Computer Networks 67 (2014) 104–122

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Review Article

Energy efficiency in wireless sensor networks: A top-down survey

Tifenn Rault *, Abdelmadjid Bouabdallah, Yacine Challal

Université de Technologie de Compiègne, Heudiasyc, UMR CNRS 7253, 60205 Compiègne, France

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form 27 March 2014
Accepted 30 March 2014
Available online 5 April 2014

Keywords:
State-of-the-art
Wireless sensor networks
Energy-efficiency

ABSTRACT

The design of sustainable wireless sensor networks (WSNs) is a very challenging issue. On the one hand, energy-constrained sensors are expected to run autonomously for long periods. However, it may be cost-prohibitive to replace exhausted batteries or even impossible in hostile environments. On the other hand, unlike other networks, WSNs are designed for specific applications which range from small-size healthcare surveillance systems to large-scale environmental monitoring. Thus, any WSN deployment has to satisfy a set of requirements that differs from one application to another. In this context, a host of research work has been conducted in order to propose a wide range of solutions to the energy-saving problem. This research covers several areas going from physical layer optimisation to network layer solutions. Therefore, it is not easy for the WSN designer to select the efficient solutions that should be considered in the design of application-specific WSN architecture.

We present a top-down survey of the trade-offs between application requirements and lifetime extension that arise when designing wireless sensor networks. We first identify the main categories of applications and their specific requirements. Then we present a new classification of energy-conservation schemes found in the recent literature, followed by a systematic discussion as to how these schemes conflict with the specific requirements. Finally, we survey the techniques applied in WSNs to achieve trade-off between multiple requirements, such as multi-objective optimisation.

1. Introduction

There is abundant literature relating to energy-saving in WSNs as numerous methods have been proposed in the last few years, and there is still much ongoing research on how to optimise power usage in battery-limited sensor networks. However, none of the proposed solutions is universally applicable. For example, if safety applications require fast and timely responsiveness, this is not the case for other applications, such as in agriculture where the delay property is not as important. We believe that WSN energy-saving problems should be tackled by taking into consideration application requirements in a more systematic manner.

In [1], Yick et al. provide a general survey of wireless sensor networks. This study reviews sensor platforms and operating systems, network services issues and communication protocol challenges, but it does not addresses the energy issues. In [2], Anastasi et al. present a valuable taxonomy of energy-conservation schemes. However, the authors mainly focus on duty cycling and data-reduction approaches. There also exist several technique-specific surveys that concentrate on only one energy-efficient mechanism (like energy-efficient routing protocols, data aggregation techniques, energy harvesting approaches

* Corresponding author. Tel.: +33 6 87 90 99 60.
E-mail addresses: tifenn.rault@utc.fr (T. Rault), abdelmadjid.bouabdallah@utc.fr (A. Bouabdallah), yacine.challal@utc.fr (Y. Challal).

http://dx.doi.org/10.1016/j.comnet.2014.03.027
1389-1286/

[3–5]) since every category of solution often represents a whole research area in itself.

Our aim is to provide WSN designers with a top-down survey that offers a holistic view of energy-saving solutions while taking into consideration the specific requirements of the applications. In this paper, we propose a new classification of energy-efficient mechanisms which integrates the most recent techniques and up-to-date references. Moreover, we give particular attention to the design of energy-efficient sensor networks that satisfy application requirements. Our study is original in that we focus on the trade-offs between meeting specifications and sustainability that necessarily arise when designing a WSN. We thus discuss mechanisms that enable a satisfactory trade-off between multiple requirements to be achieved. To the best of our knowledge, this is the first time that this approach has been taken.

The rest of this paper is organised as follows. In the next section, we present the main categories of applications we have identified and their respective requirements. Then, in Section 3, we discuss existing standards for low-power wireless sensor networks and show that current standards cannot respond to all application needs. In Section 4, we give an overview of the major energy-saving mechanisms developed so far and discuss their advantages and shortcomings regarding the set of identified requirements. In Section 5, we review techniques proposed in the literature to achieve a trade-off between multiple requirements, including network lifetime maximisation. Finally, Section 6 concludes this paper.

