THE WIMEA-ICT AUTOMATIC WEATHER STATION (AWS)

March, 2021

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1 INTRODUCTION

1.1 Background

WIMEA-ICT, which is an acronym for Weather Information Management for East Africa using Information Communication Technology [1] is a project combining research and capacity building. The was funded by the Norwegian Agency for Development Cooperation (NORAD), under the Norwegian Program for Capacity Development in Higher Education and Research for Development (NORHED) scheme. It started in November 2013, ended in December 2020 under the collaboration of four partner institutions, namely: Makerere University - Uganda, Dar-es-Salaam Institute of Technology (DIT) - Tanzania, University of Bergen - Norway and the University of Juba - South Sudan, in collaboration with the National Meteorological Authorities in their respective countries. The main aim of the project was to improve the accuracy of and access to weather information and management by East African communities through suitable ICTs for increased productivity (in the agricultural, energy, water resources and construction sectors) and safety (in the aviation, disaster management, fishing, health, mining, and defense sectors).

One of the objectives of WIMEA-ICT was to increase the density of Automatic Weather Stations (AWSs) in Tanzania, South Sudan and Uganda. With a plan to deploy 30 AWSs in Uganda, 30 AWSs in Tanzania and 10 AWSs in South Sudan, WIMEA-ICT set out to design an affordable AWSs, costing approximately USD 1,000. The WIMEA-ICT AWS is composed of different meteorological sensors structured under three nodes, one gateway for uplink communication and the server. The nodes are named according to the position and/or the heights of the sensors above the ground. The nodes that make up the WIMEA-ICT AWS are; the 2m node that has sensors for reading the relative humidity and the temperature values, the 10m have sensors that read the wind speed and the wind direction values and the solar insolation. The ground node contains sensors that read the soil temperature values, soil moisture, pressure and the rainfall and/or precipitation values. The gateway is a combination of the sink node that receives the weather data reports broadcasted by the three nodes, the particle electron with the GSM module for the internet connection to the server. At the gateway, the RTC module attaches the timestamp to the report received by the sink and the SD card temporarily stores the sensor data report before its uploaded to the server.

2 DESIGN OF WIMEA-ICT AWS

2.1 Architecture of the AWS

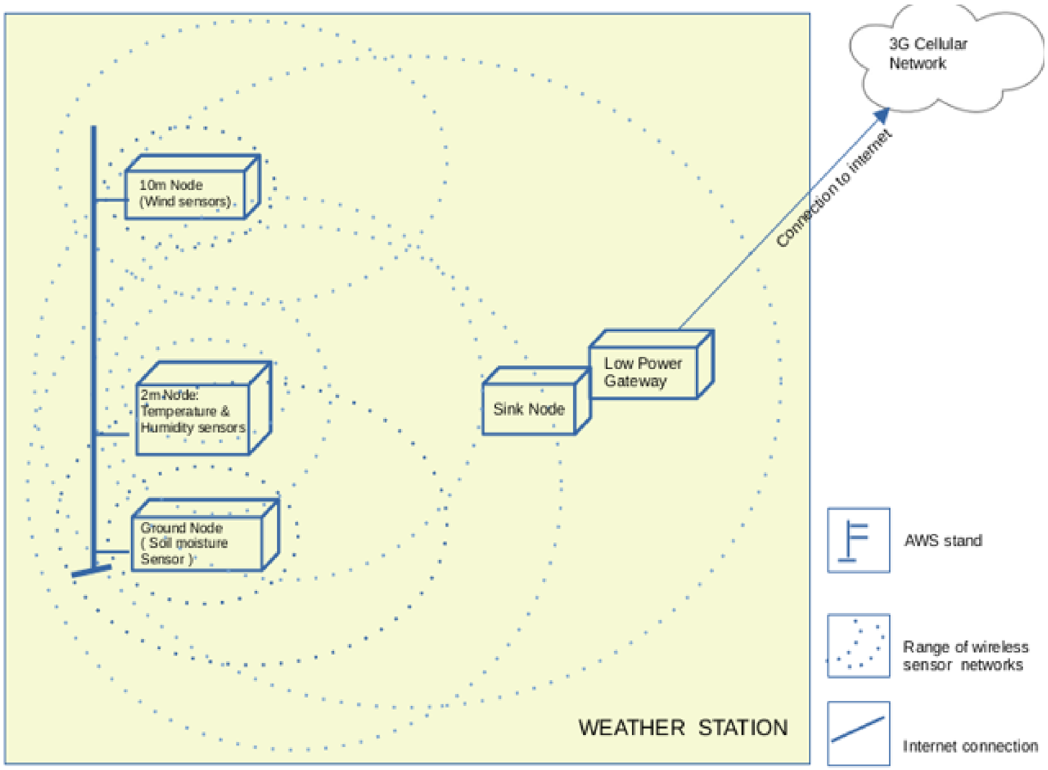

Figure 2.1: The WIMEA-ICT AWS Architecture

Figure 2.1 above illustrates the overall architecture of the WIMEA-ICT AWS. The different nodes (2m, 10m and ground) reads the weather values as per the sensors attached after a given interval, and broadcasts the readings to the sink node. On receiving the broadcast message, the sink node wakes the electron from sleep (the purpose of sleep is to conserve power), writes the data received via broadcast serially to the electron. The electron reads the data from its serial terminal, writes to a file in the SD card and either goes back to sleep in case the data is not enough for upload or uploads the entire recorded data from the file in the SD card to the server.

2.2 The WIMEA-ICT AWS Generations

Over the period of life time of the WIMEA-ICT project, the AWS has evolved into three different generations with generation one being the first and was assembled in Norway, generation two and three were designed and tested in the partner countries (Uganda, Tanzania and South Sudan). The evolution process of the WIMEA-ICT AWS involved massive upgrade and development on the gateway components, in order to achieve a desired goal of developing a low power gateway with efficient, secure and fast uplink and/or internet connection. All three generations of the AWS had an improvement on its components, especially at the gateway.

