Problem statement

Wireless sensor networks development and pervasiveness gave origin to a wide range of applications with different features and needs that share the same design constraints and limitations. Research today mainly focuses on optimization of physical, MAC and routing layer issues, on minimizing the energy consumption, and on maximizing the lifetime, scalability, and security of the systems, without focusing on the real needs of the applications and on the problems reported by the industry.

Especially from an industry perspective, the major barrier to the wide adoption of wireless sensor networks technology are the lack of easiness in WSN programming, the lack of installation ease, and the big concern about the reliability, interference, and the robustness to the dynamicity of the environment. Additional problems raised from many surveys are the significant manpower involved in the deployments and the high dependence on the individual skills of deployers.

The root of these problems lies in the fact that potential application layer protocols for sensor networks remain a largely unexplored region, and that there is no existing standard for WSN application support nowadays. The focus of the research community is today towards the lower layers of the OSI stack rather than towards a full support for applications and deployment of sensor networks.

Goals

This Thesis aims to design and implement an application support for wireless sensor networks. The goal of an application support layer is to abstract the hardware and to provide the most common features to the overlying applications, in order to simplify and speed-up the work of developers. Since the targeted applications are surveillance systems, particular focus is put on how to increase the robustness of such applications. Examples of services provided by the application support layer that has been implemented are a battery lifetime estimator, a remote query language, a logging support, and a channel quality estimator that automatically selects the best radio channel available.

In addition to the application support, also a deployment support module for wireless sensor networks is designed and implemented. This module increases the reliability and robustness of the sensor network while enabling a faster deployment phase with limited costs and manpower involved. Special optimizations are made for industrial outdoor deployments, especially in order to provide robustness to the dynamicity of the environment.

Contents

This Master Thesis focuses into the world of wireless sensor networks applications. After analyzing all the most common challenges and problems, it evinces that the needs of industrial applications and developers are mainly related to battery lifetime estimation, sensors and network remote management, deployment, auto-configuration schemes such as channel quality assessment, and on how to provide robustness to the whole sensor network.

An application support sub-layer has been proposed to solve these common challenges and to give aid to the overlying applications. The support layer sits on top of the Contiki operating system and it is designed to be modular, so that modules can be added and implemented separately. Contiki is a lightweight operating system designed at SICS and used worldwide in an extremely wide range of embedded systems.

A computationally lightweight battery lifetime estimator has been designed for all nodes carrying a temperature sensor, and gives an estimation of the battery status and lifetime given the current energy consumption, the battery voltage, and the current temperature. The consequence of such design is that there is no need of external hardware. The estimation model that I propose has been demonstrated to be accurate, and quickly adaptable to thermal excursions despite the little data inputs. This battery lifetime estimator can be used to improve the decisions of applications and enable the creation of more efficient and robust routing schemes without increasing the cost of the hardware and the complexity of CPU operations.

Sensor data querying and robustness to dynamic environments have increased with the design and the implementation of a logging support that enables the applications to perform continuous and historical queries with the same easiness of snapshot queries. The energy consumption needed to run this module is minimal, while the application can perform historical and continuous queries at the same easiness of snapshot queries, thus improving the robustness and reliability of decisions. The logging utility also enables a better monitoring of the network status and health remotely, as well as the fault detection after node failures or reboots.

Installation of sensor nodes has also been widely studied, and experiences and remarks have been illustrated especially for industrial outdoor deployments, where performance assurances are needed, but harsh to obtain, given the unpredictability of the environment in which sensor nodes are deployed. The effects of weather conditions and temperature have been studied and quantified. It is shown in the Thesis that it is possible to give performance assurances in industrial outdoor deployments, given a careful analysis of the environment. Furthermore, a real-time deployment support has been proposed and implemented. It differs from existing approaches in the sense that without any additional hardware, it speeds-up the deployment of sensor nodes also reducing the manpower involved. The concept is to help the deployer with an in-field driving support available directly in the sensor node that has to be deployed. This module is particularly efficient in terms of energy consumption given its particular design, and does not require additional hardware.

The problem of link quality estimation has also been addressed in this Thesis. RSSI- and LQI-based existing approaches are reviewed and it is shown that the LQI is not a bad estimator because of its high variance, as previously thought. It is shown that the LQI variance is not a limitation, and that can instead be exploited to obtain a faster channel quality assessment. Experimental results show that from an average of 120 packets needed to obtain a reliable estimation using the standard LQI mean value, a good assessment is possible using much less packets when using the LQI variance as metric, with an high increase in energy efficiency.

The solutions proposed in this work represent the first step towards a full support layer for WSN applications, a fundamental task in wireless sensor networks. A preliminary evaluation shows the benefits brought by the introduction of the different modules, especially in energy consumption and robustness.

Conclusions

The contributions of this Thesis are threefolded.

Firstly, it is shown how the introduction of an application support sub-layer can improve the application development, performance, and robustness.

Secondly, a new approach for speeding up the wireless sensor networks deployment has been designed, in order to meet both the need of practical solutions towards quickly deployable sensor networks and the rising demand of low-cost solutions for the deployment of wireless sensor networks. Optimizations for outdoor deployments are introduced after quantifying the negative effects of temperature and weather conditions on the radio signal strength and link quality. After quantifying these effects, it is possible to give performance assurances for industrial outdoor deployments, where persistent connectivity between sensors must be ensured, regardless the environmental conditions.

Finally, a new mechanism for fast channel quality assessment based on the variance of the Link Quality Indicator (LQI) hardware metric is proposed. A preliminary evaluation shows that it can reliably identify good links using much less packets than the widely used LQI mean, thus reducing the number of packets needed, and enabling an high increase in energy efficiency.