Workshop Sensing a Changing World, Wageningen University, **2008**

Metadata behind the interoperability of Wireless Sensor Networks

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Abstract: There is a current need not only to achieve, but also to maintain the interoperability of Wireless Sensor Networks despite frequent changes in network status. The aim of this paper is to describe a context-aware model for the interoperability of Wireless Sensor Networks. We focus on the definition of four context awareness levels based on metadata elements. Additionally, three self-awareness tasks are used to illustrate how the model can be used to maintain the dynamic interoperability of Wireless Sensor Networks.

Keywords: wireless sensor network; context-aware model; dynamic interoperability; metadata.

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1. Introduction

Sensors and sensor networks are becoming an essential source of information for planning, risk management and other scientific applications. They are revolutionising the way of geospatial information is collected and analysed (Stefanidis and Nittel 2004). Their interoperability has already been pointed out as an important issue by the Open Geospatial Consortium for the implementation of integrated sensing systems (Botts *et al.* 2007). In this paper, we focus on the interoperability of Wireless Sensor Networks (WSN) based on two perspectives: *data interoperability* and *network interoperability*. The interoperability of sensor data aims to ensure the exchange and integration of sensing data from distributed heterogeneous sensors with other kinds of information systems (Lee and Reichardt 2005). To combine data from multiple heterogeneous data sources, these data must have a well-defined syntax and semantic through metadata specifications (Balazinska *et al.* 2007). On the other hand, the purpose of network interoperability is the integration between network components, where they must exchange and act on information provided by other components or external networks (Moe *et al.* 2007). Components and networks must share their memory, energy, communication and sensing resources; therefore interoperability is needed to perform the communication between the network gateway and users as well as among networks, to exchange messages and handle the network communication (Chang and Gay 2005).

In the sensor domain, the standardisation initiatives carried out by the Institute of Electrical and Electronics Engineers (IEEE) and the Open Geospatial Consortium (OGC) are oriented to overcome the heterogeneity of devices, communication protocols, networks, data formats and structures. However, in order to support the interoperability of dynamic WSN over time is necessary to address the changes in the network status, components and functionalities (De Roure *et al.* 2005; Grace *et al.* 2008). Previous research has demonstrated that the adaptation to state changes of computing environments and sensor networks can be achieved through the use of metadata describing the system status at different periods of time (Dini *et al.* 2004, Indulska *et al.* 2006, Di Marzo Serugendo *et al.* 2007).

The main research challenge is to develop a model based on metadata for handling such a dynamic context of WSN. In a general sense, metadata provides a description of observations, processes and functionalities of WSN, as well as their configuration and status to enable the understanding of a network itself and to ensure the interoperability with other sensor networks and devices. These metadata elements integrated with self-adaptive and self-organise mechanisms are needed to maintain the dynamic interoperability through time and in despite of the network status changes. Therefore, in this paper we describe the first results of our attempt to develop a context-aware model to maintain the dynamic interoperability based on metadata elements.

2. The role of metadata in a context-aware model

Dynamic interoperability allows the monitoring of operations of different systems and their responses to changes (Manso *et al.* 2008). To maintain this dynamic interoperability among WSN, a new approach is needed to define a context-aware model that will be able to (a) provide the information needed to maintain the interoperability through time, and (b) support the mechanisms of self-adaptation and self-organisation. Previous developed context models mainly consider sensors as a mechanism to capture information about the context (Baldauf *et al.* 2007). In contrast, our model focuses on the relevant context related to the achievement and maintenance of the sensor dynamic interoperability.

In the proposed context-aware model, the metadata can generate the knowledge of the state of the sensing system in order to maintain the dynamic interoperability of WSN. Metadata are the common thread that will connect all the states and functionalities of WSN and will preserve the context of the collected data. On the one hand, they must describe dynamically the network state changes and report it back to other components and systems. For example, if a node of a network changes its position or get damaged, the system must be able to broadcast a message containing metadata in order to inform about these changes to other networks and users. On the other hand, metadata must be automatically generated and updated, since real-time data need real time metadata as well. For example, if a node fails, the network should automatically (i.e. without human intervention), reconfigure 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.

The proposed context-aware model consists of four context awareness levels. They are the sensing, the node, the network and the organisational contexts.

