Taxonomy for Wireless Sensor Networks Services Characterisation and Classification

Luís M. Borges[†], Fernando J. Velez[†], António S. Lebres[¥]
[†] Instituto de Telecomunicações, DEM, Universidade da Beira Interior, Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal
Phone +351 275 329 953; Fax +351 275 329 972, e-mail: lborges@lx.it.pt, fjv@ubi.pt
[¥] UDR- Unidade de Detecção Remota, Universidade da Beira Interior, Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal
Phone +351 275 329 953; Fax +351 275 329 972, email: lebres@ubi.pt

Abstract — **Nowadays, the users of Wireless Sensor and Actuator Networks (WSAN) are becoming more and more demanding in terms of choice and diversity of applications, and the identification of their characterization parameters is thus in order. This paper describes the WSAN characterization parameters and is an update of a previous work, but new parameters were added and new characteristics were proposed. The gathering of all these parameters allowed us to sketch up taxonomy for WSAN via an application-oriented approach, identifying the services offered by each application. For comparison purposes, tables with details from different projects in the field of WSAN are presented.**

I. INTRODUCTION

In the near future, with the technological advances in the communication area and the increasing miniaturization and integration of electronic components and embedded microprocessors, powerful networked and mobile systems will arise Examples are sensors and actuators manufactured using micro-electromechanical system technology, or MEMS. Since these sensor networks started to take part of our life, gradually more and more applications appear where these systems are used. These concepts enable a massive-scale of wireless sensor networks (WSN) applied to a range of applications, and will change the way we interact, live or even work within the surrounding ambient. Nowadays, instead of using WSN, one has only the capability to sense or detect some event, but the new generation of sensor networks, also called Wireless Sensor and Actuator Networks (WSAN) [1], is formed by small sensor nodes that combine the abilities to communicate, compute, sense and actuate, maintaining the hardware characteristics of previous WSN (microprocessor, radio transceiver, sensors and battery) but adding the actuator device. In a not so far future, these systems will, be spread onto environment and workplaces, allowing for sensing a large variety of phenomena such as the monitoring of forest fires, enabling rapid emergency response when needed and tracking pedestrian or vehicular traffic in a metropolitan context. While these technological advances emerge, new challenges for information processing in sensor networks arise. The needs in this context are novel computational representations, algorithms, protocols, design methodologies and tools which allow for supporting distributed signal processing, information storage and management, networking, and application development.

The main challenge of this study is to understand what services WSN can offer to the user, how they can be classified and characterized, while describing what applications are in the framework of WSN. Together with the description of the services and applications characteristics, relevant examples are given, in order to better understand what WSN can offer. This systematisation is essential for high standard system design.

The remaining of the paper is organized as follows. Section II presents the notions of WSN services and applications, and discusses the usefulness of a general service interface. Section III presents an update of the taxonomy for the characterization of services and applications, already described in a previous work [1]. Section IV presents an example of WSN application characterization. Finally, Section V presents conclusions and suggestions for further work.

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II. WSN SERVICES AND APPLICATIONS

A. WSN services

WSN are mission-driven service provider which efficiently delivers services subject to the required quality-of-service (QoS), physical and link layer constraints. Since WSN are service providers they can be modelled at different levels of abstraction. For each level, a set of services and a set of metrics are defined. Therefore, a service is a unit of operation upon which the various WSN components are defined. A service can be informally defined as an abstraction that encapsulates "an organizational unit" [3]. The type of a service depends on the organizational unit that is encapsulated and on the functionality exposed by the interface. WSNs are mission-oriented and it is the mission that will guide all the functionality of the sensor network and sensors collectively deliver services to accomplish the network's mission based on their sensing, computing, storage, communication, and energy capabilities and on the data that they collect and process as well.

B. WSN applications

An application in WSN can be defined as the task designated for the sensor network, and these devices could interact closely with the human user, or it can interacts with the surrounding environment where the network is embedded in the environment and nodes in the network are equipped with sensing and actuation to measure/influence environment. On the one hand, the application itself can consist of several components integrated at various places into the protocol stack (PS) without considering a service interface [4], Fig. 1a). The absence of this service interface provides an integrated programming environment, and gives the application programmer a very fine-grained control over which protocols (which components) are chosen for a specific task. However, as the permission given to the application programmer to mess with protocol stacks and operating system internals can be dangerous.

