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WIRELESS SENSOR AND ACTUATOR NETWORKS SERVICES AND APPLICATIONS: CHARACTERISATION AND CLASSIFICATION TAXONOMIES

Luís M. Borges
Instituto de Telecomunicações, IT-DEM
Covilhã, Portugal

Fernando J. Velez
Instituto de Telecomunicações, IT-DEM
Covilhã, Portugal

António S. Lebres
Unidade de Detecção Remota, UDR-UBI
Covilhã, Portugal

ABSTRACT

Nowadays Wireless Sensor Networks (WSN) users are becoming more exigent when choosing services for a certain WSN application. This paper describes the characteristics of WSN services and applications, splitting them into six main characteristics and each main characteristic is identified by specific parameters that identify the main characteristic. For each parameter a description is made in order to better understand how services are described and differentiate from each other and examples are given, referring the importance of these parameters in the services that are offered to the user. The gathering of all these parameters allowed us to sketch up taxonomy for the services in WSN regarding the applications, allowing the user to choose the application he/she wants based in these categories whilst identifying the services offered by the application. Future work will aim the detailed characterization of services offered to the main areas of WSNs considering these parameters and also on others parameters yet to be included.

I. INTRODUCTION

Wireless sensor Networks (WSNs) include special characteristics such as a large number of node, limited processing and transmission capabilities and finite lifetime in each node, due to energy sources restrictions. With the increasing relevance of WSNs in the scientific community more models and techniques are needed to analyze, verify, operate and predict their behaviour. To achieve the goals of their service specifications WSNs design should include aspects of architectures, protocols, management, interfaces, and applications. The main challenge of the study presented in this paper is to understand what services WSNs can offer to the user, how they can be classified and characterised, while describing what applications are in the framework of WSNs. Together with the description of the services and applications characteristics relevant examples are given, in order to better understand what WSNs can offer.

The remaining of the paper is organized as follows. Section II presents the notions of WSN services and applications, and discussed the usefulness of a general service interface. Section III presents the taxonomy for the characterisation of services and applications. It includes parameters as the main, traffic, and communication ones but also identifies the service components, the network parameters and the operation environments. Section IV presents a taxonomy for the classification of WSN applications. Finally, Section V presents the conclusions and suggestions for further work.

II. WSN SERVICES AND APPLICATIONS

A. *What is a service in WSNs?*

WSNs are mission-oriented 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. A WSN is a mission-driven service provider that efficiently delivers services subject to the required quality-of-service (QoS), physical and link layer constraints.

Since a WSN is seen like a service provider it could be modelled at different levels of abstraction. For each level, a set of services and a set of metrics are defined. Services and their interfaces are defined in a formal way to aid automatic composition of services, and enable interoperability and multitasking of WSNs at the different levels.

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" [1]. A service can be defined, discovered, instantiated (related with QoS constraints), invoked, and constituted by service input/output connectors. The type of a service depends on the organizational unit that is encapsulated and on the functionality exposed by the interface.

The mission determines all the functionality of the WSN. It describes a high-level purpose for the WSN, i.e., what data is of interest and what types of services are needed. For a given mission, a set of services is provided. A service includes data gathering, aggregation, and processing from the wide areas covered by the WSN. Since sensors are identified only by the regions in their range, service-related activities within a region are considered to be atomic. The service can therefore be decomposed into a set of services, each limited to a single region and involving all active sensors in that region. The sender, requesting such a service, may be in the same region or outside that region.

Each sensor has a set of sensory/control devices. These devices are described by attributes with a specified range of values and a specified resolution. For a certain mission only some devices are needed and a change on the mission may require a change of sensor configuration.

B. *What is an application in a WSN?*

An application is another component that can (directly) interact with other components by using the existing interface specifications among them, e.g., the command/event structure of TinyOS. Component-based operating system (OS) and protocol stack (PS) already enable the possibility to deal with these individual applications.

On the one hand, the application itself can consist of several components (or services), integrated at various places into the protocol stack without considering a service interface [2], Fig. 1a). Some advantages are pointed when this kind of approach is used. For example, the insertion of application-specific programming code into the WSN at various levels does not require the definition of an abstract specific service interface. Therefore, 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, there are some disadvantages arising from this generality and flexibility, as the permission given to the application programmer to mess with protocol stacks and operating system internals can be dangerous.

