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Implementation of a Water Flow Sensor Node and Energy Evaluation of 2G Transmission Strategies

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Abstract

In this report, the design choices made during the making of a water flow measuring sensor node are described and discussed to various extents. The node is to ultimately be deployed in South Sudan to monitor mini-water yards managed by the International Aid Services. A design using a hall effect water flow sensor, a microcontroller and a GSM modem is presented. Various lengths of SMS and HTTP messages are sent and the current signature they produce are compared to find out which transmission strategy is the most energy conservative. It is concluded that for a constant data volume, sending it in as few messages as possible is beneficial in terms of saving energy. It is also found that for short messages, SMS seems to be cheaper in energy compared to HTTP and the opposite is true for bigger messages. Avoiding actuators altogether has the potential to be beneficial in terms of battery life for a sensor node.

Acknowledgements

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Contents

Chapter 1

Introduction

1.1 Justification

In this report, difficulties with surveillance of a *Mini-Water Yard* are adressed. A Mini-Water Yard is a solar powered structure which pumps up ground water and stores it in a large container. This water is made available for the personal use of the local residents. Maintenance, or periodical visits of geographically dispersed water yards can be both tedious and expensive. In South Sudan, there are a number of Mini-Water Yards that do exist are spread out far away from each other around South Sudan. If the attributes that are to be observed can be sent from the station to the maintenance personnel, the frequency of required maintenance visits can be reduced as the need for the maintenance personnel to travel to the station can be elminated or reduced. To gather information about the extent to which the mini water yards are utilized, one might observe the volume of outbound water. The volume of water going out does not only give information regarding the normal utilization of the tower, anomalies in this water flow could indicate the need for a service visit.

1.2 Purpose

The aim of this thesis is to design and implement a *Sensor Node* for monitoring the water usage of yards. A sensor node is a small computer with the purpose of forwarding information read from its sensor or sensors to a server or cloud service. What this does is that it lets a remote party, such as a maintenance worker to gain information about the environmental conditions of the node, depending on what sensors the node utilizes. This relieves the maintenance personnel of having to travel to the node to observe whatever the node's sensor is there to measure.

Designing a sensor node requires a set of choices to be made, all the way from the sensor to the communications medium. In this report, the design choices made for this particular sensor node will be discussed. However, there will also be some suggestions provided regarding sensor nodes in general in other contexts. For example if a similar sensor node was designed for use in Sweden, one might favourably select another communication technology.

1.3 Research Questions

Designing the sensor node normally has to be done according to the requirement specification. In this particular case, there was no finalized requirement specification. However, there was a rough outlining of a requirement specification. This document stated that the node should be able to operate for a sensible amount of days (assumed to be somewhere around 5 to 7), the node shall send data every hour. It also would have the node being able to receive commands such as Restart, or Shutdown, in case the node malfunctioned. Since the requirement specification oultine had very little information about things that were not directly communications related, and the purpose of this thesis is to investigate communications strategies, it should be sufficient for designing a node that is able to satisfy the research questions and the aim of the thesis.

Proceeding from our requirement specification, design choices should be made to support an autonomous node. That is a node which has the ability to recharge more energy than it has to expend so that it has a net zero or positive battery charge. The research questions aim to achieve this mainly in regards to battery life. The nodes should be able to run on their battery for as long as it could reasonably take inbetween two opportunities for charging. Ideally, for a node that is run by solar power, this would be the length of a night. However because of more unpredicatble factors such as clouds, this time should be a bit longer. A few days is deemed a reasonable assumption.

RQ1: Can a sensor node be designed so that it meets it's requirements while also being able to operate autonomously?

RQ2: To what extent does the requirement of communication affect longevity of the node?

To answer RQ1, a prototype sensor node that fills this purpose will be designed and implemented. The energy it needs to operate will be compared to it's battery capacity.

To answer RQ2, energy measurements during various transmission strategies will be compared to each other. The aim of this research question is to obtain an overview of a sensor node communicating as sparsely as possible while fulfilling it's purpose.

1.4 International Aid Services

The *International Aid Services*[1] (IAS) is an international, non-governmental aid organization founded in 1989. They are largely dependent on donations and

[1] http://www.ias-intl.org/

partnerships with orgnazitions and corportations. One of the areas in which they conduct work relevant to this thesis is water and sanitation, the others being education, agriculture, evangelism, etc. The IAS mostly operate within eastern Africa. In South Sudan, the IAS has constructed autonomous water towers, which they refer to as Mini-Water Yards. A Mini-Water Yard is a water tower and ground water pump which is solar powered and operates largely autonomously. The IAS requested for a way to be able to observe the utilization of these water yards. Some of these yards are located in areas which service personnel can not easily reach.

1.5 Delimitations

Because of limitations regarding the network availability in South Sudan, there were no other apparent choices for transmission technologies. The design in this report instead utilizes 2G. Seeing as 2G is widely being shut down in developed countries, future projects should consider the use of other communications technologies.

In the common application areas of sensor nodes, conserving energy is of great importance and a major challenge as the nodes in the normal case run on batteries. This becomes less critical as the location in which we place the nodes have access to electricity during daytime. This is still relevant to some extent seeing as a power management solution has to take into consideration at the very least nighttime, but also extended cloudy periods. Therefore we can not fully rely on the solar panels and require some form of battery management.

1.6 Background

It should be noted that there are similar products[2] on the market by the time this report was written. However, these were not designed in the spirit of a sensor node as they were in comparison very expensive to deploy. These also ran on common household batteries, which is suboptimal since there is a solar panel available. Therefore it is likely that the sensor node design in this report is better suited to our context.

