PhD Forum Abstract: On the Challenges in Energy-Constrained WSNs: Trade-off between Efficiency and Robustness

Research Summary

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ABSTRACT

The trend of smaller and yet energy efficient devices leads to various new applications in both the Wireless Sensor Networks and the Internet of Things. Achieving long life times and robust communication are still two key requirements. Energy harvesting is a feasible solution to solve the life time problem. However it introduces new challenges with unpredictable energy and even intermittent computing. We present challenges and possible solutions for energy-limited and reliable wireless networks.

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1 INTRODUCTION

Recent developments in the field of both Wireless Sensor Networks (WSNs) an the Internet of Things (IoT) have shown two major trends: (1) the technology has changed and devices get smaller and yet more energy efficient and (2) the demand for longer lifetimes and robustness increases. Longer lifetimes and smaller devices are demanded by applications in the IoT, where smart things are connected to the Internet, which often limits available space and energy in them. On the other hand, applications in smart farming require reliable communication, in particular real-time and robust transmission of sensor data to the sink, in order to be able to react to local conditions and begin prevention. Another scenario is long-term monitoring, where data should arrive eventually at the sink, but time limits in the order of days are acceptable. These two trends contradict each other, because robustness and reliability often come at the cost of additional energy. Being it either additional packets or more transmission power that is used. On the other hand mechanisms and protocols can increase the reliability of networks by adding redundancy to transmitted data. Therefore a trade-off between efficiency – being measured in consumed energy – and robustness – being the number of lost packets – has to be found.

A key concept to solve the problem of limited energy is to use energy harvesting from various sources that depend on the specific application. These battery-less systems are therefore able to satisfy the need for long lifetimes while partially sacrificing robustness. In greater detail, energy harvesting often leads to the problem, that energy is – depending on the energy source – not guaranteed and difficult to predict. Additionally, in case of harvesting from solar in smart farming scenarios, energy might be available in some parts of the year, while in other parts, crops might deny energy production completely. Therefore other sources have to be found, such as harvesting energy from soil temperature differences. As shown by our study [7], this source is feasible for such applications, however, energy is barely predictable and often cuts off throughout the day. Intermittent Computing aims to solve problems by allowing the node to partially run out of energy and start when energy is available again. However, this results in the loss of its state and requires new protocols and mechanisms such as check pointing and non-volatile memory.

An even bigger problem is the unpredictability of energy in these networks. If energy storage is limited in such a case, that only enough energy is available to send one or a handful of packets, sending one should guarantee the arrival at the receiver to avoid wasting energy. However, this contradicts, both the unpredictability of energy and loss of state of nodes in such scenarios. The next section will explain more details of the problem and section 3 will present current research and future work to solve this problem.

2 PROBLEM STATEMENT

As pointed out in section 1, certain scenarios require battery-less devices, that are powered entirely from energy harvested by its environment, such as temperature gradients or solar power. However, energy might be sparsely available and even hard to predict. In larger networks with numerous nodes, this leads to a key problem, where it is unknown when someone is available to receive packets for data reception, in order to forward packets. Established routing mechanisms can therefore not be used, as time-based scheduling or wakeup mechanisms do not or only partially work due to the aforementioned reasons. In greater detail, we chose an intermittent computing scenario, where harvested energy is varying across nodes in the network and no common pattern is shared. As we have shown in [7], even in winter, enough packets can be send within the network. However, when only few slots per day are available, errors in communications and interference should be minimized to avoid wasting energy. On the other hand, intermittent computing will result in a node (partially) losing its state. Neighbors and slots might therefore be forgotten and no communication is guaranteed. Both time-based solutions and wake-up mechanisms can therefore hardly be used.

As outlined in this section, major challenges are predicting energy for scheduling communication slots with neighbors. The loss of state due to sparsely available energy additionally exacerbates the problem, as known neighbors and communication slots might

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get lost. The next section will present our current research and future work.

3 CURRENT & FUTURE RESEARCH

Our current research focuses on different aspects of the aforementioned problems. Starting with our study [7], we have shown that energy harvesting can be used to power a node including communication. However, available energy is extremely dependent on the node's location and its environment. We currently plan to deploy a sufficiently-large network powered by energy harvested from soil temperature to prove our feasibility study and get insights into heterogeneity of available energy across the network.

The deployment will use our energy harvesting platform [5] which uses an intelligent undervolting [6] approach to reduce energy consumption at higher temperatures to minimize energy consumption of the node and to increase flexibility of such systems.

This is part of a larger project called REAP, that focuses on more general aspects of reliability and robustness in networks. We aim to optimize the energy consumption in traditional networks, by sharing information about available and predicted energy across neighbors and optimize scheduling. Each node creates two models: (1) One of its reliability in terms of communication across nodes and (2) consumed and produced energy. The models can help to optimize routing in energy-constrained networks. (1) helps to identify neighbor nodes with weak or unreliable communication. The reason behind this unreliability can be effects from temperature or other environmental effects. We have made several experiments which are currently under review, that show a severe impact of temperature on the node's ability to communicate. We have complemented the existing work [1–3, 8, 9] that focuses on a single platform and have shown different results for other platforms. (2) helps to identify and avoid bottle necks, that handle more traffic than others. An alternative path with more residual energy can be chosen. Tree-based networks are therefore our focus and our solution should increase lifetime of the whole network.

Once energy consumption is optimized within the network, we focus on more complicated aspects, such as (1) predicting the State of Charge (SoC) of battery-powered, but still energy-constrained devices and (2) intermittent execution of sensor nodes.

(1) aims to provide good prediction of SoC of battery-powered devices. In collaboration with the Uppsala University, we have developed a platform to test energy storage devices such as CR2032 coin cells under challenging conditions such as outdoor networks [4]. Temperature has a huge impact on batteries and their lifetimes. Therefore studying these effects and providing a reliable prediction of the SoC can reduce maintenance costs when battery changes are required.

For (2) the key problem to solve will be how to schedule communication slots. The experiment mentioned above should give us useful information on energy distribution across the network. In greater detail, we can either derive (simple) models, or show the absence of patterns and find other solutions and mechanisms to ensure communication between neighbors. In the latter case, initially no neighboring nodes are known and new concepts are required to discover them. It is very likely that neighbors might share some energy patterns. Therefore, if a lot of energy was or is available, sending a packet has a higher probability and is therefore more likely to be received by another node. A probability-based approach is therefore to be developed in the future, where communication is scheduled based on probabilities. Another mechanism we should consider is obviously low-power wake-up radios, in order to wake up nodes if needed. However, even the sleep consumption of such systems might sum up to more energy than available throughout the day. Additionally, a wake-up signal might have no effect, if no nodes are available for receiving. If no back-channel is provided, the packet will be sent anyway, and energy is wasted. Therefore a probability-based approach can benefit here.

4 CONCLUSION

Energy constrained networks are present in many of today's networks. It can be useful to power nodes with harvested energy which in general limits the available energy and is hard to predict. Our energy harvesting platform is used to optimize energy consumption by using an undervolting approach. For communication in intermittent networks, we cannot guarantee slots and therefore new mechanisms have to be developed. Our future deployment will give insights into energy distribution in networks entirely powered from harvested energy. Depending on the distribution in the network, we plan to introduce a probability-based routing algorithm. Nodes will likely share a few patterns and therefore probabilities can be derived to ensure communication, or at least with high probability. Additionally for battery-based networks, we have developed a platform, to improve SoC estimation both batteries and super capacitors in challenging environments.

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