2.2.1 First Generation Prototype (Gen1)

The first-generation prototype of the WIMEA-ICT AWS, was designed, tested, evaluated, assembled and deployed in Norway, at University of Bergen, it was called the Bergen Prototype. Gen1 was used as a baseline design for two later generations of the AWS. The Bergen Prototype has a network of wireless sensor nodes each measuring some environmental weather parameter and transmitting it to the central gateway. The sensor nodes are small boards running an Atmega128rfa1[8][9] microcontroller with a RF circuitry and the IEEE 802.15.4[10] communication protocol in a 2.4 GHz range. The wireless sensor nodes are classified into the sink node, the 10m node, the 2m node and the ground node, each of the same device type but with different name, network address and the sensors attached to them.

The gateway used was a Raspberry Pi B+[11] running a Raspbian Operating System[12]. The gateway has a receiving node, similar to others, connected to it called the sink node. The sink node is connected to the raspberry-pi via a serial inference and is powered from the raspberry-pi. The gateway daemon, called the sense, reads the incoming frames from the sink node and saves them in a file as human readable ASCII data. The files are accessible over a TCP connection using Ethernet and visualization is possible on a webpage hosted at a webserver in the Raspberry Pi. The raspberry-pi is powered directly from its USB port using a DC adapter connected to the mains electricity. The other nodes are powered directly by supercapacitor batteries that are charged from solar panels through DC - DC converters. To prevent breakdown, the microcontroller goes to a low power sleep state when the voltage reduces to 2.4 volts.

2.2.2 Second Generation Prototype (Gen2)

The second-generation prototype of the WIMEA-ICT AWS also uses a raspberry-pi at the gateway to establish connection to the internet and upload the sensor data reports. The gateway of Gen2 is a combination of a sink node and the raspberry-pi equipped with interfaces for connection and a slot for SD card. Unlike in Gen1 where connection was through Ethernet, in Gen2 the raspberry-pi is configured with the USB Modem at the gateway in order to connect the AWS to the internet, and ensure remote access. The raspberry-pi is connected to and configured with the DC3231 RTC[13] module for correct timestamping. The Gen2 sink node is connected to raspberry-pi using female header jumper wires. The sink node receives the data from the other transmitting nodes and stores on the raspberry-pi. Other arrangements of the network of wireless sensor nodes are still the same as in Gen1 and the motes are used, Model S2 2.3 RSS2 motes[14] with a provision for an optional battery coin cell CR2450[15].

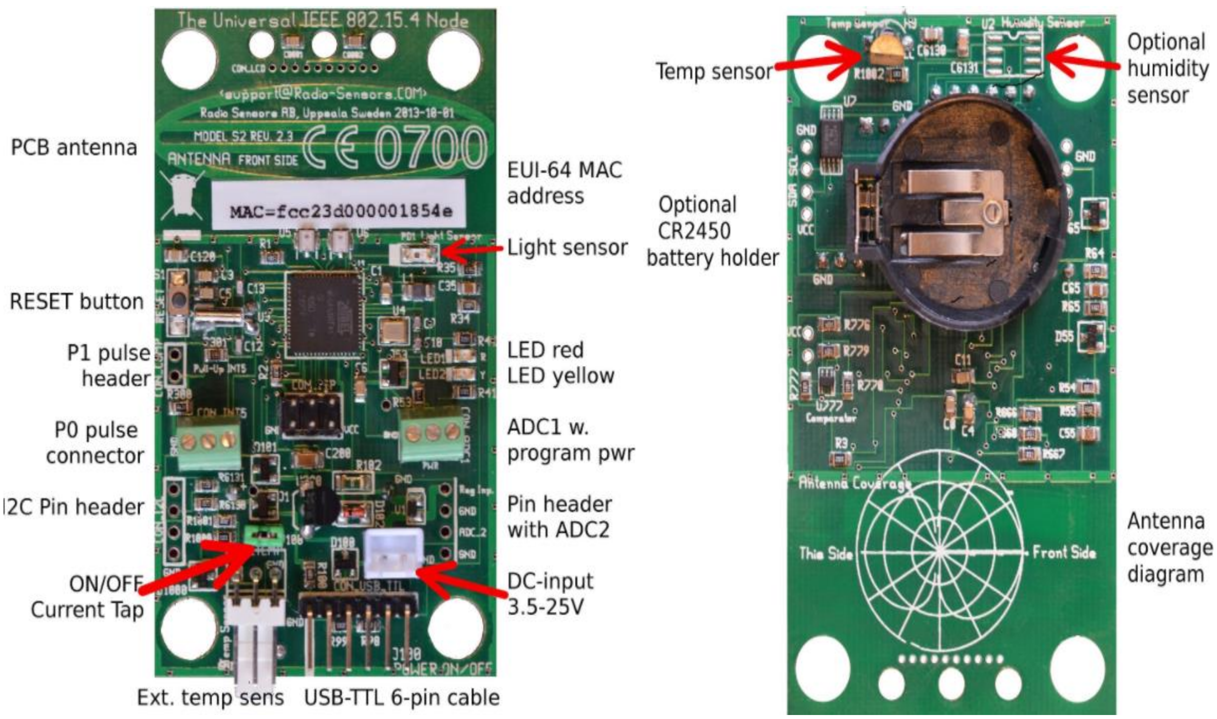

Figure 2.2: Model S2 v2.3 RSS2 mote, the Front and Back view

Figure 2.3: Raspberry-Pi B+ module

2.2.3 Third Generation Prototype (Gen3)

The third-generation prototype of the WIMEA-ICT AWS registered a great shift in its components, from the RSS2 motes through the firmware updates, gateway components replacement to the new design for the stands used for deployment. The new mote being used in Gen3 is Model S2 v2.4 RSS2 mote[14] with new changes in its design, for instance the coin cell battery holders had been removed and the P0 pulse connector and ADC1 program pwr now have the male header pins, and as well, a new pressure sensor. The new motes have Atmega256rfr2[8][9] microcontroller and is run by Contiki Operating System[16], an OS for memory constrained devices. The latest deployment of Gen3 incorporates the Particle Electron[17] as a replacement to the raspberry-pi and the USB modem that was initially being used for internet connection in Gen2. The particle electron is run by Particle Device Operating System (Device OS)[18] and is equipped with the GSM module that enables cellular connection using the sim cards from the local telecommunication companies. The electron also comes with a provision for serial connection whereby the sink node is connected to the electron serially for transfer of sensor data. The electron stores the sensor data to a file in the SD card before uploading to the server and the RTC module is used to attach a timestamp to the sensor data report. The gateway also has a newly designed PCB board (WIMEA-ICT PCB board) that has a low power usage, thus the name, 'low power' gateway. The new stand for Gen3 is as explained in subsection 2.3 below.