[2] https://sonsetlink.org/?page_id=85

Chapter 2

Theory

This chapter will serve the purpose of providing an all round understanding of sensor nodes in general so that the context of the thesis can be better understood. It also provides ground for the decision to focus on the transmitting data part of sensor nodes for this thesis.

2.1 Sensor Nodes

The backbone component of a *Wireless Sensor Network* (WSN), the *Sensor Node* is as Akyildiz et al. [1] describes, a unit that has one or several sensors, some form of data processing and the ability to send this information onward. This enables the node to be in a location of interest, while whoever reads the information can be wherever he or she pleases. A sensor node also requires a power source. When available, this could be grid power. Some sensor nodes utilize electricity generated on location. However, most commonly a sensor node will run on batteries.

Respecting that the nodes are heterogenous, Akyildiz et al. [1] (2002) clarifies several trade offs that have to be accounted for when designing the nodes. As in any design process, the trade offs need to be taken into consideration for the particular design in question. These trade offs are as explained in the sections below.

2.1.1 Quality of Service Requirements

Gungor et al. [2] write that *Quality of Service* (QoS) refers to how accurate the sensor nodes' data transmissions to the server are, compared to the reality of what the sensor nodes are meant to observe. In other words, the accuracy of the values reported to the server or cloud service.

The time it takes beetwen that the sensor node does a sensor reading, and that the processed data reaches the server or cloud service, are also part of QoS as explained by Gungor et al. [2].

2.1.2 Resource Constraints

Each node in a sensor network should have a low hardware cost so that many of them can be deployed. Theft or destruction of a few nodes should be expected, more so depending on location of deployment, and thus not produce huge expenses. This should be taken into account when designing the nodes so that they are cheap enough for a few of them to be replaced every once in a while. It is true that a node which resides out of reach for curious fingers in an indoor environment does not have to be as replaceable or robust as a node that is placed in a more volatile location.

Exposed nodes also call for a robust build, more so depending on what conditions the nodes are placed under. A node placed close to water needs to be water resistant. A human reachable node needs to be low in theft appeal, if it is not, it needs to be tough to detach and steal. A node reachable by various animals should be sturdy enough to have them do whatever harmful action they are capable of to it. Gungor [2] et al. stress that every component of an Industrial Wireless Sensor Network can be utilized to save energy, and that it is important for them to do so in order to achieve the longest possible battery lifetime without violating the QoS constraints of the requirement specification.

2.1.3 Energy Consumption for Transmitting Data

While a low energy consumption is always desireable, the nature of the WSN determines the extent as to how energy conservative the nodes are required to be. If the node does not have access to a supply of electricity such as a grid-tie or a local renewable power source, it is going to be run on batteries. This should be thought of as a common occurance for wireless sensor networks.

A battery driven sensor node has to be designed in a way so that it can do enough good during the discharge time of the battery to be worthwhile for the purpose of the sensor nodes. This is naturally not as critical for a non-battery powered node.

Akyildiz et al. [1] explain that generally, the cost of data processing is relatively cheap in terms of energy compared to that of communication. Therefore, communicating as little as possible is beneficial in terms of convserving energy. Because of the difference in energy cost for data transmission and data processing, something to consider is that it should be worthwhile to move work from the communication module to data processing. For example, if a node has multiple sensor reads for a period of time, bundling them by the end of that time rather than sending them continuously could save a lot of energy and thus battery lifetime, especially if the transmission hardware is put to sleep during this time. This method is known as *duty cycling*.

2.1.4 Energy Consumption for Receiving Data

Abdeleel et al. [3] show that both receiving and transmitting radio signals are relatively energy consuming actions compared to utilizing sensors and processing data. A sensor node per definition has to transmit data. However, by the same definition, it does not need to receive any data. Because receiving data also costs a lot of energy, it is beneficial to avoid actuators as much as possible and thereby avoid the need for the node to receive data. Not only does the actual receiving of data cost energy, if the node expects to never receive data, it can know exactly when it's transmission module needs to be used since the node is the only thing that actually utilizes it. When the node has access to the entire work schedule for the transmission module, the node can suspend it whenever there is a block of spare time, in order to save energy.

2.1.5 Energy Consumption for Microcontroller

As for selecting the microcontroller to use, Lorentzen [4] explains that a microcontroller used for such a system should feature a sleep mode. A power conservative design alongside a battery that is charged on location could produce an *autonomous* or close to autonomous sensor node. An autonomous sensor node is a sensor node with battery life longer than the time it has to run inbetween recharges.

2.2 Transmission Technology

As previously stated, the energy cost of the transmission devices are expensive compared to both sensing and data processing. While selecting transmission technology might be of importance in general when designing a sensor node, a geographical area, or circumstances of the nodes deployment can be limiting in the possible choices. GSM can be a solid candidate for transmission technology even when there are other available alternatives as it has its advantages, Perrucci et al. [12] (2009) found text messages sent by 2G to be cheaper in energy cost than messages with the same data sent by 3G.

2.2.1 General Packet Radio Service

The *General Packet Radio Service* or *GPRS*, is a packet switched data service that runs on 2G or 3G, which is what currently exists in Sudan. It is an older technology dating back to the year 2000, and thus is limited by the data rates. The small data volumes that the sensor node in this report has to work with, being at most a few hundred bytes, does not pose a problem for GPRS utilization. Essentially, GPRS allows sending general internet packets through the 2G network.

2.2.2 Energy cost of GSM

GSM draws different levels of power depending on what level of utilization it is currently under. Carrol et al. [5] distinguishes two low-use states, suspended and idle. A *suspended* device is a device that is in a state in which it periodically makes sure it is connected to it's network but performs no other task. This is to make sure that the particular device can receive text messages or calls but aims to save power. An *idle* device is a device that is awake, but not performing any task. Carrol el. al show that an idle GSM device draws almost double the power compared to that of a suspended device.