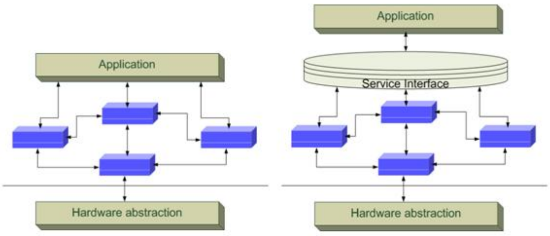

Fig. 1. Interfacing an application to a protocol stack in the a) absence or b) presence of a general service interface [4].

On the other hand, the presence of a service interface raises the level of abstraction for the interaction between the application and the WSN [4], Fig. 1 b). It is actually possible to face it as a “middleware” as it only gives easy access to certain components in a standardized way. Conceptually, WSN services are located between the application and the hardware, and each application is characterized by a set of parameters.

III. Characterization Parameters

A. Main Characteristics and Delivery Requirements

The proposed taxonomy distinguishes between the functional and technical requirements for the classification of WSN services and applications, Table I, by identifying different types of characteristics. The main objective of this taxonomy is to obtain systematization for the characteristics of services and applications and to propose possible values for the range of variation of each parameter, allowing for a better and clearer understanding of the involved complexity. This Table is an upgrade version of a previous one, presented in [2], where some parameters were presented in a simpler way. The intention of this work is to provide a more complete and detailed view of the characteristics of WSN services and applications. Note that the main parameters, e.g., associated with delivery requirements, have already been defined in [2].

B. Traffic and Communication Characteristics

Regarding the traffic characteristics, it is worthwhile to note that the rate for data transmission/modulation is given in bit per second, which is the rate the modulator can accept for transmission of binary data. For binary modulation, bit rate and data rate are the same and often the term bit rate is used to denote the data rate. But in terms of distinction the bit rate is normally denoted as the rate of transmission of a data packet which includes the useful data and the overhead bytes, while the data rate is normally denoted as the rate of transmission for the useful data alone, without the overhead bytes. Depending on the radio transceiver supported the data rate differs. The traffic generators more often used in WSNs are Constant Bit Rate (CBR), on-off or exponentially distributed traffic ones [5].

Table I
Services and applications characteristics

Characteristics	**Parameters**
Main	Delivery: Real-Time (RT) or Non-Real-Time (NRT)
	Directionality: Unidirectional (Und) or Bi-directional (Bid)
	Communication symmetry: Symmetric (Sym) or Asymmetric (Asy)
	End-to-end
	Interactivity
	Delay tolerancy
	Criticality
Traffic	Quality of Service (QoS)
	Data rate
	Latency/delay
Communication	Synchronization
	Class of service
	Bit Error Rate (BER)
	Modulation
	Communication direction
Service components	Type of traffic
	Data Acquisition & Dissemination
Network	Lifetime
	Scalability
	Density
	Sensing Range
	Self-Organization
	Security
	Addressing
	Programmability
	Maintainability
	Mobility Support
Node	Microprocessor
	Radio Transceiver
	Overall Consumption
	Sampling rate
	Type of function
	Communication range
	Power Supply
Operation Environment	**Sensor Network scenarios**
	Single hop versus multi-hop
	Multiple hop sinks and sources
	Mobility scenario
	Framework Public: Urban, Road, Rural, Commercial Private: Emergency dedicated
	Deployment scenarios Offices, Industry, Home, Military, Civil, Metropolitan

Regarding the communications characteristics, in [1], a parameter was mentioned called type of service, but it was wisely excluded here, because it is already included in the class of service parameter.

In WSNs, simple modulation techniques such as Amplitude-shift keying (ASK), Frequency-shift keying (FSK), Binary phase-shift-keying (BPSK) and Quadrature Phase Shift Keying (QPSK) are preferred choices because of their easiness of implementation, robustness and low power consumption.