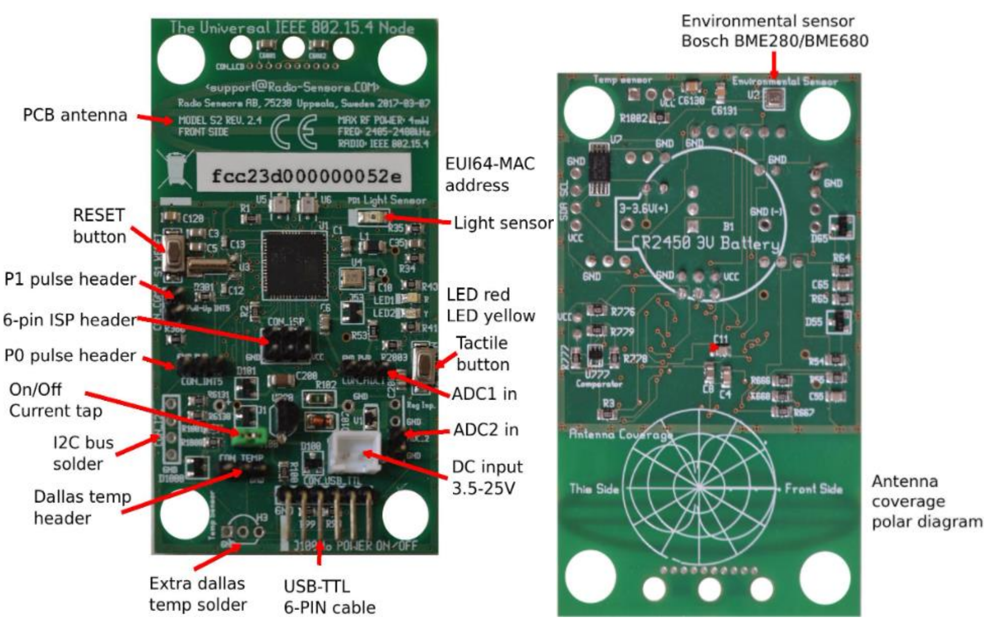

Figure 2.4: Model S2 v2.4 RSS2 mote, the Front and Back view

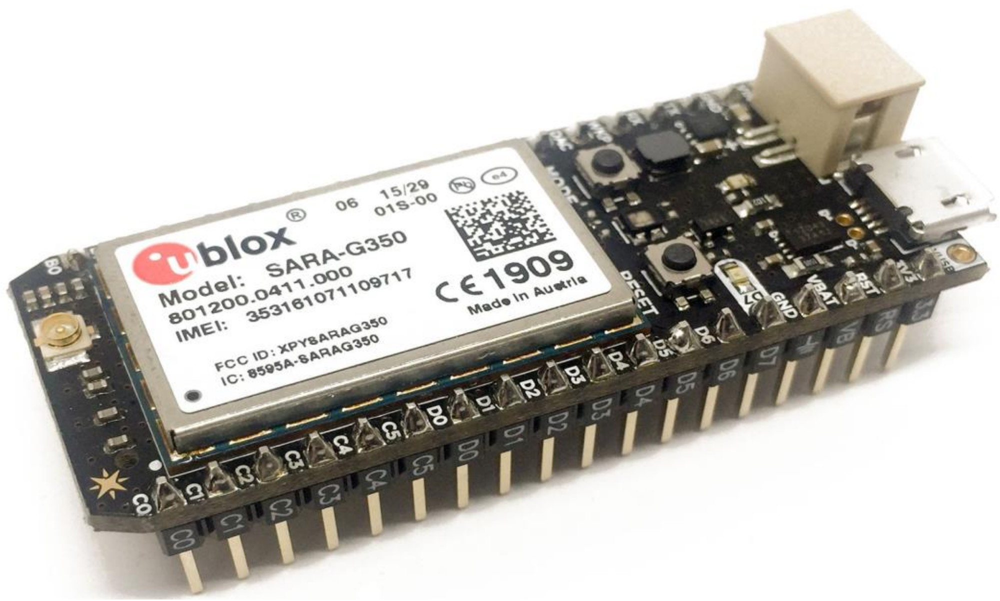

Figure 2.5: Particle Electron module with GSM module

2.3 The AWS stand

The stand for the first and the second-generation prototype of the AWS used a long pole of about 10m. The pole had a horizontal bar a 2m position above the ground to accommodate the 2m node and a provision for the gateway and the rain gauge base.

The stand for the third-generation prototype uses a T-shaped pole (with an adjustable horizontal bar) about 2m long from the ground. About 0.5m of the pole is sunk in the ground to act as the base so as to ensure that the stand is firm and fixed to the ground. The wind vane and the anemometer (wind sensors) are attached on the two ends of the horizontal bar. The enclosure boxes for the 10m node, ground node and the gateway are equally attached at proportional positions on the horizontal bar. The 2m node is attached at two-third on the pole length and is adjustable. The rain gauge base/stand is installed close to the ground at a convenient position from the ground. The new design of the stand is efficient, easy to use, elegant and neat compared to the previous stands which are about 10m long, making installation and maintenance (in terms of changing the wind sensors) quite hard and tiresome. The new stand on the other hand is shorter, doesn’t need a ladder in most cases and it can be adjusted.