On the other hand, the presence of a service interface raises the level of abstraction for the interaction between the application and the WSN [2], Fig. 1 b). Instead of having to specify which value to read from particular sensors, it might be desirable to provide an application with the possibility to express sensing tasks in terms that are close to the semantics of the application. In this case, such a service interface can hide considerable complexity, and it is actually possible to face it as a "middleware" as it gives easy access to certain components in a standardized way.

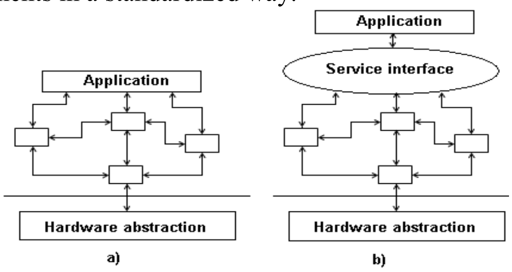

Figure 1: Interfacing an application to a protocol stack in the a) absence or b) presence of a general service interface [2].

III. CHARACTERISATION PARAMETERS

A. *Taxonomy*

The proposed taxonomy distinguishes between the functional and technical requirements for the classification of WSN services and applications, Table 1, 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.

B. *Main Characteristics*

Communications established among WSNs can be unidirectional or bi-directional. The bi-directional can be either symmetric or asymmetric. The term symmetric refers to any system in which data speed or quantity is the same in both directions, averaged over time. The term asymmetric (also asymmetrical or non-symmetrical) refers to any system in which the data speed or quantity differs in one direction as compared with the other direction, averaged over time.

Table 1: Characteristics of WSN services and applications.

Characteristics	Parameters
Main	Delivery requirements: 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: it may be end-to-end or non-end-to-end performance;
	Interactivity: interactive or non-interactive;
	Delay tolerant: The application may or may not be delay tolerant;
	Criticality: mission critical or non mission critical
Traffic	Quality of Service (QoS)
	Data rate
	Latency/delay
	Bit rate
	Generation process (Poisson or Constant Bit Rate)
Communication	Type of service
	Synchronization: Synchronous (Sync) or Asynchronous (Async)
	Class of service (constant, variable bit rate)
	Bit Error Rate (BER)
	Modulation
	Communication direction
Service Components	Type of traffic
Network	Lifetime
	Scalability
	Density
	Programmability
	Maintainability
Operation Environment	Sensor Network scenarios
	Single hop versus multi-hop
	Multiple hop sinks and sources
	Mobility scenario Node mobility Sink mobility Event mobility
	Framework
	Public: Urban, Road, Commercial zones
	Private: Emergency dedicated
	Deployment scenarios
	Offices, Industry, Home, Military, Civil, Metropolitan

For the delivery requirements, an application can be defined either as real time (RT) or non-real-time (NRT) [2]. In a real-time application specifically, NRT packets wait at a queue until the number of accumulated packets is equal to the maximum aggregation limit. On the other hand, RT packets, which are sensitive to the aggregation latency, are transmitted as soon as possible without any waiting at the queue [3]. So it may be possible to provide a result quickly but at higher energy costs, e.g., by forcing nodes to wake up earlier than they would wake up anyway, or slowly but at reduced energy costs.

Regarding the interactivity of a WSN, it refers to the type of support for simple request/response interactions, retrieving a measured value from some sensor or setting a parameter in some node. If the interaction pattern is synchronous the result (or possibly the acknowledgment) is expected immediately. Otherwise, asynchronous event notifications can be supported, e.g., where a requesting node can require the network to inform it if a certain event has happened.

WSNs may require end-to-end or non-end-to-end performance. This end-to-end parameter refers to the trust relationship in a network that is established between the sender and the receiver [3]. When considering QoS under a WSN, a non-end-to-end application performance is chosen as hop-by-hop communications are preferable when choosing alternative routes for the traffic when a given part (or path) of a link is not available.

WSN applications may be delay tolerant or not. When an application is not delay tolerant usually it is referred as a real-time application.

Finally, the criticality from the application is another relevant parameter. The application is mission-critical or non-mission-critical depending on the way the user uses the WSN.

C. Traffic Characteristics

For the traffic characteristics, latency or end-to-end delay is one of the key QoS performance parameters [5]. It is an important metric for some sensor network applications, such as real-time monitoring sensor networks, emergency response networks. There are two delay components from a WSN application's perspective: i) the data freshness, which indicates how recent the reported data is, and ii) the response time, which indicates the network application's capability to respond to environmental events or user queries within a given interval of time.

