The First Generation WIMEA-ICT Automatic Weather Station Prototype: An Evaluation Report

Maximus Byamukama [1], *Mary Nsabagwa*[2], *Emmanuel Kondela*[3]

November 3, 2015

[1]College of Engineering, Design, Art and Technology,Makerere University, Uganda
[2]College of Computing and Information Sciences, Makerere University, Uganda
[3]Department of Computer Studies, Dar-es-Salaam Institute of Technology, Tanzania

Contents

List of Figures

List of Tables

List of Acronyms

AWS Automatic Weather Station(s)

EA East Africa

GSM Global System for Mobile Communication

MCU Microcontroller

PCB Printed Circuit Board

RAM Random Access Memory

RF Radio Frequency

RS-mote Radio Sensor Mote

TMA Tanzania Meteorological Authority

TTCL Tanzania Telecommunication Cooperation Limited

UMTS Universal Mobile Telecommunication Service

UNMA Uganda National Meteorological Authority

UTL Uganda Telecommunication Limited

WIMEA-ICT Weather Information Management in East Africa

Abstract

One of the objectives of the WIMEA-ICT project, a NORAD initiative is increasing the density of Weather Station Networks in Uganda, Tanzania and South Sudan. To achieve that objective, a total of 70 Automatic Weather Station(s) (AWS) shall be designed and deployed in the three countries. Before the mass production of the AWSs, three prototypes shall be developed. The first-generation Prototype was deployed in Bergen, Norway hence the name "Bergen prototype". This report presents an evaluation of the first-generation prototype.

Needs and requirements of AWSs form a basis for the evaluation. In this report, we discuss problems associated with the Bergen prototype. We review literature on Wireless Sensor Networks, power management and uplinks to provide informed design decisions. An assessment of uplink options, power management and Wireless Sensor Networks is done. We propose a design for the second-generation prototype while categorizing design decisions under data capture and transmission, which are the main functional requirements. We base our design on attaining a robust and yet cost-effective AWS. We provide an analysis of our design, conclude the report with recommendations for improvement and also suggest future work.

1 Introduction

1.1 Background

The purpose of this report is to make a review of the first WIMEA-ICT prototype as described by the working assumptions agreed upon in [1]. The prototype is WIMEA-ICT project's first version of three Automatic Weather Station prototypes. The project seeks to improve weather information management in East Africa by increasing Weather Station Network density among other objectives. To achieve that objective, we initiated the design of a affordable and robust AWS with a first-generation prototype also called The Bergen Prototype. Before mass production of the Automatic Weather Stations, we planned to design and test three prototypes the first being subject of this paper. The first-generation prototype is already operational [2] and is providing us a basis for refinement from which we shall derive the second generation prototype, which we refer to as *The East African Prototype* in this document. While the first-generation prototype performs the basic AWS functions, we still target to improve a number of performance requirements in order to attain an optimal design. To this end, we discuss requirements of AWSs and refer to them for justification of the evaluations and recommendations we make.

The rest of the document is organized as follows:- We begin with needs and requirements discussion in this section. In section 2, we make a review of the first-generation prototype, in 3, we discuss work related work, in 4, we discuss our proposal, in 5 we make an analysis of our design decision and we lastly conclude and give areas that need to be investigated in future work.

1.2 Needs and Requirements of Automatic Weather Stations

An AWS is an instrument that measures and records meteorological parameters using sensors without human intervention. An AWS is typically composed of processing unit called data logger (CPU, volatile and non-volatile memory, and I/O interface), connected to a number of meteorological sensors, and communication unit.The World Meteorological Organization (WMO) recommends standards and requirements for Automatic Weather Stations. The recommendations are a basis for assessing performance of the first-generation prototype. Additionally, we refer to several other requirements derived from our previous country surveys and in consultation with both Uganda National Meteorological Authority (UNMA) and Tanzania Meteorological Authority (TMA). The survey findings highlight failure of many AWSs to meet non-functional requirements a reason for the failures. Below are the core functional requirements of AWS

- Capture weather data
- Process captured data
- Store collected data
- Transmit data

For several reasons, many Automatic Weather stations fall short of the above functions for failure to achieve the non-functional requirements. To that end, we give a discussion of the non-functional requirements, which we recommend for the second generation prototype. Below are the non-functional requirements we recommend for the AWS

- **Reliability:** We use reliability to refer to the probability that the AWS will perform its intended functions under specified design limits.
- **Data Quality**: Data should be free from alteration.
- Cost: Both initial and maintenance/operational costs should be low.
- **Security**: We consider security of both the weather station and data
- **Usability**: The AWS should be easy to install and configure
- **Scalability**: Ideally, the system should allow unrestricted sensor node placement. It should be easy to expand the network of sensor nodes.
- **Power consumption**:The power consumption should be as low as possible.

It is from the above requirements that we base subsequent sections to evaluate the Bergen Prototype and propose a design decision for the East-African Prototype.

2 Problem Definition

The problem is that the Bergen Prototype is not adapted to the East African context. East Africa poses a number of unique challenges and opportunities, which tend to differ from those of Bergen in which the current prototype is deployed. Because the AWS is a system made of interacting sub-components, a change in one component could also affect another. The general problem can thus be split into several sub-problems, each to be addressed individually and in light of the other sub problems. These are listed below.

2.1 Power Consumption

We believe power consumption of the Bergen prototype can be reduced substantially by changing the current gateway, the Raspberry Pi. Sources from the Internet [3] and experiments [4], the bare board consumption is about 1W. Power consumption can be reduced in three ways. First, by changing the gateway platform from the Raspberry Pi to a more power lean one. Secondly, from the data file of the current implementation [5], we see at least 5 packets received in a 1 minute time frame. The frequency with which the packets are sent increase power consumption. If frequency with which packets are sent is decreased, the gateway will be idle for a larger fraction of time. This calls for implementing power saving strategies like a sleep-wake up routines leading to a substantial power consumption reduction. Thirdly, by implementing the first and second option simultaneously.

