sensor networks. Therefore, the objective of this paper is to describe the results of an exploratory study carried out to define an interoperability model for WSN based on metadata. The study was conducted using a previous developed interoperability model (Manso-Callejo et al. 2008), which shows the important role that metadata attributes have in the formalisation of interoperability models for the implementation of Spatial Data Infrastructures. This paper presents the integration of such interoperability model with the functionalities of WSN as a first step towards defining the interoperability of WSN through metadata.

The next section describes the main WSN functionalities and introduces a brief reference of metadata in each of these functionalities. The following sections present the conceptual model used for interoperability and its application in the WSN context. Finally, we present the results and conclusions.

2 WSN FUNCTIONALITIES

In general, there are three basic functionalities of Wireless Sensor Networks (Table 1). They are: sensing, processing and communication (Yarvis and Ye 2004). Moreover, additional functionalities, such us configuration and maintenance, have been proposed to consider self-managing in WSN (Ruiz et al. 2004).

Table 1: Overview of the main functionalities of WSN.

Functionality	***Description***
Configuration	It is used in the deployment phase. It is linked to planning, placement and self-organisation. It is necessary to define the application requirement, determine the area of monitoring, characterise the environment, select the nodes, and define the type of WSN.
Sensing	It collects data from the physical world. It performs observations and measures depending on the type of phenomenon, sensors and timing (continuous / periodic).
Processing	It performs basic signal processing, and dispatches data according to the application. It also consists of the conceptual interpretation of multiple data, leading to the attribution of a new meaning to the original data.
Communication	It enables a collaborative processing of the data and signals and distributes the results to users (Yarvis and Ye 2004). It can be classified in two categories: communication application and communication infrastructure (Tilak et al. 2002).
Maintenance	It is used to configure, protect, optimise and repair a network itself, without the intervention of humans. It describes the changes, detects failure or degradation of performance, begins diagnostic procedures, and conducts preventive, corrective and proactive actions.

In Table 2, the role of metadata is summarised according to the main WSN functionalities.

Table 2: The role of metadata for different WSN functionalities.

Functionality	***Role of Metadata***
Configuration	Metadata provide the initial information for the implementation of a network, once the configuration is already established. Metadata would define WSN requirements and its composition (homogeneous/heterogeneous), organisation (hierarchical/flat), mobility (stationary/mobile), density (balanced/densely spaced), distribution (regular/irregular), size (small/medium/large), monitoring area (shape and dimension), characteristic of environment, choice of nodes.
Sensing	Metadata describe the data capture processes and define a phenomenon, sensor, transducer, measurement / observation process, data collection characteristics (periodic/continuing/reactive), sensor calibration.
Processing	This functionality needs metadata of the network and the data collection, to describe this functionality through the definition of: algorithms of control access, election of leaders, aggregations, data fusion, compression, selective suppression, filtering, counting, scaling, temporal relationship, and spatial relationship.
Communication	Metadata define the type dissemination (planned/continuous/low events/upon request), connection type (symmetric/ asymmetric), transmission (simplex/half-duplex/full-duplex), description of protocols and algorithms, location channel (static/dynamic), and flow of information (fooding/multicast/unicast/gossiping /bargaining).
Maintenance	The maintenance depends on the knowledge of the state of the network, and such knowledge is obtained through metadata, which may trigger other processes or actions such as preventive, proactive and adaptive. Metadata define the state of: topology, energy (residual energy), sensing coverage area, memory, and communication coverage area.

3 THE APPLICATION OF AN INTEROPERABILITY MODEL

We propose an integrated model for achieving system interoperability in WSN. This model was previously developed for interoperability of Spatial Data Infrastructures and it is based on attributes of spatial metadata (Manso-Callejo et al. 2008).

One of the main reasons in selecting this model was due to its support of relationships among different levels of interoperability, but not necessarily with a hierarchical relationship nature. These relations can be implemented using metadata attributes, which provide the integration of different abstract levels of interoperability. They are: Technical, Syntactic, Semantic, Pragmatic, Dynamic, Conceptual and Organisational (Table 3).

Table 3: Overview of the requirements of each level of interoperability.