Intuitively, Perrucci et al. [12] show that the energy cost of a text message is proportional to the length of the message. Therefore, if possible, the outbound volume of data should be reduced by the node rather than the end server. Sending messages has energy cost that is not related to the actual data sent, there is a ramp up energy cost and a tail cost. When a message is about to be sent, the energy that the device draws increases for a short while before any actual information is transmitted. This is known as ramp up energy cost. After a message has been sent, the energy cost remains at sending-levels for a short while before retunring to idle energy usage. This is known as tail energy cost. Therefore, bundling data as much as possible so that as much data as possible is sent while sharing the expenses of just one tail and one ramp should be a good strategy.

2.3 Related Work

This section will serve the purpose of providing insight as to what other similar projects have been made and how they differ from the one in this report. What follows is a summary of those systems.

Wang et al. [7] describe a Wireless Sensor Network based water monitoring system with the focus on water quality rather than just water flow. The Mini-Water Yards should already provide clean enough drinking water. However, adding water quality control to the Mini Water Yards, or to similar projects might be a good decision in the case of anomalies.

A similar node, which measures water flow and communicate using SMS messages which is described by Mahjoubi et al. [8]. They use a different platform for the microcontroller, they do use GSM but different hardware. They also try out various communications technologies but conclude that GSM reduces the energy cost the most.

A water monitoring sensor network implemented in northern Australia is described in the article by Le Dinh et al. [9]. It describes sensor nodes that amongst other things measure water flow similarly to the sensor node described in this report. It is aimed more towards monitoring the system when it is deployed. The report is extremely informative in regards to deploying a sensor network or a node in a practical sense such as how a lot of GPRS modules tend to malfunction after an extended period of time connected to the network.

An enviromental monitoring wireless sensor network called *SoilWeather* is implemented by Kotamäki et al. [10]. Its main focus is not water flow, but rather air properties. It is also a more practical report, for example it details maintenance of the system. It is a good resource for practical purposes in deploying and maintaining an outdoors WSN. Unlike a lot of sensor network reports, since this was implemented in Finland, this deals with problems that occur with freezing temperatures, such as sensor inaccuracies.

Jiang et al. [11] have designed a WSN for water monitoring. Unlike the sensor of this report, each node do not have a 2G module each. Instead, a set of nodes are close to a base station which has a 2G module utilizing GPRS. The nodes communicate to the base stations via the ZigBee protocol.

Chapter 3

Method

This chapter provides an overview of the system and then an in-depth look at the design choices and implementation of the node. The first half will adress RQ1, it's purpose is to explain the design of the sensor node. The second half will adress RQ2 and thus aims to evaluate the impact on power consumption the chosen strategy to communicate will have. Two prototypes will be constructed, each using a microcontroller, a hall sensor and a GSM module.

3.1 Sensor Node Design

An overview of the system can be found in Figure 3.1. The gray border labeled *Node* signifies the actual sensor node and thus what is adressed in this report. Arrows drawn in between boxes are information transferred between those entities. The leftmost box indicates the water flow sensor, which outputs to the microcontroller. The microcontroller in turn translates the sensor output to human readable data. That data is sent via the GSM modem to a cloud service. There is also a box labeled SMS commands. SMS commands can be sent to the GSM modem, they are then parsed by the microcontroller and a response is sent back to the phone that sent the command.

3.1.1 Data Processing and Transmission

To measure water volume from a hall sensor output, the following formula is used. *pulseCount* is the amount of pulses the hall sensor has produced, Q is a factor for the sensor which is used. The prototype uses a 7.5Q sensor. Q signifies the amount of *Pulses Per Second* produced per *Litres Per Minute*. *Pulses Per Minute * 60* is *Pulses Per Second*. $60Q$ is *Pulses Per Litre*. Therefore, *pulseCount / Pulses Per Litre* gives the volume in litres.

$$V = pulseCount/(60Q)$$

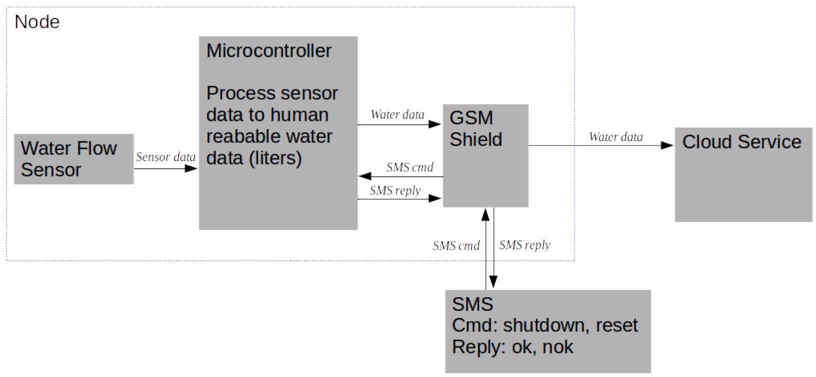


Figure 3.1: Overview of the system.

Whenever the node sends this information out it will do one of two things. Depending on the selected transmission strategy, the first being resetting it's variable for counting pulses. This so that whenever it sends information, what it sends is actually *the volume of water passed through the sensor since our last broadcast*. The second being storing the measurements for the last hour so that after a couple of hours such as a full day, it can send a big message with an array of all these 24 measurements.