2.2 Power Supply

The Bergen prototype uses solar panels to charge supercapacitors that provide power to the circuitry. Because insolation in Bergen is much lower and less available than in East Africa, we believe that the size of panels can be reduced. An active research area of one of the PhD students is the smallest possible panel size that can sustain an AWS installation given the solar irradiance in Uganda. Also, we intend to review the frequency at which data is received and sent with an objective of reducing power consumption. Reducing the panel sizes is also of particular importance because it is a way to deter vandals of AWS equipment as this was found to be a serious challenge for UNMA and TMA in the Weather Station Survey carried out in November to January 2014 [6], [7].

2.3 Communication

This sub-problem is concerned with the most reliable and cost effective way of getting data from the AWS to the central repository given the conditions where the AWS is installed. A proper algorithm can be developed to enable the choice between cellular network connection, other terrestrial wireless options (VHF/UHF/SHF), copper wire, optic fibre, satellite, Sneakernet (physical data retrieval) or some combination of some of these. The selection has to be done keeping in mind the consequences it may have on power consumption, integrity of the data and other issues.

2.4 Data accuracy

Correlations between Bergen Prototype data and a well tested Automatic weather station exhibits some degree of variance. The Figure 1 shows a one week correlation of temperature data of a Davis station and the Bergen Prototype. One thing to note is that differences increase with high temperatures and isolation. This means that the Bergen Prototype needs to be benchmarked against a standard AWS such as the DAVIS AWS above.

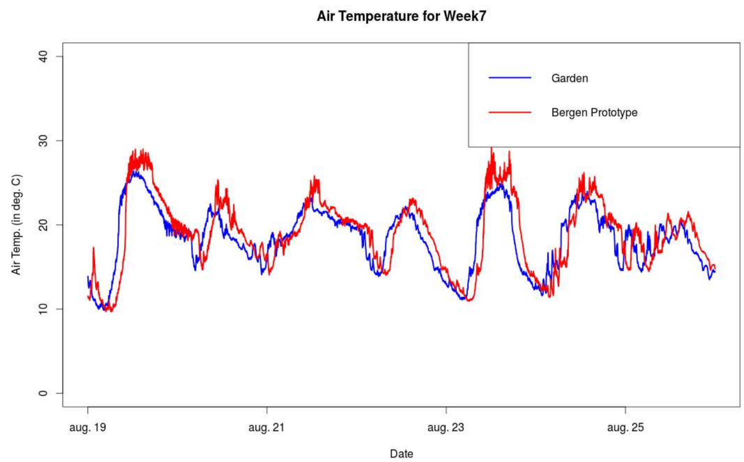

Figure 1: Temperature Correlations between Bergen Prototype and Davis

3 Related Work

In this section, we discuss the effort and reserach that is being put into the design and deployment of Automatic Weather Stations in both industry and academia, and the various technologies in use and some challenges faced.

3.1 Wireless Sensor Networks

The concept of environmental monitoring using AWS is steadily becoming synonymous with WSNs around the world especially for remote installations of AWS such as [8], and IoT applications such as [9]. WSNs offer several advantages including unmanned operation, easy deployment, scalability and real-time monitoring among others. Better still, they can be deployed in hard-to-reach areas. The deployment of WSNs in environmental monitoring further gained momentum after the ratification of IEEE 802.15.4 standard in 2003 (and later in 2007) [10]. A similar project is presented in [1], which consists of wireless sensor nodes that employ an Atmega128RFA1 microcontroller [11] with built-in RF transceivers, a wide range of meteorological sensors and a supercapacitor-based power source. The sensor nodes capture, process and transfer meteorological data to a gateway via sink-node.

Unfortunately, WSNs do not come without challenges, which are majorly constrained storage and computing resources [12],[13]. These challenges are the centre of most research in this area. There have been various efforts to reduce power consumption of the radio such as;

- The use of renewable power sources [14] and duty cycling. This is one of the areas that has received extensive attention [15]. While most of such proposals improve power saving, they still cause a degradation of quality of service and their implementation is not trivial. Optimizations are made on a selected set of layers and this may only offer energy conservation on individual layers. Cross-Layer duty cycling has been proposed [16].
- Other research efforts to address the above constraints by introducing new design methodologies and creating or improve existing protocols and applications.

Some other challenges of WSNs and their solutions have also been discussed in a wireless sensor network survey by Yick and others [17].

Another challenge is the transmission channel itself, which is unreliable in nature, and a number of phenomena can prevent a transmitted packet from reaching a receiver, such as RF interference. Inteference may cause a signal to lose integrity at the receiver and this would require the transmitter to re-transmit, at the cost of additional time and energy. Interference can come from the same WSN if the underlying medium access technology does not schedule contention-free communications. Interference can also come from another network operating in the same radio space, or from a different radio technology using the same frequency band.

3.2 Uplinks

An AWS may use a set of various uplinks with a given variation in transmission requirements such as radio transmission power and cost. The common uplinks that have been used to transfer meteorological data to the central monitoring systems are wired [18], terrestrial wireless or satellite links. The wired transmission realizes the transmission of meteorological data very well, but the deployment cost is relatively high and it is difficult to deploy cables in unfriendly environments, such as mountains. Satellite transmission offers wide coverage, but may be more expensive than terrestrial wireless transmission (see section 5.1.3).

In [19], the use of GSM/GPRS is proposed as an uplink. Sensor nodes use the IEEE 802.15.4 protocol to transmit data over a short distance. Unfortunately, the GSM module consumes much power and drains the source within hours. Similarly a project called TAHMO [20] has been developing robust network of (AWS)s in Kenya. Each station has GPRS-enabled data logger Em50G and typically uses less than 500 KB per month. The Em50G doesnt use voice, SMS (texting), or WAP protocols. The cellular carrier supplies SIM-card with an APN setting to access internet data. The Em50G doesnt require a public or fixed IP address nor does it use mobile terminated services. Other similar environmental monitoring systems have tried the option of using GPRS modems, but they were not providing a stable connection [21]. In more detail, it was found out that GPRS modems tend to lock up after extended periods of time (2-4 days) and can be recovered only by power cycling.