Figure 2.6: The New design of the AWS Stand

2.4 The AWS Components

The WIMEA-ICT AWS is composed of basically three subsystems: the remote central server, the gateway, and the meteorological sensors arranged to form a network of wireless sensor nodes. The sensor nodes are small circuit boards with a microcontroller (Atmega128rfa1[9] and Atmega256rfr2)[8] and with some sensors attached on the boards and with provision for other sensors to be attached. The nodes are classified into the sink node, the 10m node, the 2m node and the gateway, all having the same device with a difference only in the sensors installed in them, the name and the network address. Each node has a Model S2 v2.4 RSS2 mote[14] with its microcontroller containing a Radio Frequency circuitry that uses IEEE 802.15.4[10] protocol for communication, that is, sending and receiving packets (sensor data reports) in the 2.4 GHz range. This implies that the measurement of weather parameters and/or data using sensors is possible even remotely without the need for physical presence. The whole AWS system is powered by a couple of rechargeable batteries and solar panels for different nodes. During night and/or heavy rainy seasons when there is no access to sunshine, the rechargeable batteries are normally used as the primary power source for the AWS.

2.4.1 The Sensor Network

The WIMEA-ICT AWS is composed of a number of meteorological sensors, arranged in a network of wireless sensor nodes, for reading the different environmental weather parameters. The sensor network implements the principle of operation of the Wireless Sensor Networks (WSN)[19] technology. These sensors such as the wind vane, anemometer, rain gauge (a tipping-bucket), soil moisture, soil temperature, atmospheric pressure, solar insulation, temperature and humidity sensors. The sensors are categorized to make three different nodes at the WIMEA-ICT AWS, the nodes include the 2m node contains sensors that records the temperature and humidity, the 10m node has sensors that provides readings for the wind speed, wind direction, and solar insolation. The ground node contains sensors that record soil moisture, soil temperature, atmospheric pressure and the precipitation.

2.4.1.1 The 2m Node

The 2m node is composed of a sht25-sensor that records the temperature and the humidity values. The temperature and humidity sensors are encased within a light grey louvred radiation shield to prevent the sensors from direct sunshine heating up the sensor elements hence leading to errors and/or inaccurate readings. Figure below shows an illustration of the 2m node sensor in a radiation shield. The 2m node is 3.8V 270F capacitor and maintained on power by a 0.5w solar panel.

Figure 2.7: The 2m node's Radiation Shield

2.4.1.2 The 10m Node

The 10m node is composed of three different sensors: an anemometer for wind speed, wind vane for wind speed and the solar insolation sensor for measuring the power of light and heat from the sun. Figures below show the anemometer and the wind vane that make up the 10m node. The 10m node is powered by a 2w solar panel and a 3.7v lithium ion battery.

Figure 2.8: The 10m node's wind sensors (Anemometer & Wind Vane)

2.4.1.3 The Ground Node

The ground node is made up of the rain gauge (with a tipping-bucket) for measuring the precipitation, the pressure sensor that records the atmospheric pressure, the soil temperature sensor used for measuring the temperature of the soil, and the vegetronix soil moisture sensor for measuring the water and moisture content of the soil. The Vegetronix soil moisture sensor measures the soil moisture based on the volumetric content of the moisture that is in the soil and it can work for any type of soil. The ground node is powered by a 3.7v cylindrical lithium ion battery and 1w solar panel that also charges the battery during the day. Figure below shows the different sensors that make up the ground node, namely; soil moisture and soil temperature and the rain gauge (tipping bucket).

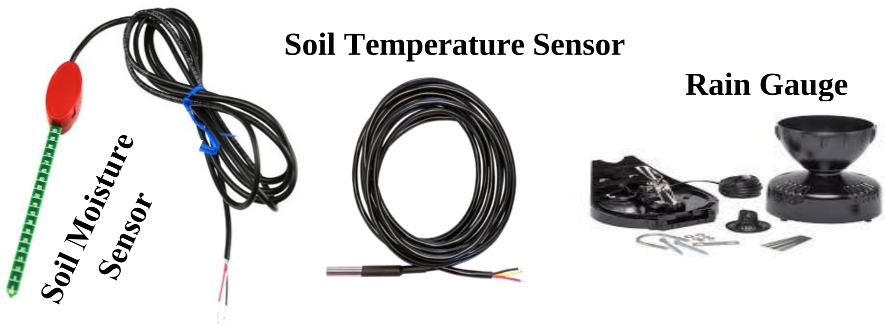

Figure 2.9: Ground node sensors (soil moisture & temperature sensors and rain gauge)

2.4.2 The Gateway

The gateway is composed of: the sink node, the particle electron incorporated with the GSM module for cellular data connection, the RTC module for real time clock provision, the SD card module with the SD card attached for temporary storage of the sensor data, the solar panel and the battery. The solar panel of 2w together with a 3.7v battery is used to power whole gateway components. Generally, its power usage is low as the name itself suggests: the low power gateway. The sink node receives the broadcasted sensor data from the three nodes and attached a time stamp from the RTC module to each of the broadcast received, forwards it over to the electron over a serial communication channel, the particle electron writes the received data to the SD card. When the electron has received a certain number of sensor reports/data, say 250, it opens up cellular connection with the help of the GSM module containing a sim card, connects to the server, opens and reads the sensor data in the file on the SD card uploading it to the server. Once the upload is complete, the connection is closed from the server and the cellular, the SD card file which was containing the sensor data reports is cleared, and the electron starts receiving and writing the sensor data reports again. The whole process is recursive at the gateway. Figure below shows the sketch illustration of the gateway fully connected.

2.4.3 The Remote Central Server

The WIMEA-ICT AWS server receives uploads (sensor data reports) from the gateway, writes it to a text file at the server and also to a central database. The server runs a TCP communication protocol[20][21] implying that the datagrams (the sensor data reports) are delivered in a correct sequence. Thus, the server is named a TCP listener, that waits for connection from the client (the gateway) on a dedicated port: 10024 and establishes a virtual connection between the server and the client such that the data streams may be passed for a period of time securely.