Interoperability Levels	***Description***
Technical	It supports the interconnection of systems using common communication protocols, hardware and software. It is related to communication infrastructures.
Syntactic	It supports the exchange of information between systems using a common data structure, language, logic, records and files. It is related to standards and format specifications**.**
Semantic	It supports the exchange of information using a common vocabulary. It is related to standards and specifications that define schemas for the exchange of information and meaning.
Pragmatic	It allows the interconnected systems to be known to each other and can explore interface applications and/or services to invoke methods or procedures in order to manage the data they need. It also allows the negotiation of the systems. The interfaces to these services should be defined.
Dynamic	It allows the monitoring of operation of other systems and the response to changes. It involves the possibility of changing services and capabilities and contains an important semantic component.
Conceptual	It refers to knowledge and playback functions based on systems documentation or description of data models and systems.
Organisational	It allows knowledge sharing about the goals of business models, regulations and policies governing the access and use of data and services.

In Table 4, the role of metadata is summarised according to different interoperability levels.

Table 4: Interoperability levels and the role of metadata.

Interoperability Levels	***Role of metadata***
Syntactic	Metadata provide the description of the data formats, encoding, structure and other aspects related with syntaxes. Depending on the WSN functionality this syntax will be related to the data collected by the sensors, the data describing the state of the network, or the data used as input and output of processes.
Semantic	Metadata allow the discovery and access to vocabularies without ambiguous meaning commonly stored in ontologies or in

	thesaurus. For example a system processes temperature data measured in Celsius and in Fahrenheit degree from different data sources. The system must know trough metadata the syntaxes and semantics to infer the relation between the data sets (Balazinska et al. 2007).
Pragmatic	Metadata enable the discovery and use of services interfaces. For example, an external network requests changing the position of nodes of other network to improve the coverage. The system must have metadata describing the interface to perform the task.
Dynamic	Metadata reflect the current state of the network after each change of state. For example metadata provide the state of the residual energy needed for the routing protocol algorithms.

4 PRELIMINARY RESULTS AND CONCLUSIONS

The preliminary results on the categorisation of WSN functionalities using the proposed interoperability model allowed us to recognise how WSN functionalities are related to different levels of interoperability (Figure 1). The organisational interoperability is supported by the configuration functionality; the technical interoperability is promoted by the communication functionality; meanwhile the processing and maintenance functionalities are involved in the pragmatic and dynamic interoperability. On the other hand, to achieve syntactic and semantic interoperability is necessary to pay attention to the functionalities of sensing, processing and maintenance. Finally, conceptual interoperability is not supported by any of WSN functionalities.

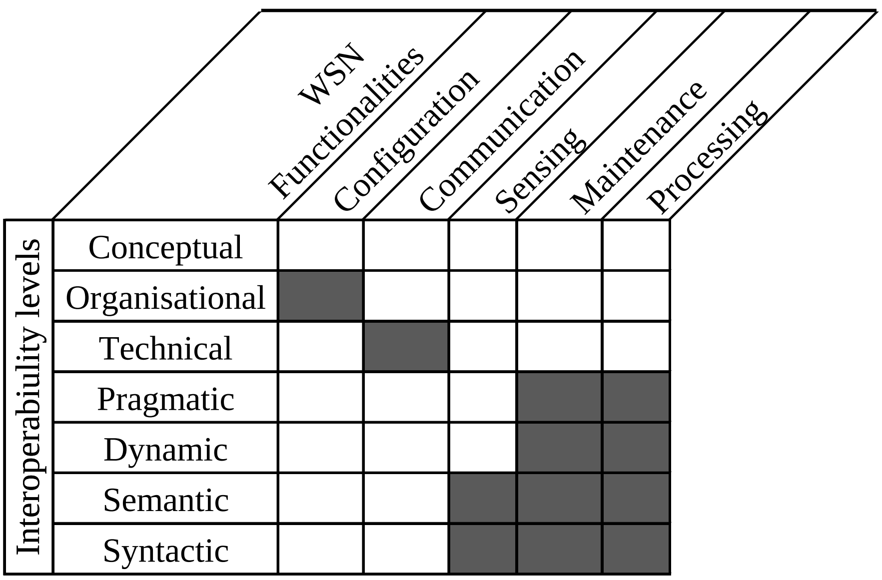

Figure 1: WSN functionalities according to the levels of interoperability.

Our exploratory study demonstrates the existence of relations between WSN functionalities and different interoperability levels. Also it identifies functionalities which require greater attention, especially in terms of its given support to interoperability levels.

The use of the interoperability model focuses our attention on the relevant aspects of WSN functionalities to achieve its interoperability. It has enabled the use of well-defined interoperability levels under the premise that these levels do not have necessarily hierarchical relationships. These relationships can be implemented using metadata and allow designing an interoperability model with several levels, depending on the purpose of the interoperability.