C. Service Components

In [2], the service components referred only to the type of traffic. However, this group of parameters was updated by adding the data acquisition and dissemination parameter. This new parameter includes three broad classes of sensor network applications emerge depending on the factors that drive data acquisition and dissemination: time-driven (Td); event-driven (Ed); demand-driven (Dd) [6]. In the time-driven class nodes collect and report data from the physical environment periodically and they are represented by a simple model in which the nodes mostly report data and perform minimum data processing. The event-driven class is represented by a reactive model that closely fits the requirements of many sensor network applications and nodes can adjust their data reporting behaviour based on certain network events. In the demand-driven class, while events in the operating environment drive data reporting in event driven sensor networks, demand-driven sensor networks enable network entities, such as end-user or software components within the network, to query the nodes for sensor data.

D. Network Components

For the network components, in [1] only a few parameters were presented, but in this paper more parameters were added which can better define the network components, e.g., the sensing range parameter, which is defined as the monitoring quality provided by a sensor network in a specific region. With different applications, different degrees of sensing coverage are required [7].

The self-organization is also a parameter that was added and is the capability that the sensor nodes have to find appropriate paths to establish the best communication between them and with master node. The self-organization of a network could be done for the entire network or for a part of the network or not to the entire network.

The security of a WSN is other added parameter and is defined as the protection level that data from the WSNs are protected. Therefore, the level of security can be high, medium, low or none [8].

The addressing scheme parameter is also a new parameter, defined as the way how sensor nodes are identified in the sensor network. The choice for addressing makes each sensor node unique within the network, helping to setup routing paths when configuring the WSN. There addressing schemes currently being used in WSNs are the following: i) Data-Centric; ii) Attribute-based scheme; iii) Localized or geographic addressing scheme; iv) Address-centric scheme (e.g. MAC address); v) Spatial IP scheme; vi) Address-Free scheme. The last characterization parameter added is the type of mobility support, which indicates whether the WSN is pre-prepared to support mobility. This feature is supported by hardware and/or firmware modules with such capability.

E. Node

The node characteristic is a new item added, comparing with the previous proposal [1]. For this new item a set of parameters are defined and are characterized by parameters that vary from one WSN application to the others.

One of the characteristics is the type of microprocessor as it forms the “brain” of the node. The microprocessor of the node will vary, depending on what kind of processing is needed for a specific WSN application. If the processing is higher than a more powerful microprocessor will be needed in order to fulfil the requirement, never forgetting the tradeoffs that will arise.

The type of radio transceiver is responsible for packet transmission and reception. It will affect other parameters, such as the data rate that the radio transceiver support, the modulation, the overall consumption of the node, the BER, the communication direction, the operating frequency of the radio transceiver and the radio range. There are some tradeoffs regarding the radio transceiver frequency, the data rate and the radio range when choosing the radio transceiver. When the radio transceiver frequency is low, the radio transceiver data rate will be low (radio range will be higher) and if the radio transceiver frequency is high, then the radio transceiver data rate will be high (radio range will be low).

The overall power consumption of the node is also an important characteristic, as it distinguishes between different WSN applications according to the energy supply to the node, which is a limited resource. The main concern is to maintain the node active while not discarding the overall performance of the node. Depending on what types of sensors/actuators are attached to the node, the overall consumption will be different from a WSN application to another.

Another parameter is the sampling rate which is defined has the frequency that the sensor attached to the node is read from the microprocessor and different sensors could have different sampling rates.

The type of function of nodes is also another characteristic where a node in a WSN can assume different functions. A node could be sensor node and/or actuator node or could be a sink node.

Besides, the communication range of the node is also an important characteristic and is related with the type of radio transceiver used in the node. There are some tradeoffs when relating the radio transceiver frequency with the data rate and the communication range. The last characterization parameter is the power supply of the node, an important parameter because it is related to the overall consumption of the node and is assured by using batteries, but more recently small devices that take advantage from kinetic energy or using clean energy are being used to get energy for the nodes.

F. Operation Environment

The operation environments proposed in [1] already have the final definition of the operation WSN operation environments and scenarios.

