Application-aware Techniques for Energy Efficient Data Collection in Wireless Sensor Networks

Usman Raza
University of Trento
Bruno Kessler Foundation, Trento, Italy
raza@fbk.eu

***Abstract*—Wireless Sensor Networks (WSNs) are distributed systems composed of battery-powered nodes that sense and collect information about the physical world. They enable applications in a wide variety of domains including but not limited to environmental monitoring, health care and disaster management. In such applications, nodes communicate the sensed information over multiple radio links until it reaches its destination referred to as the sink. As wireless communication is the most energy hungry operation, the data collection causes the biggest drain from battery. This motivates research on energy efficient mechanisms for data collection.**

Though there is a plethora of protocols proposed in research literature, they are not designed to collaborate with the applications. One opportunity from such collaboration is exploiting complete knowledge about application characteristics to make data collection more energy efficient. This enables underlying layers not to provision the resources more than the needs of the application and therefore save valuable battery power. The aim of this thesis is to explore a complex interplay between application characteristics and adaptive mechanisms across network stack using concrete real world deployments. It will propose a generic framework that integrates the adaptations to achieve near-optimal energy efficiency for heterogeneous applications.

I. Introduction

Wireless Sensor Networks consist of a huge number of sensor nodes that monitor a target environment over a long duration. These small devices are usually equipped with limited battery power that is consumed by different activities such as sensing, computation and communication. Since the nature of a vast majority of applications is such that the continuous supply of power and/or power maintenance is impossible, power consumption is one of the premier constraints. As radio communication causes the biggest energy drain, efforts are needed to reduce the communication overhead of multi-hop data collection for a long network lifetime. We also argue that WSNs have wide variety of applications each with its own diverse needs and requirements that should be met with a limited battery budget.

One approach to reduce the communication overhead is to take advantage of application characteristics like error tolerance, delay tolerance, data rate and traffic pattern. These properties help in custom-tailoring the system for optimal energy savings in contrast to application agnostic approaches that run the risk of over-provisioning the resources. This paradigm is explored in several research works. However, their scope is limited in two ways a) They base their tuning decision on limited number of rigid assumptions about the characteristics. As these characteristics vary from application to application, the solutions do not adapt well to the changed scenario. Application programmers have to replicate efforts every time there is a change in the application profile. We believe that this is a significant hurdle in a wide adoption of WSNs. b) The solutions provide suboptimal performance as they do not take a full advantage of various adaptive mechanisms available across network stack simultaneously. It is desired to come up with generic and flexible solutions that can optimally tune the whole network stack for a wide variety of *heterogeneous* applications. The solution is not trivial as it tries to find the best trade-off between potentially conflicting goals that are generality and efficiency.

The objective of this doctoral thesis is to propose a generic cross-layer framework that achieves near-optimal lifetime for heterogeneous WSN applications while meeting their demands. The framework consists of application-aware adaptive mechanisms across the network stack and tools and techniques to integrate them in a coordinated fashion. Various adaptive mechanisms include model-driven data acquisition at the application layer, beaconing and load balancing on the routing layer, link scheduling and radio duty cycling at the MAC layer. The premise of our work is that by mathematically modeling the application characteristics, demands and network protocols, we can optimize the protocol parameters to maximize the network lifetime.

In the rest of the paper, we describe related works and our problem statement along with the approach to solve it.

II. Related Work

Hybrid solutions crossing network layers achieve extremely low radio duty cycles and so the energy efficiency. Dozer [1], Koala [2], DISSense [3], Breath [4] are full vertical solutions that co-design different networking layers to reduce the duty cycle up to 0.1%. However, these staggering performance gain comes at some limitations on application profile. Dozer is especially designed for a very low data rate without any guarantees on data latency. In case of moderately high traffic, collision of transmissions destined to different tree parents is probable resulting in frequent change in their TDMA schedule. Furthermore, it does not scale well with a large number of children per parent. Its routing protocol is also prone to choose poor quality parents. Koala achieves significant energy savings at an expense of longer delay in the arrival of sensed data. To get reasonable energy efficiency, it needs to accumulate a sizable volume of data before sending to the sink. Time to gather data can be on the order of days for a very low data rate applications like environmental monitoring. The design of Breath unrealistically assumes that the nodes know their approximate location of deployment and can be organized into clustered that are connected in a line topology.