Besides GSM/GPRS networks, the work demonstrated in [22] compare alternative wireless links for transfer of data from sink nodes of remote WSNs to a central repository. Experiments have been made using two of the amateur radio bands, the 144 MHz band (VHF) and the 433 MHz band (UHF). The parameters studied include throughput, range, power-requirements, portability and compatibility with standards. Similar environmental wireless sensor network projects have been known to use off-the-shelf solutions in [23] and [24]. A 900 MHz radio modem called FreeWave Ranger is used in these projects. This device can give 115.2kbps throughput with about 90 km range with clear line of sight. Similarly, the work in [25] presents a vision for a new generation of amateur radio networking. The work offers an opportunity to design, develop, deploy and implement new narrow-band, wireless network protocols, and to experiment with new applications. It connects seamlessly with the Internet, enabling amateur devices to appear and be part of and directly accessible from the Internet. The Internet-connected forms a unique large-scale test-bed that will enable amateurs and others to use these new networks to collect data from meteorological and other environmental sensors that are distributed over large, remote areas and make these observations available in real time over the Internet.

The main industry players in use a variety of options in this area, depending on the applications. We looked at equipment from Vaisala, Davis and Campbell Scientific among others. In [26], a Vaisala HydroMet Automatic Weather Station MAWS201 is used to transfer a record of meteorological data using a UHF radio modem.

Satellite communication may offer long distance transmission but may use more power than terrestrial options. In [27] a long-range environmental monitoring system, uses a Skystar 360E modem and 900MHz ISM Band to transmit meteorological data via KU-band satellite link with a high reliability of 97% with an interval of 10mins. It reaches up to 64Km via very small aperture terminal (VSAT), with a maximum inbound data rate of 3.5Kbps, while the maximum outbound data rate to the central server is around 20Kbps.

3.3 Power

Automatic weather stations are powered using a wide range of techniques. In accessible areas with grid power, the stations may be connected to the grid and in remote areas, they are powered by batteries charged using either solar power or wind. In [28] the Australian Bureau of Meteorology shows a typical AWS used by them that could be powered by AC or other options. In the first generation prototype, the sensors are powered by supercapacitor batteries being charged by solar energy. The use of supercapacitors to power wireless sensor nodes is steadily growing, with some work cited as early as 2006 [29] and some even deployed in the particular case of an automatic weather station[30].

4 Design Proposal

Following from challenges of the Bergen prototype, lessons from similar systems and requirements, we now propose a design for the East African prototype. We classify our design proposal into data collection and transmission

4.1 Data Capture

Under data capture we discuss the hardware used in sensing.

4.1.1 Sensors

The actual sensor devices to be used are the responsibility of another set of component on the project. Sensors were already selected with the exception of a rain gauge. Table 1shows sensors to be used in the East Africa (EA) prototype. We propose to use the same sensors, which are used in the Bergen Prototype. The parameters to be measured are listed in section 3 of the Weather Information Management in East Africa (WIMEA-ICT) progress report [1]. The RC3 concerns on this matter are:

- Type of sensor (Active or Passive): This determines whether the sensor will need power to operate or not and if active, how much power
- Electrical / Electronic interfaces supported by the sensor: The Microcontroller (MCU) processing measurements must have support for these interfaces
- Distance of the sensor from measurement point: This determines the length of conductors and possibly affects data integrity.

Distance of sensors from the ground is crucial for this design and as such is also included in table 1 below.

Table 1: Selected Sensors for use

Parameter	**Sensor**	**Distance From Ground(m)**
Temperature	SHT25	2
Relative humidity	SHT25	2
Atmospheric Pressure	PM6511	2 or 10
Solar Insolation	S1223, VTB8440,BPW20R	10
Dew Point	Calculated	
Precipitation	To be Decided	0
Wind speed	InspeedWortex Series II	10
Wind direction	InSpeed E-VANE2	10
Soil Temperature	DS18B20	0
Soil Moisture	VH400	0

The first-generation prototype uses an Radio Sensor Mote (RS-mote) mote [31] which has two analog inputs among other components. We shall use the same for the East African prototype. All sensors will be connected directly to a wireless-enabled microprocessor unit on a Printed Circuit Board (PCB), which will capture and transmit data to the gateway. For sensors at a distance from the PCB, such as the soil moisture sensor, the PCB tracks will be extended by flexible wire to the sensor location.

4.2 Data Transmission

Under this section, we discuss transmission media including both uplinks and sensor to gateway links. We also discuss hardware and software specifications for the gateway.

4.2.1 Sensor-Gateway link

Sensors will communicate with the gateway wirelessly using IEEE 802.15.4 protocol. This protocol is specifically for low data rate and short-range wireless networking[32]. Frames of a maximum of 127 bytes will be sent out at configured time intervals, one minute being the default.

4.2.2 Gateway

We have chosen ATMEGA128RFA1 for the gateway because it contains an integrated IEEE 802.15.4 transceiver and consumes very little current. That is, less than 200nA during deep sleep mode [11], a feature which will be useful for radio duty cycling in order to reduce power consumption. Also, a contiki has been ported to the RS-mote [31] and is already being used by the current prototype. Contiki was chosen because of its small memory footprint among other advantages. We shall use the same operating system for Version 2 of the EA prototype.

Other platforms can be investigated later in preparation for the 3rd generation prototype. The programming language will be C.

The gateway will be programmed to achieve the following tasks:

1. Receive radio frames
2. Buffer radio frames in Random Access Memory (RAM)
3. Save the frame as a string into an existing ASCII text file
4. Upload the frame using a selected uplink through one of the standard interfaces
5. Set the next wake up time and go to sleep

The East African Prototype shall support the use of all types of uplinks listed below.