In our case the interoperability levels with stronger relationships are the semantic, syntactic, pragmatic and dynamic levels. This result is different from the previous one obtained for Spatial Data Infrastructure, mainly because of the dynamic nature of WSN and its emphasis on self-management.

This exploratory study has also shown the major role of metadata on the interoperability of WSN. From a more general point of view, metadata in sensor network must have an *active* role in order to provide detailed information required for trigging or executing process and algorithms of the network. Due the frequent changes of states of the network, metadata must be *dynamic* in order to represent these changes and report it back to other systems and components. For example if the nodes of a network change their positions or get damaged, the system must be able to send a message with metadata in order to inform about it to other networks and users. In addition, the creation and maintenance of metadata in WSN must be *automatic*, since real-time data needed real time metadata too. For example, if a node fails, the network should automatically, without human intervention, recalculate new routes to send data. In the same way if a node changes its location, the data collected (and their metadata) must reflect the new position.

Finally, this study has pointed out a “conceptual shift” from defining metadata for WSN towards defining metadata for the interoperability of WSN. Further research will focus on the implementation of a concrete case of study for the evaluation of this interoperability model and to propose a set of metadata attributes for WSN that will be based on the Sensor Web specifications as well as new metadata attributes.

5 References

Akyildiz, I., Su W., et al. (2002). "Wireless sensor networks: A survey" Computer Networks 38 (4): 393-422.

Balazinska, M., Deshpande A., et al. (2007) "Data management in the Worldwide Sensor Web" Pervasive Computing IEEE 6(2): 30-40.

Botts, M., Percivall, G., et al. (2007) "OGC Sensor Web Enablement: Overview and High Level Architecture" OGC White Paper ref .OGC 07-165.

Dini, P., Gentzsch W., et al. (2004) "Internet, GRID, self-adaptability and beyond: are we ready?" Database and Expert Systems Applications. Proceedings 15th International Workshop 782-788.

Graybeal, J., Watson, S., et al. (2007) "Sensor Metadata Interoperability Workshop Report" Marine Metadata Interoperability Project.

Heinzelman, W., Kulik, J., et al. (1999). "Adaptive protocols for information dissemination in wireless sensor networks" In Proceedings of the 5th Annual ACM/IEEE international Conference on Mobile Computing and Networking 174-185.

Intanagonwiwat, C., Govindan, R., et al. (2003) "Directed diffusion for wireless sensor networking" IEEE/ACM Transactions on Networking 11(1): 2-16.

Liang, S., Croitoru, A., et al. (2005) "A distributed geospatial infrastructure for Sensor Web" Computers & Geosciences 31: 221-231.

Manso-Callejo, M.A., Wachowicz, M., et al. (2008) "Towards an Integrated Model for Information System Interoperability Based on Spatial Metadata attributes" Transaction in GIS (submitted).

Moe, K., Hartman, B., et al. (2007) "Sensor Web Technology Meeting Report" Earth Science Technology Office (ESTO), Advanced Information Systems Technology (AIST), National Aeronautics and Space Administration (NASA)

Ruiz, L., Nogueira, J., et al (2004) "Sensor Network Management" In Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems, M. Ilyas and I. Mahgoub, Boca Raton.

Tilak, S, Abu-Ghazaleh, N, et al. (2002) "A taxonomy of wireless micro-sensor network models" ACM SIGMOBILE Mobile Computing and Communications Review 6(2): 28-36.

Werner-Allen, G., Lorincz, K.; et al. (2006) "Deploying a wireless sensor network on an active volcano" Internet Computing, IEEE 10(2):18-25.

Yarvis, M., Ye, W. (2004) “Tiered Architectures in Sensor Networks” In Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems, M. Ilyas and I. Mahgoub, Boca Raton.

Yoshitsugu, O., Tomohiro, K., et al. (2007) “Evaluation of Metadata-Based Data Aggregation Scheme in Clustering Wireless Sensor Networks” Knowledge-Based Intelligent Information and Engineering Systems, Lecture Notes in Computer Science. Springer 4694: 477-483.

Zhang, C., Guan, H., et al. (2006) “Model-aided metadata management for wireless sensor networks” Advances in Grid and Pervasive Computing. Lecture Notes in Computer Science. Springer 3947: 259-268.