Another characteristic is the support of QoS in WSNs that is still a largely unexplored research field. This is mainly because WSNs are very different from traditional networks. QoS it is accepted as a measure of the service quality that the network offers to the applications/users. From the network perspective, the network's goal is to provide the QoS services while maximizing network resource utilization. Two perspectives of QoS in WSNs can be described as:

i) **Application-specific QoS** - Applications impose specific requirements on the deployment of sensors, in the number of active sensors, in the measurement precision of sensors and so on, [6]
ii) **Network QoS** - From the point of view of network QoS, the application that is actually carried out by itself is not so important, but how the data is delivered to the sink and corresponding requirements.

Generally, there are three basic data delivery models for network QoS: i) event-driven, ii) query-driven, and iii) continuous delivery models [9]. Application requirements (end-to-end, interactivity, delay tolerant, and criticality) are summarized in Table 2.

Table 2: Application requirements in a QoS network.

Parameter	Class		
	Event-driven	Query-Driven	Continuous
End-To-End	x	x	x
Interactivity	✔	✔	x
Delay Tolerant	x	Query-specific	✔
Criticality	✔	✔	x

When referring to the "speed" of data transmission/ modulation, two concepts emerge. One is the symbol rate, the inverse of the symbol duration (called bit rate for the binary modulation). Second, the data rate, the rate, in bit per second, that 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. Depending on the radio transceiver supported the data rate differs.

D. Communications Characteristics

There are many types of services such as services used for the network, i.e., and communication tasks, routing, localization, or during the initialization of a node the localization of a data sink for sensor data [10]. Another type of service is the service for the sensors, i.e., instrumentation and aggregation tasks, where each type of sensor can show different requirements at WSNs that are being transformed into a multi-service medium, leading to the convergence of voice, video and data communications. Each type of service has a particular constraint and it has to be satisfied for the communication to be effective. For example, voice or video are delay sensitive and have to be transmitted within a certain delay. Therefore, the service for each type of traffic needs to be met [10]. For example, a type of service for the sensors is temperature monitoring.

To support WSN applications, and based on QoS parameters, three classes of services must be supported:

i) **Best-effort delivery (no QoS) -** It is addressed with ABR (Available Bit Rate) class of service, where the traffic is processed as quickly as possible [12].

ii) **Real-time delivery of time-based information -** It could be Constant Bit Rate (CBR) or Variable Bit Rate (VBR) with time requirements. In the WSN literature, CBR data traffic is commonly employed (e.g.[13]). There are also a few studies that use VBR (e.g., Poisson distributed [14]) data sources. For VBR [15], based on QoS parameters, there are authors that consider an application with a variable bit rate as *soft* QoS one [16]. These more general service classes map into four specific service classes:

i) **CBR -** The values produced by the CBR WSN applications are sent out at a relatively constant bit rate and so the nodes are served with a constant bit rate agreed during the initial setup of the WSN [17].
ii) **Variable Bit Rate – Real Time (RT-VBR) -** The bit rate varies between zero and a peak value as agreed during the connection setup phase [18].
iii) **Available Bit Rate (ABR) -** ABR is a class of service where the data is sent as quickly as possible, but there is no guarantee to the timeliness and assurance of actual delivery.
iv) **Unspecified Bit Rate (UBR) –** It is a best effort service without performance guarantees. UBR is used for WSN applications that require mobility [19].

Examples for each type of service are presented in Fig. 2. The possible values for the type of delivery, the type of information, and for the data loss are presented in Table 3.

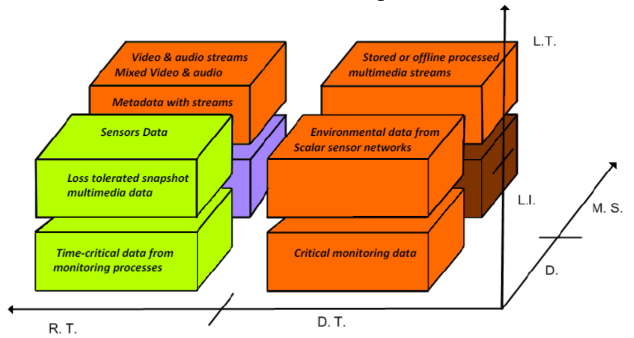

Figure 2: Service and traffic classes.

Table 3: Acronym definition.