2.5 Power Ratings

The WIMEA-ICT AWS uses three solar panels of different ratings for recharging and keeping the batteries at the different nodes up to full charge capacity. The 0.5watt solar panel is used at the 2m node for recharging the 270 farads capacitor. The 1watt solar panel charges the cylindrical lithium ion battery at the ground node. The 2 watts solar panel is used at the gateway and for the 10m node. The solar panels are of different ratings because the power consumption at the respective nodes varies and as such the battery powers are drained at different intervals. This implies that the different nodes would all have different recharging requirements, hence the different solar ratings. The choice of these solar panel power ratings was also influenced by the need to ensure that the AWS consumes very low power which is efficient, reliable and easy to maintain. Figure 2.11 below shows the different solar panels used at the WIMEA-ICT AWS, all of which have different ratings in watts and voltage values.

Figure 2.10: Solar Panels at WIMEA-ICT AWS of ratings 2w, 1w, and 0.5w respectively

3 HARDWARE DESIGNS

3.1 The low power Gateway

A WIMEA-ICT custom Printed Circuit Board (PCB) was designed with slots for inserting a Particle electron module, which enables the AWS gateway to connect to the internet via 3G cellular network. The Particle Electron[17] contains the necessary GSM modules and it allows insertion of a SIM card. On the same PCB, there are slots for inserting an SD module - and an SD card in it - which is used to store the weather data before it gets uploaded to the WIMEA-ICT web servers via the internet connection.

The sink node, which receives weather sensor data from other nodes in the network, is connected to the PCB by use of serial ports (TX and RX). By this connection it forwards sensor data to the PCB continually as it receives it.

Power supply is by batteries, also connected to the PCB. The sink node then draws power from the PCB by jumping technique. In order to minimize power consumption, the gateway goes to sleep mode whenever it is not actively uploading data to the web servers. While in the sleep mode, data keeps piling onto the SD card until a specified amount of it accumulates. At that moment, the gateway must be woken up by a signal through the external interrupt connection to upload the data and go back to sleep mode again

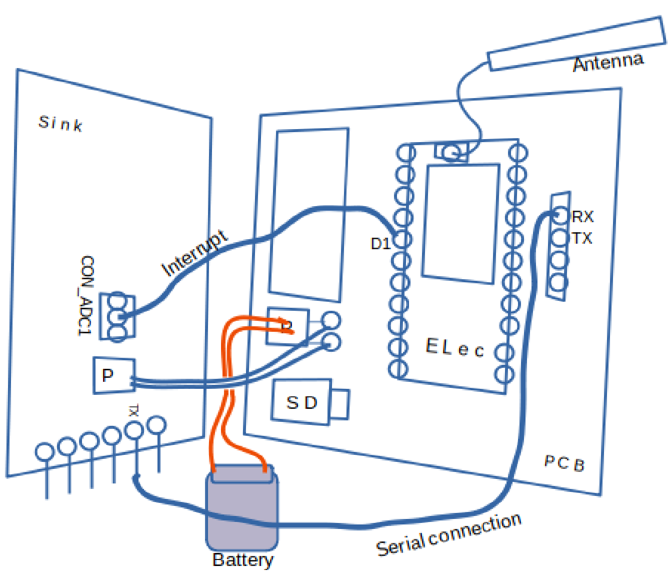

Figure 3.1: The WIMEA-ICT AWS low power gateway connection

4 THE AWS DEPLOYMENT

The deployment of the WIMEA-ICT AWS involves a number of steps taken, from assembling and packing the AWS components (the stands, the sensors and the nodes components, the tool kits), this steps normally takes place in the lab (in this case the WIMEA-ICT lab) a day before the actual day of the deployment. On the day of deployment of a particular AWS, a number of activities are carried out. The stand is fixed in the ground. Hole of about 0.5m deep is made in the ground and the stand is firmly fixed in the ground with a concrete base made to cover the remaining perimeter of the 0.5m deep hole.

Figure 4.1: Fixing the old 10m pole on the concrete slab with screws and nuts

For the older design of the stand used in Gen1 and Gen2 of the WIMEA-ICT AWS, the concrete base is made with a slab containing provision for screws. These screws are used to support the 10m long pole that has the wind sensors attached, the horizontal bar at a 2m height position from the ground for the 2m node and the rain gauge base stand at a position closure to the ground. Figure 4.1 above shows the 10m pole being fixed on the concrete base. Other designs of the stand had the

2m node on its own T-shaped stand of 2m above the ground and also the ground node. For instance, the Makerere station uses such design of the stand.

Once the stand (new stand design) has been fixed to the ground, the rain gauge stand is adjusted to position close to the ground, the 2m node holder is equally adjusted to about two-third of the stand length from the ground. The top of the T-shaped stand contains the wind sensors attached to it, the enclosure boxes for all the three nodes and the gateway are also attached on it (the top of the stand). The soil sensors are inserted in the ground, below the soil surface level such that the sensors (soil moisture and soil temperature sensors) are fully covered in the ground. The rain gauge is also fixed on its stand close to the ground. After the stand has been fixed on the ground, the nodes are then configured, that is, setting the names of the node, updating the location of the station and configuring the gateway with the server to ensure that the sensor data from the nodes can be uploaded to the server. Figures 4.1 – 4.9 below shows how the stands are fixed for different stations and other setup activities that follow such as attaching the sensors, the top part, 2m and rain gauge ridges as well as configuring the nodes and the gateway with the server.

Figure 4.2: Making the concrete for fixing the stand

Figure 4.3: Making the concrete base and fixing the stand

Figure 4.4: Fixing the rain gauge base on the stand close to the ground

Figure 4.5: Attaching the 2m node on the stand and adjusting to the right position

Figure 4.6: Attaching the top part of the stand

Figure 4.7: Adjusting and fixing the soil and wind sensors and rain gauge

Figure 4.8: Configuring the nodes and server connection

Figure 4.9: Introducing the AWS to Stakeholder with brief walkthrough on the components

5 CHALLENGES

No matter how efficient and effective a given system or technology is, there will always be few challenges, setbacks and glitches when it comes to the actual operation. WIMEA-ICT AWS as a new advancement in technology, isn't immune to such challenges, thus, below are some of the challenges.