IV. APPLICATIONS CHARACTERIZATION

Tables are being produced that contain the typical values for the parameters for each application, covering each of the characteristics of WSN services and applications by considering actual WSN research and development projects. As the construction of these Tables is an elaborated process, until now, there is only three applications practically fully parameterized, namely metropolitan operation – road monitoring and military ones. Tables II and III present a small example of the aspect of the main and traffic characteristics tables. Many of these parameters are common to different applications, and the only difference between different applications is a small subset that may make the difference.

Table II
WSN services and applications-Main characteristics

Parameters	Application		
	Road monitor	Military	
		Border monitor	Surveillance
Delivery	RT & NRT	RT	RT & NRT
Directionality	Bid	Bid	Bid
Communication Symmetry	Sym	Sym	Sym
End-to-End connection	Non End-to-End	End-to-End	End-to-End
Interactivity	Interactive	Interactive	Interactive
Delay tolerance	Non Delay tolerant	Non Delay tolerant	Non & Delay tolerant
Criticality	Mission critical	Mission critical	Mission critical

Table III
WSN services and applications-Traffic characteristics

Parameters		Application		
		Road monitor	Military	
			Border monitor	Surveillance
QoS		Network QoS	Network QoS	Network QoS
Data Rate (kbps)		250	19.2	38.4
Delay	Min.	125 ms (48 nodes)	8 ms	2s (60 nodes)
	Max.	6 s (2340 nodes)		

V. CONCLUSIONS

This paper gives an overview on a taxonomy for the characterization parameters that define the services of a WSN application. The description of the parameters allows the reader to identify what are the services that a specific WSN can offer. Although this subject is still open for discussion, and the identified parameters are not static, this study already represents an effort to join together the contributions from different studies and authors.

The gathering of all these parameters allowed us to sketch up taxonomy for WSAN via an approach oriented to applications and the researcher/developer can plan and choose the most relevant parameters for his future WSAN application while considering values from other similar works, shown in the previous Tables. The conclusion of the characterization of services offered to WSN applications was left for further work. A proposal for future work is the establishment of threshold (boundary) values for parameters for each application or service, e.g., in terms of QoS.

REFERENCES

[1] R.Verdone, D. Dardari, G. Mazzini and A. Conti, *Wireless Sensor and Actuator Networks- Technologies, Analysis and Design*, Elsevier, London, UK, 2008.

[2] L. M. Borges, F. J. Velez and A. S. Lebres, "Wireless Sensor and Actuator Networks Services and Applications: Characterisation and Classification Taxonomies", in *Proceedings of WPMC 2008 – The 11th International Symposium on Wireless Personal Multimedia Communications*, Lapland, Finland, Sep. 2008.

[3] D. Gračanin, M. Eltoweissy, A. Wadaa and L. A. Da Silva, "A Service-Centric Model for Wireless Sensor Networks", *IEEE Journal on Selected Areas in Communications*, Vol. 23, No. 6, June 2005.

[4] H. Karl and A. Willig, *Protocols and Architectures for Wireless Sensor Networks*, John Wiley & Sons Ltd, West Sussex, UK, 2005, Sections 1.5 & 3.4.

[5] F. Chen and F. Dressler, "A Simulation Model of IEEE 802.15.4 in OMNeT++", in *Proceedings of 6. GI/ITG KuVS Fachgespräch Drahtlose Sensornetze*, Poster Session, Aachen, Germany, July 2007.

[6] R. Shah, "Data Mules: Modeling a Three-Tier Architecture For Sparse Sensor Networks", in *Proceedings of IEEE International Workshop on Sensor Network Protocols and Applications*, Anchorage, Alaska, USA, May 2003.

[7] Z. Shelby, M. Huttunen and P. Ráez, Applied Wireless Sensor Networks, Public presentation, University of Oulu, Finland, 2006.

[8] R. Jurdak, *Wireless Ad Hoc and Sensor Networks: A Cross-Layer design Perspective*, Springer, New York, New York, USA, 2007.

[9] L. M. Borges, A. Rente, F. J. Velez, L. R. Salvado, A. S. Lebres, J. M. Oliveira, P. Araújo, J. M. Ferro, "Overview of Progress in Smart-Clothing Project for Health Monitoring and Sport Applications," in *Proceedings of ISABEL 2008 - First International Symposium on Applied Sciences in Biomedical and Communication Technologies*, Aalborg, Denmark, Oct. 2008.