Traffic classes	Acronym	Description
Type of Delivery	R.T. D.T.	Real Time Delay Tolerant
Type of information	D. M.S.	Data Multimedia streams
Data loss	L.I. L.T.	Loss intolerant Loss Tolerant

The boxes with green colour are RT-VBR, while the orange boxes refer to CBR ones, and examples for the applications in boxes with others colours (hidden boxes) are not defined. Another communications characteristic is the modulation that is used by the transmitter. When referring to the optimization of transmission parameters the choice of modulation scheme as well as the choice of radiated power (within legal constraints) can significantly influence the BER.

For digital data represented by bits, the notion of BER is even more important because it describes the probability that a bit delivered to a higher layer is incorrect and is a good indicator of link reliability. 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 for their ease of implementation, robustness and low power consumption [20]. Finally, the communication direction of the channel is the capacity to load or transmit a signal. There are three types of communication direction, simplex, half duplex, full duplex.

E. Service Components

With the wireless video sensor nodes coming of age, a new albeit nascent field of research has sprung up, namely exploration of the possibility of use of video/acoustic sensors to set up WSNs, to monitor and convey data in the form of only video, only audio, or both video and audio streams. Basic components are audio, video and data. Moreover, audio can be subdivided into voice (VOI) and ambient (AMB), video can be supported by streaming video (STM), whereas data can be low-rate (LOD), medium-rate (MED) or high-rate (HID). Three broad classes of sensor network applications emerge depending on the factors that drive data acquisition and dissemination: time-driven; event-driven; demand-driven [21].

F. Network Components

An essential characteristic that WSNs have is the lifetime of the network. The lifetime of a network has direct trade-offs against QoS: investing more energy can increase quality but decrease lifetime. Concepts to harmonize these trade-offs are therefore required. The precise definition of lifetime depends on the application at hand. A simple option is to use the time until the first node fails (or runs out of energy) as the network lifetime. Other option includes the time until the network is disconnected in two or more partitions.

Other characteristic is the scalability of the network, which is the amount of sensor nodes devices that the network can support. Nowadays WSNs include a large number of nodes and therefore the quantity that a WSN can support depends on the employed architectures and protocols that must be able to scale to these numbers [3]. The density of the network is another network characteristic of the WSN and is defined as the number of nodes per unit area, where can vary considerably. Different applications will have very different node densities.

The programmability from the sensor nodes of a WSN is another network characteristic because not only will it be necessary for the nodes to process information, but also they will have to react flexibly on changes in their tasks. These nodes should be programmable, and their programming must be changeable during operation when new tasks become important. Therefore, the devices that constitute the WSN are or are not programmable.

The last network characteristic is the maintainability of a WSN. Both the environment of a WSN and the WSN itself change (depleted batteries, failing nodes, new tasks), the system has to adapt. In this sense, the network has to maintain itself and it could be able to interact with external maintenance mechanisms to ensure its extended operation at a required quality [23].

G. Operation Environments

Before describing the operation environment where the WSN can be deployed it is a need that the term source and sink should be defined. A source is any entity in the network that can provide information, that is, typically a sensor node and it could also be an actuator node that provides feedback about an operation. A sink, on the other hand, is the entity where information is required.

The first scenario is the single-hop versus multihop networks. Because of the limited distance, the simple, direct communication, between source and sink is not always possible, specifically in WSNs, which are intended to cover a lot of ground. To overcome such limited distances, an obvious way out is to use relay stations, with the data packets taking multi hops from the source to the sink. The concrete distance where direct and multihop communications are in balance depends on a lot of device-specific and environment-specific parameters.

The second scenario is the *multiple sinks and sources*. Until now, only networks with a single source and a single sink have been illustrated. But in many cases, there are multiple sources and/or multiple sinks present. In the most challenging case, shows multiple sources that should send information to multiple sinks, where either all or some of the information has to reach all or some of the sinks.

The third scenario is the *mobility scenario*. In the scenarios discussed above, all participants were stationary. But one of the main virtues of wireless communication is its ability to support mobile participants. In wireless sensor networks, mobility can appear in three main forms:

i) **Node mobility -** The wireless sensor nodes themselves can be mobile. The meaning of such mobility is highly application dependent;

ii) **Sink mobility -** While this can be a special case of node mobility, the important aspect is the mobility of an information sink that is not part of the sensor network. This sink can be a human user requesting information via a PDA while walking in an intelligent building;

iii) **Event mobility -** In applications like event detection and in particular in tracking applications, the cause of the events or the objects to be tracked can be mobile. In such scenarios, it is important that a sufficient number of sensors at all time cover the observed event.