5.1 Complexity of the technology:

Automatic Weather Station (AWS) as the name suggests, runs automatically without the need for human labor and/or physical presence at the weather station in order to read and record the weather data. AWS makes use of meteorological sensors in the reading of weather data and communication protocol for sending the weather data to a remote server. This in itself is even more complex already because different components from different suppliers need to be interconnected and configured to work as a single system, thus, the challenge of complexity of the technology.

The WIMEA-ICT AWS uses the same principle as explained in the previous paragraph. As presented in chapter two of this document, WIMEA-ICT AWS is composed of the transmitting nodes, the gateway, and the remote server. A transmitting node is composed of the Universal IEEE 802.15.4 Radio Sensors AB Node with an integrated 802.15.4 transceiver on the MCU for transmitting and receiving data over a radio frequency through a broadcast. The transmitting nodes are run by a firmware built in Contiki OS, an operating system for low power, memory constrained devices (written in C). The gateway is composed of the sink node, the particle electron, the RTC (Real Time Clock) module for time and the memory card for temporary weather data storage. The sink node is the same as the other transmitting nodes but it differs in the firmware running it. Its firmware is a modified version of the firmware running the other transmitting nodes. The particle electron contains an in-built GSM module for uplink connection, uploading weather data to the remote server. The particle electron runs its specific firmware and platform dependent on particle.io, the supplier of particle electron. The central server has a TCP listener responsible for receiving the uploaded data. The listener is written in Node, which serves two major purposes, namely; writing the data to a specific file that resides on the server and storing that same data to the central database.

Complexity of the WIMEA-ICT AWS increases with the increase of the different components interconnected and configured to function as single systems. Another argument on complexity of the WIMEA-ICT AWS arises from the fact that the different components run on different platforms thus increasing the cost of maintenance. The transmitting nodes and the sink node are based on the Contiki OS platform, the particle electron is platform dependent on the particle and the server is Nodejs.

5.2 Damage to the equipment

The WIMEA-ICT AWS is a low-cost low power Automatic Weather Station run by affordable equipment and items. These equipment however, easily wares out and gets used up and in most cases gets damaged. For instance, the station is powered with inexpensive low voltage batteries that don't last for quite a good number of months before replacement or being damaged. The constant charge and discharge cycle and in the worst case over draining of the battery voltage usually shortens the life-span of the batteries and as such, they get damaged easily. The solar panels that are used to charge the batteries as well cannot withstand all conditions for a long time without getting damage. The solar cells are constantly wearing out and the power terminals detach from the solar implying it can no longer be wired and thus unusable.

5.3 Procurement challenges

The WIMEA-ICT AWS batteries especially the cylindrical lithium ion is not available on the local market and due to COVID-19 with issues and restrictions it came along with, procurement from the suppliers became so hard and nearly impossible especially during the eve of the WIMEA-ICT AWS batch 2 deployment. Thus, there was a need to switch to an available supplier which took even more time before the batteries were sourced. The batteries needed to be tested first since they were new to WIMEA-ICT and their reliability was not yet known which equally needed more time. The particle electron comes with its batteries which is used at the gateway and it's more reliable.

5.4 Tax clearance and their cost implication

Most of the items and the components of the WIMEA-ICT AWS are imported from abroad and for it to reach to the shipping destination, different charges are incurred and taxes are as well levied on such equipment. Sometimes the tax and the shipping cost can be twice or in worst case thrice the actual cost of the item being imported. This greatly increases the cost of setting up the AWS which was supposed to be of a very low cost and affordable. The tax clearance process can sometimes take longer than expected especially due to the COVID-19 issues and restrictions. This as well slows down the process of the AWS deployment.

5.5 Harsh Weather

Weather conditions ranging from extreme that damages the glass and eventually the solar cells thus, reducing on the amount watts it outputs. Sometimes even the connecting wires from the solar panels breaks due to the extreme heat. The rain gauge becomes rapidly clogged by debris such as leaves, sand, dust and/or bird droppings. The solar panel's cells can also get covered by dust and/or bird droppings thus blocking the heat intensity reaching the solar cells, hence reducing the total watts produced by the solar panel. The enclosure boxes also become rigid, dirty and broken, thus water seeps into the box and destroys the components especially through short circuits.

5.6 Tall stand

The stands used for the first, second and some of the third generation WIMEA-ICT AWS were 10 meters long and the wind sensors were attached at 10m height above the ground on that stand. This implies that whenever there is need for replacing the wind sensors, the pole has to be removed from the concrete base and lowered to the ground so that the wind sensors can be reachable. The whole process is hectic and it needs labor and manpower so as to achieve the dismantling of the long 10m stand. The wind sensors may even be accidentally damaged especially when the stand is to fall down during the process of installing it. This will also amount to unnecessary and unaccounted for cost of establishing the AWS. Figure 4.1 shows the installation process of the stand.

5.7 Firmware Corruption

The firmware that run the AWS nodes are of two types from two different platforms. The three nodes are run by the Contiki OS based firmware because its (the firmware) is built on the Contiki platform. The sink node also runs a Contiki OS firmware. The particle electron is run by a different firmware developed on a Particle Device OS platform. These two firmware like any other software system, are not immune to bugs and failures due to faults. Thus, the firmware may at any point in time get corrupt and fail to run, implying that such a particular node will not be online and running.

In case the electron firmware also runs into errors and fails, the whole station will be offline, that is, it won't function until the maintenance team surface and debugs the firmware or the entire AWS.

5.8 Power Consumption

Some components of the WIMEA-ICT AWS have a high-power consumption rate compared to the rest. For instance, the gateways particle electron draws too much power especially when running the GSM module. The cellular mostly consumes power when it's being turned on and off and also when it's running. Some nodes also withdraw power, for instance, the 10m node’s wind sensors, anemometer require between 5VDC to 12VDC power up its circuit board while the wind vane needs about 5VDC and the whole Model S2 v2.4 RSS2 mote needs at least 2.5V. These voltages may as well vary depending on the load at the different nodes, that is, the number of sensors attached at the particular node.

