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Lessons learned on solar powered wireless sensor network deployments in urban, desert environments

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ABSTRACT

The successful deployment of a large scale solar powered wireless sensor network in an urban, desert environment is a very complex task. Specific cities of such environments cause a variety of operational problems, ranging from hardware faults to operational challenges, for instance due to the high variability of solar energy availability. Even a seemingly functional sensor network created in the lab does not guarantee reliable long term operation, which is absolutely necessary given the cost and difficulty of accessing sensor nodes in urban environments. As part of a larger traffic flow wireless sensor network project, we conducted several deployments in the last two years to evaluate the long-term performance of solar-powered urban wireless sensor networks in a desert area. In this article, we share our experiences in all domains of sensor network operations, from the conception of hardware to post-deployment analysis, including operational constraints that directly impact the software that can be run. We illustrate these experiences using numerous experimental results, and present multiple unexpected operational problems as well as some possible solutions to address them. We also show that current technology is far from meeting all operational constraints for these demanding applications, in which sensor networks are to operate for years to become economically appealing.

1. Introduction

The convergence of computation, communication and sensing has led to the emergence of *wireless sensor networks* (WSNs), which allow distributed monitoring over extended areas. Wireless sensor networks have the potential to be very powerful tools to address a number of operational issues, including pollution monitoring [36,28], emergency response during catastrophic events [7] or environmental monitoring [6]. Furthermore, wireless sensor networks have the potential to offer economically appealing solutions to these problems (both in terms of hardware costs and deployment costs).

Despite their significant benefits over more traditional wired sensor network architectures such as [53], wireless sensor networks have seen limited use in critical urban sensing applications to date. While sensor networks were expected to have an explosive growth in the 2000s, the actual number of deployed systems is significantly below the most pessimistic forecasts, as illustrated for instance by the `ON World, In-Stat, WTRS, Harbor Research` 2006 forecast which predicted that between 80 million to 150 million units would be shipped in 2010, while only 45 million units were shipped one year later in 2011. One of the biggest issues arising with wireless sensor networks is their relative lack of performance and reliability, which prevents the use of highly sophisticated software

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that would be required for many applications. In particular, small scale deployments in a controlled setting can be deceptively easy, and do not convey the real difficulties associated with extensive and long wireless sensor network deployments [24,18,22].

In urban environments, sensing systems [36,27] include smart parking sensing systems [31], traffic flow sensing [17], pollution sensing, or smart infrastructure applications, such as in [38,42]. In this article, we investigate the network component of a prototype urban traffic and flood monitoring system using Lagrangian and Eulerian sensing. Since a large fraction of the overall cost of an urban wireless sensor network is due to installation, we chose a solar powered, wireless sensing system to allow fast and inexpensive deployment, lowering the global cost of the installed system. However, full wireless sensor networks present unique challenges with respect to wired, externally powered sensor networks typically used for traffic sensing, such as the `PeMS` system [53], or the `Sensys` system [17], which has an hybrid architecture: it consists in a set wireless nodes connected to a base station, which is itself connected to internet through wires.

While wireless sensor network have been extensively used in the past, relatively few applications are related to urban sensing. In particular, wireless sensor network solutions in urban environments are rarely fully wireless, and usually consist in mixed architectures with a wired network of gateways and relatively small wireless networks around them. In addition, a large number of urban areas are located in arid or desert areas, for instance in North America, north Africa or central Asia, and constraints arising from these climatic conditions can make successful sensor network deployments extremely difficult to achieve in the long term.

Unlike existing traffic sensing infrastructures, the proposed traffic sensor network is to use both fixed (Eulerian) and mobile (Lagrangian) traffic data, and to process the data at the node level (using a macroscopic traffic flow model) to generate traffic estimates [10]. Eulerian traffic data is generated by fixed traffic flow sensors, while Lagrangian data is collected from vehicles equipped with a positioning device and a short-range transceiver. Given that this sensor network is to be deployed in an urban desert environment, we initially focused on all the operational constraints associated with the operation of a wireless sensor network in desert cities, including packaging, deployment constraints, energy management and long term reliability. The first implementation of this system was carried out using `Libelium Waspmotes`®, a commercial hardware platform based on `Arduino` platforms, which we believe is typical of the WSN products available on the market. Over a period of two years, we conducted several tests and deployments to evaluate the performance of the system, as well as its reliability. The experience obtained from these experiments has driven our current research activities, which lie in hardware development, energy aware routing protocols, and middleware/OS development.

The rest of this article is organized as follows. Section 3 describes the envisioned traffic sensing architecture. Section 4 describes the experimental results arising from deployments of this wireless sensor network, focusing only on the networking component of the system. We also show how the hardware limitations severely constrain what can be implemented in practice. We then present the lessons learned from a series of sensor network deployments in Section 5, in which we cover all aspects of the system, from planning to data analysis, covering various experimental issues such as packaging, operational constraints for deployment in urban areas, and hardware reliability problems.

2. Related work

The problem of scalability of outdoors wireless sensor networks [1] has been extensively studied in the literature. In [30], the authors deploy a wireless sensor network aimed at improving the yield of potato fields by protecting them against phytophtora, a fungal disease that spreads easily among plants. The deployment related in this article did not go according to plan due to code stability problems, poor coordination during deployments as well as the general assumption that the hardware supplied was ready to operate immediately.

Another work worthy of mention is the WSN deployment for habitat monitoring which took place in Great Duck Island off the coast of Maine [33]. It is among the first WSN deployments and as a result there have been many lessons learned out of this experience. An article [47] was dedicated to the lessons learned from this experiment, and the reasons behind nodes failure, packet losses and poor link quality.

Another research study has been conducted by Corke et al. [19], who explored the intricateness of WSN more comprehensively. This study is the result of several different projects conducted over a period of 6 years. It spans diverse applications such as microclimate monitoring for rain forest, cattle monitoring, virtual fencing and ground water quality monitoring at different depths. Among environmental monitoring applications, a study done in India [40] focused on landslide monitoring using wireless sensor networks, including 50 geological sensors and 20 wireless sensor nodes.

Another article [6] relates the conditions for successful deployments of wireless sensor networks in mountain environments. The authors of this article have derived important conditions for successful outdoor deployments, though their sensor network operates in environmental conditions that are far away from the extreme heat and dust encountered in Western Saudi Arabia.

More recent articles [24,45] address challenges arising when deploying indoor wireless sensor networks. However the operation of such networks is typically very different from the operation of an outdoor WSN, as the former typically do not have energy harvesting and operate under very low power. In addition, the environmental conditions indoors are not particularly harsh in terms of temperature, humidity and link quality variations due to environmental factors (other than time-varying obstructions). Another issue of outdoor sensor networks is node accessibility, which is not a concern for indoor environments.

The intrinsic problems of wireless sensor networks have often been tackled in the literature, for instance in