Rationale for an Adaptive Communication Stack for Wireless Sensor Networks

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***Abstract*—This paper introduces the first steps towards a configurable and adaptive communication stack for Wireless Sensor Networks, which aims at both easing code deployments and being operated under various applications. In addition to the evaluation methodology, we present sample scenarios that could benefit from this architecture.**

I. Introduction

Along with the miniaturization and price-cutting of embedded devices, Wireless Sensor Networks (WSN) become more and more considered nowadays as a viable solutions for military, home, environmental or health purposes. While research is still very active in this area, small to medium scale networks have already been deployed, for example for monitoring purposes on rock glacier (SensorScope [1]), or volcano [2]. Indeed, programming applications for embedded sensors has been made easier thanks to various efforts around operating systems designs (e.g. TinyOS[1], Contiki[2]). All provide high-level programming languages made for people not necessarily expert in the embedded systems field.

However, those actual deployments have shown that the communication stack is usually designed from scratch to fit exactly the energy requirements imposed by the application. Especially, many efforts have been done at the Medium Access Control (MAC) layer to reduce the usage of the wireless medium (considered as the biggest source of energy consumption) to the minimum [3].

We can raise two major issues from this observation: first, deploying a WSN requires a strong expertise of the communication stack, especially at the MAC layer. Second, a MAC layer scheme designed for a specific deployment would not fit any other scenario. This induces a possible reduction of the overall network performances if the application requirements are subject to change during the lifetime of the network.

As we will present in section II, little effort has been done to address the latter through the specification of a versatile MAC layer. Still, there is room for our proposed contributions: we propose in section III to assist code deployment by allowing the end-user to set some very high-level and simple deployment parameters used for lower layers configuration. In section IV we define how adaptation at the MAC layer could be achieved by observing environmental and networking parameters. An evaluation of this proposal as described in section V would corroborate the usefulness of such framework, and a large-scale deployment as presented in section VI would validate the future implementation of our solution.

[1] http://www.tinyos.net
[2] http://www.sics.se/contiki/

II. Related Works

The idea of a versatile MAC layer in WSN has been first pointed up with the specification of B-MAC [4]. B-MAC defines a set of interfaces that can be used by upper layers to configure some of the MAC behaviours: for example, the initial and congestion backoff values can be set for every packet sent on the medium. This feature of B-MAC makes it a suitable layer to implement other protocols, for example Z-MAC [5]. However, using B-MAC requires a strong expertise in medium access control for the users willing to build their communication stack on top of it.

III. Easing Code Deployments

Sensor network deployments are often classified according to the way sensors communicate with the sink stations: time-driven, event-driven, query-driven. As query-driven applications are remotely controlled by the stations that initiate the communications, we rather focus on *time-driven* and *event-driven* scenarios.

Obviously, *time-driven* and *event-driven* applications highly differ and an optimal design would lead to different communication stacks for each deployment. Yet, the strong expertise needed by such operations stands in the way of easy sensor network deployments. Although non-expert users would encounter difficulties fixing relevant values or features, they might release useful information to initialize the medium access policy. Indeed, several high-level parameters could be extracted such as the expected network density, the communications frequency, the desired radio link reliability and so on. We aim at alleviating code deployments by automatically detecting correct parameters for lower layers through the interpretation of those high-level information set by the user.

IV. Configurable and Auto-adaptive MAC layer

We are now giving some details about the initialization of the MAC layer and the way we are planning to have it auto-adaptive regarding observed environment or system parameters during the network lifetime. First, these optimizations aim at building an energy-efficient MAC layer, without considering much expertise from the persons in charge of the network deployment. Second, we target multi-application sensor networks, whose key features (such as the medium access policy for instance) would adapt to the requirement of the ongoing application.

As already mentioned, it would be possible to configure some key aspects of the MAC layer from the application level. For instance, in lowly dense radio environments, features like RTS/CTS or link-layer acknowledgments might simply be useless. Once the WSN has been deployed with a pre-configured communication stack, we expect to further improve the adaptation of the MAC layer through observed facts in the environment or from the upper layers. As an example, the change from an event-driven to a time-driven application on some of the nodes in the network could impact the scheduling mechanism at the MAC layer.

Obviously, a misbehaviour in the communication stack of some of the sensors could lead in disastrous effects such as the partition of the network. It is thus essential to have an analysis of the impact of each adaptation that would be operated at the MAC layer. It is also important that such versatile MAC layer does not induce a big implementation overhead, as it is primilarly designed for memory constraint devices.

V. Evaluation

A. Simulation Environment

As a first step, the evaluation of our architecture will be performed on the WSNet[3] simulator. We especially want to demonstrate that a frozen communication stack would simply not fit to multi-application sensor networks. For this purpose, we have implemented the B-MAC scheme with various application models. Following the principles exposed in section III, the B-MAC module is interfaced by a set of high-level parameters that describes the application model, which the user can set prior to the simulation. Those parameters are used at the initialization time. A cross-layer communication model then allows the upper layers, and especially the application layer, to provide B-MAC with a set of valuable information during the simulation. The MAC layer then uses them as an input in its adaptation decision process.

B. Sample Scenarios

We aim at validating our framework through both simulations and experimentations. In order to exhibit the difficulties that would be encountered with a fixed MAC layer and several applications, we have defined three scenarios. Traditionally, event-driven and time-driven sensors deployed over a remote environment are considered. We also introduce a third scenario matching our multi-application view of a sensor network; event-driven sensors are deployed over an area and, upon an unusual event, some of them, located in the region of interest, might decide to turn into a time-driven mode so that regular reports would be sent from this area of interest to the sink stations. The goals of this scenario are twofold; first it aims at addressing the adaptability of the tested MAC layers and, second, it targets heterogeneous sensor networks.

There are many solutions with which we might compare. Meanwhile, as we aim at specifying a MAC layer adaptable for various kinds of applications, comparing our solution with the existing standard (IEEE 802.15.4[4]) for communications in such networks sounds like a relevant choice. This consensual solution fits a large range of use cases while other existing solutions are most of time limited to a specific application.

VI. Conclusion and Perspectives

We have presented how a configurable and auto-adaptive communication stack could improve both the ease of deployment and the overall performance of an heterogeneous WSN. We expect to validate the presented architecture through simulation and real experimentation against existing standards.

A closer look at the IEEE 802.15.4 norm has already revealed a lack of features ready for some optimizations. For instance, the energy-efficiency aspect is poorly addressed once a dense multi-hop network is considered. Using both simulation and experimentation, we will try to show that it is possible to preserve the versatility of the MAC layer while ensuring low energy consumption and reliable communications. The national SensLAB platform[5] will provide a strong basis to have our solution implemented and evaluated on real sensor nodes networked at a large scale.

In this paper, we only mentioned the medium access layer. Along with application changes, the way sensors communicate may evolve thus imposing different choices to be made during multi-hop transmissions. Therefore, our ambition is to use similar methods to configure and adapt the network layer based on application information.

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[3] http://wsnet.gforge.inria.fr

[4] http://standards.ieee.org/getieee802/download/802.15.4-2006.pdf

[5] http://www.senslab.info