Poster: Towards Dependable IoT Systems Using Self-Adaptation

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Abstract

Realizing dependable Internet-of-Things (IoT) comes with numerous challenges. For large-scale IoT deployments, one particular challenge is handling uncertain operating conditions, such as interference in the wireless communication between devices and gateways or changing availability of services. Without proper mitigation of such uncertainties, dependability goals of IoT systems, such as reliability and energy efficiency, may be jeopardized. In our research, we study how self-adaptation can be applied to realize dependable IoT systems regardless of uncertainties. Self-adaptation equips an IoT system with a feedback loop that tracks the uncertainties and adapts the system as needed to maintain its quality goals. Our focus is on large-scale IoT systems with mobile devices. In this paper, we study a typical adaptation problem of IoT where mobile devices need to adapt their power settings while moving in an heterogeneous environment to ensure reliable and energy efficient communication. We evaluate the approach using a simulator of DingNet, an IoT system that is deployed in Leuven, Belgium.

1 Introduction

Smart city applications, such as traffic management and area surveillance are deployed on large-scale Internet-of-Things (IoT) systems. Ensuring the dependability goals of such systems, e.g., reliable and timely transmission of data, is challenging due to uncertainties such as changing environment conditions and interference of the network.

The underlying problem is that such uncertainties are difficult to predict before the system is deployed. To tackle this problem, an IoT system can be equipped with a feedback loop that tracks uncertainties, analyses the current situation, and adapts the IoT system to ensure its quality goals. Systems equipped with such a feedback loop are commonly referred as self-adaptive systems [3].

In our research, we study LoRaWAN-based[1] IoT systems with battery-powered devices that collect data that is communicated to gateways for further processing. Existing work usually only considers stationary devices [1]. We focus on systems with mobile devices, paving the way to new applications such as target tracking. Key dependability goals for these systems are reliable data transmission and energy efficiency. In [2], we devised a basic algorithm to adapt the settings of a single mobile device that moved in a static environment with one gateway to ensure its dependability goals. Leveraging on that basic work, our research objective is now to develop an integrated self-adaptive solution to realize resilient IoT systems for large-scale smart city applications with many mobile devices that interact with multiple gateways positioned in a dynamically changing environment.

In this paper, we present our first results to realize our research objective. In particular, we study a typical adaptation problem of an IoT system where two devices that move in a heterogeneous environment with multiple gateways need to adapt their power settings dynamically to ensure reliable and energy efficient communication. We evaluate the solution using a simulator of DingNet, an IoT system that is deployed in Leuven, Belgium.

2 DingNet and Adaptation Problem

DingNet[2] is a LoRaWAN network that covers the city of Leuven by 14 gateways. Battery-powered IoT devices can sense environment parameters and send the data to gateways. Reverse traffic enables adaptation of the settings of devices.

To support our research, we developed a simulator of DingNet that is freely available.[3] Figure 1 shows a part of the map of Leuven. The antenna symbols represent gateways that are placed at high buildings. The wireless sensor symbols represent mobile devices.

In this paper, we consider a scenario where devices track the quality of the air while moving through an environment with buildings, forest, etc. These areas are characterized by different levels of network interference. Concretely, we consider two devices, D1 and D2, that move from A to B and C to A respectively (see Figure 1). D1 sends data samples at maximum power every 10 meter it moves.[4] D2 sends

[1] https://www.thethingsnetwork.org/docs/lorawan/
[2] https://admin.kuleuven.be/icts/english/services/dingnet
[3] https://people.cs.kuleuven.be/danny.weyns/software/DingNet/index.htm
[4] Other network parameters such as spreading factor are kept constant.

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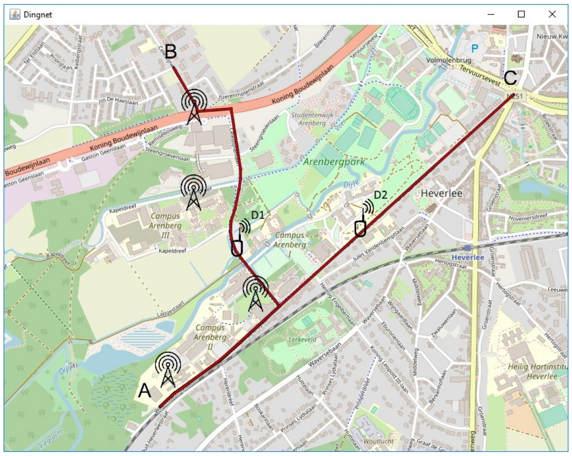