3.1.2 SMS Commands

While minor, the ability to receive SMS commands was implemented for off-location micro management. A "Restart" command shall shutdown and restart a node. A "Shutdown" command shall deactivate a node fully. This requirement makes it so that the nodes have to listen for incoming commands every once in a while. The microcontroller is programmed so that it will open incoming SMS-messages and parse them to execute their contained commands.

3.1.3 Cloud Service

This should provide a platform for readings to be saved. For this system, ThingSpeak is used. Thingspeak will take incoming HTTP messages directly from the sensor node. These messages contain the volume of water which the

Figure 3.2: An Arduino Uno Rev3 is the platform for this sensor node.
`https://store.arduino.cc/usa/arduino-uno-rev3`

sensor node has measured up since last transmission. The data is then saved and can be visualized using MatLab.

3.2 Power Management

Since there is an 18 V power source in the form of the output of the solar panels, the system can rely on this power source during sunny hours. However it has to also use a battery. During dark times it needs to be able to operate for 72 hours. An *autonomous* system, is a system that expends less energy than it is able to consistently recharge itself with. To achieve a somewhat autonomous system, it will have to be able to charge the battery during sunny hours. A system which charges itself more frequently than every 72h hours and enough battery time to last longer than that will for the purpose of this thesis be considered autonomous.

It should be desireable to turn off the sensor nodes during periods of inactivity. However, the node can not now when the Mini-Water Yard is about to be used. Therefore it can not know when it would be okay to sleep for long periods of time.

3.2.1 Frequency of Transmission

Since it has been estabilished that in sensor nodes, communication is relatively the most expensive task in terms of energy, communicating as infrequently as

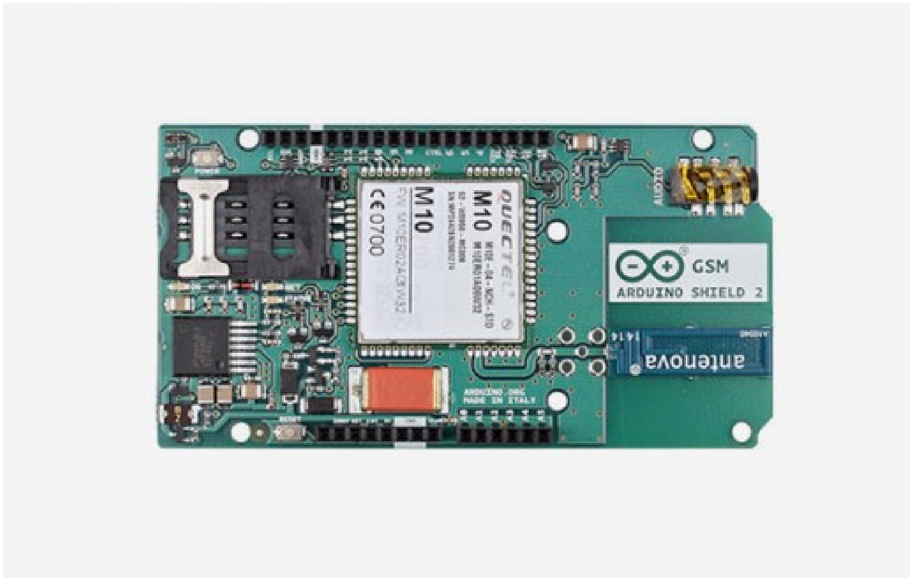


Figure 3.3: The node uses an Arduino GSM Shield 2 to communicate.

possible in regards to the requirements of the node is desireable. To evaluate this, the node is configured to different frequencies of transmission and it's energy consumption is measured.

While the original idea was to send reports of water measured once every hour, the data reports by the nodes can be argued to be not very time critical. If the nodes accumulated measured volume for an entire day, information about when the water is consumed would be missing. A more sensible strategy would be for the node to every hour, store the measured volume of water for that particular hour and by the end of the 24 hour period, send a bigger message with these 24 measurements.

Extending the time between broadcasts while increasing the size of the data of the broadcast should always be worthwhile until we hit the *Maximum Transmission Unit* (MTU), of the message. The MTU is the maximum size that a container can hold data. By then increasing the size of the data sent would not make for fewer messages since it would have to be split into several messages. However, there are two main aspects that have to be taken into consideration: how time critical the information is, and the risk of the node going down and thus lost measurements.

3.2.2 Test Setup for Overall Power Usage

To evaluate the transmission strategy and gain insight into how it affects the system's battery life, code containing different strategies is loaded on to the microcontroller. Energy consumption is then measured for the different strategies.

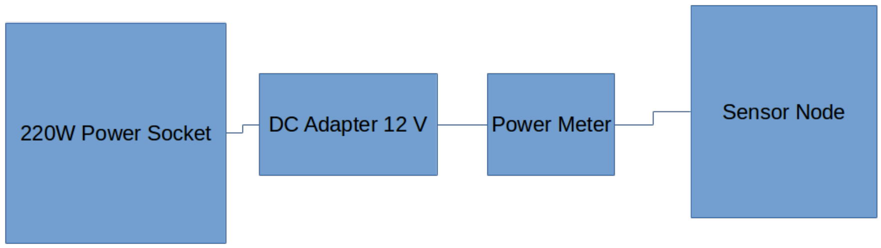


Figure 3.4: Overview of the Test Setup for Power Usage

To make a test setup for this, a power meter is attached to the power cord of the sensor node. An overview is found in Figure 3.4. The node is then left to run for 24 hours. The following strategies could be tested: sending one message after four hours, sending one message after two hours and then another after two more hours, sending one per hour for four hours, and finally never sending anything. The configuration which does not send anything is not practical in any way, but still provided for reference.

