Implementing NB-IoT: Communication with a Load Cell

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Abstract

IoT technology has been proclaimed as a new technological prowess that will change our economy as well as our cities and way of living. Despite these bold statements, IoT is far from being easily implemented by companies not directly working with any of the enabling technologies, such as telecom. Narrowband-IoT (NB-IoT), a new radio protocol focusing on wide area coverage and low power consumption, is being heralded by the 3GPP as one of the key technologies necessary to push society into the age of IoT. NB-IoT networks are still extremely new in a lot of countries, and while the SIM-cards necessary to use these networks can be readily purchased from telecom companies, the lack of implemented projects might scare the everyday layman looking to implementing IoT within his/her business. The purpose of this paper is to provide an example for how an IoT device can be implemented in practicality, specifically with a scale. A micro-controller is hooked up to a load cell, from which the data produced is sent to the net via a cloud platform.

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Chapter 1

Introduction

IoT (Internet of Things) is a broad, diverse and growing field within the IT sector. Many organizations predict that it will come to impact large areas of our daily life, and many telecom companies are experimenting with different kind of real world applications that can benefit from this change. The basic idea is the same for everything, which is to take a device and connect it to the internet. Examples range from simple toasters to complex self-driving cars.[2] The focus is to enable communication between devices without the need for a human middleman, thus optimizing whatever application is being implemented. A simple example is a building equipped with multiple IoT-enabled thermostats, which are controlled by a central heating system. Given effective software, heating can be regulated in an energy efficient manner while still keeping visitors adequately warm throughout the day. Another example might be a parking meter, which can forward the availability of its parking spot to some central system which in turn forwards the closest available spot to an end-user. The potential applications are numerous, but factors such as energy consumption and security have proven huge roadblocks that pose huge challenges to most IoT projects.

Vetek is a Swedish scale supplier located in Väddö, situated approx. 100 kilometers north of Stockholm. Vetek constructs their own scales and weighing systems, as well as reselling products from other manufacturers.[8]

Vetek aims to improve their services, and as such are interested in the possible use cases of IoT technology, and ultimately see how that can be applied to their own products. With something as simple as an IoT-enabled scale, they can offer customers products that can be placed in remote areas without needing constant checkups, enabling long term monitoring and easier analyzation of data. An example might be monitoring road salt depots, to enable smarter refill routes during winter time, or a fodder station to map the behaviors of local wildlife.

The biggest challenges for this type of device lies in energy consumption and broadcast range. Low energy consumption is needed so that any maintainer doesn't need to make constant check-ups to switch batteries all the time. This poses limitation on the type of scale that can be used, which in extension affects parameters such as scale accuracy and capacity. A wide broadcast range is needed so that the device isn't limited by having to be close to a base station. This puts restraints on what type of communication protocols can be used, as traditional ones such as Wi-Fi and Bluetooth won't work in the aforementioned examples.

With the advent of IoT, the 3GPP (a standardization organization for telecom) has developed new wireless communication protocols intended to be used by these devices. One of these, the NB-IoT (Narrowband-IoT) protocol is particularly suitable for the challenges mentioned above, as its focus lies (among else) in wide area coverage and long battery life. A microcontroller (a small computer) is needed to handle the data polled from the scale, as well as sending it via some wireless communication protocol. The microcontroller chosen for this project is a FiPy, as it has the capability to handle multiple wireless technologies, one of them being NB-IoT. The only other technology needed is some form of power source, as well as an ADC (Analog-to-Digital Converter) that connects the microcontroller and the scale.

In this paper, an attempt is made to implement the above. Due to hardware difficulties, a functioning connection between the scale and the microcontroller couldn't be established, so a virtual scale was implemented instead. Some behavioral restrictions are placed on the code running the microcontroller, to closer resemble a real-world application. Examples of these behaviors are handling of erroneous data and disconnection of the scale.