1. **Wire (Optic Fibre or Copper)**: Cellular service providers in both Uganda and Tanzania have a copper wire infrastructure. Tanzania Telecommunication Cooperation Limited (TTCL), and Uganda Telecommunication Limited (UTL), have copper as a core part of their network, and its use for private services can be arranged if the terminal equipment is close to an access point. The main disadvantage is that this service is only available in urban areas or rural townships. Other commercial cellular service providers like MTN Uganda are phasing out these links and replacing them with optic fibre for higher throughput.

   Using optic fibre as an uplink may be a viable option. Excluding commercial cellular network providers that use optic fibre as part of their infrastructure, there is a national optic fibre backbone in Tanzania [33]. The Ugandan Government and Google are still in the process of laying fibre cable [34],[35]. For the larger part, the use of such uplinks and the tariffs to be associated with them requires agreements between meteorological authorities and the service providers or government.

   If the gateway is deployed indoors for reasons including security or access to grid power, and a wired connection is available, then the uplink can be implemented using a protocol such as Ethernet. In such a case, the gateway can connected via Ethernet controller. One such device that was reviewed is the RTL8019AS [36] from RealTek which is a full duplex Ethernet controller. A ready to use module employing this controller and an ATMEGA128 on a single PCB has been found to be readily available [37]. The RTL8019AS is also supported by Contiki.

2. **Commercial cellular service**: These have seen an exponential growth in East Africa, with a penetration rate (subscriber-based and not geographical reach) of 53% in Uganda [38] since their introduction in the 1995 and 69% in Tanzania[39]. Such high penetration rates, and the existence of service providers in competitive oligopolies which lower prices, make these networks major contenders in general point to point communication nationwide and as such, they are the main uplinks in use for both UNMA and TMA.Terminal equipment is readily available and no additional licensing is required from end users. As such, we looked at a number of Global System for Mobile Communication (GSM)/Universal Mobile Telecommunication Service (UMTS) capable devices that can be used in the East African Prototype.

   Because of the gateway choice, only Non-USB devices have been considered. Several modules have been investigated including SIM900 [40] and SIM800 [41] series from SIMCOM, the SARA-G3 series [42] and LISA-U2 series from U-Blox [43] and the intel XMM 6255 [44]. The active power consumption for all these modules in 2G mode is roughly similar (300-500mA) and all have sleep currents below 1mA. The SIM800 series has a readily available compact breakout board(2.5cm x 2.5cm)[45] and has a wide development community. It is also relatively cheap (about $9). The boards support standard AT commands and manufacturer enhanced AT commands for specific functions. All support at least one standard interface on the ATMEGA128RFA1 such as UART (RS-232 and SPI) and I2C.We recommend that several of these are tested and a final decision made.

3. **Dedicated RF**:UHF/VHF as described in the IEEE 802.11af specification summary [46] and other dedicated Radio Frequency (RF) transmission techniques can be used under a two scenarios. That is as a last mile solution from the AWS to a core network such as optic fibre or commercial cellular network [47] and as a direct uplink to a gateway within range.

   The selection of an appropriate VHF/UHF device will depend heavily on the location of the AWS. The antenna height and transmission power will depend on the transmission distance required and the nature of surroundings (such as vegetation). The appropriate devices are left open for now. However, some devices that were looked at and can be investigated for short ranges (1-2 km clear Line of Sight (LOS)) include those based on the PT2272 and PT2262 pair from Princeton Technologies Corp. [48] and the XBEE Pro 900HP, a long range 900MHz RF module that, according to the manufacturer works up to 40km LOS with a high gain antenna [49]. These both expose a serial interface (RS232) that the micro-controller can use and could be suitable for scenarios in which the gateway is powered from mains (for example indoor gateway deployments) such that the power required for these long distances is not a critical issue.

4. **Satellite**: This is favorable for Machine to Machine (M2M) communication especially when the two machines are separated by very large distances. It is also an option to consider in the absence of cellular network coverage. We looked at available options from Iridium [50] and NuPoint systems [51] including their tariff plans. At first sight, the devices are quite expensive although the tariffs [52] seem acceptable, depending on the service provider. The Iridium 9602 can be used for short burst machine to machine communication and costs between 250 to 500 USD [53]. It is portable and exposes an RS-232 compatible interface. The systems at NuPoint did not have any prices attached. In Uganda, some projects and schools use VSAT for dedicated internet service, such as that offered by Uganda Telecom Ltd.[54].

5. **Physical Data Transfer (Sneakernet)**:An SD card will be used over the SPI interface of the host device. All local data will be stored on this card. A human observer will be able to retrieve this card and save it to a computer.

4.3 General Design Issues

The mechanical frame, which will hold the sensor nodes should be strong and corrosion resistant. We propose designing tripod masts made of stainless steel, aluminium, carbon fibre and galvanized iron. Because the metal fabrication industry is very well developed in East Africa, we recommend that the mechanical frame be manufactured locally.The 2m mark should have a flat panel with screw holes to enable the enclosure to be tightened. We recommend using an adjustable panel to ease adjustments in orientation.

Material for the pole on which the 10m node will rest must be light and rigid. It also needs to be affordable.

Radiation shield design for the node that hosts temperature and humidity sensors has already been started and sample shields have already been printed. One good idea that has been shared is to have a solar insolation sensor on top of the shield. The design of these shields will be a collaboration between RC1 and RC3. The WIMEA project can arrange for the purchase of a 3D printer to enable fast prototyping. Such design could be made a task for undergraduate students to enable faster progress.

We suggest the use of standard drill bits and standard cable glands to create IP66 (or better) compliant enclosure boxes for the electronics. IP66 is a chosen rating because the tropical downpours in East Africa could be sufficiently strong and last a long enough time to penetrate the enclosures.

4.4 Power Supply

The power supply design is one of the things expected to change because of differences in solar intensity and duration between East Africa and Bergen, Norway where the current prototype is deployed. We recommend that more experiments are carried out to establish facts. A lot of work has already been done using supercapacitors to power the RS-mote [55] and other gateways [4]. An RS-mote has already been shown to run for about six weeks on a single charge. We anticipate better results with the East African deployments. We propose conducting experiments on the use of hybrid power supplies and very small solar panels to charge the storage devices (see future work). We expect that results from these experiments will be ready before June 2016.