Tests

1. 1 message with 4 measurements per 4 hours
2. 1 message with 2 measurements per 2 hours
3. 1 message with 1 measurement per hour
4. No messages

Expectedly, strategies with fewer, bigger sends should be cheaper in terms of energy than the ones with more frequent sends. These were arbitrarily selected with large gaps inbetween the transmission times to outline the effect off different strategies.

3.2.3 Test Setup for Transmission Power Usage

The purpose of the second test is to more precisely gain an understanding of what different message sizes and techniques can do to the energy expendature of the system as a whole. For this test setup, a separate microcontroller is used which reads a hall effect current sensor, namely an ACS712. The ACS712 was selected on the simple basis of being available at the time. Any enough fine grained current sensour should do. The ACS712 is attached to the power cord of the water flow sensor node. The microcontroller that reads the current sensor measures the value every millisecond. Every 50 ms, it outputs the average for the last 50 ms. During this time the sensor node is made to send SMS messages of various lengths (1, 2, 50, 100, 200 characters). The same test setup and the same tests are done after the node is configured to send HTTP messages rather than SMS-messages. This is to see if there is any difference in the energy cost of these two techniques. Idle and suspended current is also measured with the ACS712.

When the sensor node is configured to send HTTP packages across GPRS. The message sent is POST header trailed by a string of characters. This string is set to various lengths and the tests were carried out in the same manner as the SMS tests.

Chapter 4

Result

In this chapter the major steps taken in the design process are explained so that a node can be replicated. It also presents the results from the various energy related measurements done on that particular design for the different transmission strategies.

4.1 Overall Power Usage by Transmission Strategy

Utilizing the test setup described in section 3.2.2, the total energy used during each of these 24 hour periods is measured. To achieve as equal circumstances as possible for the test runs, no water is ran through the water flow sensor. Because of the identical result of the first four tests, more tests were conducted that decreased the time between sends even further. In Table 4.1, the left columns holds time between transmissions of the microcontroller and the right column show how much energy the system used in total for the 24 hours of the test. The only observable effect was that when the time between transmission was set to 3.25 minutes or less, there was a slight increase in overall energy expendature.

4.2 SMS Energy Consumption

The test setup described in section 3.2.3 is used to measure the current that the water flow sensor node draws. The current for every output time can be seen in the figures in this section. Two distinct states should be recognized across every diagram; The idle state that has the current meter at the two lowest measurement values and the sending state which is strictly above said values.

Leaving the the sensor node turned on and connected to the GSM network has the ampere meter fluctuating at 0.12 to 0.13 ampere. This is the idle state as described in section 2.2.2.

Table 4.1: Energy use for various transmission strategies

Time between transmissions	**Energy Measured**
*No transmissions	0.028 kWh
4 h	0.028 kWh
2 h	0.028 kWh
1 h	0.028 kWh
30 min	0.028 kWh
15 min	0.028 kWh
7.5 min	0.028 kWh
3.25 min	0.029 kWh
1.625 min	0.029 kWh

To ease interpreting these measurements, there is a table below that displays the time between the point where the sensor node is no longer using idle energy to the point where the node has returned to idle energy usage. This time period is hereafter referred to as the *send time*.

Table 4.2: Send time for various messages and lengths

Characters	$SendTime_{SMS}$ (s)	$SendTime_{HTTP}$ (s)
1	5.0	5.9
2	5.3	6.0
50	5.4	6.0
100	5.6	6.1
200	9.2	6.5

A rough approximation of these results with time as linear function of data size is that $SendTime_{SMS} = 5 + 0.02 * x$ where x signifies characters sent. The constant part in time of an SMS, i.e. the time that is not dependent on the amount of data being sent, is roughly 5 seconds. HTTP appears to take more time to send the smallest possible data containing message but less time to send the larger messages.

4.3 GPRS Energy Consumption

As for the energy cost of GPRS, the result graphs can be found in Figure 4.2. The y-axis represent the voltage of the system and the x-axis represent time. The send times for these transmissions can be found in Table 4.2.

Table 4.3: Idle and suspended current

State	Current (mA)
Suspended	115
Idle	125

4.4 Idle and suspended energy usage

The following test measures current for each state described in section 2.2.2. The node is left with the GSM modem in an idle state, and then in a suspended state and the average current for each state is measured and can be found in Table 4.3.

4.5 Extrapollation of Current Signatures

4.5.1 Comparing Bundling Strategies

Assume that a node is to be created and it has to last 7 days without battery recharge while still meeting it's requirements of communication, which is occasionally sending data to the server. The requirement that a node should be able to operate for a week without recharge is translated to 168 hours.

For this example, assume we send 200 characters of measurement data every 24 hours for 7 days, or 168 hours. That is 7 200 Bytes sendings, or 6.5 second periods averaging at about 130 mA. Note that this assumes that we use HTTP packets to send these messages as they are more efficient than SMS for this data size. Assume also that we have the modem fully turned on 20 seconds daily for this send and suspend it for the remainder of the day (23h 59m 40s). This lets us divide a day into the three following time periods. Note that they sum to 24h.

$$T_{SuspendedHours} + T_{IdleHours} + T_{SendingHours} = 24$$

$$T_{SuspendedHours} = 23 + (59/60) + (1/60 * 2/3)$$

$$T_{IdleHours} = (1/60) * (1/3) - T_{SendingHours}$$

$$T_{SendingHours} = (1/60) * (6.5/60)$$

Now the energy consumption of the system for a day would be all that time multiplied by the corresponding consumption for the state the system is in during those times.

$$J_{Daily} = (T_{SuspendedHours} * 115\ mA) + (T_{IdleHours} * 125\ mA) + (T_{SendingHours} * 130\ mA)$$

$$J_{Daily} \approx 2760\ mAh$$

$$J_{Weekly} = 19320\ mAh$$

Seeing as there are common phone batteries with 20000 mAh capacity, it is safe to say that there is an autonomous node design possible that can last for 7 full days without battery recharge.

