Research summary

Research topic: Energy-awareness in Large-scale Internet of Things Networks
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Thesis statement

The goal of my thesis is to research ways to improve energy efficiency in IoT networks, which contain various devices including sensor nodes and smartphones. In my research, I will use a bottom-up approach by starting with modeling of traffic impact on energy consumption in single wireless nodes to large-scale IoT networks. The result of my work will be energy and interference models for WSNs and energy management middleware for IoT networks. As of now, I have published work in traffic scheduling and currently working on a large-scale 802.15.4/CoAP network emulation experiment and interference modeling.

Problem domain

The detailed objectives of my research are stated as follows:

- Modeling the relationship between energy consumption of sensor nodes and network traffic.
- Modeling interference in sensor nodes with the goal to better understand channel conditions that affect energy efficiency.
- Building energy consumption models of collective mobile devices from the network perspective.
- Building a large-scale emulation platform for IoT networks; analyzing and pinpointing the sources of congestion in large-scale IoT networks.
  investigating congestion control mechanisms in IoT networks and analyzing their impact on energy consumption.

Related work

Problems of energy efficiency are very acute when it comes to wireless devices [1][2]. In a modern smartphone, the wireless network interface card (NIC) is one of the largest energy consumers, following energy consumption from the microcontroller and touch screen [3]. However, compared to other components, energy efficiency of the NIC is not improving in line with that of the other components. As a matter of fact, it might reach its limitation due to the physical properties of the radio antenna and the corresponding elements, including power amplifier, baseband processing circuit, among others. Thus, alternative approaches to improve energy efficiency are presently explored, among them is predicting and scheduling traffic [4], which I'm currently working on [5].
To be able to understand the impact of traffic on energy consumption of a mobile device, it is fundamental to gain insight into the characteristics of the network traffic shape, from both a single application perspective and multiple applications perspective. Furthermore, as more and more sensors are integrated into mobile devices, it is essential to understand the energy consumption from the integrated sensors separately and their impact on the energy consumption of the host mobile devices. Taking a step further, as mentioned before, wireless devices naturally work in the form of networks, therefore it is beneficial to view the energy consumption of connected devices from the network perspective as a whole [6]. This viewpoint not only enables deep understanding of the way devices interact with each other, and its impact on the corresponding energy consumption, but also possesses high potential to detect and pinpoint congestion occurring within the network [7].
Currently, there is no good understanding of traffic characteristics of applications running on large-scale IoT networks [8]. For example, it is currently not clear where congestion could occur in a large-scale IoT network, how serious consequence the congestion would impose, because no large-scale real-life deployment is available. There have been some large-scale simulation studies

[9][10], however these works possess a certain number of limitations. For example, most simulators are essentially event-driven; it is not possible to test for behavioral problems related to timings etc. Furthermore, most simulators use simplified models; thus, they fail to provide realistic estimate of real traffic volume and shape. On the other hand, emulation uses the same code as it will be used on a real device. Henceforth, it can provide more accurate and realistic results for network traffic. A large-scale emulation platform for IoT networks is still missing in the current state-of-the-art literature.

Methodological approach

Multiple methods will be used to conduct the research work mentioned above, ranging from analytical approach (mathematical modeling), through simulation, to proof-of-concept implementation. Specifically, the following approaches will be used in each of the research topics:

1. Empirical survey of the state of the art in traffic and energy modeling from single devices and large-scale networks.
2. Energy models for network traffic from mobile devices, such as sensors and smartphones. After empirical measurements of energy consumption by the device during wireless transmission, mathematical models can be devised, which describe relationship between transmitted data and consumed energy on the device.
3. Traffic scheduling schemes for mobile devices. Once we are able to model energy consumption of transmitted traffic, we can propose network traffic scheduling schemes, implement them as a proof-of-concept with testing on real devices.
4. Building a large-scale IoT network emulator, to study congestion, latency and other network characteristics in various application scenarios.
5. Measurements of network traffic in large-scale wireless networks, with focus on congestion, latency and impact of those on energy. By running various scenarios on the emulator, it is possible to analyze what are the main causes of congestion and latency in large-scale IoT networks. Based on the analysis, we can propose, for example, new congestion control schemes. We can implement those schemes as a proof-of-concept and test them in the emulator.
6. Energy models for large-scale IoT networks. After analyzing the traffic behavior in the IoT network, we can derive network-level energy models and new methods to improve energy efficiency.

Expected contribution to the field of sensor networking

- Energy models for wireless sensor nodes;
- Large-scale IoT network emulator;
- Understanding of traffic characteristics in large-scale networks, such as congestion, latency, effects of interference etc;
- Energy models for large-scale wireless networks;
- Traffic prediction models for large-scale networks;
- Network-level congestion control and other approaches for improving energy efficiency.

Results so far

As of now, I have done some research into traffic scheduling on mobile devices [5] and almost completed my work on a large-scale CoAP/802.15.4 network emulator - MAMMOTH[11].

Biographical sketch

After getting my Bachelor's degree in my home country Estonia at the University of Tartu, I came to Finland as an exchange student to the now defunct Helsinki University of Technology. Being impressed by the level of education provided here, I stayed and completed my double Master's degree at the Data Communications Software Lab. During that time I got involved in research related to energy efficiency of mobile devices, specifically related to wireless network traffic, under the supervision of Yu Xiao.

After graduating with a double Master's degree (NordSecMob – an English language Master's Programme) from Aalto and Tartu universities, I started my doctoral studies at DCS Lab under the supervision of Prof. Antti Ylä-Jääski. At first I was focusing on energy efficient traffic transmission on single devices, but soon realized that there is a huge opportunity for achieving energy savings with network-level traffic control, especially in different Internet of Things (IoT) scenarios. After that insight my research work crystallized into a bottom-up approach of gaining energy savings by traffic control, starting from device level and all the way up to large-scale network level.

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