4.5 Overall System Architecture

In the current prototype, we have 4 nodes termed as the sink, 2m , 10m and the ground nodes. The only parameter the sink node measures is atmospheric pressure.This node is located away from the other nodes because the gateways power source is from AC mains. For cases in which the AWS installation will be near office premises such that the gateway can be housed and possibly powered from indoors, the current architecture sufficesi.e, all nodes are outdoors and the sink node is indoors connected to the gateway. An alternative architecture could work in cases where the gateway is attached to the AWS itself. The total number of nodes can be reduced by at least one, using the following guide:

1. The 10m node and the measured parameters will remain untouched
2. The gateway will be installed at 2m from ground level, and hence all parameters measured at 2m can be measured directly by the gateway itself.
3. The ground node will measure the same parameters, with the addition of precipitation once a suitable rain gauge is been agreed upon.

The justification is that this reduces the total number of motes needed hence lowering power consumption and downlink signal quality. In cases where the gateways 2m installation compromises uplink signal strengths, the default architecture can be used. Figure 2 illustrates the suggested alternative architecture.

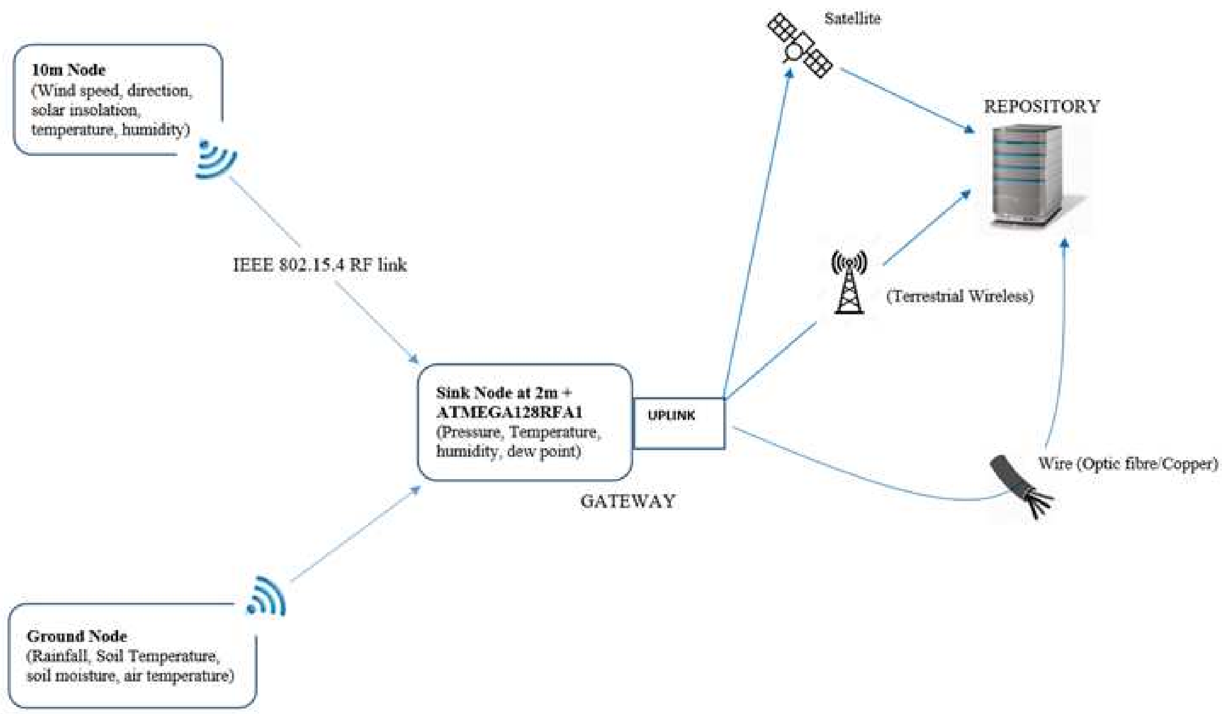

Figure 2: Proposed Alternative Architecture for EA Prototype

5 Proposal analysis and Implementation

We analyze our proposal with reference to the non-functional requirements discussed in section 1. In regards to reliability, Below are some of reasons an AWS might fail to perform functions of either capturing or sending data.

5.1 Analysis

5.1.1 Power Consumption

The ATMEGA128RFA1 will have a better power performance by default because it inherently consumes less current than the Raspberry Pi and the same voltage. It also supports a sleep mode and will permit radio duty cycling. To implement this on the Pi, we'd have to shut it down and reboot it each time, leading to some time wastage in the boot process of the order of 10-30 seconds [56]. Some packets from the sensor nodes could be sent so close to each other than there would not be enough time to power cycle the Pi to and from sleep.

5.1.2 Scalability

The nodes broadcast data that is picked up by any node configured to be a sink node. As such, the prototype will be highly scalable. Any new node to be added can simply be brought into the vicinity of the sink node and its data will be captured.

5.1.3 Reliability

Failure to capture data may result from faulty sensors, lose cabling or power issues. Despite the fact that we are using renewable solar energy, AWSs could still suffer from insufficient power. We suggest the use of duty cycling and low power sensors as a means of saving the limited power. Additionally,we will select robust devices such as cables, sensors and protective material for the implementation. The weather shield should protect sensors from harsh conditions such as dust, rain and direct radiation among other things.

In a Wireless Sensor Networks, failure to send data may result from network-related problems, presence of objects between nodes among other reasons. In regards to network-related problems, our surveys revealed consistent failure to pay for transmission costs. For that reason, we have assessed all the uplink alternatives in relation to cost and availability. We also recommend that more tests are carried out to confirm the claims on coverage before the actual deployments. Due to the variation in network coverage and cost implications, we shall in some cases be required to make trade offs to execute the AWS functions.