Assume that we are given the requirement that the node has to communicate it's readings hourly. Now 24 different 10 second periods with the modem switched on are required and the node needs to send 9 characters every time to reach the data size of the first scenario. This time SMS is selected due to the smaller data size of the sending.

$$T_{SuspendedHours} = 23 + (56/60)$$

$$T_{IdleHours} = (4/60) - T_{SMSSendingHours}$$

$$T_{SMSSendingHours} = 24 * (1/60) * (5.2/60)$$

The energy of these follows the same pattern as for HTTP.

$$J_{Daily} = (T_{SuspendedHours} * 115\ mA) + (T_{IdleHours} * 125\ mA) + (T_{SMSSendingHours} * 130\ mA)$$

$$J_{Daily} \approx 2761\ mAh$$

$$J_{Weekly} = 19327\ mAh$$

The difference is 7 mAh. While noticeable, this does not make a distinct difference in the batteries that are available to fulfill the requirements.

4.5.2 Impact of Sleep

Assume that the node has to utilize actuators. This has the effect that the node has to constantly listen for incoming messages. In other words, the node has to always be able to receive data and thus can not suspend it's modem. For this scenario, GPRS messages of 200 characters are to be sent once a day.

$$T_{IdleHours} = 24 - T_{SendingHours}$$

$$T_{SendingHours} = (1/60) * (6.5/60)$$

Energy consumption is as follows.

$$J_{Daily} = (T_{IdleHours} * 125\ mA) + (T_{SendingHours} * 130\ mA)$$

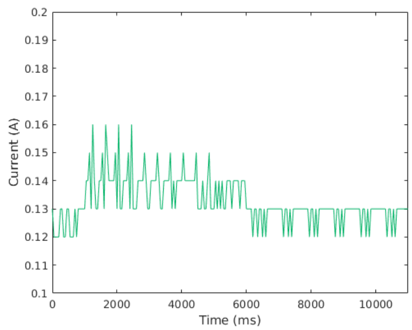
$$J_{Daily} \approx 3000\ mAh$$

$$J_{Weekly} = 21000\ mAh$$

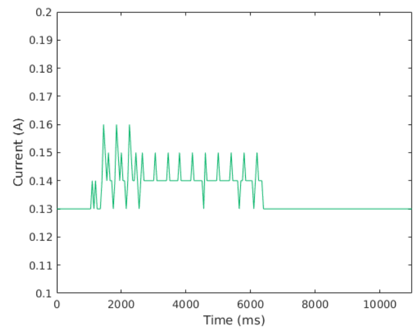
Now this scenario produces a significantly higher energy consumption. 20000 mAh batteries are no longer acceptible for this sensor node.

Figure 4.1: Current signature when sending SMS messages

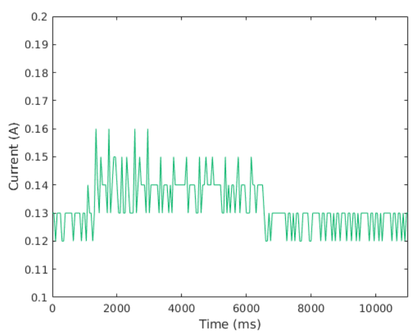
(a) Single character SMS message



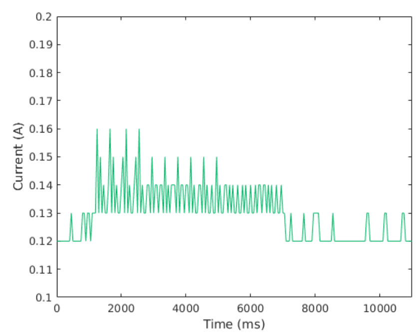
(b) 2 characters SMS message



(c) 50 characters SMS message



(d) 100 characters SMS message



(e) 200 characters SMS message

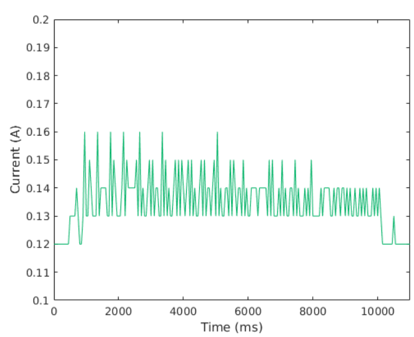
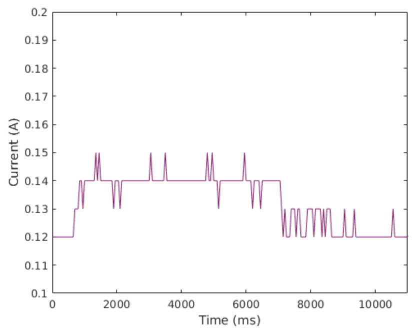
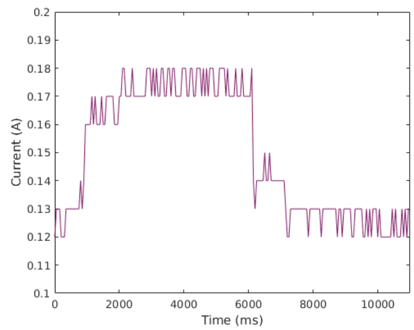