Figure 1. Map of Leuven area used for experiment

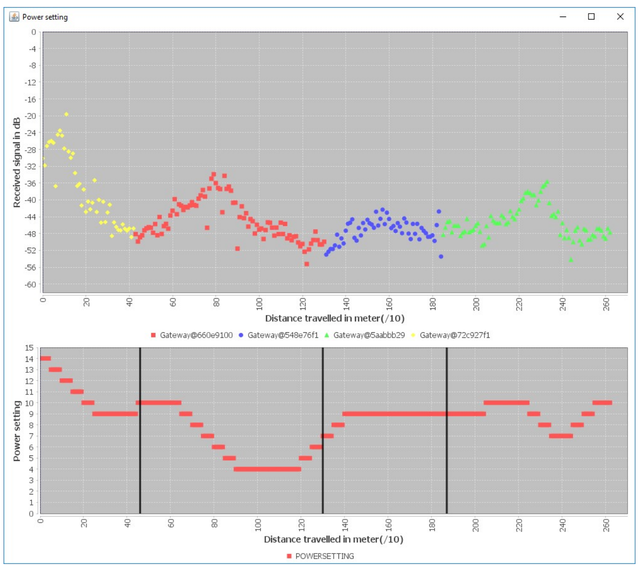

Figure 2. Signals received from D1 and power adaptation

data samples randomly distributed between 1 and 15 meter it moves. We consider the following adaptation problem:

How to adapt the power settings of devices when moving through the environment such that the data is transmitted reliable with minimum energy consumption?

3 Self-adaptation Approach

To tackle the problem of realizing dependable IoT systems, we leverage on principles from self-adaptation [1]. To that end, a feedback loop is added to the IoT system that monitors uncertainties, reasons about the system, and adapts it if needed to realize the system goals.

Figure 3 shows the architecture of the self-adaptive system we applied to tackle the adaptation of Section 2.

Each mobile *Sensor Device* samples the air quality and sends the data to the *Application* via the *Gateways* within their communication range. The *Managing System* deployed at the *Application Server* realizes a feedback loop. The *Knowledge* repository maintains an up to date model of the IoT system and its environment. The *Monitor* tracks via the

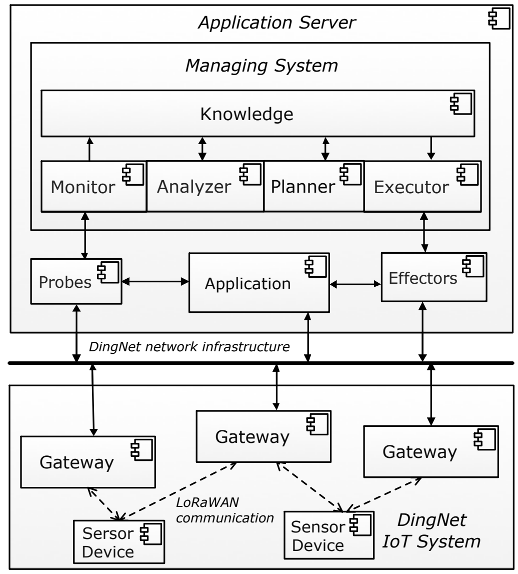

Figure 3. Architecture of self-adaptive IoT approach

Probes uncertainties and data relevant to the adaption problem, such as the signal strength of messages received by the gateways. This data is used to update the system model. The *Analyzer* checks whether the strengths of the signals per device are within a required range and if this not the case, the *Planner* is triggered. The planner then determines a new power setting for the device. If the signal is too low, the power will be increased to ensure reliability. If the signal is more as needed, the power will be decreased to save energy. Finally, the *Executor* will enact the change via the *Effectors*.

Figure 2 (top) shows the strength of the signals of device D1 received by different gateways while moving from A to B (signals shown for the gateways that received the strongest signals). The feedback loop tracks the signal strength and tries to keep it within a window between -42 and -48 dB, which ensures a reliable communication, by adapting the power setting of the device as shown in Figure 2 (bottom). Compared to a conservative setting with maximum power setting, the adaptation approach consumes 62% less energy.

4 Conclusions and Outlook

In this paper, we explained the problem of ensuring dependability of IoT systems in the face of uncertainties. We showed how self-adaptation enables to tackle this problem, and illustrated this with first results. In future research, we plan: (i) to introduce additional uncertainties such as changing weather conditions, which will raise the need for more advanced system models and runtime analysis techniques, (ii) to take into account additional resilience goals such as latency; and (iii) to apply the approach in the field and perform an empirical study to evaluate the study results.

5 References

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