Chapter 2

Background

This section aims to give the reader a bit more background into the circumstances of the technologies used in the paper. We will discuss the background of the NB-IoT protocol and how it affected the groundwork of this paper, as well as expand on some of the concepts mentioned in the previous chapter. This is relevant information for people seeking to replicate the paper in some part, whether it's about acquiring and working with similar hardware or making basic software design choices about energy efficacy.

As mentioned in the previous chapter, there are pretty high hopes regarding the expansion and profitability of the IoT industry as a whole. To enable this growth and functionality, the 3GPP developed various new radio technologies, the two most prominent being NB-IoT and LTE-M. LTE-M has the most functionality, including voice capabilities and device positioning. Thanks to its wider bandwidth frequency it also has lower latency and boasts a data rate up to 1 Mbps.[7] In return, device complexity and costs are higher compared to NB-IoT. The focus of NB-IoT was to enable indoor coverage, low cost development, long battery life and high connection density, which makes the technology ideally suited for low data rate applications in extremely challenging radio conditions.

Because of the novelty of IoT and the NB-IoT, the technology isn't easily accessible, and the required SIM-cards are only available to purchase for a hefty sum. As of writing this paper, a trial-kit from Telia (in Sweden), containing 5 SIM-cards for a period of 6 months currently costs €450.[6] Compared to other communication protocols, they are not as simple to implement out of the box, but the potential benefits should be enticing enough for many innovators to start experimenting.

According to Swedish telecom company Telia, they were the first to introduce the NB-IoT technology in Sweden, as well as the Nordic countries overall.[6] They further claim that their network will be in range for over 99.9% of Sweden's population, as well as provide a speed of 200 kb/s in more than 95% of the country.[5] The grand opening of the network was on the 24th of May, and pilot projects were conducted as early as a year before this, in multiple locations across the country. Telia currently offers a starter kit for any actor interested in the technology, with a trial period of 6 months that includes access to Telia's IoT portal and APIs as well as 5 SIM cards, each with a 30MB data cap per month. Telia doesn't seem have many competitors when it comes to the Swedish IoT market, though Tele2 have partnered up with Nokia to offer similar services, and according to a press release from 2018, they have rolled out both LTE-M and NB-IoT across their networks.[3] Telenor has launched a IoT network in Norway with NB-IoT functionality in 2018[4], and according to an exchange with their customer support, followed suite in Sweden in the beginning of October. **TODO: How do I reference a private email conversation?** The fact that Telia already has partnered up with a multitude of cities and companies give the indication that they have a head start in the market.

2.1 Requirements

Aside from security, one of the biggest challenges regarding IoT devices relate to limitations arising from energy infrastructure. As mentioned earlier, one of the core issues NB-IoT aims to achieve is to be a low-power technology, thus decreasing the maintenance needed for battery-powered devices. A claim often paraded with NB-IoT is that it enables a battery-time of up to 10-years[1], though it's worth mentioning that over such a period of time the underlying IoT technology (in the form of microcontrollers/sensors) will probably require more frequent maintenance than the batteries themselves. However, if an IoT device constantly transmitted data for days on end, its energy supply would run out rather quickly. Therefore, it's also important that energy consumption is something that's accounted for when writing the code for an IoT application. Questions worth considering are **how often** and **when** to send data, in order to ensure device effectiveness while still maintaining energy efficiency.

After questioning Vetek about possible use cases that a battery-powered IoT device would fit into, the most common examples boiled down into monitoring weights that would change in a linearly decreasing fashion.