Figure 4.2: Current signature when sending HTTP packages

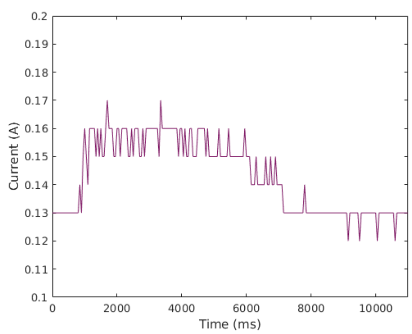
(a) Single character HTTP package



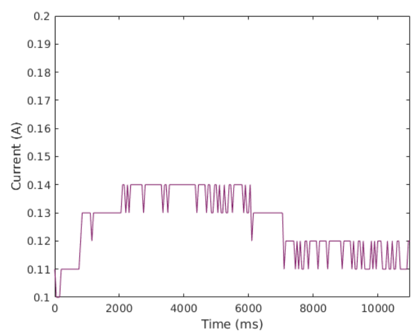
(b) 2 characters HTTP package



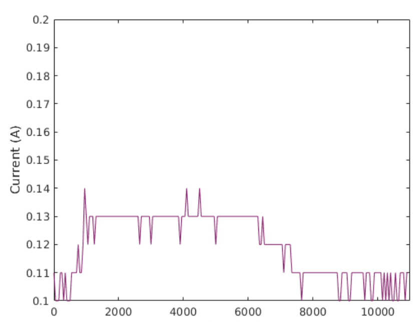
(c) 50 characters HTTP package



(d) 100 characters HTTP message



(e) 200 characters HTTP message



Chapter 5

Discussion

The following chapter conforms to a structure split into three sections. First, the methodology is discussed in it's two subsections: design and evaluation. Secondly, the results are discussed, also split in the subsections design and evaluation. Finally, a short section adresses the the work from an ethical perspective.

5.1 Method

This section covers discussion related to the method chapter.

5.1.1 Sensor Node Design

The design choices produced a functional node. However, there has been no evaluation of accuracy or power usage of the selected sensor in comparison to other sensors. There was a brief literature study on available sensors which did point towards thermistors as a viable alternative. The network technology was selected due to availability rather than energy usage. That being said, it is unlikely that widely spread out sensor nodes will be using anything but GSM for communications in South Sudan. There is no other obvious candidate for transmission technology other than GSM.

Lewis [13] mentions thermistors as a viable choice of sensor for flow measurement. A thermistor requires some tinkering to be placed within a pipe. However, thermistors are extremely cheap and a design utilizing them can produce cheaper nodes. That might have been beneficial to look into for the purpose of keeping the overall system cost down.

2G was selected for communication due to limitations of what was available on location. Asplund et al. [15] states that for file transfers smaller than 200KB, 2G is more energy efficient than 3G due to the comparatively high tail energy of 3G. Therefore 2G might be a suitible contender against 3G for sensor nodes even in the case of 3G being available.

As explained in Section 3.2, Power Management, the microcontroller can not utilize it's sleep mode because it does not know when pulses from the sensor are about to arrive. There are however potentially more efficient ways to count pulses. Some dedicated hardware buffer that counts pulses while the micro-controller sleeps could use less energy than the microcontroller itself and thus contribute to energy saving. This should be looked into to achieve a more energy efficient node.

5.1.2 Energy Evaluation

Method selection for evaluating the energy consumption of the node was based on what equipment was available at the time. Selecting different methods could yield more precise results. Vergara et al. [14] utilize a simulated state machine where the wattage for every state is known. Then the time spent in each state during simulation is used to estimate the energy cost of various actions. This is something that might have been interesting to look into. Given an accurately built state machine, their method might have yielded results that could point to exactly how much energy a message of a particular sort or volume costs and thereby the actual impact on battery life the various choices can have.

5.2 Result

This section covers discussion regarding the result chapter.

5.2.1 Implementation Problems

The sensor node was constructed with the selected Arduino framwork, the GSM Shield 2 and hall sensor. The library for controlling the GSM Shield 2, <GSM.h> had some issues with the overall design of the node. <GSM.h> ran serial communication on the only hardware interrupt pins of the Arduino. There was a library <PinChangeInterrupt.h> that was able to run interrupts on non interrupt pins. However, these two libraries had different definitions of serial communications that were incompatible with eachother. <GSM.h> had only defined serial communication for digital pins, so the solution made for the prototype was to comment out the definitions for the digital pins made by <PinChangeInterrupt.h>, and run the water flow sensor on an analog pin. This problem appeared mainly because of the selected libraries and is not a general micro controller problem.

5.2.2 Overall Power Usage by Transmission Strategy

Regarding the tests for overall power usage for various transmission strategies. Measuring equipment of finer granularity should have been used. The current measurements show that broadcasting as often as every 7.5 min is free in terms of energy, which is not true. The relation between energy used and frequency of equal size transmissions should be roughly linear. In other words, the longer messages that are being transmitted, the more energy is spent sending the message. However, impractically short time between transmissions had to be used to provoke a change in measured energy usage that the measuring instrument could pick up. Another solution to this problem would be to run the tests for longer periods of time such as a week or two weeks.

These measurements were done using a household energy meter and an adapter before the sensor node. Therefore, some of the energy measured in these tests should amount to what the adapter drains. Note that while this particular adapter will not be used on location, something similar still has to be there since the solar panel does not deliver the voltage that the system itself uses.

5.2.3 Power Usage for Communication

While both tests would also benefit from measuring equipment of finer granularity, they are still useful in the reasoning behind selecting transmission strategy. The results in table 4.2 shows that the time spent in a highly energy consuming state grows less than linearly proportionate to the data size. With more precise measuement equipment, one might dive deeper into exactly how much energy can be saved this way.

The difference of energy use found between suspended and idle states of the GSM modem turns out to be an area in which it is possible to save energy. For a sensor node that does not require any actuator, in other words, a node that only needs to send messages and never receive any, the ability to suspend it's communcation device should be utilized.