Besides the WSN scenarios it is important to define the operation framework that can be organized into two subsets:

- **Public -** Urban, Road and commercial zones
- **Private -** Emergency zones.

The scenarios of mobility are characterised by a triangular distribution (like BSDN networks) for the velocity of the mobile elements of a mobile WSN. For the mobile WSN that confers to the node a mobility scheme some authors [24] consider that the average velocity is V_{av}=0.1m/s. Other authors [25] consider that the average velocity is V_{av}=0.42m/s. When using mobile WSN in telemedicine three different velocities are assumed: 2m/s (walking), 10m/s (normal-speed car), and 20m/s (high-speed vehicle).

For the mobile WSN that confers to the sink a mobility scheme some authors [26], [27], [28] consider that the average velocity is between V_{av}=1 m/s and V_{av}=10 m/s. The default mobile sink in [29] speed is set to 10 m/s i.e., the fastest human speed.

IV. Applications Classification

The diversity of multimedia application motivates the need for their classification, and a good way to expose the different types of WSN applications is taxonomize sensor networks and systems into two categories: C1WSNs, Fig. 3, is a category with WSNs mainly multi-hop, massive data flows, dynamic routing, high density network and have large-scale multipoint-to-point systems; C2WSNs, Fig. 4, is a category with WSNs mainly single-hop, static routing, and low/medium density network, source-to-sink applications, support confined short-range spaces and defined transaction-based data flows.

Besides the organization of WSNs into these two categories, the applications in each of the categories can also belong to two different classes depending on the user requirements, which impose specific characteristics at the WSN. These classes are the following: i)event detection (ED), and spatial and time random process estimation (PE), which can be found in [1].

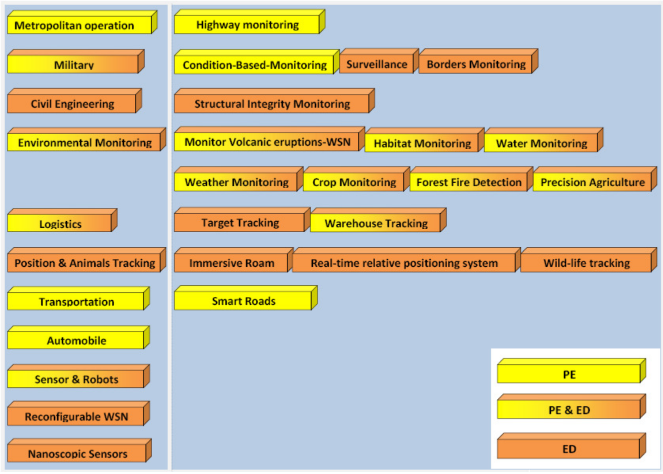

Figure 3: C1WSNs applications.

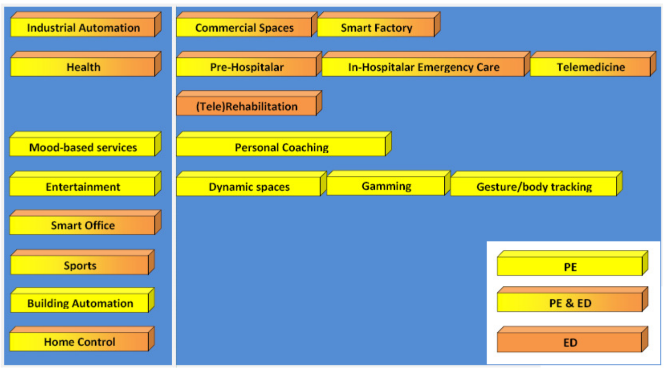

Figure 4: C2WSNs applications.

V. Conclusions

This paper gives an overview on the taxonomy for the characterisation 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 to discussion, and the identified parameters are not static, this study already represents an effort to join together the contributions of different authors and a view to from a coherent vision, and allows for the designers and users to know what type of parameters identify certain service(s) of an application.

A taxonomy for the classification of WSNs applications was also proposed together with i) event detection and ii) process estimation classes.

The actual characterisation of services offered to WSN applications is left for further work. It will involve the determination of the range of variation of the parameters mentioned above. Another proposal for future work is the establishment of threshold (boundary) values for the parameters for each application or service, e.g., in terms of QoS.

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