5.9 Wasps

The enclosure boxes, the radiation shield and the rain gauge base provide good habitats for insects like wasps and other dangerous insects. Wasps normally build their nest on these components and turn out to be a threat to the maintenance team. For instance, when the wasps get hidden in the radiation shield, it can be hard to detect, thus, you end up getting caught off-guard by the wasps.

5.10 Packet dropping

When the node reads the sensor data reports, it broadcasts the reports in the form of packets to the sink node. On reception, the sink node writes the report to the electron serial line, the electron reads the reports and writes it to a file in the SD card and later uploads it (the records from the file) to the server. During the transfer from the node to the sink node, the packets can be lost especially when more than two broadcast data arrives at the sink at the same time. The second packet may be dropped at the sink and as a result such a packet gets lost or some parts of the first report is overwritten by the second report, implying the first report shall be incomplete. In some cases, during upload of the reports to the server, packet dropping may also occur especially in the instance when internet connection got interrupted.

5.11 Blockage of sim cards

The particle electron has a GSM (referred to as the cellular module in this section) module for cellular connection using a local telecom sim card. On powering up, the startup cellular module reads the sim credentials and turns the cellular on and off for the purposes of setting up. When this module is run, it tries to connect to the sim card's cellular network. Turning off the cellular module will force it to go through a full re-connect to the cellular network the next time it's (cellular module) being turned on, this can lead to aggressive reconnect if connection to the cellular is done frequently.

During the upload time, the cellular module is turned on which forces it (cellular module) to go through a full re-connect to the cellular network verifying whether the APN provided matches that of the sim card provided. This can lead to aggressive reconnection if connection to the cellular is done frequently. Once the cellular is ready, connection between the gateway and the server is established, sensor data report is read from the file in the SD card and uploaded to the server. After a successful upload the cellular module is turned off and the electron goes back receiving reports from the sink and writing to a file. This whole process is repeated continuously for as long as AWS is up and running.

However, due to the fact that the cellular is constantly turned on and off, implying the sim card is connecting to and disconnecting from the cellular network, the telecom company supplying such a sim card ends up blocking the sim card for security reasons. When this happens, the gateway will not be able to connect to the internet and the sensor data will as well not be sent to the central remote server. In other words, data from that station shall be inaccessible.

5.12 Poor quality memory cards

Most memory devices have limited write cycles while the read cycles can be much greater. Memory cards (some) especially the common types in the local market can easily get corrupted and have few write cycles and are not reliable. Once the card's write cycle is over, it can no longer be written to, hence corrupted. Original memory cards, especially the SanDisk memory cards have up to 100,000 write cycles with unlimited read cycles and cannot be easily corrupted. As explained in the previous section, the electron writes the data to the SD card and reads it for upload to the server, of which the process is running over and over again. Thus, for a memory card that is not original, it (memory card) can be easily corrupted, the sensor won’t be stored and lost. Since the whole component is interconnected, fault is one module or component will result in the whole station going off and no data will be accessible.

6 PROPOSED SOLUTIONS TO CHALLENGES

In order to address the challenges, different solutions are proposed down here for the specific challenges. Complexity in technology can be reduced by managing the demands and requirements, implementing and optimizing only specified requirements. Even though the AWS firmware is from two different platforms, making the design simple and tailored to priority requirements as well keeping the component simple can help reduce the issue with complexity.

The other challenges related to weather condition, wasp, firmware corruption and damage of the components can possibly be solved by designed a consistent maintenance programs that would involve updating the firmware after a given period of time, replacing the component parts especially when it becomes used up, cleaning the components regularly by the maintenance team, for instance removing debris from the rain gauge, cleaning the solar panel cells to remove dust and/or birds droppings, killing the wasps and removing their nest and constant checking to ensure that wasp doesn't have its habitat at the nodes.

Procurement issues can be solved by securing at least two reliable suppliers of the same component materials for instance the batteries such that whenever one supplier is not in position to provide the items required, the alternative would be acquiring from the other supplier. In Uganda, for items being used for research purposes, tax exemption can be applied for and as a result such items would not be tax. Thus, in order to handle tax clearance issues, it's advisable to request for exemption for the items that are being imported, if it's for research work anyway.

New design of the stand had been proposed and implemented as a replacement to the other longer stands. This new stand solves all the problems that were faced with the old stands. For instance, the stand is only about 2m long implying that one can even reach the wind sensors on foot. The stand also has all the nodes and the gateway attached on it as well as the wind sensors attached on the two ends of the top horizontal part of the T-shaped stand. Figure 2.7 shows the new design of the WIMEA-ICT AWS stand.

Packet dropping can be handled by ensuring that there is a reliable network especially on connection to the server so that all the data can be uploaded to the server. Packet dropping at the sink node can be eliminated by synchronization between the sink and the other transmitting nodes.

The configuration of the nodes should be done in such a way to ensure that there is at least a two seconds lag on the reporting intervals of the different transmitting nodes. This will give the sink node more time to wake up the electron and write the data packet received before another one arrives. As a result, cases of overwriting some parts of the previous report by the current report as well as dropping of the reports (packets) shall be eliminated. Sim card blockage is normally caused by the aggressive reconnection (multiple) attempts made by the GSM cellular module to sim card's cellular network, and also repeated failures to connect. For instance, when the reconnect to the cellular network is made frequently especially after every 10 minutes by turning on and then off the GSM cellular module, the sim card shall be blocked. Since the connection request is made once on powering up the gateway and every time the gateway is uploading data to the server, the upload count (number of lines sensor data reports written to the SD card) should be configured to a number that will approximate at least a one-hour lag from the last upload.

In order to solve the challenge of the frequent memory card corruption, trusted suppliers producing original memory cards should be sourced. This involves verifying whether the specification indicates that the memory card has up to about 100,000 write cycles because these types are durable and do not get corrupted easily.