As for selecting to transmit with either HTTP via GPRS or SMS messages, it was found that for larger messages (100 character payload and more), GPRS seems to spend less time in a high energy state. The opposite seems to be true for smaller messages, where SMS messages had the system spending less time in a high energy state. Therefore, given that a sensor node should be sending small messages, SMS-messages might be a better choice for energy saving and vice versa.

Another argument for sending SMS-messages is dependent on location, or more specifically the 2G providers available. Utilizing mobile data, which the internet packages through GPRS do, almost always has some traffic cost. However some providers allow for unlimited SMS messages to be sent within a certain contract. This should be reviewed before committing to a transmission method.

It should be noted that the location of transmission might affect the behaviour of these sends. The tests performed in this report were all carried out in the same location in Mjärdevi, Linköping. The test location has good reception. Nodes might eventually be located in areas with poor reception and that might affect results. For these locations, power useage should be higher during communication and average bitrate should be lower.

When posting to a cloud service or internet server, the package that it receives should most likely be an internet package. If SMS messages is selected as transmission method then it might need to be received and parsed before it reaches the server. This can be achieved with a microcontroller, a GSM modem and an Ethernet module.

Looking at Figure 4.2b, it remains unknown as to why that test in particular had the sensor node reaching and holding noticeably higher currents throughout the test. The test still shows a distinct idle current and a send current, and it shows a send time that is similar to that of Figure 4.2a which follows expectations. The only thing that should really increase overall current usage of transmission is if the node reads the signal strength of the network as weak; The tests were all conducted in the same location and should therefore be under practically the same conditions regarding percieved signal strength. Since the message size should not affect idle energy, and that is read noticeably different, the high current of this test is most likely an inaccuracy of the current sensor.

5.2.4 HTTP for Sensor Nodes

The messages used for the current signature tests had the sensor node transmit a HTTP message. As it costs energy to receive data as stated in the Energy Consumption section 2.1.4, a sensor node would save energy by using a connectionless protocol, such as a UDP-based application rather than HTTP, which is TCP-based.

5.2.5 Tradeoffs in Energy Savings

As one might notice in green computing, reducing the energy cost usually comes with a price, often materialized in performance. This section aims to adress some of the weigh offs with this particular sensor node. The current used when transmitting SMS-messages averages at around 0.14 A at 5 V, and when idling 0.125 also at 5 V. Sending 200 characters in 50 character messages has the node in the high energy state for 21.6 seconds as opposed to 9.2 seconds which is the length of time that would take for one 200 character send. If a certain node is required to send 200 characters daily, sending them all at once as opposed to in packets of 50 will save it 8,68 J every day.

One should also consider the risk for destruction that a node is in and weigh that against the importance of battery life. As mentioned earlier, if a node is storing a value that is to be sent and it is destroyed before being able to transmit, that measured value is also lost. Therefore the balance goes between saving as much energy as possible and making sure that the measurements reach the server. While one can argue for any frequency of transmission, the value which is selected is to some extent an arbitrary weigh off. However when taking energy consumption into consideration the answer to the question *How often should a node transmit data?*, the answer would be *as infrequently as reasonably possible*.

The degree as to which the measurements are time-critical should be considered and weighed in as well. For this sensor node in particular, there is no problem with having a few days to a week of slack between measuring and transmitting. For some sensor network such as a fire alarm, a few seconds slack might be the greatest acceptible time between sensing and transmitting.

5.3 Answering the research questions

To answer the research questions, the extrapollations from the result chapters are used. First off, RQ1, wether or not we can create a node that can last 7 days without battery recharge while still meeting it's requirements of communication. The answer to that draws from section 4.5.1. Yes, since this example creates a node which draws around 19000 mAh weekly, and there are common batteries that has 20000 mAh or more, it is undoubtedly possible to create such a node.

The answer to RQ2 draws from the same extrapollation, but also from that following section, 4.5.2. The research question aims to explore the impact that the requirement of communication has on the battery lifetime as a whole. These two extrapollations investigate the impact from both the frequency of communication but also the the utilization of sleepmode. This because wether or not the node needs actuators should be part of the requirement. To answer the research question, the impact of bundling messages seems to be very small whereas the impact of actuators is more significant.

5.4 The work in a wider context

The sensor node could be seen as a form of surveillance. However, seeing as virtually every home with water pipes has the same form of surveillance at an even more personal level (per home rather than per community), this should not be a violation of privacy. A goal with the work is to help the remote communities and could thus be thought of as positive.

Another topic to bring up would be the network security. Currently the node does not bring anything more to the table than what is already given with the 2G network. What is created in this project is a proof of concept. Should one want to deploy such a unit, some security evaluation should be done. Currently it is very easy to send false messages to the sensor node and break open the node to have it send false messages to the cloud service.

Chapter 6

Conclusions

This report concludes that bundling data can be beneficial for GSM-based projects. Bundling data produces a fewer total of outbound messages, and thus avoids some of the energy ramps and tails that come with each message. This should be done as much ass possible to save energy. It is concluded that for a constant amount of characters, sending those in as few messages as possible is the best strategy for reducing power cost. Regarding wether to chose SMS or HTTP given the availability of GPRS, it is concluded that SMS messages has the node spending less time in a high energy state for small messages (100 characters or less) while for large packages (200 characters or more), HTTP performs better. Therefore, SMS is a sensible choice for small messages but HTTP makes more sense with bigger payloads. A sensor node's need for actuators should be discussed since a node with a suspended GSM modem saves a noticeable amount of energy as opposed to a node with an idle GSM modem.

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