TODO: Explain why the three following subsections were chosen

2.1.1 Data Reading Interval

In most IoT devices the relevant data is provided by some form of sensor, whether it be a scale, thermometer or something entirely different. The type of sensor being used has a huge impact on the IoT device, especially when considering that they have to be powered by the same energy source. However, it's safe to assume that in most cases (depending on the sensor), the data transmissions will be the part of the device that will consume the most amount of energy during the lifetime of the device. Nonetheless, it's also important to factor in how often the device polls the sensor for data. The simplest way of deciding when to poll data from a sensor is to let it do so at a fixed and constant rate, often enough to be relevant, and seldom enough as to not waste precious energy. The same can be said for the actual transmission of the data, though this will be discussed elsewhere in the paper **TODO: Where?**

However, if within the context of the application we can conclude that no data needs to be polled (for a while), then subsequently no data will need to be sent, and thus we save energy on both ends of the system. For some applications there might even be longer periods of downtime where it's not relevant to conduct monitoring on the given sensor, *e.g.*,during nighttime, closing hours, etc. Another interesting angle is modifying the reading rate depending on the data itself. A simple example of this would be to have a slower reading interval at stable values, and increase it when experiencing large enough changes. Given the conditions of an IoT device powered by batteries, it's not unreasonable to assume that readings might not always be accurate at times. Depending on the sensor, spikes and drops of false values might occur, and not taking these scenarios into account would be prudent. In the following chapter we will explore a possible implementation regarding the reading rate of sensor data depending on the output of the data values.

2.1.2 Sensor Failure

In this paper, we define sensor failure as a sensor giving too many unreliable or false data values to be considered functional. The goal of identifying such a state in an IoT device is to prevent unstable data from being interpreted as valid, which in turn can save the end user from unwanted consequences. Depending on the longevity and purpose of the device, the threshold of when to declare a sensor as failing may differ, especially as this state can be quite fluid. A functional sensor means different things for different devices and applications. A simple way might be to conclude that if x% of data is considered invalid during the last 24hrs, an alarm should be raised to the device administrator. Complications arise when failures need to be reported quickly, or estimated more thoroughly. It's also possible that the sensor can be temporarily unreliable due to external circumstances, and given enough time, these circumstances might **TODO: vanish/recede/pass**. On one extreme you can have a device that reports failures too frequently and bogs down whatever dashboard is handling it's status report. On the other, you can have a device taking too long to determine a sensor failure that otherwise useful data could have been monitored if an error had been raised in time. In the following chapter we will look at possible way to handle sensor failure in a somewhat fluid manner, with the goal of being responsive while still allowing the sensor some leeway.

2.1.3 Sensor Disconnect

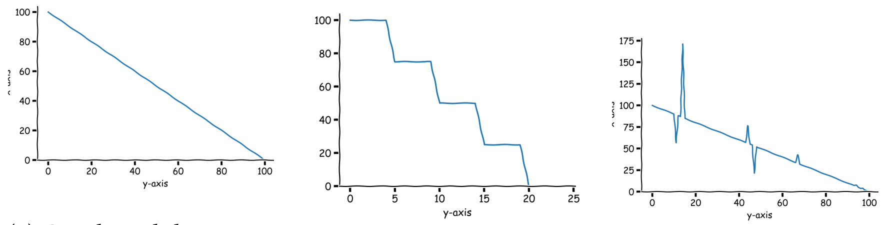
We define a sensor disconnect as when no credible data is being produced at all. If the sensor doesn't recover, immediate maintenance is needed for any continued functionality. If

Chapter 3

Design & Implementation

3.1 Data Reading Rate

3.1.1 Behaviors



(a) Graph with linear decrease

(b) Graph with plateaus

(c) Graph with spikes

To determine what we want to achieve in this aspect, it's useful to first define some behaviors from which we will base our assumptions on. In figure 3.1a we see our base case, with a simple linear decline in data values. In figure 3.1b we see data the goes through some changes periodically, but stabilizes itself between the changes. In figure 3.1c we see a clear linear decrease with some spikes in data values here and there, which we can assume to be faulty measurements.

3.1.2 Implementation

We're interested in modifying the data reading rate depending on the changes in data values. This can be done in a number of ways, but a simple start might be to measure the delta in the last x amount of values and increase/decrease the rate depending on it's relation to delta.