When data is successfully captured but for some reason sending fails, we are proposing a buffering mechanism. This is a small sized memory onto which data is temporarily stored for short term connection problems. On the contrary, if communication failure is prolonged, secondary storage can be used. This facilitates permanent storage from which data can be picked when the link improves or by physical transfer.

In cases where data is not received for a long time, we propose sending alerts either by email or to mobile phones. These messages should originate from the receiving end since the entire weather station may be unable to send such messages.

5.1.4 Data Integrity

Compromising data integrity during data capture can be reduced through proper selection of sensors. We shall follow WMO recommendations whenever possible. During data transmission, errors may be introduced from human or media alteration. All the kinds of errors must be detected and corrected using various techniques. The errors may be as a result of channel fading, data collision, hideout phenomenon and others. Various detection and correction techniques can be explored to test the data integrity while evaluating their effects on energy, timing of data delivery, space requirements, bandwidth, complexity and accuracy of the output.

We recommend calibration of the sensors in order to improve data integrity during the data capture. While some aspects including non linear nature of the sensors may manifest themselves in most sensors, some aspects are specific to sensors. We recommend that each selected sensor be tested, calibrated and benchmarked under varying environmental conditions to correct the sensor outputs. Unlike data capture, transmission calls for an evaluation of the available error detection and correction standards. Unfortunately, since Wireless Sensor Networks are constrained, through investigation of effects of such algorithms must be studied to recommend one that does not compromise the performance of weather stations.

5.1.5 Cost

We evaluate cost in terms of both initial and operational costs. Operational costs include replacing faulty devices and paying for communication costs. We suggest the use of easily available components in our designs. Local manufacture of the weather station stands is encouraged to further reduce costs.

In terms of communication, we suggested a combination of uplink alternatives to cater for communication costs. We have suggested switching to different uplink options if they offer cost and reliability benefits. Table 2 gives a comparison of two uplink options. While one may be expensive, it may be the only option in places that may be hard to reach.

Table 2: Sample Transmission Costs

Uplink	**per MSG ($)**	**Max MSG Size (Bytes)**	**per KB(SMS)**	**per KB(GPRS)**
GSM/GPRS	0.00035[4]	160	0.00224	8e-9[5]
Satellite	0.06	50	1.2288	NA

In the above table, it is shown that the cost of sending a single byte of data using a GSM text message

5.2 Implementation

Implementation of the EA prototype will involve software and hardware prototyping, unit testing and assembly. The following activities will take place:

1. Commencement of prototyping for open source Contiki firmware for RS-mote. This will include writing modules for

   - Data acquisition
   - RF transmission and Reception
   - Using the serial port for viewing data and debugging the mote

   We are already familiar with the use of the Contiki OS and have started writing modules for particular tasks as we learn further.

2. Hardware prototyping. This will involve:

   - Making the physical connections and making sure the software interacts well with the hardware.
   - Design and/or optimization of the solar radiation shield
   - PCB to host the node and the power supply.
   - Fitting nodes in their enclosures

3. Unit Testing: Testing shall be done simultaneously with prototyping. The primary goal of unit testing is to take the smallest piece of testable software in the application, isolate it from the remainder of the code, and determine whether it behaves exactly as you expect [57]. The software modules, hardware connections, RF signal and PCB tracks will all be tested as they are developed.

4. Assembly: In this phase we shall put everything together to create an installable AWS in Uganda and Tanzania.

The timeline for this implementation is shown in the Gantt Chart below. We expect to finish the assembly by week 4 of January 2016.

The budget for the equipment needed for the prototyping exercise is shown below. This includes prototyping components and deployment equipment and tools.

[4]Using data from cheapest bundle of Airtel Uganda. 4000 SMS for 5000 UGX (approx. 1.4 USD): More at http://www.africa.airtel.com/wps/wcm/connect/africarevamp/Uganda/Home/personal/voice-and-text/extras/sms/

[5]weekly upload = 6 reports x 127 bytes/report/min * 10080 minutes/week = 7MB data (max) and yet considered the price of an 80MB package. A special bundle could be created just for the AWS for even a much cheaper price

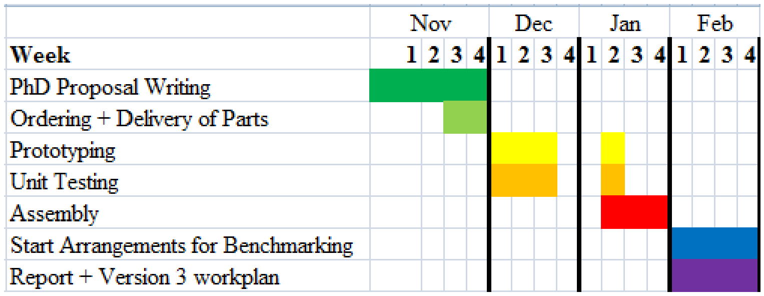

Figure 3: Timeline

6 Future Work

The cost of data transmission is a high both in terms of power and money. The problem is escalated by the frequency with which AWS send data. This data may be meteorological or AWS status data. While meteorological data should be sent frequently, AWS status data does not need this. It is important to look into the frequency at which different types of data are sent. Additionally, coding methods need to be investigated to ensure that smaller packets are sent but yet represent huge amounts of data. Care should also be taken to ensure that the coding does not waste the AWS limited resources like power and memory.

Mobile GSM Telecommunication costs have become a competitive market. Many companies have resorted to promotional offers, which are cheaper than the regular cost of SMS messages and calls. Unfortunately, some good offers are normally available during the night hours. We would like to investigate the possibility of automatically switching uplink options to such offers for cost-saving benefits. Another aspect, which the project can pursue is collaborating with telecommunication companies for customized data packages.

Research on appropriate battery technology to use. It could be the case that other battery technologies with large capacities could power the stations very well until a scheduled human visit. Or, some clients may prefer panel-less designs in which case the choice of battery is critical. Our design is largely based on ultra-capacitors whose minimum voltage is rather high (2.4V) compared to the lowest voltage at which many micro-controllers can operate (1.8V). Given the load profile of the AWS and environment in which it will be installed, the best storage technology for the worst case conditions should be investigated.