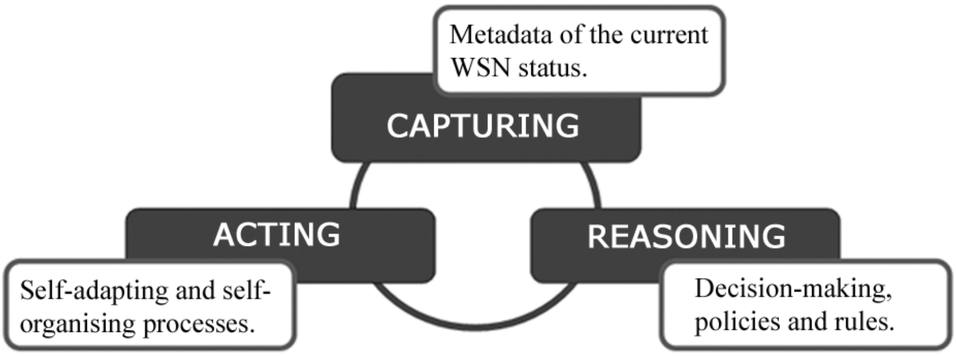
- The *sensing context* describes the sensing conditions, performs the sensing operations, and help to evaluate and understand the potential sensor data (Campbell *et al.* 2008). It is related with the sensing metadata that contains (a) the spatial information, such as the sensor and data localisation, spatial reference or local reference; (b) the temporal information, such as instant time or interval of observation; and (c) thematic information, such as feature of interest and phenomena (Sheth *et al.* 2008). Other descriptive metadata of this context are the data capture and observation processes, data collection characteristics (periodic, continuing, or reactive), etc. The OGC Observation & Measurement data model and Sensor Model Language are related to this context.
- The *node context* describes the state of memory, communication devices, sensors, actuators, and processor for each individual node. The nodes could be able to participate in collaborative tasking through different networks, such as data transmission processes, and in-network data aggregation. A standard specification related to this context is the IEEE 1451 that describes the transducer interface to communicate it with other components. It focuses on the static hardware and specifies the TEDS (Transducer Electronic Data Sheet) which contains detailed information for sensor identification, model and functionalities. Another specification is the Sensor Model Language that defines an XML encoding to describe the sensor system and processes with the aim of discovering sensors, locating and processing low-level sensor observations and listing taskable properties. Previous work has mentioned a hybrid description of sensors that automatically embed information from TEDS into SML (Indulska *et al.* 2006; Hu *et al.* 2007).
- The *network context* describes the current configurations and topologies of interoperable networks. These metadata are dynamic and some of them could derive from the node context as emergent properties of the network. Some examples are the network composition (homogeneous, heterogeneous), organisation (hierarchical, flat), mobility (stationary, mobile), density (balanced, densely spaced), distribution (regular, irregular), size (small, medium, large), topology, residual network energy and memory, sensing coverage area, communication coverage area, in-network process capacities, etc.

- The *organisational context* is related to how organisational aspects of the WSN affect its dynamic interoperability. It is associated with goals, restrictions, security, and privacy issues. For example the interoperability of a WSN may be forbidden for security reasons; or certain nodes can have limitations to interoperate because of restrictions imposed to conserve their energy.

The first three awareness levels are associated with the network itself, while the fourth is associated with non-physical aspects of the WNS. Furthermore, these contexts are related among them. For example, to compute the network coverage area (network context) is necessary to know the position of the nodes (node context). On the other hand, for security reasons only authorized systems (organisational context) are allowed to access to certain sensing functionalities (sensing context).

Three main tasks of self-awareness have also been defined in our model to maintain the dynamic interoperability in WSN. They are capturing, reasoning and acting (Figure 1).

Figure 1. The self-awareness tasks of the proposed model



The *capturing* task collects metadata that describe the sensing system, the current network configuration, and the environment restrictions. The network dynamics should be automatically captured and described (i.e. self-descriptive). In the *reasoning task* some rules and policies are applied to maintain the dynamic interoperability over time. These rules are fed by the metadata of the WSN current state. Then a decision making process determines what should be done to maintain the dynamic interoperability. The *acting task* runs the self-adaptive process internally in the network and self-organising process to maintain the relations with other WSN.

The main goal of the proposed context-aware model is to manage the self-awareness tasks using the context-awareness level to maintain the dynamic interoperability of WSN. For example, several WSN have been integrated with the goal of sensing a physical phenomenon (e.g. acoustic, humidity, temperature) with an adequate spatial coverage. The capturing task generates metadata about the node positions of the different interoperable sensor networks. The reasoning task can use this metadata to generate the geographical knowledge about the current status of the sensing system. In doing so, it is discovered that two nodes are too close one to each other. Based on the rule "*If the nodes are less than 5 meters away, then it must continue capturing data from only one of them*", the reasoning task uses policies to "choose" one of them. It is also important to point out that in order to perform this reasoning, a common vocabulary and ontology is needed. Finally, the acting task triggers a self-adaptive process to only capture data from the selected node using a common service interface.

3. Conclusions and future work

In this paper we provide the description of a context-aware model to maintain the dynamic interoperability in WSN. This model consists of the interaction between context awareness levels (sensing, node, network, and organisational) and tasks (capturing, reasoning, and acting). The context awareness levels describe the context in which the dynamic interoperability takes place, meanwhile the self-awareness tasks collect metadata from the context awareness levels, support the decision-making using the metadata contexts, and trigger self-adaptive and self-organise processes in order to maintain the interoperability. It shows how metadata is a key factor to maintain the dynamic interoperability in the proposed model. At this time, we are using the metadata elements for the context model focused on the capturing task. Further research will be focused on extending the metadata elements for the reasoning and acting tasks. We will also implement the context model (i.e. context awareness level and self-awareness task) as a proof-of-concept.

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