To do this we need a *short term buffer* of a fixed size that contains x amount of recently read values in chronological order. This buffer should act as a FIFO-queue, so that the first element added to the buffer is the first one removed during an overflow. Measuring the delta of all the values in the buffer, we compare it to a threshold value that will either decrease, increase or maintain the current interval of reading data. When we say the delta of *all* values in the buffer, we mean the delta between each data point summed up. Assuming a buffer of 10 values, we would calculate the sum as follows:

$$\sum_{n=0}^{8} x_n - x_{n+1}$$

Starting with figure 3.1a, the values go from (100-0) in 100 data points on the x-axis. Calculating the delta for the first 10 values would be simple. The short term buffer would be: [100, 99, ..., 91]. The total delta would be (100-99) + (99 - 98) + ... + (92 - 91) = 10. For this example we can say that our determined threshold for decreasing our reading interval is ≥ 15, and an increase at ≤ 5. In our current example the reading rate is maintained.

In figure 3.1b the slopes are steeper, and would thus generate a larger total delta. Assuming a buffer length of 10, the first 5 values would be 100, and the other 5 would be 75. Our delta calculation would give us a value of 25, which would warrant a increase in our reading rate. In figure 3.1c the calculation would work the same as as in 3.1a, with the exception of some outlying data points. In regards to data reading rate, we can handle these values in two ways. Either we filter them in some way, or include them. Depending on the application, filtering can be easy. For example, perhaps we know that values $\geq$ 150 are impossible for our sensor, and thus we can manually check each values to see if they adhere to our specific bounds. Perhaps we know that such rapid changes in said values aren't possible, and we can filter them based on that. One way of doing this might be to calculate the average value of the short term buffer, and only allow new data within a range of *x* amount of units. Given the short term buffer [100, 99, ... 91], the average value would be 95.5. In our application we know that data points can only reasonably change with about 20 units, assuming a minimum reading rate. We set the limit to 30 units to give the program some leeway. In either way, extreme data points can be filtered.

A valid question at this point is *how often* we should perform this delta measurement, and of course the answer depends on the needs and workings of the application. Some applications might benefit from adjusting their reading rate very tightly, while others might only want to do this periodically.

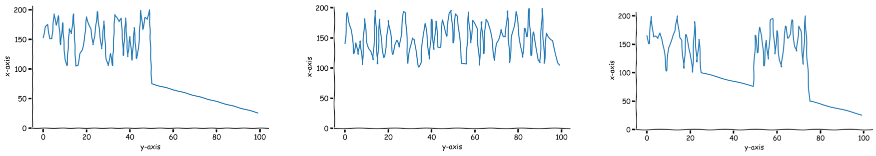
To sum up the important design choices when considering how often the sensor should be polled, we considered:

- What values we **compare** our short-term delta to. When should we decrease, increase or maintain our current data reading rate.
- What values are **valid** in the context of our application.
- How **often** we should adjust our reading rate interval.

3.2 Sensor Failure

3.2.1 Behaviors

In the previous chapter we defined a sensor failure as a state where the sensors measures invalid data for such a period of time that the sensor isn't deemed functional. Functional can mean different things for different applications, such as that one successful reading an hour is enough for one case, while one successful read per second might not even be enough for another. The question of how to determine successful readings versus unsuccessful ones are beyond the scope of this paper and varies greatly from sensor to sensor. We will aim to implement one way of handling the device state when these faulty readings do occur.



(a) Graph with some faulty data (b) Graph with only faulty data (c) Graph with two intervals of faulty data

In fig 3.2a, the sensor first reads faulty data but then recovers and starts producing valid data halfway through. In fig 3.2b all the data produced is faulty. In fig 3.2c there is one interval of faulty data followed by recovery, and then it repeats this pattern one more time.

3.2.2 Implementation

Starting from figure 3.2a we receive faulty data from the sensor. Normally we might expect the occasional value to not be valid without raising any alarms, but after receiving 10 in a row

3.3 Sensor Disconnect

Chapter 4

Results

4.1 Discussion

Chapter 5

Conclusions

5.1 Future Work

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