Hybrid-Supply Systems: In a given AWS installation, the load profile of the gateway will vary during reception and transmission of data and during sleep or active modes. It may be the case that a good alkaline battery, which are relatively cheap, can sustain all activities other than transmission, which may need another type of storage that can unleash a huge current flow in a short time, such as an ultra-capacitor. Also, if the storage devices are full, there is no need to discharge them if the solar panel power is still available. An idea to look into is a hybrid-supply with automatic switch over between battery, capacitor and solar panel.

7 Conclusion

We evaluated the first generation prototype from several angles by looking at the power system, the gateway, the sensors and the uplinks. We compared with available literature, the needs and requirements and make a design proposal for the EA prototype. Once realized, there will be need to perform benchmarking and calibration tests to bring the accuracy of the prototype as close as possible to a standard instrument.

References

[1] B. Pehrson and R. Olsson, "WIMEA-ICT Research Component 3 Progress report 2014," Sep. 2014. [Online]. Available: http://dx.doi.org/10.5281/zenodo.30674

[2] WIMEA-ICT, "The Bergen Prototype Plots." [Online]. Available: http://wimea-ict.gfi.uib.no/sensors/plots.html

[3] Raspberry Pi Foundation, "Raspberry pi faq. section i." https://www.raspberrypi.org/help/faqs/, accessed: 2015-10-15.

[4] Amos Nungu, Robert Olsson, Jiannan Guo, Bjorn Pehrson, "Towards single watt nJoule/bit Routing." UbuntuConnect, nov 2014.

[5] [Online]. Available: http://wimea-ict.gfi.uib.no/sensors.dat

[6] M. Nsabagwa, M. Byamukama, J. Sansa-Otim, and R. Okou, "REPORT ON THE STATUS OF WEATHER STATIONS IN UGANDA," Nov. 2015. [Online]. Available: http://dx.doi.org/10.5281/zenodo.33156

[7] A. N. Emmanuel Kondela and B. Pehrson, "Status of existing weather observation station network in tanzania and the possibility to automate and densify." IEEE Africon 2015, September 14 - 17.

[8] N. Hema and K. Kant, "Local weather interpolation using remote aws data with error corrections using sparse wsn for automated irrigation for indian farming," in *Contemporary Computing (IC3), 2014 Seventh International Conference on*, Aug 2014, pp. 478–483.

[9] P. Marino, F. Machado, S. Otero, F. Fontan, and C. Enjamio, "Internet-based sensor system for environmental monitoring," in *Sensors, 2004. Proceedings of IEEE*, Oct 2004, pp. 40–43 vol.1.

[10] D. Miorandi, E. Uhlemann, S. Vitturi, and A. Willig, "Guest editorial: special section on wireless technologies in factory and industrial automation–part i," *IEEE Transactions on Industrial Informatics*, vol. 3, no. 2, pp. 95–98, 2007.

[11] Sparkfun, "Atmega128rfa1 development board," https://www.sparkfun.com/products/11197, accessed: 2015-10-20.

[12] L. M. Oliveira and J. J. Rodrigues, "Wireless sensor networks: a survey on environmental monitoring," *Journal of communications*, vol. 6, no. 2, pp. 143–151, 2011.

[13] L. Doherty, J. Simon, and T. Watteyne, "Wireless sensor network challenges and solutions," *Microwave Journal*, vol. 55, no. 8, pp. 22–34, 2012.

[14] D. Kong, T. Li, X. You, X. Sun, B. Wang, and Q. Liu, "The research of long-distance data transmission based on meteorological sensor network," *International Journal of Future Generation Communication and Networking*, vol. 7, no. 1, pp. 59–70, 2014.

[15] R. C. Carrano, D. Passos, L. Magalhaes, and C. V. Albuquerque, "Survey and taxonomy of duty cycling mechanisms in wireless sensor networks," *Communications Surveys & Tutorials, IEEE*, vol. 16, no. 1, pp. 181–194, 2014.

[16] L. D. Mendes and J. J. Rodrigues, "A survey on cross-layer solutions for wireless sensor networks," *Journal of Network and Computer Applications*, vol. 34, no. 2, pp. 523–534, 2011.

[17] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer networks*, vol. 52, no. 12, pp. 2292–2330, 2008.

[18] H. S. Bagiorgas, M. N. Assimakopoulos, A. Patentalaki, N. Konofaos, D. P. Matthopoulos, and G. Mihalakakou, "The design, installation and operation of a fully computerized, automatic weather station for high quality meteorological measurements," *Fresenius Environmental Bulletin*, vol. 16, no. 8, pp. 948–962, 2007.

[19] D. Antolín, A. Bayo, N. Medrano, B. Calvo, S. Celma, and C. Azcona, "Analysis and implementation of a wireless sensor network with remote access through sms," in *Circuits and Systems (LASCAS), 2012 IEEE Third Latin American Symposium on.* IEEE, 2012, pp. 1–4.

[20] R. L. Wilby, "Climate for development in africa (climdev)–climate sciences and services for africa. strategic research opportunities for climdev-africa." 2014.

[21] T. Le Dinh, W. Hu, P. Sikka, P. Corke, L. Overs, and S. Brosnan, "Design and deployment of a remote robust sensor network: Experiences from an outdoor water quality monitoring network," in *Local Computer Networks, 2007. LCN 2007. 32nd IEEE Conference on.* IEEE, 2007, pp. 799–806.

[22] A. Sayin, "Vhf/uhf uplink solutions for remote wireless sensor networks," 2013.

[23] G. Werner-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees, and M. Welsh, "Deploying a wireless sensor network on an active volcano," *Internet Computing, IEEE*, vol. 10, no. 2, pp. 18–25, 2006.