2. WSN applications and their requirements

In this section, we propose a taxonomy of WSN applications, given in Fig. 1, and we summarise in Table 1 the specific requirements of each described application.

2.1. Healthcare

Wireless sensor networks used in healthcare systems have received significant attention from the research community, and the corresponding applications are surveyed in [6–8]. We identify two types of healthcare-oriented systems, namely, *vital status monitoring* and *remote healthcare surveillance*.

In *vital status monitoring* applications, patients wear sensors that supervise their vital parameters in order to identify emergency situations and allow caregivers to respond effectively. Applications include mass-casualty disaster monitoring [9], vital sign monitoring in hospitals [10], and sudden fall or epilepsy seizure detection [11].

Remote healthcare surveillance concerns care services that are not vital and for which the constant presence of a healthcare professional is not necessary. For example, as illustrated in Fig. 2, body sensors can be used to gather clinically relevant information for rehabilitation supervision [12], elderly monitoring [13] or to provide support to a physically impaired person [14].

WSNs used in healthcare must meet several requirements. In particular, they have to guarantee **hard real-time data delivery delays**, **confidentiality** and **access control**. They must also support **mobility** and provide **Quality of Service**. Indeed, in the context of early and life-critical detection of emergencies such as heart attacks and sudden falls, the real-time aspect is decisive. In this case, situation identification and decision-making must occur as quickly as possible to save precious minutes and the person's life. Therefore, the data delivery delay between the nodes and the end-user must be short in order to meet hard real-time requirements. It is also necessary that healthcare networks support node mobility to ensure the continuity of service when both patients and caregivers move. Additionally, exchanged healthcare data are sensitive and medical information must be kept private by restricting access to authorised persons. Thus, achieving confidentiality and access control through a communication network requires the establishment of mechanisms for data protection and user authentication. Furthermore, when WSNs are integrated into a global hospital information system, critical data such as alarms share the bandwidth with less sensitive data such as room temperature. Therefore, traffic prioritisation is essential to satisfy strict delay requirements through QoS provisioning.

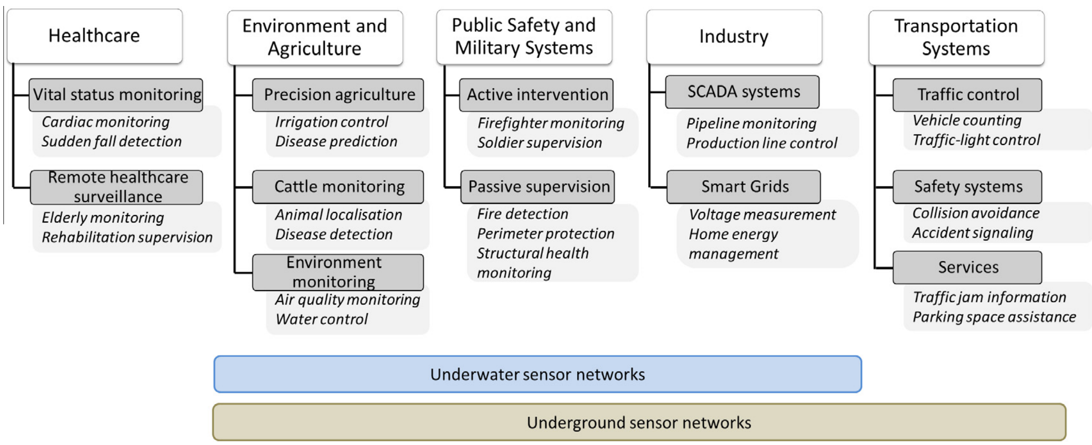

Fig. 1. Taxonomy of WSN applications.