III. Problem and Approach

Our problem is to devise cross-layer adaptive solution for data collection in WSNs that reduces the nodes radio duty cycle to achieve near-optimal energy efficiency for a wide variety of application profiles. Finding the optimal parameter configuration of energy-aware adaptive protocols is a complex problem. We describe our methodology structured by two major contributions of our work:

1) *Adaptive Cross-layer Protocol Development:* We will propose adaptive protocols at multiple layers that improve energy efficiency of existing techniques and respond to varying requirements of the applications. We will focus on vertical solutions that synergize data reduction techniques from the application layer, load balancing and adaptive beaconing from the routing layer and radio duty cycling from MAC layer. We expect to explore solutions based on the sound theoretical underpinning provided by Markov chains and different computational intelligence paradigms [5].

2) *Optimal Parameter Configuration:* We will model the energy efficiency as a multi-parameter optimization problem constrained by application characteristics and resource constraints. The solution will help us tune the protocol parameters at various layers.

Any contribution in above two areas will be thoroughly evaluated on real WSN deployments and testbeds to ascertain their benefits. The novelty of the solution comes from the fact that it intends to achieve energy efficiency for *heterogeneous* WSN applications. We foresee the originality of the solution in the following:

- Improving on existing adaptive protocols for better energy efficiency and conformance to application requirements without over-provisioning the resources
- Encoding the application layer requirements and characteristics generically, a feature lacking in most of the current research work for application-aware designs
- Modeling adaptive protocols, enabling better analysis of protocol-specific overheads that are overlooked in most of proposed techniques
- Using a sound mathematical approach to solve multi-parameter optimization problem defined by properties and demands of the system
- Taking a holistic view of the system and making adaptation at multiple layers in a coordinated fashion

We intend to use existing techniques to compare our proposed adaptive solutions. We will compare our generic cross-layer technique with other vertical solutions like Koala, Dozer, DISSense and Breath. We like to highlight that not a single solution among them is a good benchmark for all application types. However, a combination of them cover a broad spectrum of applications.

IV. Conclusions

Application awareness is a promising paradigm that can reduce energy consumption in WSNs while meeting the demands of applications. Current state of art techniques use it to optimize the protocols for energy efficient data collection. These solutions provide suboptimal energy efficiency due to their inability to exploit multiple energy-aware mechanisms across the network stack simultaneously. Moreover, solutions are designed around rigid assumptions about application characteristics, making it hard to extend them to wide class of heterogeneous applications. This work overcomes this technological hurdle by proposing a generic and yet energy efficient cross-layer adaptive protocols for data collection in WSNs.

Acknowledgments

The author thanks his PhD supervisor Dr. Amy Murphy and the support provided by EU Cooperating Objects Network of Excellence (CONET—FP7-2007-2-224053).

References

[1] N. Burri, P. von Rickenbach, and R. Wattenhofer, "Dozer: ultra-low power data gathering in sensor networks," in *Proc. of the Int. Conf. on Information Processing in Sensor Networks (IPSN)*, 2007.

[2] R. Musaloiu-E., C.-J. M. Liang, and A. Terzis, "Koala: Ultra-low power data retrieval in wireless sensor networks," in *Proc. of the Int. Conf. on Information Processing in Sensor Networks (IPSN)*, 2008.

[3] U. Colesanti, S. Santini, and A. Vitaletti, "Dissense: An adaptive ultralow-power communication protocol for wireless sensor networks," in *Proc. of the* 7^{th} *Int. Conf. on Distributed Computing in Sensor Systems (DCOSS)*, 2011.

[4] P. Park, C. Fischione, A. Bonivento, K. Johansson, and A. Sangiovanni-Vincent, "Breath: An adaptive protocol for industrial control applications using wireless sensor networks," *IEEE Trans. Mobile Comput.*, vol. 10, no. 6, June 2011.

[5] R. Kulkarni, A. Forster, and G. Venayagamoorthy, "Computational intelligence in wireless sensor networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 1, 2011.