[24] G. Werner-Allen, J. Johnson, M. Ruiz, J. Lees, and M. Welsh, "Monitoring volcanic eruptions with a wireless sensor network," in *Wireless Sensor Networks, 2005. Proceeedings of the Second European Workshop on.* IEEE, 2005, pp. 108–120.

[25] T. J. Salo, "Narrowband ip over amateur radio networks (niparnets) next-generation networking for amateur radio," 2013, accessed: 2015-10-27. [Online]. Available: https://www.tapr.org/pdf/DCC2013-NIPARnets-AB0DO.pdf

[26] P. Heil, S. Gerland, and M. Granskog, "An antarctic monitoring initiative for fast ice and comparison with the arctic," *The Cryosphere Discussions*, vol. 5, no. 5, pp. 2437–2463, 2011.

[27] M. Toledano-Ayala, G. Herrera-Ruiz, G. M. Soto-Zarazúa, E. A. Rivas-Araiza, R. D. B. Trujillo, and R. E. Porrás-Trejo, "Long-range wireless mesh network for weather monitoring in unfriendly geographic conditions," *Sensors*, vol. 11, no. 7, pp. 7141–7161, 2011.

[28] Australian Bureau of Meteorology, "Automatic weather stations for agricultural and other applications," http://www.bom.gov.au/inside/services_policy/pub_ag/aws/aws.shtml, accessed: 2015-10-27.

[29] F. Simjee, *Everlast: Long-life Supercapacitor-operated Wireless Sensor Node.* University of California, Irvine, 2006. [Online]. Available: https://books.google.no/books?id=RyP_NwAACAAJ

[30] Rafael Lajara, Jorge Alberola, Jos Pelegr, Toms Sogorb, J.Vicente Llario, in *2007 International Conference on Sensor Technologies and Applications title=Ultra Low Power Wireless Weather Station year=2007, pages=469-474.*

[31] Robert Olson, "The Universal IEEE 802.15.4 Sensor for WSN and IoT applications." [Online]. Available: http://radio-sensors.com

[32] IEEE Standards Association, "Part 15.4 low-rate wireless personal area networks (lr-wpans)," sep 2011.

[33] NICTBB, http://www.nictbb.co.tz/map.php, accessed: 2015-10-23.

[34] John Nasasira, "Global south-south development expo mini partnership forum on enhancing ict development and connectivity for lldcs," http://unohrlls.org/custom-content/uploads/2014/04/Presentation-Hon.John-Nasasira-Minister-of-Information-and-Communications-Technology-Nairobi.pdf, oct 2013, accessed: 2015-10-23.

[35] Google Inc., "Google project link," https://www.google.com/get/projectlink, accessed: 2015-10-20.

[36] Realtek Semiconductor Corp., http://www.realtek.com.tw/products/productsView.aspx?Langid=1&PFid=15&Level=4&Conn=3&ProdID=22, accessed: 2015-10-25.

[37] http://propox.com, Poland, http://pl110144744.fm.alibaba.com/product/117634927-0/MMnet01.html, accessed: 2015-10-25.

[38] Uganda Communications Commission, http://www.ucc.co.ug/data/qmenu/3/Facts-and-Figures.html, accessed: 2015-10-25.

[39] Tanzania Communications Commission, "March 2015 quartely report," http://www.tcra.go.tz/images/documents/telecommunication/telcomStatsMarch15.pdf, mar 2015, accessed: 2015-10-25.

[40] http://www.simcom.eu/index.php?m=termekek&prime=1&sub=40&id=0000000147, accessed: 2015-10-20.

[41] http://www.simcom.eu/index.php?m=termekek&prime=1&sub=40&id=0000000246, accessed: 2015-10-20.

[42] "Sara g3 series," https://www.u-blox.com/en/product/sara-g3-series, accessed: 2015-10-20.

[43] "Lisa u2 series," https://www.u-blox.com/en/product/lisa-u2-series, accessed: 2015-10-20.

[44] INTEL Corporation, "Intel xmm 6255 modem with intel smarti ue2p transceiver," http://www.intel.com/content/dam/www/public/us/en/documents/white-papers/xmm-6255-smarti-ue2p-paper.pdf, accessed: 2015-10-20.

[45] "Sim800l quad-band network mini gprs gsm breakout module," www.dx.com/p/sim800l-quad-band-network-mini-gprs-gsm-breakout-module-382445.

[46] IEEE Standards Association, https://standards.ieee.org/findstds/standard/802.11af-2013.html, accessed: 2015-10-25.

[47] C Cordeiro, H Gossain, R Ashok, DP Agrawal, *Brazilian Symposium on Computer Networks*. UFRN/DIMAp, 2005, ch. The Last Mile: Wireless Technologies for Broadband and Home Networks,.

[48] SeedStudio, http://www.seeedstudio.com/depot/2KM-Long-Range-RF-link-kits-w-encoder-and-decoder-p-321.html, accessed: 2015-10-20.

[49] Digi International, http://www.digi.com/products/xbee-rf-solutions/modules/xbee-pro-900hp, accessed: 2015-10-20.

[50] Iridium, https://www.iridium.com/products/types/Transceivers, accessed: 2015-10-20.

[51] Nupoint Systems, http://www.nupointsystems.com/satellite-transceiver/, accessed: 2015-10-21.

[52] https://www.satellitephonestore.com/iridium-short-burst-data-service-plans, accessed: 2015-10-21.

[53] http://www.discoverytelecom.eu/catalog/2321.html, accessed: 2015-10-21.

[54] http://www.utl.co.ug/internet/dedicated-services/dedicated-internet-service-over-vsat/, accessed: 2015-10-23.

[55] B. Pehrson and R. Olsson, "Powering devices using ultra-capacitor batteries." IEEE Africon 2015, 2015.

[56] https://www.raspberrypi.org/forums/viewtopic.php?f=29&t=25777, accessed: 2015-10-23.

[57] Microsoft Corporation, "Unit testing," https://msdn.microsoft.com/en-us/library/aa292197%28v=vs.71%29.aspx, accessed: 2015-10-25.