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8 APPENDICES

8.1 Appendix A: AWS components and Importance

Referring to section 2.4 of this document, the WIMEA-ICT AWS consists of a network of sensor nodes each measuring some environmental parameters and transmitting it to a central gateway and the gateway then uploads those data to the server. This section provides the high-level functionality of the different components as it was already previously discussed in section 2.4

8.1.1 Sensor Network

The wireless sensor nodes (2m, 10m and ground nodes) are used for measuring the different environmental parameters such as temperature, humidity, wind speed and direction, soil moisture and temperature, precipitation, solar insolation and pressure. The nodes then transmit the measured parameters as a data packet to the gateway.

8.1.2 The Gateway

The gateway has a receiving node connected to it called the sink node, of the same type as the other nodes. The sink node receives the packets transmitted by the other nodes and sends the packets as a sensor data report to the electron using a serial communication since the sink and the electron are serially connected. The electron first writes this report to the SD card before uploading it to the central server. After the electron has written a given number of reports to the SD card, it establishes the connection to the remote server over cellular connection, reads the data report from the SD card and uploads it to the server.

8.1.3 The Remote Central Server

The server is where the data from the different AWS are stored. When a particular gateway for a given station uploads its data to the server, the server performs two basic fundamental activities, that is, writing the data to a ***.dat*** file located at the server which corresponds to that station. The second task performed by the server on upload is, inserting that same data to the central MySQL database.

8.2 Appendix B: Suppliers

To make up a fully functional WIMEA-ICT AWS, a number of components are required for the full system to run and fully function. The components are acquired from different suppliers and below is a list of different suppliers providing at least an item making up the AWS components.

1. Davis Instruments Corp. Inc.[22] an American company, is the supplier of the rain gauge and the soil moisture sensor
2. Inspeed.com LLC[23] supplies the wind sensors, that is, the wind vane used for recording the wind direction and an anemometer which is used for measuring the wind speed.
3. Vegetronix Inc.[24] is responsible for supplying the soil moisture sensors that records the moisture contents of the soil.
4. Particle Industries, Inc.[25] is the manufacturer and supplier of the particle electron used at the WIMEA-ICT AWS gateway majorly for internet connection.
5. Shenzhen Jubaolai Electronics Co. ltd supplies the DS3231 RTC Module used for generating the real time on which a particle report (packet) was received at the sink node.
6. Shenzhen Kingbolai Industries Co., ltd[15] are the manufacturers and suppliers of different types of lithium ion batteries some of which are used for powering three nodes of the WIMEA-ICT AWS. For instance, the High capacity 3.7V rechargeable lithium battery ICR18650 is used at the nodes (2m, 10m and ground node) and the LIR2032 Coin Type, Lithium-ion Rechargeable Button Cell 3.6V 40mAh batteries used for powering up the DS3231 RTC Module.

8.3 Appendix C: Useful Resources

No.	Resource	Link
1	Low power gateway designs	
2	Sink node firmware	[26]
3	Source node firmware	[27]
4	The AWS monitor source code	[28]
5	The AWS monitor Manual	[28]
6	The WIMEA-ICT User manual	[27]
7	Contiki operating system	[16]
8	The Particle electron	[17]

Table 1: Useful Resources for the WIMEA-ICT AWS

8.4 Appendix D: Common AWS problems and Signs

The WIMEA-ICT AWS is expected to perform and keep-alive that it stays online and running constantly. Because of some challenges and problems that the AWS can be faced with, the AWS end ups either go off or partially perform. The common problems that AWS may run into includes among others what is discussed below.

Power issues. In some circumstance, battery power may be drained to below recommended voltage either because the battery has become faulty or the solar panel is no longer supplying the necessary power for recharging the battery. Once this problem surfaces, the node will go off and will not be able to read and transmit the sensor data, thus, on checking the data records on the server, the sensor data from such a node shall be missing from the data file of that particular station.

Firmware corruption. The normal flow of the firmware is, on powering up, the firmware running the mote is supposed to start reading the sensor data using the sensors attached to such a node and broadcasting it, in an interval of about 15 or 30 seconds. In case of any issue with the firmware, the mote will constantly be resetting and that means the node shall not be able to read and transmit the sensor data and the data from that node shall be missing on the server. The problem of a mote resetting can also be common at the sink node especially when either the RTC module is missing or faulty. In this case the whole station would be down.

8.5 Appendix E: WIMEA-ICT Deployments and locations

The WIMEA-ICT has so far deployed a total 30 AWS in almost all the regions in Uganda. The first batch of the deployment had 11 AWS installed and the latest batch two had an additional 19 AWS being installed giving it a total of 30 WIMEA-ICT AWS installed. There are about 9 AWS in the northern region, 13 AWS in the eastern region, and 8 other AWS are installed in the central region. Below is the list of the different locations by region, where the WIMEA-ICT AWS has been installed.

8.5.1 Central Region

1. Entebbe Airport, Wakiso district
2. Makerere University, Kampala City
3. NARO, Kawanda, Wakiso district
4. Kyambogo University, Kampala City
5. NARO, Kamenyamigo, Lwengo district
6. Bishop Cypriano Kihangire Secondary School, Luzira, Wakiso district
7. Mubende Municipal Council, Mubende district
8. NARO, Kituza, Mukono district

8.5.2 Northern Region

9. Adjumani Town Council, Adjumani district
10. Adilang Sub County, Agago district
11. Alero Sub County, Nwoya district
12. Atiak Town Council, Amuru district
13. Lalogi Town Council, Omoro district
14. Lamwo Town Council, Lamwo district
15. Latanya Sub County, Pader district
16. Orom Sub County, Kitgum district
17. Palaro Sub County, Gulu district

8.5.3 Eastern Region

18. Pallisa Town Council, Pallisa district

19. Ongino Sub County, Kumi district
20. Namayingo Town Council, Namayingo district
21. Ikulwe, Mayuge Town Council, Mayuge district
22. Busoga College Mwiri, Kakira Sub County, Jinja district
23. Kige, Kagumba Sub County, Kamuli district
24. Nawaikoke Health Center, Kaliro district
25. Airfield, Jinja City
26. Iganga Senior Secondary School, Iganga Municipal Council, Iganga district
27. Bugaya Sub County, Buyende district
28. Kidera Sub County, Buyende district
29. Bukwo Town Council, Bukwo district
30. Bududa Town Council, Bududa district